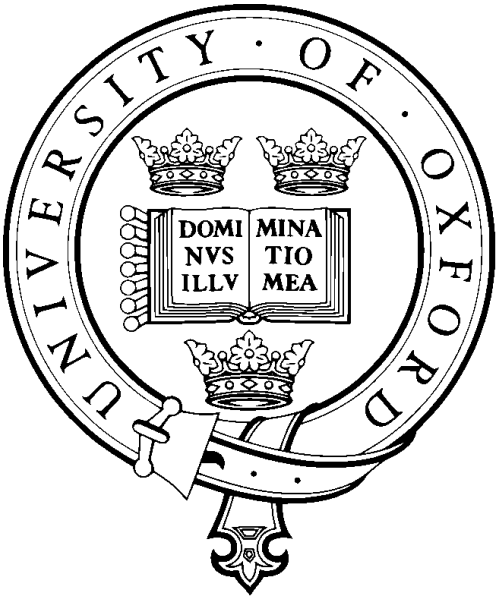
Improving Precision in Age Estimation from the Female Pubic Symphysis: A Novel Technique for CT



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Abstract

Due to the skeletal emphasis of both physical and forensic anthropology, biological profiling has traditionally been advanced through the study of archaeological, historical, donated, and autopsied remains. In recent years, this has grown to include samples obtained through medical imaging, specifically that of computed tomography (CT), though these investigations have remained largely retrospective. While these types of studies are in keeping with past precedent, this preference for anonymous skeletal material under-utilizes the other half of the human equation – the living owners of those skeletons and the ways in which they live their lives.

Through the development of a new technique – the Truesdell Composite Method, or "TCM," this study sought to explore the feasibility of incorporating direct public engagement into the process of biological profiling research. Over the course of six months, 1,238 volunteers (653 male, 585 female – ages 18 to 101) were interviewed, face-to-face, before being CT scanned at Oxford University's Churchill Hospital. These interviews were facilitated by a six-page questionnaire detailing demographic (biological affinity, age, height, weight, etc.), lifestyle (diet, activity level, inflammation, infection, osteoporosis, arthritis, smoking by ounces or cigarettes per day, alcohol consumption by unit per week, etc.), and pregnancy history (age at first birth, epidural, SPD, caesarean, birth weight, length of labour, etc.). The answers to these questions, along with the results of additional Suchey-Brooks (1990) and Hartnett (2010) symphyseal analyses, were then compared to the actual age of each individual. Sex (p=0.008, effect size=1.86), smoking (p=0.010, effect size=1.85), activity (p=0.033, effect size=0.69), and menopause (p=<0.0001, effect size=7.69) all returned significant results while, surprisingly, parity did not (number of pregnancies, p=0.846; number of births, p=0.895), nor did any pregnancy related factors.

Subjects were placed into appropriate Suchey-Brooks ranges an average of 89.4% of the time, but only 49.4% of the time was the mean within a decade of the actual age and, within that, only 27% of the time was it within 5 years of the actual age. This is likely a reflection of the sample's propensity towards older individuals (~50% over 65 years). The Hartnett Method fared less well overall, with subjects being placed into appropriate ranges 75.5% of the time but, then, within the ranges themselves, fared slightly better than Suchey-Brooks with means within 10 years of actual age 65.4% of the time and 39.1% within 5 years. When using the TCM, estimations to within 10 years of actual age increased to 83.9% and to 67.7% within 5 years. For Suchey-Brooks, this constitutes a 34.5% increase in precision to within 10 years of the actual age and a 40.7% increase in precision to within 5 years. For the Hartnett Method, precision to within 10 years was increased by 18.5% and to 28.6% within 5 years. It is hoped that the TCM, and with it these increases in precision, will be particularly relevant to females and to individuals over the age of 60 years.

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The dead can only speak through the mouths of those left behind, and through the signs they leave behind them.

- Galbraith 2014

1

An Introduction and Review of the Literature

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Abstract:

Over the course of its nine chapters, this thesis will seek to present a novel technique for the estimation of age from the pubic symphysis as well as a new methodology for data collection to be used in the practice of biological profile studies in forensic anthropology. The significance of this is threefold: 1.) the introduction of a means of increasing precision (or nearness to known age) in age estimation, especially useful for women over the age of 65 years, 2.) the incorporation of medical imaging technology into biological profiling research and collection building, and 3.) the direct involvement of and engagement with currently living volunteers, each of whom able to provide extremely detailed life history information to dovetail with their skeletal data.

This chapter, "An Introduction and Review of the Literature," will introduce the reader to key concepts regarding skeletal age estimation, both past and future, with particular attention to the pubic symphysis, and provide the foundational knowledge necessary for the understanding of subsequent chapters. This chapter is designed to provide the reader with a comprehensive but concise methodological history regarding ageing from the pubic symphysis in an effort to clarify the necessity of further scholarship in this area. It will also introduce and outline the seminal techniques, both old and new, which form the basis of the technique developed over the course of this project. By highlighting both the advantages and disadvantages of the methods currently available, this chapter will familiarize the reader with the literature surrounding age estimation from the pubic symphysis as well as the methods chosen for this research and why they were appropriate.

1.0 Forensic Anthropology in Context

The Oxford English Dictionary defines Anthropology, a combination of the Greek *ánthrōpos* (human) and *lógos* (study), as "the study of human societies and cultures and their development (socio-cultural)" as well as "the study of human biological and physiological characteristics and their evolution (physical)" (Oxford English Dictionary 2016). Merriam-Webster defines the same as "the science of human beings; *especially*: the study of human beings and their ancestors through time and space and in relation to physical character, environmental and social relations, and culture" (Merriam-Webster 2016).

Still further, The Royal Anthropological Institute defines Anthropology, as:

> *"the study of people - their evolutionary history, how they behave and adapt to different environments, as well as the ways in which they communicate and socialise. [It] is concerned both with the biological features that make us human (such as physiology, genetic makeup, and evolution] and with social aspects (such as language, culture, politics, family and religion)"* (Royal Anthropological Institute 2016).

Purposefully broad, this all-encompassing purview encourages an almost limitless array of specialties and sub-specialties within and across the wider discipline, supporting a system in which large, well-established "fields within the field" such as socio-cultural anthropology, linguistics, physical anthropology, and archaeology co-exist in symbiosis with smaller, more narrowly focused, continually diversifying areas of study (political ecology from socio-cultural anthropology, for example; and Semiotics from linguistics).

One such sub-field, calved from the larger glacier of physical anthropology, is that of *forensic* anthropology – a discipline that, instead of observing how a body behaves outwardly in a given environment (how it creates, navigates, and shapes the world in which it exists), investigates how it behaves inwardly in a given environment (or how that world creates and shapes *it*). Forensic anthropologists, therefore, work from the "inside out," examining variation through the lens, or from the perspective, of the body itself in order to draw conclusions and place an individual in their wider landscape, community, and context.

Consequently, this involves studying the body's innermost structure – the skeleton, both its anatomy and physiology – to ascertain the extent to which

extrinsic factors such as lifestyle and environment (together with intrinsic factors like gene inheritance) impact or imprint upon bone. Research in this area is critical to understanding what may or may not affect certain aspects of skeletal development or function (such as morphology or growth) and is what enables the anthropologist to distinguish one person from another (or one skeleton from another, more appropriately) as well as "tell the story" of an individual - what he or she looked like, where he or she lived, possible occupations, habits, or misadventures, who and what was important to him or her, and, if no longer living, how he or she may have died.

Unlike bioarchaeologists, who also tell these stories but for those who lived in the past, forensic anthropologists work exclusively with contemporary populations – that is, individuals either currently living or who have died within the past 100 years (Marquez-Grant and Fibiger 2011). This narrowed timeframe - and thusly concentrated emphasis - in turn lends to a uniquely focused, frontline command of skeletal variation among modern (contemporaneous) humans, a skill set proven to be particularly relevent to the application of law, hence the "forensic" designation.

1.0.1 Forensic Anthropology and its role in society

When a body is found but is unidentifiable by the usual "soft tissue" means (visual recognition, tattoos, birthmarks or scars, fingerprint analysis, etc.), whether due to advanced decomposition, skeletonisation, concealment

attempts, dismemberment, or thermal destruction (fire), the skeletal expertise of the forensic anthropologist is often called upon to aid in identification.

This could include individual medico-legal cases (homicides, suicides, accidents, natural, or undetermined deaths) for which no personal documentation can be found (a body washed ashore after drowning, for example; or a hanging victim discovered in the woods) as well as cases of larger scope such as mass disasters (earthquakes, tsunamis, tornados, etc.), mass fatalities (plane crashes or bombings), and human rights abuses in times of conflict (mass graves). Alternatively, anthropologists are being increasingly asked to perform assessments on living individuals through medical imaging - radiographs, CT, MRI, and Ultrasound - in cases where either little biographical information is known (asylum seekers, victims of sex trafficking or modern day slavery, adoptions from countries where age is uncertain, etc.) or for comparison purposes such as in cases of suspected abuse (child pornography) or cheating in professional sports. Additionally, information of this kind also acts to document the demographic profile of a community (including transitioning funerary practices) as well as trends in public health such as age specific fractures (child or elder abuse) and patterns of disease as well as the tracing of differential immune responses to the spread of said diseases.

1.0.2. The Biological Profile

In order to assist with these identifications, forensic anthropologists rely on a suite of observations collectively known as "the biological profile." Traditionally, this has included four major components: ethnicity,[1] sex, age, and stature. Often referred to "the big four" or "the four pillars of the biological profile," these constituent parts work together to establish a basic but essential description of an individual in question – what he or she looked like, whether he or she was (biologically) male or female, approximately how old he or she was, and how tall he or she stood in life. In specifying these characteristics, the anthropologist (working with the police) may be able to winnow down a missing persons search and, ultimately, match the skeleton being assessed to someone reported missing. This, in turn, may then lead to the arrest of a perpetrator and bring much needed closure to loved ones left behind (Bass 2005; Byers 2010; Haglund and Sorg 1997; Ramey Burns 2007).

[1] A note on terminology: The terminology of "race" as a descriptor has long been a contentious issue for physical and forensic anthropologists; however, that being the case, no consensus term has been agreed upon for the purposes of identification. Some advocate "ancestry," "phenotype" or "biological affinity," and while these labels are much more clinical and, therefore, further removed, they are nonetheless unhelpful in a society where the concept of "race" is the norm. For illustrative purposes, when a body is found and the investigator has a tentative ID, he or she will ask friends, relatives, or neighbours to describe what the decedent looked like in hopes of making a match. Those relatives, friends, and neighbours will not say "she was half German, a quarter Irish, and a bit French," leaving the investigator to infer that the person in question must then have had features consistent with what is considered to be Caucasian. To the contrary, they will respond, "she was white," because 1) that is the term they are used to, 2) it is simple and direct, and 3) they are unlikely to know any biographical information beyond that. Furthermore, in being unclear, the investigator risks confusing, offending, or making things more difficult for loved ones during a time of grief. For these reasons, while clearly antiquated and problematic, "race" unfortunately remains the term best suited to purpose. The official UK census uses the term "ethnicity," which most anthropologists would associate with cultural, and not biological, identity and so, perhaps, is even less appropriate. However, as that is the official UK census terminology and, as such, the term presented to patients, for continuity, it will also be used here. See the American Academy of Physical Anthropology's "Statement on Biological Aspects of Race" (1996) for more information as well as a full discussion on the subject.

Each of these elements posses issues and considerations unique to them; however, estimating age from the human skeleton is possibly the most variable and complex of the four. This is because, while Ethnicity and Sex are categorical (Ethnicity may be one of three - "negroid," "mongoloid," or "caucasoid" – while sex is either "male" or "female"), Age, like Stature, is continuous. Unlike Stature, though, which can be quickly and easily measured in centimeters or inches, no direct physical measurements exist for the estimation of age.[2] Within the biological profile, therefore, age estimation (or simply "ageing") is unique as it is neither strictly categorical nor is it strictly continuous, but a mix of both. Furthermore, while the evaluation of ethnicity allows for three "official" designations, Sex for two, and Stature for at most 97 equal possibilities (the tallest recorded human height, in inches)(Guinness World Records 2016), in terms of age a person may be anywhere from seven weeks (when ossification commences in the womb) to 122 years old (the oldest authenticated age on record)(Guinness World Records 2016) – a spectrum encompassing an tremendous array of skeletal change, from developing embryo to fetus to perinatal to juvenile to adolescent to young adult, middle adult, and finally senile or elderly adult. It is for this reason that ageing, the most complex component and therefore the one in most need of refinement, was chosen as the focus for this project. However, to understand how age can be interpreted from the skeleton it is first necessary to understand how bone works.

[2] While no outward measurements similar to those for Stature exist, a histological analysis (in which osteons are counted) can be useful in estimating age at death from adult bone (though this would be inapplicable for estimating age from the living). See Kerley (1965) and Crowder and Dominguez (2012).

1.1 An Introduction to Bone and How it Works

When asked to describe bone, chances are most people will respond with adjectives such as “dead,” “white,” “dry,” “brittle,” or “old.” This is because, by the time the average person sees bone - whether displayed in a museum or shown on television or film – that is, indeed, what it has become. In life, however, this could not be further from the truth. Bone, like any other organ in the body, is a vital and dynamic self-contained yet inter-connected system in a constant state of motion.

The skeletal system performs many essential functions which include producing blood (hematopoiesis), lymphocytes, cartilage, and bone, converting and storing energy in the form of fat (lipids), acting as a mineral reserve for calcium and phosphorus (the regulation of which keeps synapses firing and muscles contracting), as well as acting as a scaffold for muscles to anchor to and lever against (enabling movement); nevertheless, it is for its structural and defensive qualities that it is most commonly recognized as without the architectural framework the skeleton provides, the body would have no way of keeping its 10 “soft” organ systems (cardiovascular, nervous, endocrine, muscular, integumentary, digestive, reproductive, urinary, respiratory, and lymphatic) upright, stabilized, and functioning properly. At the same time, without the protection afforded by the “armour-like” rigidity of the bone itself (most notably the skull, which houses the vitally important brain and sense organs, and the pelvis, which defends the bowels and reproductive organs), those same “soft” structures would be left completely open and vulnerable to

repeated, potentially life threatening, injury. This ability to provide both support and strength at the "macro" level is made possible by the unique placement and organization of its multi-layered cells at the "micro" level.

Osseous tissue is classed as a type of dense irregular connective tissue, a tissue characterized by "more or less numerous cells surrounded by an extracellular matrix of fibrous and ground substance" (Ramey Burns 2013) – in other words, comprised of cells suspended in or surrounded by fluid. This fluid is important as it allows for the transportation and exchange of oxygen and nutrients between the blood stream and the cells ("diffusion"), as well as the reverse for the removal of waste. This type of arrangement also endows an element of stability due to the viscosity generated by the fibrous "filler" of the matrix (most commonly type 1 collagen) but not nearly enough to accommodate the mechanical demands of the skeleton. Bone is, therefore, also a *mineralized* connective tissue – meaning that, instead of simply containing networks of connecting cells as the other types do, it also "incorporate(s) minerals into [its] soft matrices… typically [to] form a protective shield or structural support" (Espinosa et al. 2009).

1.1.1 Bone Development and Remodeling

Every bone in the human body is produced following this "fluid first, mineral second" design. Development bone by bone, however, differs slightly and is dependent upon location, purpose, and projected size.

Ossification first begins in the "flat" bones of the skeleton, or in those where protection is the primary function. These include the bones of the skull (including those of the face), the pelvis, the sternum and ribs, the scapulae, and the lateral end of the clavicle. This ossification occurs "intramembranously," or directly within the surrounding tissue and without the need of a pre-existing template. By the sixth week post-fertilization[3] (or by day 37), the embryo has already developed limb buds (both hands and feet), hand plates, and the precursors of the face (the pharyngeal arches)(*Figure 1*). It is during this time, Carnegie Stage 16 (O'Rahilly and Muller 2010; The Visible Embryo 2016; The Virtual Human Embryo 2016; Hill 2016), that stem cells embedded within the mesenchyme at the desired site are called into action by the targeted release of RUNX2 / CBFA1 (Runt-related transcription factor 2 / core-binding factor alpha 1), TGF-*beta*1 (transforming growth factor beta 1), and bone morphogenetic proteins ("BMP"s) 2, 4, and 7, triggering them to differentiate into specific bone building cells called "osteoblasts" (Gilbert 2000; Ducy 2000; Augello and De Bari 2010). In turn, this newly formed cluster of osteoblasts becomes the body's first "ossification centre." Once differentiated these osteoblasts line up (creating an "osteoid seam"), and form "tight" (which waterproof them from the surrounding extracellular fluid) and "gap" junctions (which allow them to communicate and



Figure 1: The embryo at six weeks

[3] When discussing the age of an embryo, two terms are simultaneously used. The first is "gestational" or "embryonic" age, which is counted from the date of the mother's last reported menstrual cycle. "Fetal" age is counted from conception, or fertilization, and is therefore delayed by approximately two weeks. During obstetric care, a pregnancy is generally considered to be 40 weeks as it is based on gestational age while the "actual" age of that fetus would be 38 weeks. Because it is more specific, fetal age will be used here.

work as one unit). They then begin to secrete "osteoid," the fiber-filled fluid discussed in the previous section.



Figure 2: "Rope-like" collagen fibrils

This osteoid, at 90% of its volume, is composed almost entirely of type 1 collagen fibrils which group together to create rows of long, fibrous "ropes," fixed in space by the viscosity of the matrix (*Figure 2*). The remaining 10% (ground substance), meanwhile, contains a mix of proteoglycans (including hyaluranic acid and chondroitin sulfate, both lubricants), glycoproteins (such as osteonectin, which binds calcium to hold it in place), and non-collagenous proteins (osteocalcin, which manufactures the calcium; alkaline phosphatase, which crystallizes that calcium by transforming it into an insoluble salt; and osteopontin, which, along with bone sialoprotein 2, regulates the production and direction of those salts (Flashcard Machine 2016).

To begin the mineralization (or "calcification") process, the long interconnected "ropes" of collagen shuffle, align, and cross-link (enzymatically) to form an evenly spaced, parallel scaffold of fibrils. This scaffold is then quickly permeated by a number of "matrix" or "intercellular vesicles" – self-contained clusters of calcium and phosphorus, bonded to form calcium phosphate (Nudelman et al. 2010; Boonrungsiman et al. 2012). These vesicles "roam in the solution and, when they come into contact with the collagen fibril, they bind to a specific region on the collagen and diffuse into the fibril, filling all available

space" (Nudelman et al. 2010).[4] Next, once securely anchored, these matrix vesicles rupture and the calcium phosphate released undergoes a "double decomposition reaction" whereby it is transformed into amorphous calcium phosphate. Finally, this amorphous calcium phosphate - in response to localized signaling from adjacent collagen receptors (Traub et al. 1992; Nudelman et al. 2010) - begins to "precipitate," or crystalize, and become what is known as "hydroxyapatite" ($Ca_{10}(PO_4)_6(OH)_2$). The production of these crystals will now continue until ossification is complete and will eventually occupy approximately 70% of the calcified bone (*see Figure 3, below*).

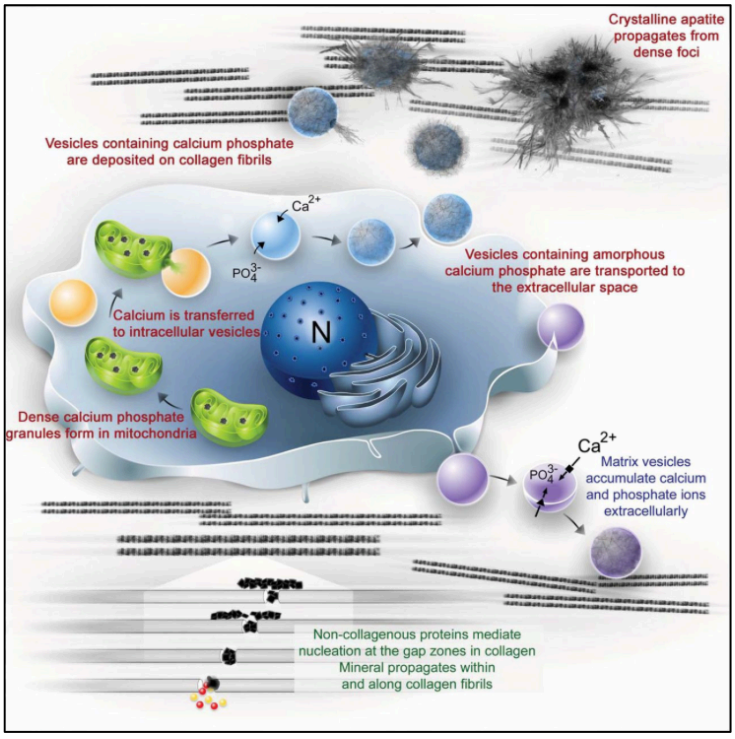


Figure 3: The calcification process

[4] Whether these vesicles are released individually by the osteoblast, form independently from free-floating particles in the osteoid, are manufactured by the mitochondria, or are encoded into the collagen fibrils themselves has yet to be clarified as, indeed, the process of mineralization itself remains enigmatic. That all theories could be correct and occurring simultaneously - as evolution advances through side steps and gradual replacements – is also possible (see Wang et al. 2010; Wiesmann et al. 2005 for an excellent review).

As these crystals continue to proliferate along the fibres they necessarily begin to overlap and build upon each other, creating random needle-like projections known as "spicules." These spicules, in turn, continue to grow upwards and outwards until they eventually meet and merge. This results in the formation of a thinly connected lattice of bony, bridge-like structures called "trabeculae" (*Figure 4*). Bone at this stage is often categorised as haphazard and is referred to as "woven" or "fibrous" bone.

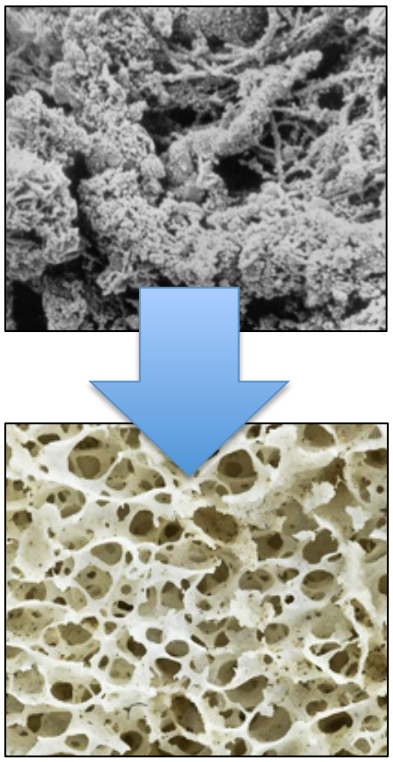


Figure 4: Formation of trabeculae

Like any other structure in the body, this new tissue requires nourishment to survive and nourishment is supplied by blood. By no coincidence, circulation is in place and up and running by the eight week of embryonic development (Cunningham et al. 2010) – nearly the same time as the commencement of ossification. This means that the blood vessels and capillaries needed for nutrient exchange and waste disposal have already been forming in and around the growing bone. Due to its porous nature and weak architecture, trabecular (or "cancellous" or "spongy") bone remains structurally vulnerable. To remedy this, it is always encased within layers of thick "compact," or "cortical," bone.

The periosteum, from the Greek *peri* ("around") and *ostoun* ("bone"), is a heavily vascularised sensory sheath adhered to the outer surface of every bone in the

human body. It is connected by a layer of velcro-like "Sharpey's Fibers" and is also extensively innervated. Its inward facing side is lined with smooth, flat "osteoprogenitor" cells which, when called into action for either growth or repair, differentiate into osteoblasts and set about replacing old or damaged bone. During the eighth week of development, rows of newly formed blood vessels (along with the nerves they also supply) line up and encircle the unprotected trabeculae to create what is known as a "bone collar" or "periosteal cuff." Stimulated again by TGF-*beta*1 (among other things, parathyroid hormone for example), the periosteum differentiates its dormant progenitor cells into bone forming osteoblasts and directs them to calcify the tissue surrounding these vessels and nerves creating parallel tubes of bone - formed from concentric rings called "lamellae" - effectively ossifying the cuff and establishing an armoured perimeter around the weaker spongy bone (see *Figure 5, below).*

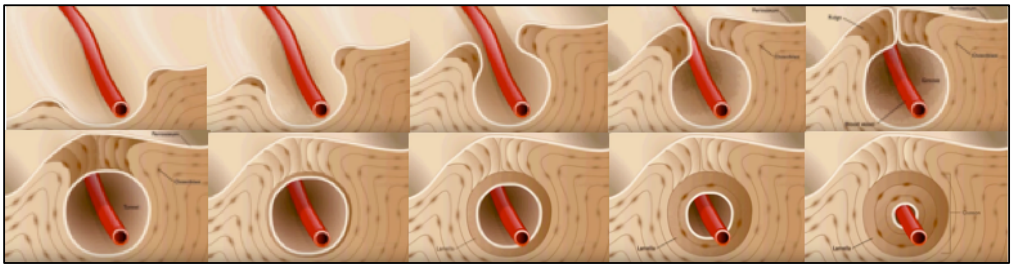


Figure 5: Appositional growth through lamellae formation

This type of ossification is slightly different to the bone formation previously discussed. While the "fluid first, mineral second" model remains the same – osteoblasts to osteoid (extracellular matrix) to collagen fibrils to precipitate (hydroxyapitate crystals) – it is simply the assembly that changes. As discussed

previously, trabecular bone is created through the rapid and irregular aggregation of delicate bony spicules, which branch up and out to form interconnecting trabeculae. In contrast, "compact bone" does not gain ground spicule by disorganised spicule but by "appositional growth" instead. Apposition is "the condition of being side by side or close together" (Oxford English Dictionary 2016). Appositional *growth*, therefore, refers to the acquisition of new bony territory through the incremental, step-wise expansion of pre-existing neighbouring cells.

As seen in Figure 5, in the formation of new cortical bone, stimulated periosteal cells concentrate and intensify osteoblastic activity at the "advancing" or "calcification front," or in the direction desired growth. As these osteoblasts secrete their osteoid, many at a time and in all directions, several are engulfed by the sea of viscous fluid and become trapped in the matrix (much like an insect in amber). When this happens, these cells, instead of dying, undergo reprogramming and are transformed into a new, more complex type of cell called an "osteocyte." Once charged with one task only – to build bone on command – these promoted osteoblasts will now be responsible for a multitude of crucial tasks, including the long distance transfer of sensory and response information (the skeletal equivalent of synapses in the nervous system) as well as the localised monitoring and maintenance of the bone they now inhabit. In order to perform these tasks, osteocytes communicate with each other though a vast network of radiating processes called "filopodia," spindly finger-like projections (similar to nervous dendrites) which connect osteocyte to osteocyte (or "lacuna" to "lacuna," more specifically – lacunae are the hollow niches in

which osteocytes reside). These processes burrow their way through the hardened matrices around them, carving a system of tunnels or channels called "canaliculi" ("little canals") as they go.

These parallel tubes of bone, which contain all of the sub-structures described thus far - blood vessels and nerves (which, if running vertically, occupy the "central canal" or, if running horizontally connecting tube to tube, occupy "perforating" or "Volkmann's" canals), lamellae, osteocytes, lacunae, and canaliculi – are known collectively as "Osteons," or "Haversian canals" (after Clopton Havers, the man who first described them). This type of "hierarchical structure" – by which the whole is made stronger through the sum of its parts – is, in turn, what lends the skeleton its strength and integrity, its shape, and its capacity for self-repair. Figure 6 (*below*) illustrates this system in its entirety.

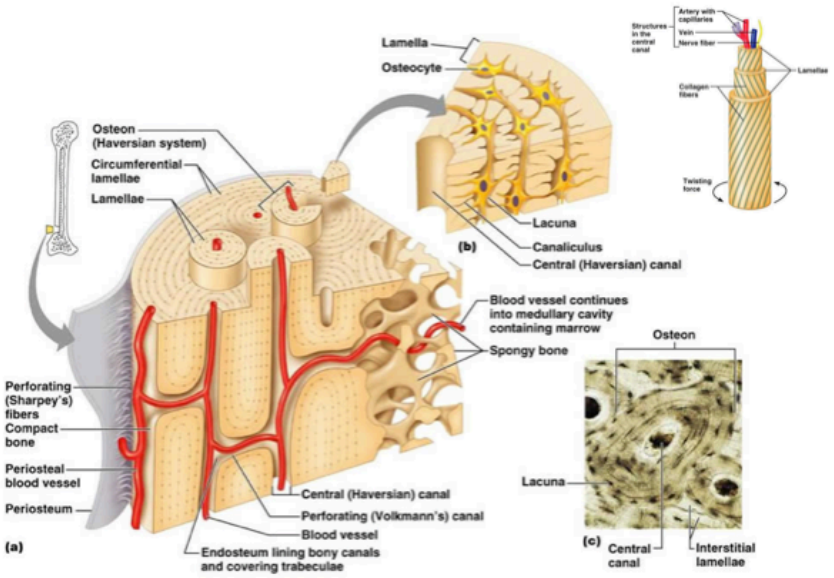


Figure 6: The osteon

As with any mineralized tissue (pearl, shell, sponge, antler, dentin, etc.), this multi-layered, interdependent design allows for "remarkable combinations of stiffness, low weight, strength and toughness" (Espinosa et al. 2009:1060) with "added functionality such as self-healing … due to the incorporation of minerals in[to] soft protein networks and tissues" (Barthalet 2007:2908). Much like tempering clay to increase its hardness and durability, by embedding a fortifying substrate into each organizational level…

> *"loads and stresses are transferred throughout several length-scales, from macro to micro to nano… result[ing] in the dissipation of energy within the arrangement. These … hierarchical structures are therefore able to distribute damage [evenly and effectively to] resist cracking" (Barthalet 2007:2910).*

The reason, therefore, that cortical bone is so strong and so resilient (as opposed to trabecular bone which does not contain osteons), is its complex yet coordinated multi-scale design (*Figure 7*).

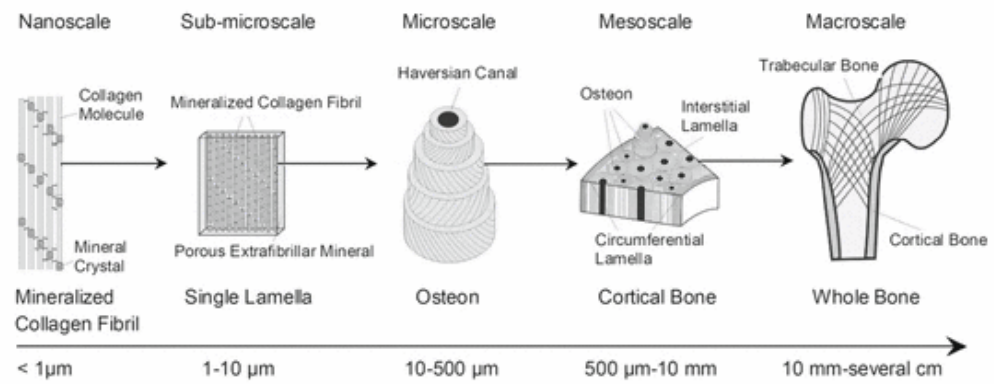


Figure 7: The multi-level, or multi-scale, structure of bone

In addition to intramembranous ossification, by which the "flat" bones of the axial skeleton – or those responsible for protection - are fashioned, appendicular bones – or those responsible for locomotion - are formed through a process known as "endochondral ossification." As the name would suggest, endo (*within*) chrondral (*cartilage*) ossification is characterized by the infiltration and eventual take over of a pre-existing cartilage model. Initially, this type of bone formation is nearly identical to intramembranous ossification in that a primary ossification center (a cluster of osteoid secreting osteoblasts) is established within surrounding tissue (in this case cartilage as opposed to mesenchyme), a periosteal "cuff" is formed, and bone is built appositionally from the inside out. It is only in its final stages where the endochondral model begins to differ substantially, allowing for the elongation or "length-wise growth" necessary for "long bone" formation.



Figure 8: The embryo at seven weeks

By Carnegie Stage 18, or by day 42 post-fertilization (week seven), hyaline pre-cartilage "condensations" have begun to form the digital rays (the finger and toes) and chondrification has commenced in the clavicles (the medial end) and vertebral bodies, as well as in the humeri and radii (*Figure 8*). These condensations rapidly form the pre-cursors, or templates, for the shape each bone will eventually take (O'Rahilly and Muller 2010; The Visible Embryo 2016; The Virtual Human Embryo 2016; UNSW Embryology 2016).

Approximately 15 days after the initiation of intramembranous ossification, by day 52 post-fertilization (Carnegie Stage 22, or week eight), the calcification of those cartilage models has begun and will continue several decades into adult life (Scheuer and Black 2000)(*Figure 9*).



Figure 9: The embryo at eight weeks

As stated earlier, once endochondral ossification begins it follows the same basic pattern as does intramembranous ossification. Blood vessels arrange themselves around the target tissue – in this case, the hyaline cartilage model – and by doing so convert the existing perichondrium to periosteum. The highly vascularized periosteum once again forms a bone collar, encircling the site while exploratory capillaries spread out into the cartilage and "hijack" the chondrocytes within. These chondrocytes swell, cease to function normally, are forced into mitosis (multiplication by division), and begin to secrete alkaline phosphatase – the same enzyme that enabled calcification (through the formation of calcium salts) in the intramembranous model. This deposition, in turn, interrupts the diffusion of oxygen (and other nutrients) that the cartilage relied upon for survival, effectively isolating and asphyxiating its innermost cells. Starved and suffocated, these cells soon die and become hollowed shells of their former selves. This collapse is referred to as "cavitation." It is upon these remnants, then, that osteoblasts – ushered in with the encroaching vascularization of the "periosteal bud" - colonize and calcify the necrosed cartilage scaffold, establishing a locus of spongy (or trabecular) bone, this time not through aggregation but by appropriation. This small but expanding island

of bone is now the primary ossification center. Secondary ossification centers later form in the same way as the first, but on either end of the long bone (as opposed to the center), and attach themselves at known intervals. This enlargement of the primary ossification center, both in height and circumference, as well as the fusion of secondary ossification centers, is the mechanism of long bone growth and maturation (*Figure 10, below*).

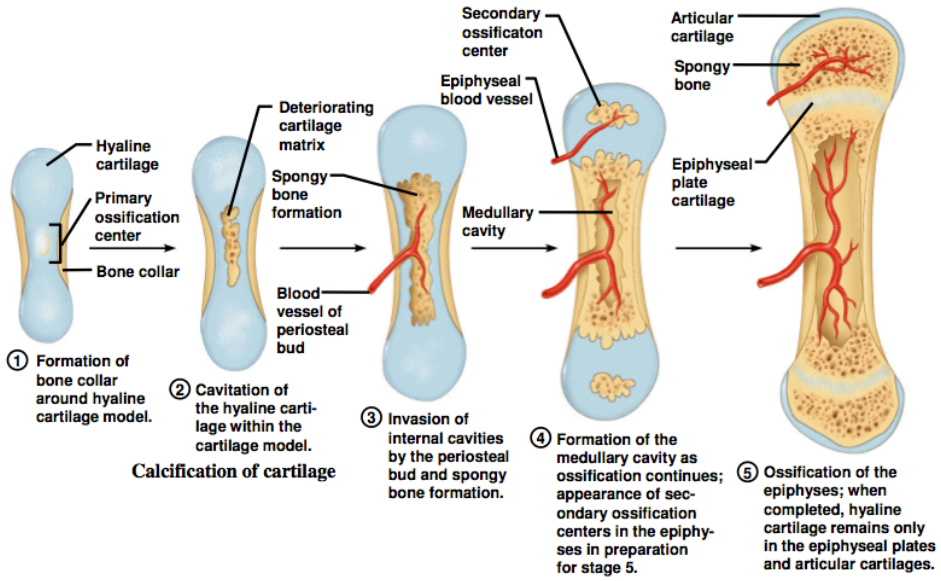


Figure 10: Appositional growth through secondary ossification centres

As the center, or "mid-shaft," expands, it increases both "interstitially" (length-wise) and appositionally (concentrically). Interstitial growth is achieved through the gradual pushing of calcification (and cartilage) towards the ends, or "epiphyses," of growing bone and is accomplished through the precise and systematic orchestration of several "zones." These zones – the "resting" zone, where activity has yet to commence; the "proliferation" zone, where the

chondrocytes divide; the "hypertrophic" zone; where they swell and secrete their alkaline phosphatase (allowing for crystalisation); the "calcification" zone, where the osteoblasts begin to mineralize the osteoid matrix; and finally the "ossification" zone, where the process concludes in new bone formation - follow the same collagen replacement model as that described above (*Figure 11*).

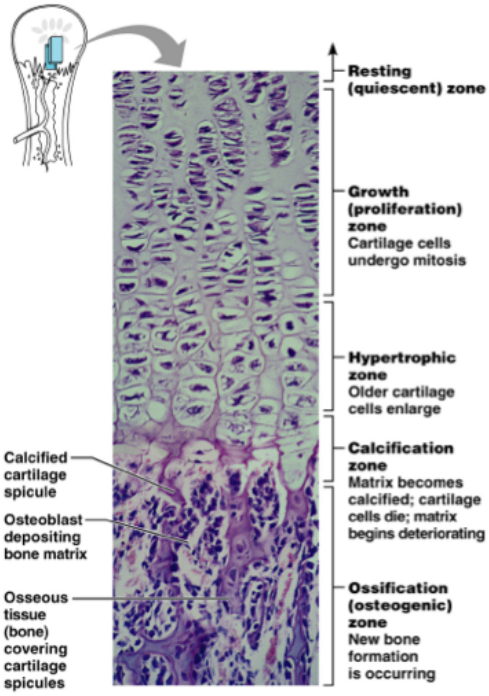


Figure 11: Histological growth "zones" in the formation of bone

Unique to interstitial, or length-wise growth, however, is that, due to the rapid ballooning of the chondrocyte population in the "proliferation zone" (and then the further swelling of those already crowded cells in the "hypertrophic zone"), when forced against the rigidity of the periosteum, which remains fixed and unyielding, these excess chondrocytes suddenly occupy more space than is available and are, consequently, squeezed either upwards or downwards, taking on the appearance of stacked "towers" of cells which direct growth along the long axis, or "diaphysis," of the bone - simply for lack of any other option.

Meanwhile, as bone is increasing length-wise it is also increasing in thickness. This type of growth takes place through the symbiotic partnership of two simultaneously opposing yet coordinating forces: osteoblasts building bone,

moving inwards, and osteoclasts resorbing bone, moving outwards. Osteoblasts, differentiated from progentitor cells lining the underside of the periosteum, secrete bone matrix onto the external bone surface to lay down sheets of mineralized collagen, or "lamellae." These lamellae are identical in structure to those found in the osteon complex, but as they encircle the entire bone instead of a single osteon, they are known as "circumferential lamellae" as opposed to simply "lamellae" or "concentric lamellae" (*Figure 12*).

In opposition to the accumulation of these circumferential lamellae is osteoclastic resorption, or the enzymatic removal of bone, along the endosteal (inner) surface of the diaphysis (shaft). Crucially, to ensure that growth remains proportional, these two processes communicate and act in tandem – as one outer lamella is deposited, an equal amount of inner trabeculae is resorbed. This deposition and resorption dyad, therefore, effectively serves to push bone formation outward, expanding its circumference without sacrificing its functionality or strength, while at the same time establishing the long hollow "medullary cavity" necessary for the eventual reserve and production of yellow marrow (*Figure 13*).

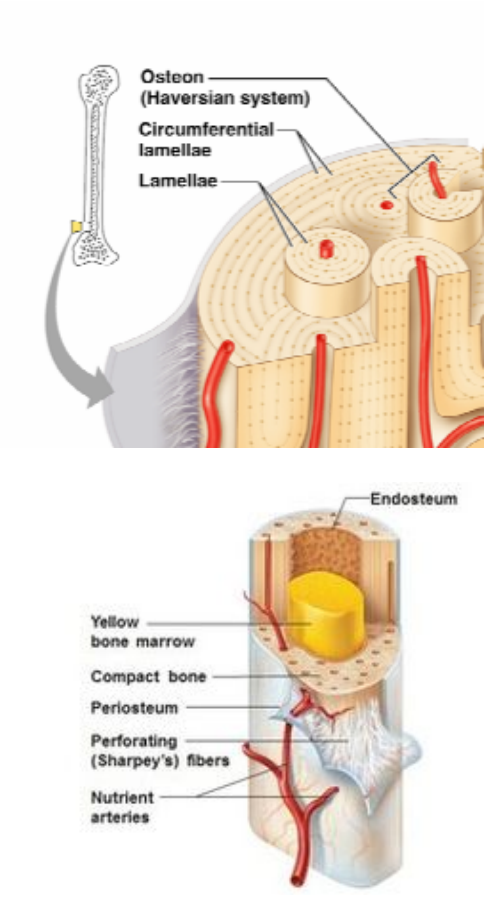


Figure 12: Detail of concentric lamellae and medullary cavity

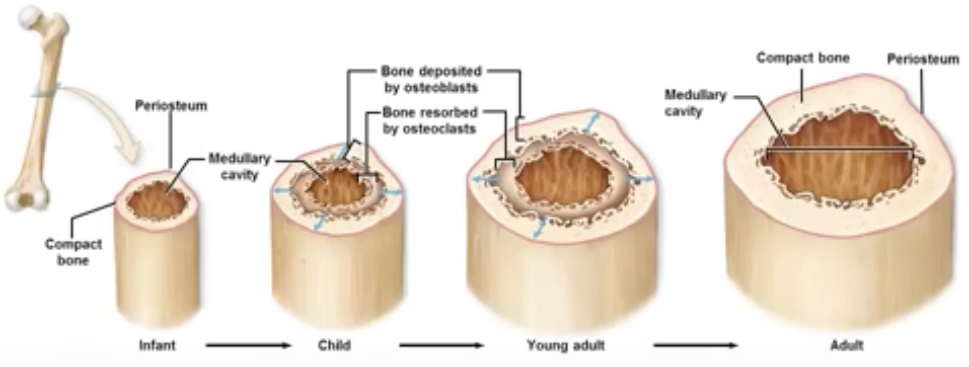


Figure 13: The deposition / resorption dyad and its creation of the medullary cavity

It is in this way – through interstitial and appositional growth – that bone increases both in overall size and length, guiding maturation from the earliest embryo all the way through to the third or even fourth decades of life (through the completion of late fusing secondary ossifications, i.e. the medial clavicle and pubic symphysis, respectively)(Falys and Prangle 2015; Brooks and Suchey 1990; Scheuer and Black 2000). It is also, aside from tooth development (which follows its own trajectory and, therefore, will not be discussed here), the primary method of determining age from the human skeleton.

1.2 Age Estimation from the Human Skeleton

As previously stated, bone, as a living tissue, maintains a perpetual state of motion and is never static. This is because, in addition to its role in supporting, protecting, and moving the body, it is also responsible for blood production (both red cells, which supply and transport oxygen around the body, and white cells, which provide the body's immune defense) and mineral regulation, namely the exchange of calcium and phosphorus. Furthermore, thanks to the

formation of the "medullary cavity" as discussed in the previous section, long bones are also able to store and release energy in the form of lipids (Abrahams 2007; The Cleveland Clinic 2016). As a result, the human skeleton is ceaselessly forming (through osteoblast activity) and reforming (through osteoclast activity), thus being, itself, ceaselessly formed and reformed – approximately 20% of the skeleton is remodeled yearly (The Cleveland Clinic 2016). Over the course of a lifetime, therefore, any given bone in the human body will find itself on a spectrum moving through "generation" (growth), "stasis" (neither growth nor senescence), and, finally, "degeneration" (decline). Where on this spectrum an individual falls at the time of the anthropologist's examination determines what age he or she will be estimated to be.

1.2.1 Generation (Young Adult)

As discussed in previous sections, bone growth begins in the embryo around the sixth week of development and continues in the form of both interstitial and appositional growth, linked and working in tandem, throughout childhood and into early adulthood. This growth is linear and, therefore, occurs at predictable rates. To estimate age from the fetal skeleton, then, direct measurements (as opposed to visual inspection or non-metric traits) are considered to be most accurate and so remain most frequently used. These measurements include both overall length ("crown-rump length," "crown-heel length," etc.) as well as the length and width of individual bones (most commonly the femur). These measurements – once available only from the accumulation of autopsy specimens - have now, for decades, been observed and documented *in utero*

through the use of non-invasive ultrasound, allowing not only for the verification of accuracy on vastly larger, irrefutably aged samples but also for the development and dissemination of simple, easy-to-implement regression and prediction equations (foundationally Fozekas and Kosa [1978] but see also Schaefer et al. [2009] for an excellent synthesis of methodologies). While caution and population specific metrics must be applied, as maternal environment (primarily nutrition) has been shown to impact upon the developing skeleton (Krishnamachari and Iyengar 1975; Godfrey et al. 2001; Chang et al. 2003; Black et al. 2013), for very young individuals, long bone measurements - coupled with soft tissue development, if available (see Piercecchi-Marti et al. 2004 and Chikkannaiah et al. 2012) - remain the most effective methodology for the estimating of pre and perinatal (skeletal) age.

Sub-Adults

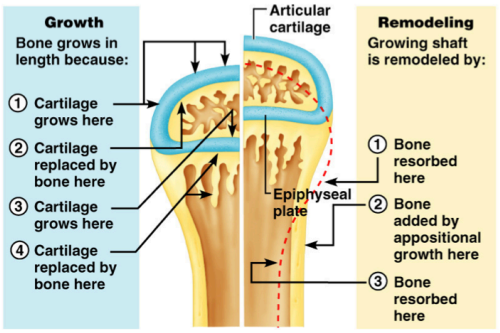


Figure 14: Appositional growth in sub-adults

In estimating age in sub-adults,[5] however, emphasis shifts from dimensional measurements (though still valuable; see Mays 1999 or Scheuer and Black 2000) to suture closures (such as the spheno-occiptal synchondrosis of the

[5] Distinctions exist in other biological and socio-centric fields between the terms "juvenile" (considered pre-pubescent children) and "adolescent" (post-pubescent children, i.e. "teenagers"), which share the commonality of "childhood" but represent two separate decades of pre-adult development - as well as two vastly different places in culture and society. For the same reason "immature" is also problematic. To avoid confusion, the term "sub-adult" will be used here.

basilar skull) and the status, or degree, of "epiphyseal union" exhibited by individual bones. As described in the previous section, interstitial growth pushes calcification towards the proximal (upper) and distal (lower) ends of developing bones - creating length - while secondary ossification centers close in towards the middle (concurrently increasing in girth due to appositional growth) (Figure 14, above). This sandwiching, the result of equal encroachment from above and below, creates a flat disc of intermediary hyaline cartilage referred to as the "epiphyseal (or growth) plate." The area in which this occurs is called the "metaphysis."

These centers, and with them their epiphyseal plates, then ossify once maximum length (which is genetically pre-programmed but subject to hormones) has been reached, creating the bones of an adult (*Figure 15, below*). It is in this way that the skeleton, which at birth begins with approximately 300 bones (from an initial 806 ossification centers in the fetus), finishes maturity with an eventual total of 206.

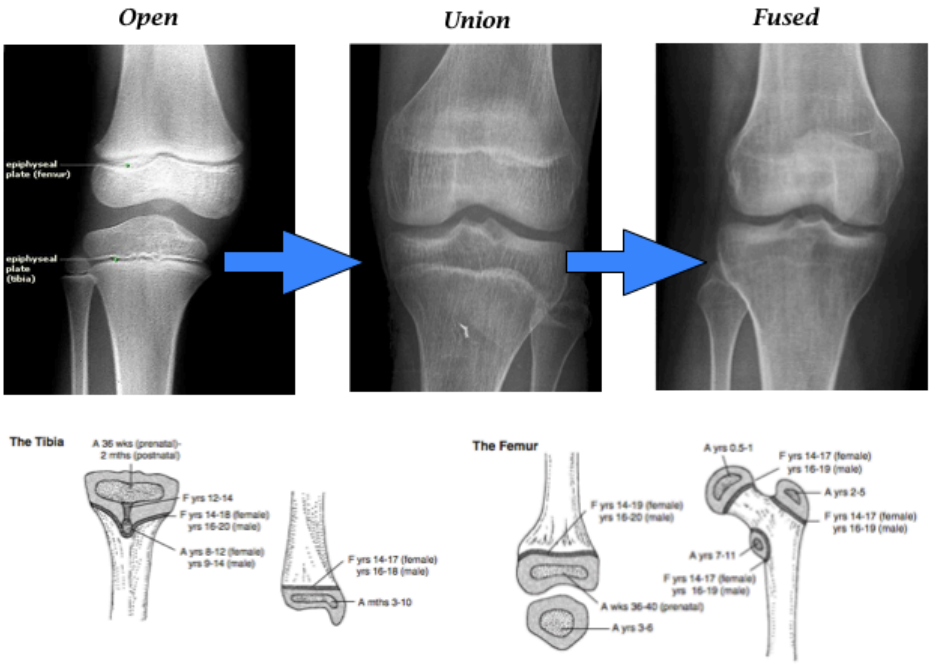


Figure 15: The progression of epiphyseal closure as illustrated by the tibia and femur

The timing and degree of these fusions are particularly useful to forensic anthropologists as they, when taken as a whole, represent a "snap shot" of the skeletal development reached by a particular individual at the time of examination (Scheuer and Black 2000; Schaefer et al. 2009). For example, used most regularly for skeletal assessments of questioned sub-adults are the left hand and wrist (*Figures 16 and 17, below*). In theory, if all relevant epiphyses have fused, the owner of the hand and wrist in question must then be at least 14-17 years of age, if female, or 16-20 years of age, if male (taking circumstances such as malnutrition, disease, or environmental stress into account)(Greulich and Pyle 1959; Tanner and Whitehouse 1975, Gertych et al. 2007; Thodberg et al. 2009; Gilsanz and Ratib 2005).

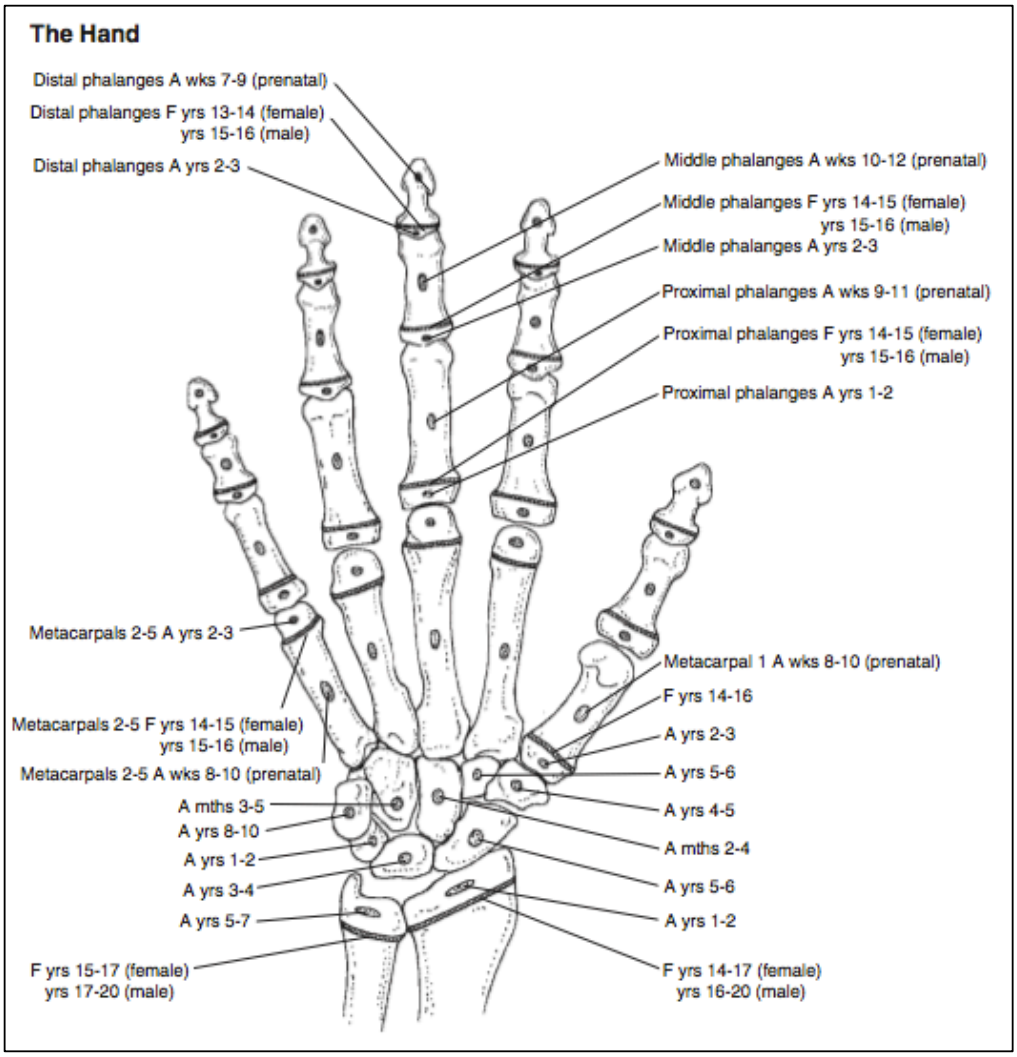


Figure 16: Appearance of ossification centers and epiphyseal fusion timing for the wrist and hand (from Scheuer and Black 2000)

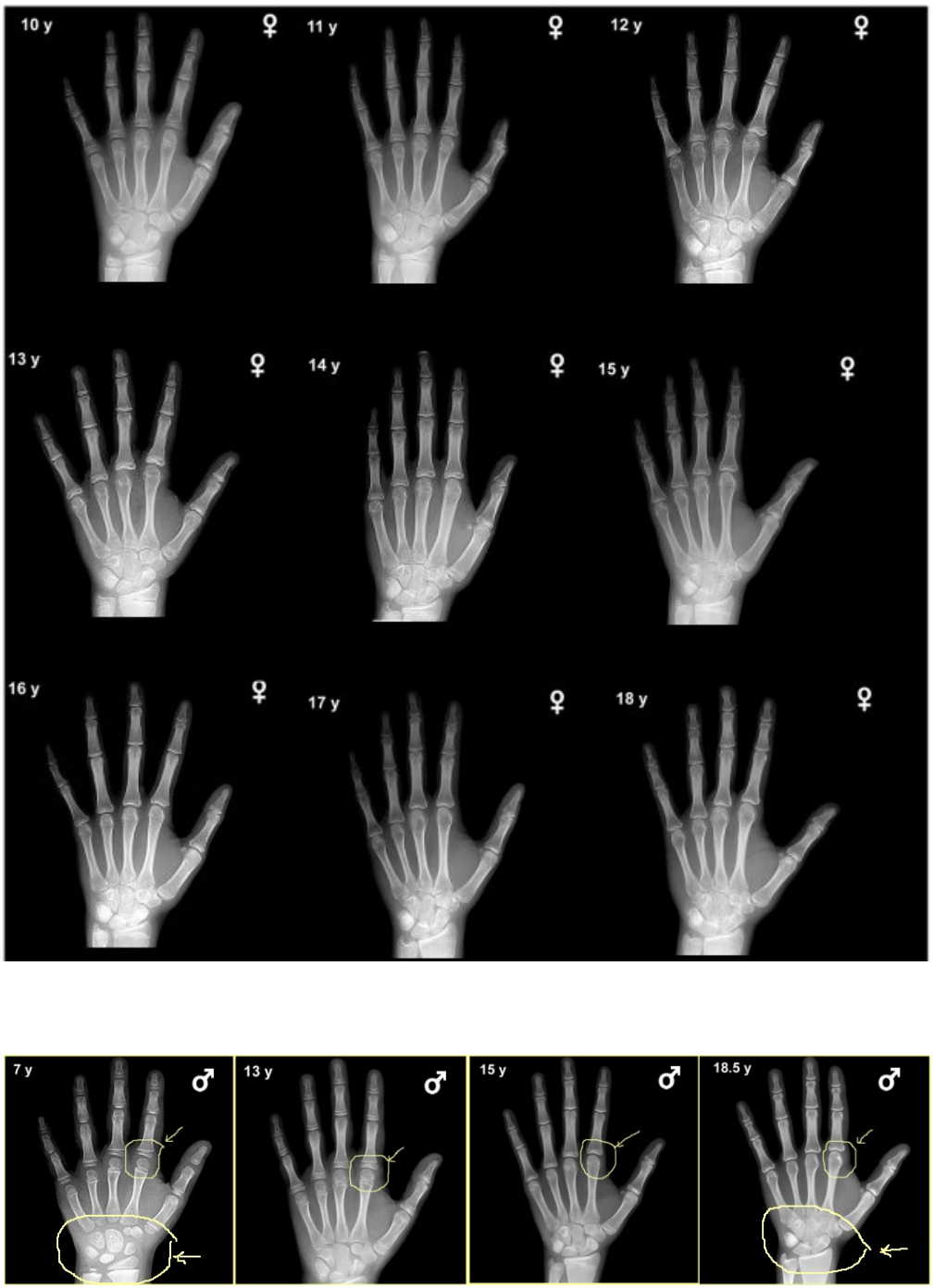


Figure 17: Appearance of ossification centers and epiphyseal fusion timing for the wrist and hand as seen by radiograph (Gilsanz and Ratib 2005)

These types of epiphyseal "markers" exist for virtual every bone in the body and every stage of childhood, with entire books devoted to the subject (Scheuer and Black 2000; Schaefer et al. 2009); however, as this thesis deals primarily with age estimation in adults (or those aged 18 years or older), and takes particular interest in those for whom dental eruption has ceased to be diagnostic (those generally aged 21 or older), the author will focus only on the maturation indicators particularly useful to that demographic.

When the dentition has fully erupted and all epiphyses have fused at both the proximal and distal ends of the humerus, radius, ulna, femur, tibia and fibula, as well as in the hands and feet, an individual is commonly assumed to be an "adult." Once this has been determined, the next question naturally becomes - "How old of an adult? Is this a young adult (typically between 18 and 30 years, exemplifying "generation"), a middle-aged adult (approximately 30 to 50 years, exemplifying "stasis"), or an elderly adult (50 or 60 plus years, exemplifying "degeneration")?"

Under 25

One of the first areas consulted to answer this question is often the "iliac crest," or the superior margin of the wing of the ilium (one of the bones that make up the pelvis)(*Figure 18*).

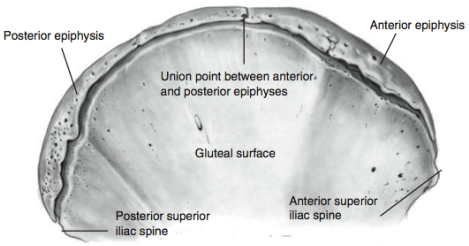


Figure 18: Epiphysis of the iliac crest (from Scheuer and Black 2000)

Perhaps the single best indictor of "under 25 years" versus "over 25 years," estimating age from the iliac crest is characterized by the appearance, attachment, and fusion of a distinct, separately forming apophysis, or "flake."

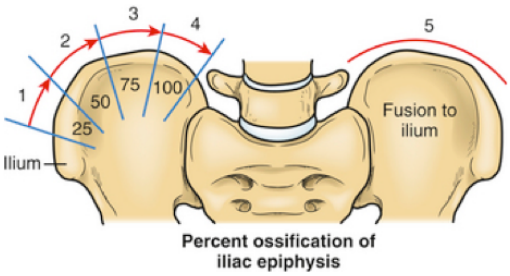


Figure 19: Illustration of iliac fusion by Risser stage

This flake, the combined product of two endochondral ossification centers, "ossifies in a stepwise fashion from anterolateral to posteromedial along the iliac crest" (UpToDate 2011)(*Figure 19*). In more clinical settings this is documented by the assignment of zero to five "Risser Sign" grades or stages (after Risser's work with scoliosis in 1958). "Risser grade 0 corresponds to no ossification. As depicted above, grade 1 describes up to 25 percent ossification; grade 2 describes 26 to 50 percent ossification; grade 3 describes 51 to 75 percent ossification; grade 4 describes greater than 76 percent ossification; and grade 5 describes full bony fusion of the apophysis" (UpToDate 2011). These grades, in turn, correlate to population specific ages.

In addition to the Risser Sign, more forensically based methodologies (tailored more towards identification than treatment) are also widely in use. These include primers such as Scheuer and Black (2000) and Schaefer et al. (2009), which place apophyseal fusion between 14 and 21 for females and between 17 and 22 years for males (*Figure 20)*, as well as dry (Suchey and

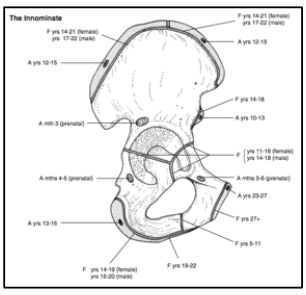
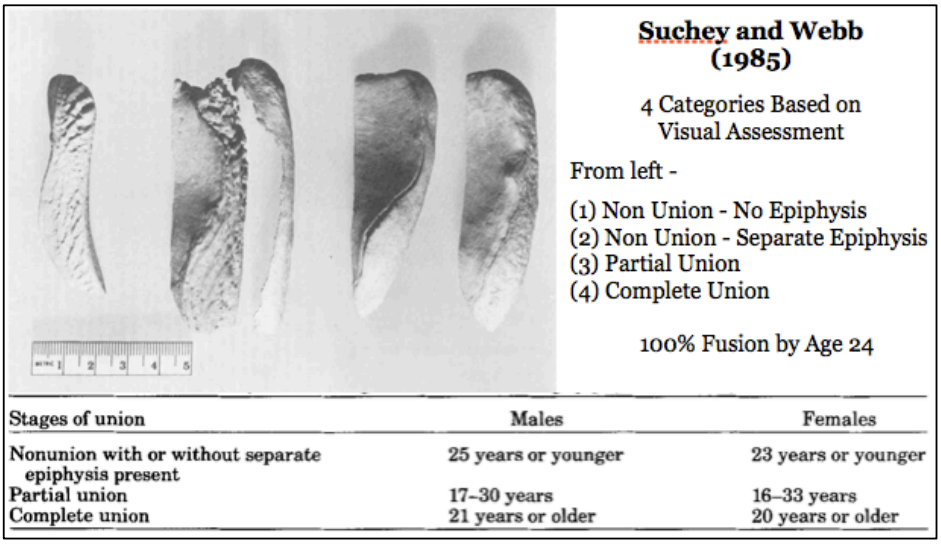


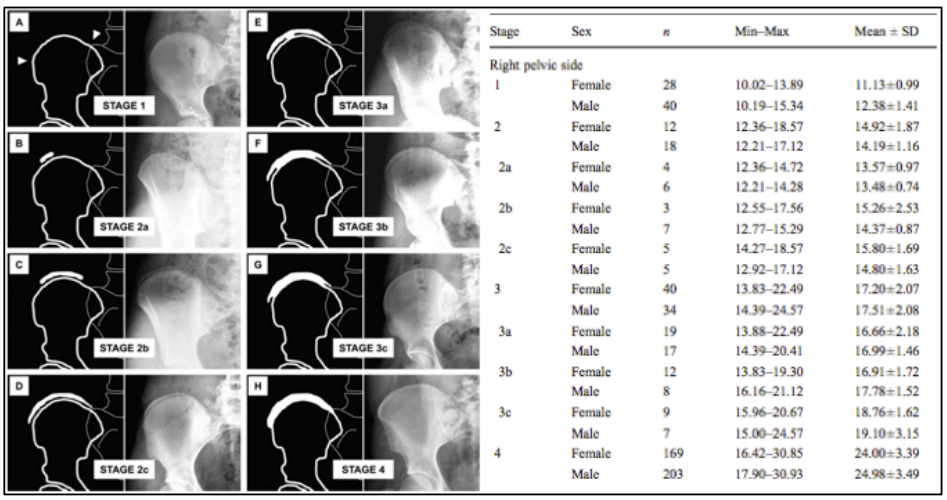
Figure 20: Fusion of the innominate (from Scheuer and Black 2000)

Webb 1985) and in vivo (Schmidt et al. 2011; Wittschieber et al. 2013) bone observations (*Figures 21, 22*, and *23*, respectively).



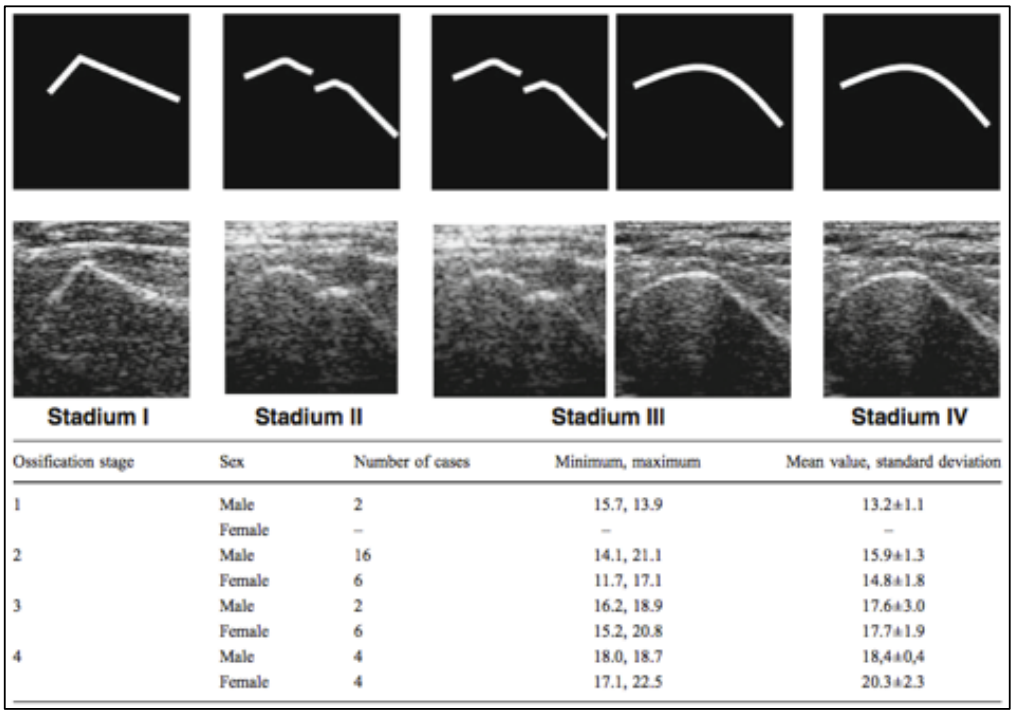
Stages of union	Males	Females
Nonunion with or without separate epiphysis present	25 years or younger	23 years or younger
Partial union	17–30 years	16–33 years
Complete union	21 years or older	20 years or older

Figure 21: Iliac epiphyseal / Apophyseal fusion timing (Suchey and Webb 1985)



Stage	Sex	*n*	Min–Max	Mean ± SD
Right pelvic side				
1	Female	28	10.02–13.89	11.13±0.99
	Male	40	10.19–15.34	12.38±1.41
2	Female	12	12.36–18.57	14.92±1.87
	Male	18	12.21–17.12	14.19±1.16
2a	Female	4	12.36–14.72	13.57±0.97
	Male	6	12.21–14.28	13.48±0.74
2b	Female	3	12.55–17.56	15.26±2.53
	Male	7	12.77–15.29	14.37±0.87
2c	Female	5	14.27–18.57	15.80±1.69
	Male	5	12.92–17.12	14.80±1.63
3	Female	40	13.83–22.49	17.20±2.07
	Male	34	14.39–24.57	17.51±2.08
3a	Female	19	13.88–22.49	16.66±2.18
	Male	17	14.39–20.41	16.99±1.46
3b	Female	12	13.83–19.30	16.91±1.72
	Male	8	16.16–21.12	17.78±1.52
3c	Female	9	15.96–20.67	18.76±1.62
	Male	7	15.00–24.57	19.10±3.15
4	Female	169	16.42–30.85	24.00±3.39
	Male	203	17.90–30.93	24.98±3.49

Figure 22: Iliac epiphyseal / Apophyseal fusion timing (Schmidt et al. 2011)



Ossification stage	Sex	Number of cases	Minimum, maximum	Mean value, standard deviation
1	Male	2	15.7, 13.9	13.2±1.1
	Female	–	–	–
2	Male	16	14.1, 21.1	15.9±1.3
	Female	6	11.7, 17.1	14.8±1.8
3	Male	2	16.2, 18.9	17.6±3.0
	Female	6	15.2, 20.8	17.7±1.9
4	Male	4	18.0, 18.7	18,4±0,4
	Female	4	17.1, 22.5	20.3±2.3

Figure 23: Iliac epiphyseal / Apophyseal fusion timing as seen by ultrasound (Wittschieber et al. 2013)

While several concurrent techniques exist for estimating age from the maturation of the iliac crest, general consensus most commonly places completion of fusion between the ages of 20 and 24 years (McKern and Stewart 1957; Webb and Suchey 1985).

When cross-referenced with the completion of the medial border of the scapula (which fuses between the ages of 17 and 22), the proximal ends of the rib bones (which fuse between the ages of 17 and 25), the costal notches of the sternum (which fuse between the ages of 18 and 25), the second transverse ridge of the sternum (which fuses between the ages of 15 and 25), the sacro-iliac epiphysis of the sacrum (which also fuses between the ages of 18 and 25), and the long bones, ischial tuberosities, hands, feet, lateral clavicles, and annular rings of the vertebrae (all of which should be fully fused by the age of 20 or 21), an

individual fitting this fusion profile may be confidently placed in the first half of, or even midway through, their third decade of life (Todd 1920; Albert and Maples 1995; Scheuer and Black 2000).

25 to 35

To place an individual into the second half of their "20's," as opposed to the first, the anthropologist must look to both the sacrum and the clavicle.

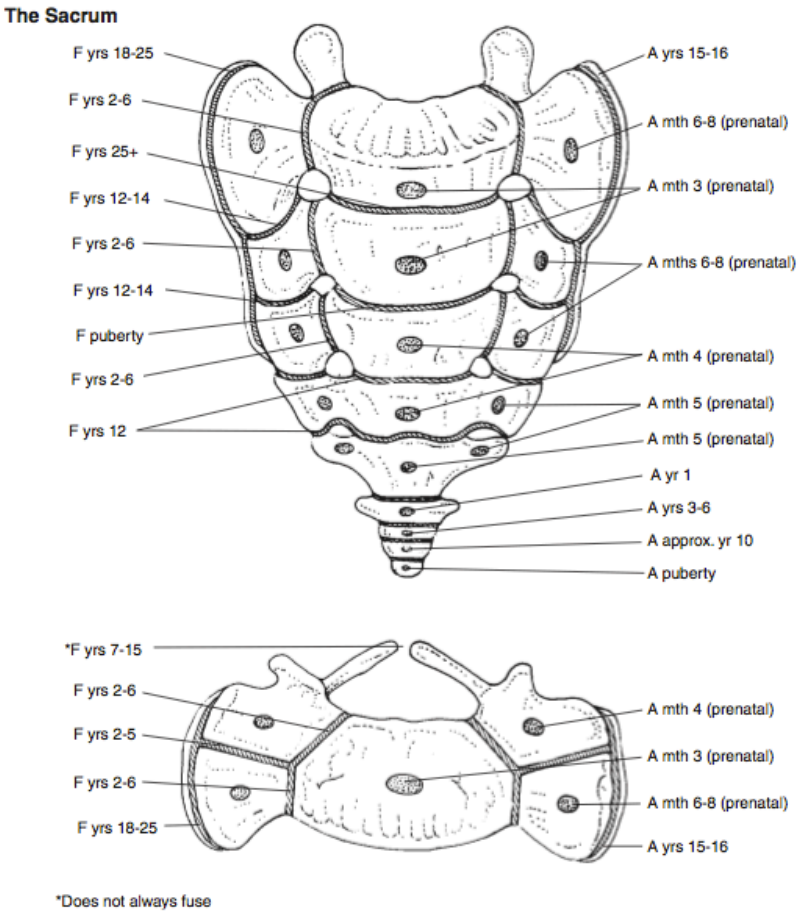


Figure 24: Epiphyseal / Apophyseal fusion of the sacrum (from Scheuer and Black 2000)

As can be seen in Figure 24 (*above*), during the second half of the third decade of life - that is, between the 25th and 30th years - the first and second sacral vertebrae become fused through endochondral ossification and interstitial growth. Additionally, according to Passalacqua (2009), it is during this time that "the vertebral ring is [also] fusing or completely fused to the body of S1." Furthermore, the auricular surface, which until this point had displayed a "billowy" or "youthful" appearance with fine granularity, has begun to move towards transverse organization and a courser granularity (Buikstra and Ubelaker 1994; Passalacqua 2009), a trait that will continue into advancing age.

Also moving towards completion during the late "20's," so as to be fully finished by the first half of the fourth decade (between ages 30 and 35), is the medial aspect of the clavicle (McKern and Stewart 1957; Suchey and Webb 1985; Schaefer 2008; Schultz et al. 2005)(*Figure 25*). This is the skeleton's *second to last* active epiphysis, though it is seldom regarded as such (Bass 2005; Ramey Burns 2007; Byers 2010)(this thesis contends that the pubic symphysis represents the final fusion in that it remains active up to two decades longer).

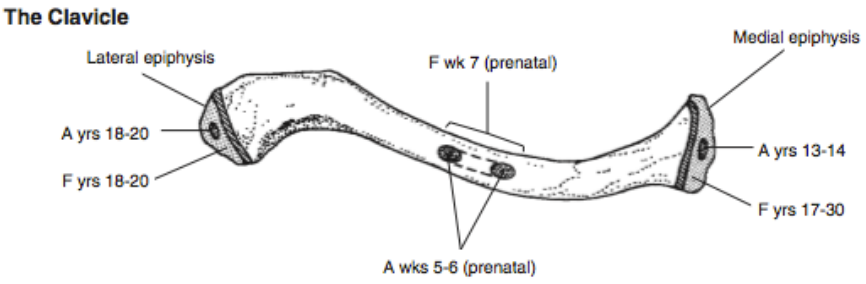


Figure 25: Epiphyseal / Apophyseal fusion of the clavicle (from Scheuer and Black 2000)

The medial clavicle ossifies in much the same way as the iliac crest, with the appearance and gradual attachment of a secondary ossification center in the form a "cap" or "flake" (*Figure 26, below*).

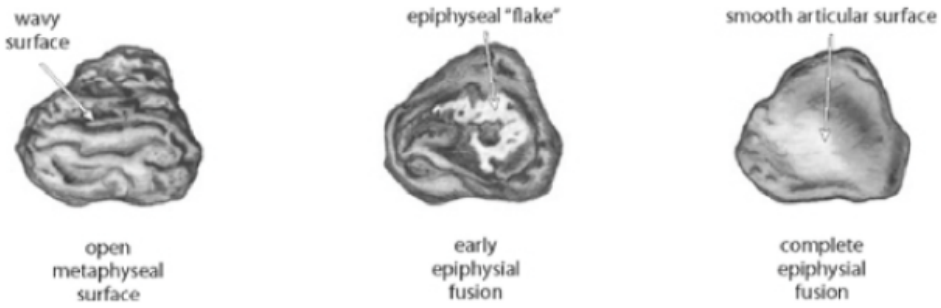


Figure 26: Flake formation at the medial clavicle (from Ramey-Burns 2008)

Like the flake of iliac crest, which may be correlated to chronological age through the observation of its graduated expansion over the epiphysis, so too may the step-wise development of the flake of the clavicle be used for the same purpose and in the same way (*Figure 27*).



Figure 27: Fusion progression at the medial clavicle (Todd 1928); from left (1) Non Union – open epiphysis, (2) Non Union – separate epiphysis, (3) Partial Union, and (4) Complete Union

Appearing and ossifying separately during the first half of the teenage years (around 13 or 14 years of age), this flake begins adhering to the epiphyseal surface by the mid to late "teens" (generally by the age of 16) and is present, to some degree, in all individuals by the age of 25 (Todd 1928; McKern and Stewart 1957; Schaefer et al. 2009; Kellinghaus et al. 2010; Shulz et al. 2013).

As stated by ageing from the clavicle's first proponent, however, "as for the date of the first ossification of the epiphysis, there is no practical significance... Nature is quite unconcerned over this as she is over the date of commencing ossification of the carpals and tarsals" (Todd 1928:34), a sentiment later echoed by McKern and Stewart who, due to variability (open epiphyses as late as 21 years and full closures as early as 23 were also observed), cautioned it was "impossible to associate particular ages with stage of [clavicular] union - only a probable age for beginning union (17) and a definite age for the last stage of union (30) can be given" (1957:92). In 1985, Suchey and Webb found cases of final closure as high as 34 years in their sample (particularly in the case of African American females). It is the completion of fusion, then, by providing "above / below" distinctions, that is most beneficial to the estimation of age.

When estimating age from the adult skeleton, therefore, individuals exhibiting total fusion of the medial clavicular epiphyses – combined with the first and second sacral vertebrae - may be placed with reasonable confidence to between the latter half of the third decade and the first half of the fourth decade of life (or to between 25 and 35 years of age).

35 to 45

Only one area of the skeleton continues to exhibit epiphyseal activity after the fusion of the medial clavicle has ceased - that of the pubic symphysis.

"The pubic bone may be the last component of the human skeleton to complete its development, with the secondary centre(s) of ossification appearing at puberty and the physis closing variably in the 3rd decade of life... Following physeal closure, the pubic bone continues to remodel and may only achieve [its] fully mature form at around 45 years of age" (Read 2013).

The pelvis consists of three discrete segments which, together, form what is known as the pelvic "basin"; the right innominate, the left innominate (both themselves a sum of an ilium, ischium, and pubic bone), and the sacrum, centrally uniting the two. As demonstrated by Figure 28 *(right)*, the sacrum occupies the posterior portion of the pelvic complex while the two innominate bones, informally referred to as the "hip bones," curve around and down to meet at the midline. The site where these two bones come together, separated only by a central disc of fibrocartilage, is the pubic symphysis. Like the intervertebral discs of the spine, the pubic symphysis "cushions against compressive loads, provides shock absorption and contributes to passive stabilization" while, at the same time, acts as "a central hub of mechanical [cross-braced] linkage between the abdominal wall and the lower limbs" (Read and Anderson 2007). Unlike the shoulder or knee, this is a non-moveable joint; however, as its purpose is to absorb shock and to evenly distribute weight between the upper and lower halves of the body, the cartilaginous disc of the



Figure 28: The pubic symphysis

pubic symphysis does not ossify but, instead, retains some "give" (about 2mm in the average person).

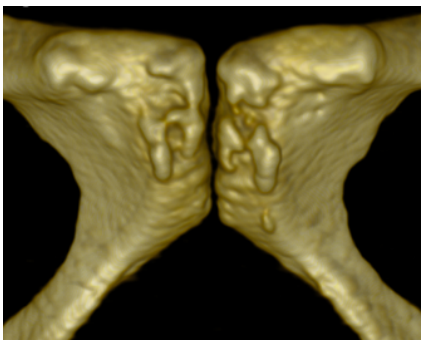


Figure 29: Ossific Nodules



Figure 30: Age related transformation at the pubic symphysis (young to old)

It is in this cartilage that the pubic bones' secondary ossifications appear, this time in the form of multiple "ossific nodules" (as opposed to the plate-like "flakes" of the iliac crest and clavicle), which may remain small and discrete or combine to form larger conglomerates (Figure 29). This activity – the appearance of secondary ossification centers, their attachment, and their eventual fusion to the adjacent pubic bones – occurs universally (regardless of population) and in a cumulative linear fashion, allowing for an observation of that progression over the course of an individual's lifetime (*Figure 30*), thereby enabling reasonably predictable correlations with chronological age. Because of this regularity, the pubic symphysis continues to be "the most preferred region" (Garvin and Passalacqua 2012) for estimating age from the human skeleton as "even when used in conjunction with other criteria [it] is universally considered to be the most reliable" (Meindl and Lovejoy 1985:29). As this topic will be discussed extensively in future sections, however, only a brief summary will be provided here.

Currently, the most frequently used technique for age estimation from the pubic symphysis is that of the "Suchey-Brooks Method for Ageing the Os Pubis" (1990)(Meindl et al. 1985; Falys and Lewis 2011; Garvin and Passalacqua 2012), a six phase system introduced as a revised simplification of Todd's (1920) original ten phases. Both methods rely primarily on visual "picture matching," or placing the bone being assessed into one of six categories based upon how closely it resembles an illustration on the page (and / or plaster casts). A text description is also provided. From this combination of picture and text, the observer chooses the phase (I, II, III, IV, V, or VI) he or she feels is the best fit. The corresponding age range for that phase then becomes the estimated age for that individual (*Figure 31, below*). Further revisions to this technique include the addition of a seventh phase (Berg 2008; Hartnett 2010), with re-evaluated age ranges throughout.

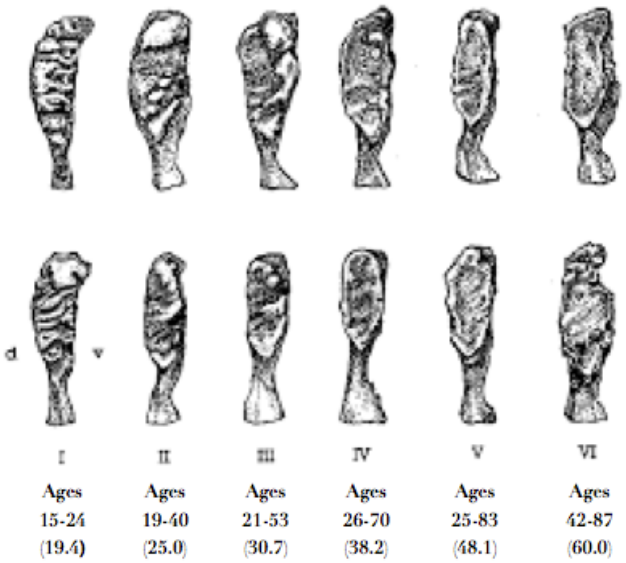


Figure 31: Suchey-Brooks (1990) phase distinctions with corresponding ages

In critique of this method, however, McKern and Stewart (1957) cautioned that this type of approach (condensing several diagnostic features to create an "overall" impression) "… result[s] [in] a static method of age determination, since variability of each feature [is] lost, only those pubic bones which are close to the typical can be aged with reasonable accuracy" (McKern and Stewart 1957:72) adding that "if a particular pubis does not happen to coincide quite closely with one of Todd's ten phases, then it is not possible to age it" (1957:31). Instead, they advocated their own component-based system by which each feature would be assessed and scored separately (then tallied at the end for a composite score), allowing for individual variation. At the time, this was seen to be an improvement over Todd's inflexible archetypes; however, repeated testing has proved that the simpler "picture matching" techniques yield consistently higher levels of intra and inter-observer accuracy (Meindl et al. 1985b; Angel et al. 1986; Katz and Suchey 1986; Lungmus 2009; Wade et al. 2011) than do more complicated quantitative component-based systems, perhaps because they are exactly that – simpler. Pasquier et al. (1999) term this the "simplicity / accuracy ratio."

While the "Suchey-Brooks Method" remains the most popular technique by far, it has also been widely criticized for its ambiguity and "unacceptably large" (Cox 2000) age ranges. In terms of coverage, for example, the Suchey-Brooks method will almost invariably be accurate regardless of the practitioner's estimate as "the accuracy of the … Suchey-Brooks method [is] based on the width of the estimated intervals of age, which include most of adulthood, making it difficult for the chronological age to fall out of the estimated interval" (Rissech et al.

2012:154). Perhaps the most egregious example of this is Phase V, which places a questioned female anywhere between 25 and 83 years of age - a span of 58 years. This limitation is further exacerbated by the tendency to assign multiple phases when faced with uncertainty or lack of confidence (Garvin and Passalacqua 2012), compounding the problem by widening the final range designation even more. In light of these issues, many practitioners have come to acknowledge that, while still technically accurate, "the [Suchey-Brooks] ranges are so broad with such enormous areas of overlap, [they become] almost meaningless" (Cox and Mays 2000: 69).

While the ideal technique for estimating age from the pubic symphysis continues to be a subject of debate, that epiphyseal "generation" finishes before the 50th year of life remains indisputable. In re-evaluating Todd's 1920 study, Meindl et al. (1985) concurred that "the 30 to 35 [year] age period [was] clearly modal for the '*active epiphyseal phase*' (Todd stage VI)," and that transition to the subsequent "*immediate post-epiphyseal phase*" (Todd stage VII) began between the ages of 36 to 40 years. For Suchey - Brooks, cessation of epiphyseal activity occurs within the period of transition between phases three (still active) and four (complete)(mean age 38.2) and for Hartnett (2010), whose phases closely mirror those of Suchey-Brooks, fusion occurs by the age of 43.26 (the mean age for her phase 4). Gilbert and McKern (1973) place (female) epiphyseal completion between the (mean) ages of 35.60 (component III, stage 3 – still active) and 39.9 (component III, stage 4 - complete).

Several revised techniques, both archetypal and component-based, have since been introduced with varying success (Hanihara and Suzuki 1978; Meindl et al. 1985; Berg 2008; Hartnett 2010; Chen et al. 2008, 2011; Slice et al. 2015; Dudzik and Langley 2015). Regardless of author or paradigm, however, the (mean) age for epiphyseal completion at the pubic symphysis appears, for all methods, to center around the age of 40 years (Todd / Meindl et al: 36-40; McKern and Stewart: 39.9; Suchey-Brooks: 38.2, Hanihara and Suzuki: 38; Hartnett: 43.26), never breaching the 45th year of life. Therefore, if epiphyseal activity has ceased at this location (as well as everywhere else), the practitioner may, with reasonable certainty, estimate an individual to be within their late fourth or early fifth decade of life, or between the ages of 35 and 45 years (though technique specific ranges will span significantly higher to account for error).

1.2.2 Stasis (Middle Adult)

Between the ages of 45 and 55 - 60 years (most commonly, though variation is ever present) the skeleton enters into a brief period of relative "stasis," or "state of inactivity or equilibrium" (Oxford English Dictionary 2016) caused by "the equal action of opposing forces or influences" (Dictionary.com), wherein all epiphyses have fused but somatic decline (deterioration) has yet to begin in earnest. Todd (1920) called this period "pre-degenerative" (following directly after "immediate post-epiphyseal"), but it is more commonly referred to as "middle adult." This phase could also be termed "(visual or) macro stasis" (as

this refers to that which may be seen by the naked eye; at the micro level, of course, bone is never static).

During this equilibrium, overall density may begin to decrease (though not drastically), and micro-porosity and mild irregularities may occur - for instance, the outline, or "rim," around the pubic symphysis may begin to scallop or "ruffle" (Suchey-Brooks [1990] phase 5b; Berg [2008] phase 5; Hartnett [2010] phase 5 or 6, depending on density; Chen et al. [2011] score 2 for variables "H" and "I") and the vertebral bodies may begin to exhibit signs of wear (Watanabe and Terazawa 2006; Listi and Manhein 2012) – however, in each case, shape and structural integrity remain intact. During this period, the skeleton appears to be neither "young" nor "old," as generation has ceased but *de*generation remains, as yet, unremarkable. Individuals fitting this "fully fused but not in noticeable decline" profile may be confidently estimated to be in stasis, or (roughly) between 45 and 60 years of age.

1.2.3 Degeneration (Old Adult)

It is not until the age of approximately 60 years that degradation begins to appear in earnest in the form of osteophytic changes, pathology, and structural erosion of increasing severity. In contrast to the generating skeleton, for which each fusion brings a greater degree of ageing clarity, in the declining skeleton this senescence brings with it obliteration, variability, and an inconsistency that, for many practitioners, renders the universal application of standard methods difficult or even impossible. Because of this, much of the literature has

traditionally stopped at this age (or even earlier). Indeed, in a five year audit (2004-2009) of 200 articles appearing in three field leading journals (the *International Journal of Osteoarchaeology* [IJO], the *American Journal of Physical Anthropology* [AJPA], and the *Journal of Archaeological Science* [JAS]), "the three most frequently cited maximum ages were 50+ (43%), 45+ (29%) and 40+ (8%)… [with only] 18% of studies stat[ing] [that] age could be assessed over 55 years" (Falys and Lewis 2011:710). In addition to the above mentioned deterioration, this is likely also fundamentally influenced by the lack of 60+ individuals included (fewer than 25%) in *any* of the original development samples for the methods most widely used today – Todd, 24%; Suchey-Brooks, 15%; Iscan and Loth, 19%; Lovejoy et al. 13% – resulting in final phases dismissed as "simply '50+' with [little to] no description of the degenerative changes that occur once an individual has reached full maturity" (Merritt 2014:17). This also helps to explain why so many of the early (pre-millennial), foundational methods consistently underage - making age estimation in older individuals doubly problematic. Falys and Lewis (2011) go on to concede, however, that "… some techniques do allow for older ages to be identified (i.e. public symphysis, auricular surface, sternal rib ends), and some scholars make the most of these older ranges; however, when suggesting an age over 46+ years [when epiphyseal fusion ends], it is essential to provide justifications for identifying the very old if we are to accept these observations" (Falys and Lewis 2011:713).

Paradoxically, in estimating age from post-epiphyseal adults, these justifications rely almost exclusively upon skeletal degradation – the very thing that,

according to the literature, disqualifies age estimation in the first place. However, though historically disregarded as overly variable, generic, and obstructive, degeneration has recently proven to be anything but and, thanks to a steadily growing interest and an increasing inclusion of older individuals in modern studies, this tide may be, at last, be turning.

If osteoblasts are the heroes of bone *generation* (see 1.0.4.1, "generation"), then osteoclasts are the villains of *de-generation*. The skeleton owes approximately 80% of its mass to dense, osteon-filled (two-thirds by volume) cortical bone (for protection and movement) and approximately 20% to weaker, but more tensile, trabecular bone (for mineral release and hematopoieses)(Morgan et al. 2013). As discussed in previous sections, both types of bone – whether compact or spongy - contain embedded messenger, or relay, cells called osteocytes (upgraded osteoblasts strategically positioned around the lamellae), which receive and transmit information via a vast network throughout the skeleton (approximately 42 billion, forming 23 trillion connections which, if laid end to end, would stretch 175,000 km [Buenzli and Sims 2015]), similar to the synaptic connections of the nervous system. At any given time, approximately 80% of this trabecular bone and approximately 95% of this cortical bone is "inactive" (Morgan et al. 2013); however, when the skeleton experiences hormonal (such as a drop in serum calcium levels) or mechanical stress (such as a kick to the "shin" or a fall from a height, or even something as small as a muscle pulling too strenuously against its attachment or an alveolar micro-fracture due to normal talking or chewing [Wolff's Law]), these osteocytes are responsible for sensing the amount of damage done and for the organization of a proportionate repair

response. It is posited that this "sensing" takes place via the disruption of normal fluid "flow" within the canaliculae network, resulting in violent waves (on the micro-scale) that damage local osteocytes through cellular-level shearing - leading to premature death (apoptosis)(Rochefort et al. 2010). These sudden, unexpected deaths, then, induce local osteoclasts and osteoblasts into action, initiating a reparative process known as "remodeling."

As proposed by Parfitt et al. (1996), this type of skeletal "damage control" follows an observable, cyclical pattern – that of "quiescence" (inactivity), "activation," "resorption," "reversal," "formation," and then, finally, quiescence again (*Figure 32*, *below*).

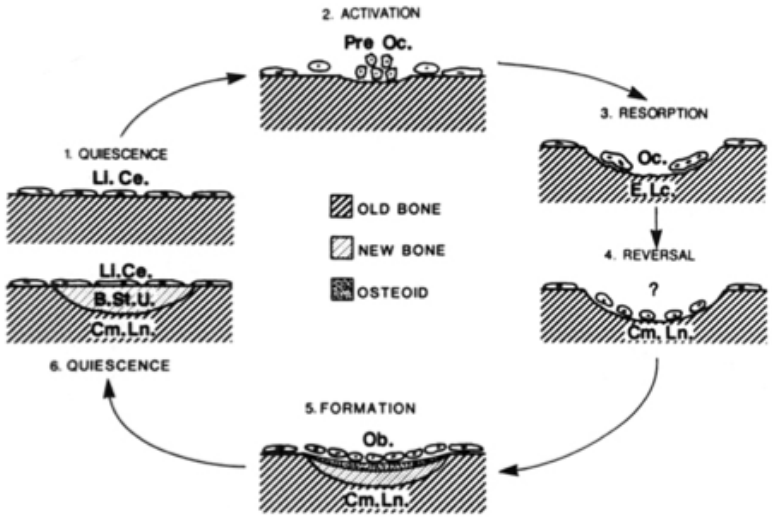


Figure 32: Cycle of bone remodelling

Upon sensing an insult (or imbalance) local osteocytes differentiate dormant hematopoietic mononuclear (stem) cells through the expression of PU.1, "a transcriptional activator specifically involved in the differentiation and

activation of macrophages" (Cell Signaling Technology, Inc. 2013)(macrophages being the type of white blood cells that swallow up, digest, and rid the body of unwanted material - from the Greek *μακρος* ["large"] and *φαγειν* ["to eat"], or "large eaters"). "For intra-cortical remodeling, [these] osteoclast precursors travel to the [damaged] site … via the circulation [chemotaxis], gaining access … by either a Volkmann or Haversian canal. In trabecular remodeling, [this] occurs at the sites that are apposed to bone marrow cells" (Morgan et al. 2013:14). Once there, this transcription factor allows for the "switching on" of the target cell's c-fms ("colony stimulating factor") and RANK ("receptor activator of nuclear factor kB") surface receptors (in a slightly hypoxic environment), to which M-CSF (or "macrophage colony stimulator factor") and "RANKL" (the ligand of RANK, made by osteocytes) can bind, respectively (what decides the fate of this pre-osteoclast, however, is the amount of opposition the RANKL receives from its inhibitor, osteoprotegerin, or "OPG" - if OPG is more prevalent than RANKL at the time of osteoclastogenisis, the unfinished cell will fail to activate and undergo apoptosis, if RANKL is more prevalent the cell will continue on to maturity). The activation of NF-kB signaling, the result of RANKL binding to the RANK receptor, then activates several downstream "TRAP" (tartrate resistant acid phosphatase) and "TRAF" (TNF [tumour necrosis factor] receptor associated factor) cascades deep within the inner cell, which, in turn, create the osteoclast's characteristic multi-nucleation (and subsequent size)(*Figure 33, below*). In the adult skeleton, this first phase, "activation," occurs about every 10 seconds (Morgan et al. 2013:14).

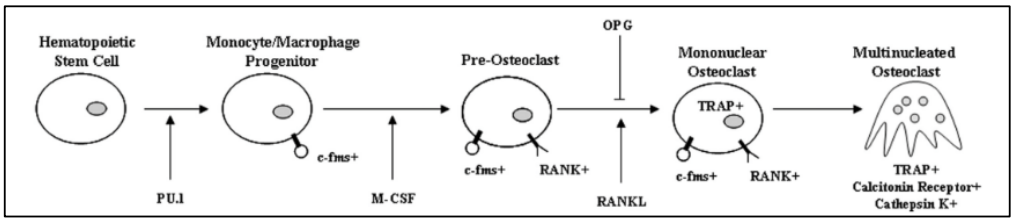


Figure 33: Creation of an osteoclast

Once matured, the osteoclasts set about repairing any site-specific damage surviving osteocytes deem in need of mending. This initiates the second phase - "resorption."

To begin resorbing, osteoclasts must first isolate and sequester the area in need of repair - and ONLY that area – leaving the surrounding (undamaged) bone untouched. To do this they attach to the bony surface (directly above the fracture site) by developing "complex, dynamic adhesion structures known as 'podosomes' ... contain[ing] actin filaments, cortactin, Wiscott-Aldrich syndrome proteins, paxillin, CD44 and attachment-related protiens such as vinculin and talin" (Arnett 2013). These podosomes then gravitate towards one another to form a tightly fitted line, creating a "dense ring known as the 'sealing zone.' [This 'sealing zone'] anchors the osteoclast ... to its substrate and isolates a compartment beneath the cell where [targeted] bone destruction [will] take place" (Arnett 2013:154). Within the sealing zone, the osteoclast then gastrulates to form what is known as a "ruffled

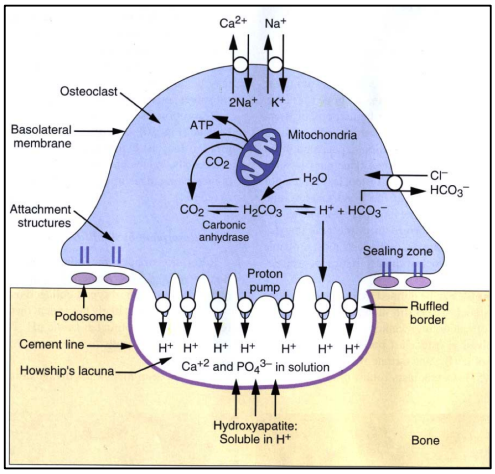


Figure 34: The osteoclast and its action

border," a series of folds intended to dramatically increase its surface area. From these folds the osteoclast then proceeds to systematically break down both the organic (collagen) and inorganic (hydroxyapitate) constituents of the bone by secreting a controlled, concentrated bath of acids (primarily cathepsin K) and enzymes (metalloproteinases), effectively dissolving and digesting the osseous tissue until there is nothing left (for a meticulously detailed summary of the chemistry of this process, see Arnett 2013). The empty, or "excavated," spaces this leaves behind are called "resorption pits (or bays)" or, alternately, "Howship's Lacunae" (*Figure 35*).

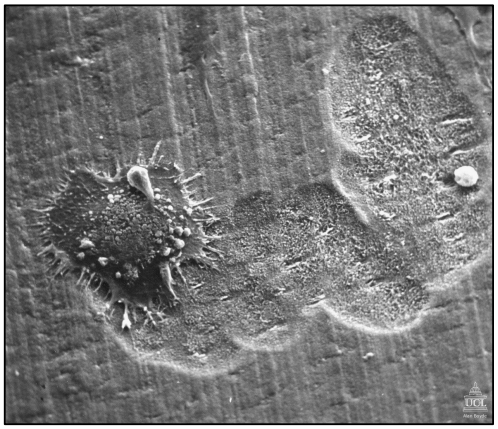


Figure 35: Resorption

As these huge, bone-eating cells carve their way through the damaged lamellae they do so in the form of "cutting cones" – so named for their pyramidal shape. Positioned at the front of these "cones" are approximately 10-20 osteoclasts, arranged conically, burrowing forward much like the bit of a drill. Directly behind them, in the vacuum created, lies an area known as the "reversal" zone. In "reversal" (Parfitt's third phase), the osteoclasts have done their part but the osteoblasts to follow in their wake (approximately 1,000-2,000 of them) have yet to be created. This reversal phase / zone, then, acts as a sort of "staging area," allowing the time (around 12 days) and space necessary for a "reversal" of purpose, ushering in the last phase - "formation" - with the differentiation and activation of osteoblasts, soon to be

depositing osteoid into the empty (resorbed) spaces and forming new bone as described in previous sections (Yuan, no date). This interdependent, reciprocal partnership between osteoclasts and osteoblasts (together referred to as "BMU's," or "basic multicellular units") is known as "coupling."

"Under normal conditions, the remodeling process of 'resorption' followed by 'formation' is closely coupled and results in no net change in bone mass. However, [while] the rate of cortical bone remodeling … may be as high as 50% per year in the mid-shaft of the femur during the first two years of life, eventually [it] declines to a rate of [only] 2% to 5% per year in older people" (Morgan et al. 2013:13). This drop in bone turnover occurs for several reasons, the first being that bone stem and precursor cells, like any other cells in the body, have a finite lifespan and can support only a limited, pre-determined amount of replication cycles before entering into decline. Additionally, the prevalence of those division cycles become fewer and farther between the older an individual becomes (Martin et al. 1970). As a direct consequence of this, fewer osteoblasts are created to offset the osteoclasts and, as a result, "the amount of bone deposited with each cycle of remodeling decreases" (Boskey and Coleman 2010:1338, referencing Szulc and Seeman 2009) with age.

A second reason for decreased bone remodeling in the degeneration skeleton is that quantity is not the only thing lost with division after a certain age, it affects quality as well (the "Hayflick phenomenon"). This is due to ever shortening telomeres (the end caps of each chromosome in the cell's nucleus), which lose a bit of their length each time a cell divides. Older cells will therefore, by default,

and by virtue of more divisions, have shorter telomeres than do younger cells and the shorter the telomeres, the less healthy and productive the cell. Bone produced by these older, less optimal cells is exponentially more "susceptib[le] to mechanical damage [due to decreased collagen cross-linking ability, resulting in a loss of strength; increased matrix waste debris in the form of "advanced glycation end products," or AGE's; larger crystals, less effective mineral composition, etc.], increased apoptosis [leading to inferior communication as well as an increase in the mineralization of vacated lacunae, making bone brittle and prone to fracture), alterations in intracellular signaling [primarily Wnt pathway connections, which are responsible for successful differentiations], and impaired regulation of gene expression" (Boskey and Coleman 2010). A third factor is that with the shortening of telomeres comes the increase of oxidation, a process detrimental to cellular health (telomeres provide a shield against free radicals, but as they disappear so to does that protection). Lastly, it has also been shown that, after the third or fourth decade of life, the body shifts away from producing osteoblasts and begins to focus its energy towards adipogenesis, or the accumulation of marrow fat - "mechanistically, there appears to be a predominant differentiation of mesenchymal stem cells (MSCs) into adipocytes at the expense of osteoblasts" (Demontiero et al. 2012). In other words, with age, the resources that were once going almost exclusively towards the creation of osteoblasts are now being funneled away and put towards the creation of fat cells instead. These factors – limited lifespan, depreciation through division, oxidation damage, and resource reallocation – collectively result in substantially diminished bone formation through the suppression or compromise of quality osteoblasts.

Contrastingly, while osteoblast production decreases with age, osteoclast production increases (Chung et al. 2014; Domentiero et al. 2012; Marcus et al. 2008; Oursler 2016). This is due in large part to the decline of OPG (osteoprotegerin), the receptor decoy of RANKL. As previously discussed, when OPG is expressed in greater concentration during osteoclastogenesis, the formation of that osteoclast is aborted. When RANKL is more prevalent, the osteoclast multi-nucleates and is allowed to continue on to maturity. This opposing yet coordinated system of "checks and balances" ensures that osteoclast production does not outpace osteoblast production, and vice versa. OPG, however, is produced by the osteocyte, which is itself a form of osteoblast. As more osteocytes die and fewer new osteoblasts are produced to replace them, the levels of OPG secreted by them, naturally, also declines. With less OPG to inhibit RANKL, therefore, osteoclast production increases by default. This is especially problematic for women, as OPG is also estrogen derived, magnifying this affect after menopause.

At the same time, as mentioned previously the ageing of cells (through multiple replications) also disrupts the efficacy of the Wnt signaling pathway, which is responsible for cell communication and differentiation. Because of this, the production of the protein sclerostin becomes poorly down regulated and, consequently, increases (similar to the proliferation of weeds if a garden is left untended). The purpose of sclerostin is to suppress bone formation by triggering osteoblast apoptosis. Under normal circumstances this is both helpful and necessary, as when expressed by newly embedded osteocytes during mineralization to ensure that osteoblasts don't overfill their BMU

(Moester et al. 2010). However, in ageing bone already compromised by the decrease of osteoblasts and the increase of osteoclasts, this addition only further contributes to and accelerates resorption imbalance. This, along with the drop in OPG regulation and the accumulation of hyaluronan, osteopontin, and AGE's in the extra-cellular matrix, may help to explain why osteoclasts have been shown to preferentially resorb older bone (Henriksen et al. 2007).

Taken together, these changes at the micro (cellular) level – the systematic decrease of osteoblast activity coupled with the subsequent rise of osteoclast activity – manifest at the macro (surface) level as a diffuse loss of overall bone mineral density (Perkins et al. 1994; Wade et al. 2011). While decreased density may also appear in younger individuals as a result of metabolic disruptions such certain pathologies or malnutrition, is most commonly associated with the advancement of age.

As bone removal continues unabated (unchecked by the "formation" that formally tempered it), trabecular struts begin to thin, creating a honeycomb of inner cavities, while, at the same time, outer cortical bone is also being resorbed. This degradation, from both outside and in, compromises structural integrity and increases risk of fracture (*Figure 36, below*).

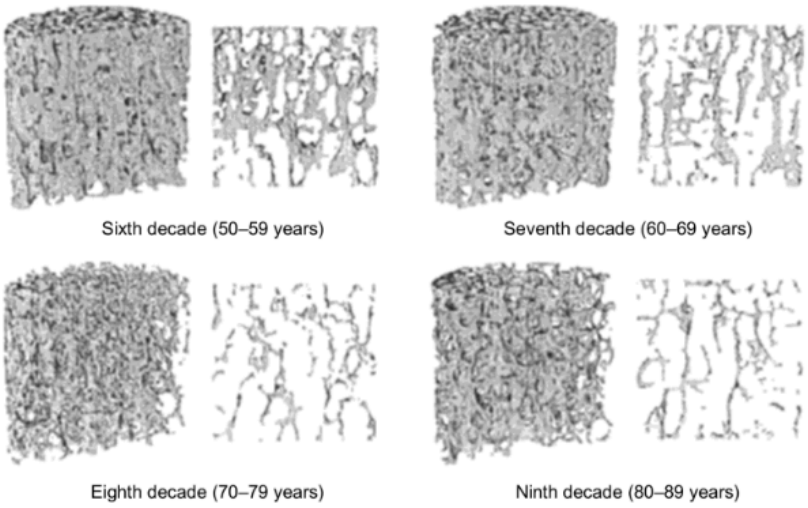


Figure 36: Age related decline in the structural integrity of bone

It is this undermining of internal and external integrity that becomes the hallmark of the degeneration phase in the "old" or "elderly" adult skeleton. Most notably, this degradation concentrates around joint articulations in the form of erosion, pitting, porosity, and granularity, as well as osteophytic and arthritic activity (the result of a lifetime of mechanical strain).

One such articulation is that of the fourth rib (Iscan and Loth 1985; Iscan 1991), or the fifth or third, with caution (Dudar 1993). Connected to the sternum through bars of hyaline cartilage (which provide the elasticity needed for breathing), these articulations, as do all things mechanical, wear with time and use. This wear, in turn, assumes the same type of continuous, linear, prediction-enabling progression exhibited in the fusing, or "generating," skeleton - except in reverse, and with wider intervals (*Figure X, right*). Beginning with an open epiphysis, this "costal" or "sternal rib end" technique may also be applied to the young. However, as the joint surface degrades from smooth, flat, and dense to irregular, cavitated, and attenuated, it is after the age of 30 - 35 (when the clavicle flake has attached), or, arguably 45 (when epiphyseal activity at the pubic symphysis has ceased), that this method displays its greatest utility for the estimation of adult age. Originally a component system (Iscan and Loth 1984), this method was later converted to the phase-based paradigm (Iscan and Loth 1984, 1986) for which a terminal phase of "60+" was provided. Later revisions, however, have pushed this final range significantly higher – with mean ages into the eighth (Iscan and Loth 1985, 1986; Iscan 1991) and even ninth decades of life (Hartnett 2010b), though overall ranges remain relatively wide. Use of the first rib as a similar indicator of age has been proposed (Kunos

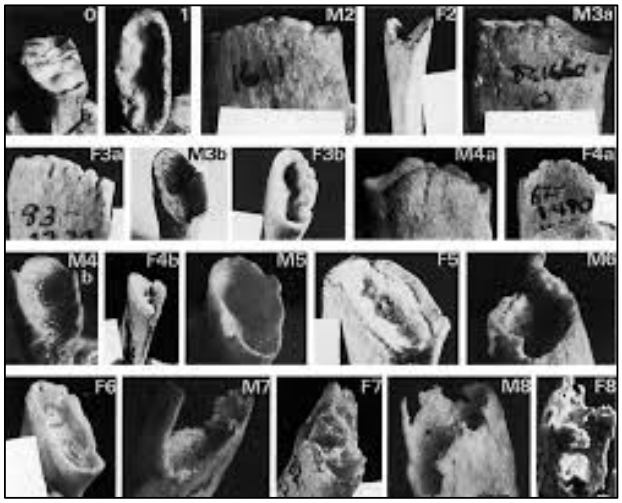


Figure 37: Age related changes to the sternal rib end (from Iscan and Loth 1985)

et al. 1999; DiGangi et al. 2009), but has so far achieved only limited success (Schmitt and Murail 2004; Sullivan 2012).



Figure 38: The auricular surface (degraded)

A second technique characterized by this trajectory of degeneration is that of the auricular surface. Located at the sacro-iliac junction of the pelvis, this flat, ear-shaped area of bone echoes the costal pattern above in that it begins life as a smooth, dense open epiphysis before the scales tip towards a series of destructive changes such as porosity, pitting, increasing granularity (roughness), and erosion – all stemming from a progressive loss of density, itself brought about by age-related deregulation of osteoclast activity (*Figure 38*). While, due to its position, the auricular surface preserves much better than some of the more fragile elements of the adult skeleton, many find it difficult to master (Osborne et al. 2004; San Millan et al. 2013; Murray and Murray 1991), thereby making its efficacy highly dependent upon the training and experience of each practitioner. Originally terminated at "60+" (Lovejoy et al. 1985), more recent revisions have yielded slightly older ranges - mean age 72.25 (stage VII, Buckberry and Chamberlain 2002) and mean age 73.05 (composite Group IV, Igarashi et al. 2005) - though these are, themselves, not without issue (large, overlapping ranges, small sample size, unclear scoring, inconsistency across age groups, etc.).

Another indicator considered – along with texture and appearance – when scoring the auricular surface is that of "lipping," or the bony build-up often observed around the edges of cartilagenous joints. Characterized as an irregular, raised or protruding rim or border, lipping is often one of the more emblematic features of advanced age (or wear) in the human skeleton. As such, in addition to its role in ageing the auricular surface, it has also proven integral to another seminal technique – that of age estimation from the pubic symphysis.

As previously discussed, the pubic symphyseal epiphysis completes active generation (fusion) by the 45th year of life. It then enters into a brief stasis, or "pre-degenerative," period until the ages of approximately 55 to 60, after which point, as befitting the trend, degeneration assumes focus. By this time, the face has broadened and flattened thanks to the "filling in" of its ridge and furrow system (through the attachment and assimilation of ossific nodules) and has adopted a smooth, slightly rounded "rim" or outline, which now serves to encircle and isolate it from its surrounding structures (chiefly the inferior and superior rami). Around the age of 55 years, this outline begins to swell (Suchey-Brooks phase 5.1) before quickly reducing again, leaving the rim irregular in shape, but unbroken (Suchey-Brooks phase 5.2)(*Figure 39)*. Marked deterioration begins shortly after as the porosity (first micro, then macro) that existed prior to this deflation now intensifies, creating

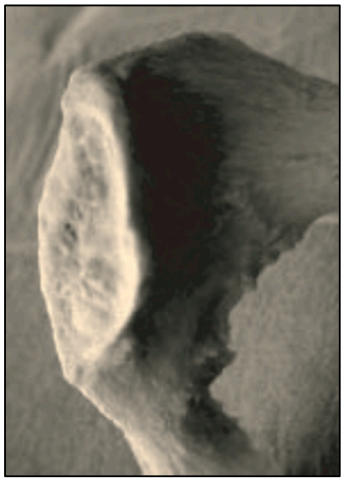


Figure 39: The symphyseal face with swelled, rounded rim (Suchey-Brooks phase V)

large “sink holes” as the bone’s compromised structural integrity – again the result of loss of density - undermine the surface from below.

Furthering this decline, bone is not the only tissue to diminish with age. Sarcopenia - the age-related atrophy of lean tissue mass (most notably that of skeletal muscle, but organ tissue is not immune) - is already present and accelerating in adults aged 60 and older (Patel et al. 2013; Cruz-Jentoft et al. 2014; Cooper et al. 2015). With less tissue (meaning fewer cells) to hold it, the amount of aggregate water in the body also decreases. “Water is the most abundant component of articular cartilage, contributing up to 80% of its wet weight” (Fox et al. 2009:463). This loss of water in older and elderly adults, therefore, contributes directly to the dehydration (and subsequent “shrinkage”) of cartilage. The bones of amphiarthroidal joints (such as the auricular surface and the pubic symphysis) are lined with hyaline cartilage (and are fibro-cartilage adjacent as well). Thinned by dehydration, this cartilage becomes more prone to wear and can no longer afford the same level of protection it once did, putting the bone beneath at greater risk for mechanical damage. This inevitable damage then leads to increased inflammation, which, in turn, leads to an inflammation response. This inflammation response (plus any actual damage) stimulates the periosteum, which initiates remodeling in an effort to fix the problem (Schett 2007). Finally, this repair results in the haphazard production of extraneous new bone (in the form of nodules referred to as “osteophytes”) in and around the joint surface. In the case of the pubic symphysis, these osteophytes accumulate around the outline of the face, where

innervation and vascularization are more plentiful (as its purpose is shock absorption, the inner disc must remain avascular to avoid injury).

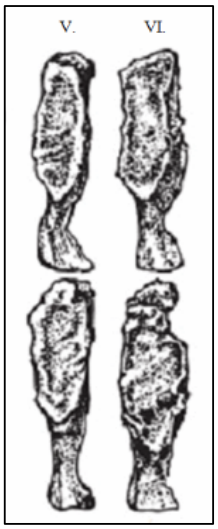


Figure 40: Comparison of Suchey-Brooks phases V and VI

This presence of osteophytic activity, together with a crumbling of the articular surface and the gradual erosion of the outline, typify the terminal phase of degeneration at the pubic symphysis (*Figure 40*). For Suchey and Brooks (1990), this translates to an age range of 42 to 87 years (with a mean age of 60). For Berg (2008), who split Suchey and Brooks' final phase (VI) in two, transition into phase six (his now penultimate phase) occurred at 50.3 years while transition into phase seven (his new terminal phase) occurred at 65.9 years. For Hartnett (2010), who also split Suchey and Brooks' final phase, these age ranges become 56 to 86 (mean, 72.34) for phase six and 62 to 99 (mean, 82.54) for phase seven.

Additional techniques relying upon the formation of osteophytes include those developed for the acetabulum (Rissech et al. 2006; Calce 2012), the vertebrae (Watanabe and Terazawa 2006), and the clavicle (Falys and Prangle 2015). Like the methods presented above, these techniques monitor the degradation trajectory of an individual skeletal element from epiphyseal closure through to complete degeneration. Unlike the above techniques, however, degeneration here is measured almost exclusively by the degree of osteophytic activity present.

Age estimation from the acetabulum (Rouge-Maillart et al. 2004; Calce 2012; Rissech et al. 2006) is assessed by three criteria: the amount of osteophytic activity between the lunate surface and the rim (which creates a deepening groove); the amount of osteophytic activity present at the lunate's superior border (and whether it destructures the rim); and the amount of osteophytic activity at the apex (measured by its elongation into the acetabular notch). By this method, when activity – in the form of erratic, disruptive overgrowth - is sufficiently pronounced in all three areas (*Figure 41*), it may be assumed that an individual is over the age of 65 years (category three - "Old Adult 65y+"), however no further precision or specificity is possible.



Figure 41: An acetabulum exhibiting osteophytic activity

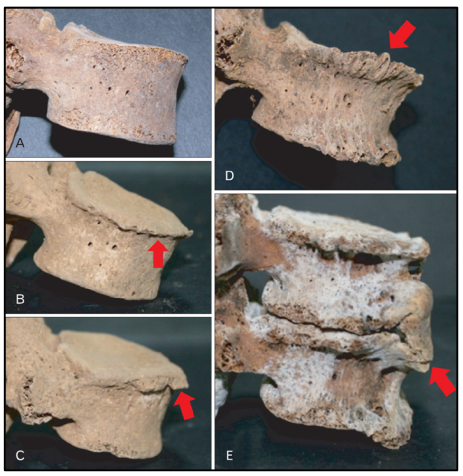


Figure 42: Vertebral bodies exhibiting osteophytic activity

Unfortunately, the same must be said when ageing from the vertebrae (*Figure 42*). In their 2006 study, Watanabe and Terazawa palpated and radiographed 138 adult males and 87 adult females (at autopsy), scoring them on a scale of 0 – 3 "based on the height of the process of vertebral column, which represented spur, lipping, and bridging of osteophyte formation at the superior and inferior margins of the vertebral bodies" (Watanabe and Terazawa 2006:156). These scores formed the basis of

the "osteophyte formation index," a regression equation from which they concluded "in all the parts of the vertebra, there was a significant correlation between [osteophyte] score value and age" (Watanabe and Terazawa 2006:156). With confidence intervals of 68%, the authors state that males fitting the criteria for their terminal stage, "3," generally fell between the ages of 60 and 80 (the penultimate decade assessed), leading them to believe "osteophyte formation progresses even after the age of 60" (Watanabe and Terazawa 2006:159). In seeming contrast, however, they further report that none of the 87 females examined over the course of their study exhibited the degree of osteophytic activity necessary to reach that final level (though this may due in part to the vagueness of score 2, which reads simply "degree between scores 1 and 3"). From this, Watanabe and Terazawa advocate their method as useful tool for the estimation of age in the elderly. In contradiction, however, while investigating the potential of vertebral osteophytic growth as a method for ageing themselves, a separate team of researchers came to the opposite conclusion, stating that "… osteophytosis and osteoarthritis are [indeed] significantly correlated with age; however, the relationship is not strong enough to yield predictive power for establishing age beyond a general estimate" Listi and Manhein 2012:1539).

Finally, in revisiting age estimation from the medial aspect of the clavicle, Fayls and Prangle (2015) utilize progressive degeneration and the degree of osteophyte formation in an effort to extend the its utility to the

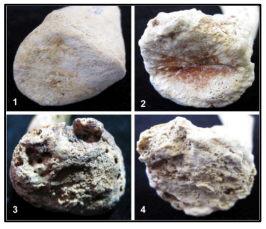


Figure 43: The medial clavicle exhibiting osteophytic activity

mature skeleton (*Figure 43*). Similar to the Buckberry and Chamberlain (2002) method for ageing from the auricular surface, this technique individually scores porosity, granularity, and osteophytic activity before condensing those composite scores into a series of phases. Using this technique, based solely on degeneration, a validation study of 56 specimens (conducted by the authors) yielded results of 96.4% to within the 95% confidence interval. While this study doesn't escape some of the pitfalls common to other methods – most notably large, overlapping, and, in this case, inconsistent female age ranges (47 years for phase II, though only 4 years for phase V) – it nevertheless presents a positive step forward regarding ageing in mature adults in that it focused specifically and exclusively on older individuals, or those occupying the end of the generation – stasis – degeneration spectrum (allowing for mean ages well into the ninth decade of life).



Figure 44: Ectocranial sutures

Additional techniques for ageing the adult skeleton that warrant mention include: age estimation from the suture lines of the skull (*Figure 44, left*), both "endo," (Acsadi and Nemeskeri 1970) and "ecto" (Perizonius 1984; Meindl and Lovejoy 1985) (though, due to wide variability and a propensity for sutures to remain open as often as they close regardless of age, this method has been largely abandoned unless no other options are available [Brooks, 1955; Key et al. 1994; Garvin and Passalacqua 2012]); age estimation from the sacrum (Passalacqua 2009) (though this describes only general age-related change such as macro-porosity and loss of density and ends at "50+" years); age

estimation from the patella (Sakaue 2008) (though the author himself admits that "the method of age-at-death estimation developed in [his] study was [vague and] not very accurate": 50), and, lastly, the histological counting of osteons (Kerley 1965; Thompson 1979; Stout and Paine 1992; Cho et al. 2002) (though invasive, expensive, time-consuming, and highly subject to dietary health and lifestyle, differential remodeling rates between bones ["asymptotes"], and the interpretation errors of inexperienced practitioners) (Lazenby 1984; Pfieffer et al. 1995; Paine and Brenton 2006; Villa and Lynnerup 2010)(*Figure 45, below*).

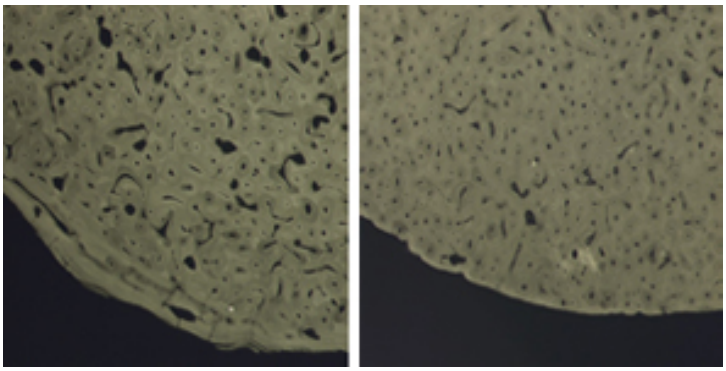


Figure 45: Histological slices enabling the counting of osteons

As illustrated by the above methodologies, age estimation from the degenerating "old," or "elderly," adult skeleton remains fundamentally split between those who believe no useful information may be gathered after a certain age (as degeneration is often considered too variable and inconsistent to be reliable) - that age being as early as the completion of epiphyseal closure (45+) or as late as the onset of meaningful deterioration (60/65+) - and those who believe that degeneration may, in itself, be diagnostic, capable of pushing the ageing threshold much higher, even up into the final decades of life. In the literature, this divide also appears to separate larger schools of thought, and

even disciplines, with traditional physical anthropologists and bio-archaeologists more often advocating the former (most likely due to the poorer preservation of dry, friable archaeological bone) and forensic anthropologists and forensic radiologists more amenable to the latter (most likely due to their work with more well preserved, "fresh," and living bone). Additionally, many of the seminal "50+" or "60+" techniques in current use were originally developed on archaeological or (if not at the time, now) historical samples - and continue to be tested and re-tested on (often the same) archaeological or historical samples - even though, as stated by Falys and Prangle, "by using a catch-all age bracket of 46+ years for all 'older adults,' archaeological age distributions do not accurately represent the record of older-aged adults" (Falys and Prangle 2011:203). This sampling bias, then, may perhaps, above all, best explain the continued presence and persistence of the "45+," "50+," or "60+" age bracket despite mounting evidence (Berg 2008; Hartnett 2010a, 2010b; Falys 2014; Falys and Prangle 2015) that better precision in ageing mature adults may, indeed, be possible.

Of all the areas used to estimate age from the adult skeleton perhaps none suffers from this ambiguity more acutely than the pubic symphysis. As has been shown, much of the confidence surrounding current techniques rests upon the status of formation, attachment, and assimilation of secondary ossifications, or "nodules." Once that epiphyseal activity has ceased, however, and degradation (considered to be less consistent and, thus, less reliable) has begun, that surefooted fusion-based confidence abruptly ends - leading inevitably to the types of forensically and demographically unhelpful 36+ (McKern and Stewart

1957), 40+ (Hanihara and Suzuki 1978), 50+ (Todd 1920; Meindl et al. 1985; Byers 2010), and 60+ (Krogman 1962; Suchey and Katz 1986a; Suchey and Brooks 1990) "catch all" categories described above.

Not only do these terminal phases neglect at least one third of an individual's lifetime (life expectancy for the average Briton is expected to reach 85.7 years for men and 87.6 years for women by the year 2030)(Bennett et al. 2015), but, in addition, they also tend to underage the older individuals they do include (Djuric et al. 2007; Berg 2008; Lungmus 2009) - likely the result of utilizing younger samples during methods development, for which older subjects were either purposefully eliminated (Suchey and Brooks 1990) or were never there to begin with (McKern and Stewart 1957).

While also present in areas such as the sternal rib ends (Iscan and Loth 1985) and auricular surface (Lovejoy et al. 1985), among others, this high level of imprecision manifests most problematically at the pubic symphysis as, though method updates for the sternal rib ends and auricular surface have been adopted with some success (Hartnett 2010b and Buckberry and Chamberlain 2002, respectively), the same can not be said for the pubic symphysis, where the majority of practitioners still report using the original Suchey-Brooks Method and its attendant ranges, almost exclusively, though more recent updates – with refined ranges - have since become available (Falys and Lewis 2011; Garvin and Passalacqua 2012). Lastly, this lack of precision may be especially problematic for post-epiphyseal women as their ranges are much wider and even more forensically impractical than those of their male counterparts, ballooning from a

narrow nine year age range when the epiphysis is open (phase I) to a 44 year range surrounding the time of fusion (phase IV), to 58 and 45 year ranges for the immediate post-epiphyseal (phase V) and late post-epiphyseal (phase VI) stages.

It is the author's belief that the degradation underlying these "catch all" categories is not as variable or unreliable as assumed and that consistency – and, with it, precision - does *not* end with the onset of degeneration, meaning it may, in fact, be equally as diagnostic for age estimation in older individuals as epiphyseal fusion timing is for the young. Indeed, this has already been demonstrated at the medial clavicle (Falys and Prangle 2011) and again at the ischial tuberosity (Falys 2014), both of which have been aged successfully, and with reasonable precision, using degradation alone.

To further test this hypothesis, this study will seek to improve precision in age estimation from the pubic symphysis – the area most frequently used, yet most in need – to a range of 25 years or less, with particular emphasis on females over the age of 45 years (the age by which epiphyseal fusion is complete). As this level of precision is currently unavailable through existing methodologies, the author will also need to purpose-build a new, more sensitive technique. To do this, a deeper understanding of the pubic symphysis and its history as an age indicator is required.

1.3 Skeletal Age Estimation from the Pubic Symphysis

The pubic symphysis, or symphysis pubis, represents the most anterior inferior aspect of the anatomical structure known as the "bony" pelvis.

1.3.1 Pelvic Anatomy

The pelvis is a multi-bone structure situated halfway between the upper and lower body and acts as an intermediary connecting the trunk and lower limbs (*Figure 46*). "Basin-like" in shape, it supports and protects the urinary, gastrointestinal, and reproductive systems.

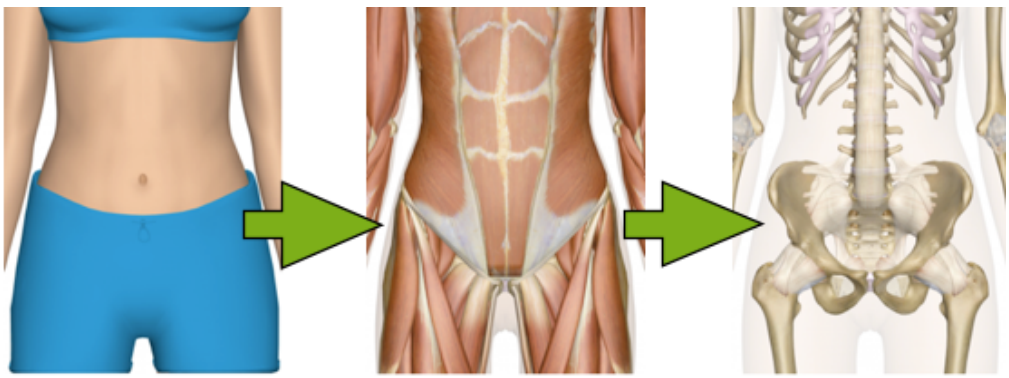


Figure 46: Location of the pelvis within the body

In non-human mammals (with the exception of closely related primates such as gorillas and chimpanzees), the pelvis remains long, tall and narrow, with the pubic bones fused at the mid-line to better facilitate twisting and climbing (*Figure 47, below*).

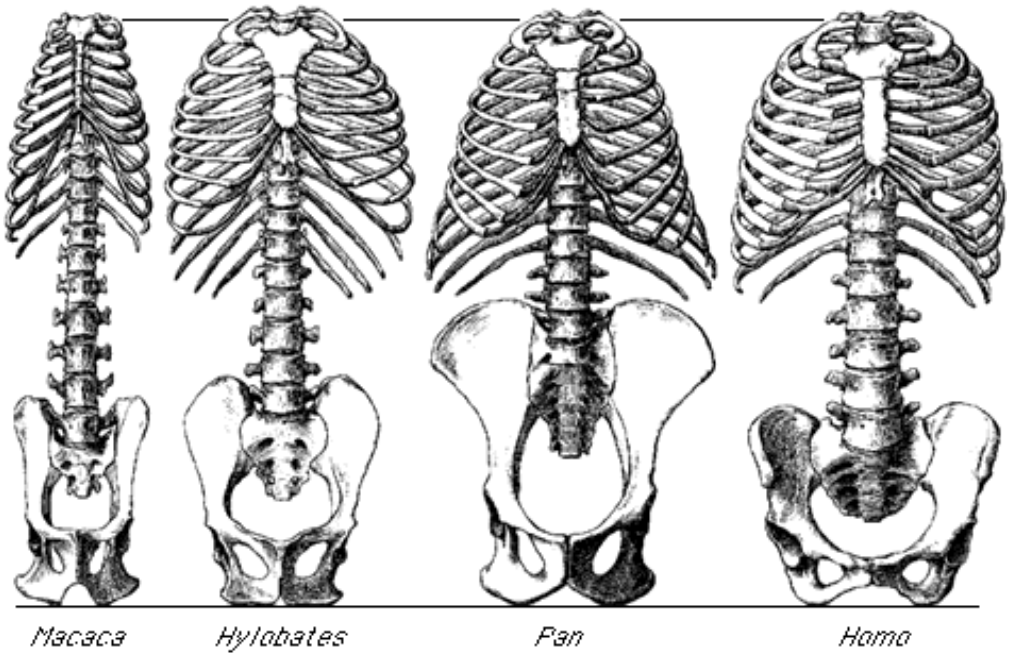


Figure 47: Comparative primate (axial) anatomy

In humans, however, these bones grew gradually shorter, wider (more laterally rounded and flared), and thinner (that is, with decreased surface area) as bipedalism and its new demand for balance introduced a suite of unprecedented evolutionary "trade-offs," which forced the existing musculature to adapt:

> *"To walk upright in an energetically efficient manner with a minimal risk of injury, the pelvis must be robust and have a shape that maximizes muscle lever arms and minimizes load. The ability to regulate body temperature is affected by the width and depth of the pelvis, which plays a crucial role in determining overall body proportions and the body's surface area-to-mass ratio, thereby influencing heat loss through the body's surface. Finally, and most critically from a selective stand- point, pelvic shape must allow the delivery of a healthy infant without harm to the mother. These goals are not all achieved by the same pelvic morphology, yet all three demands must be met. Therefore, selection has favoured compromises between these often contradictory pressures"* (Gruss and Schmitt 2016:1).

These adaptations lead to a re-alignment of the body's center of gravity (as muscles re-shaped so, too, did the bones around them), pulling it incrementally up and back - resulting in the extension (straightening), elongation, and lordosing of the spine. This new need for stability, in turn, created the (current) human pelvis.

Composed of four individual skeletal elements – the sacrum, coccyx (the terminal bones of the vertebral column) and innominate bones (which are composites of several elements themselves) – the pelvis is divided into "true" (posterior, or "pelvic") and "false" (anterior, or "abdominal"), separated by the *Linea Terminalis* (*Figure 48, below*).

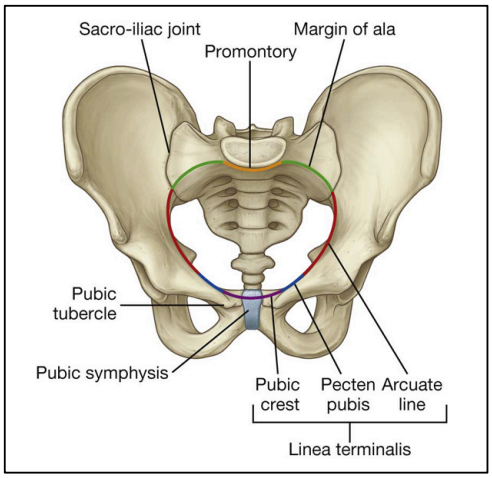


Figure 48: Pelvic terminology

As its name suggests, the "false," or abdominal, pelvis faces ventrally (and tilts inferiorly) in anatomical position and is responsible for the pelvis' wide, rounded "bowl shaped" concavity - necessary for holding the abdominal organs and supporting the muscles of the pelvic floor. It is bounded superiorly by the crests of the ilia and inferiorly by the rim of the pelvic inlet (the coloured ring in its entirity, *Figure 48*), forming the abdominal cavity. The "true," or pelvic, pelvis, on the other hand, is bounded superiorly by the pelvic inlet and inferiorly by the pelvic outlet (formed by fascia connecting

the pubic bones and ligaments, ischial tuberosities, sacro-tuberous ligaments, and coccyx), creating the space known as the pelvic cavity.

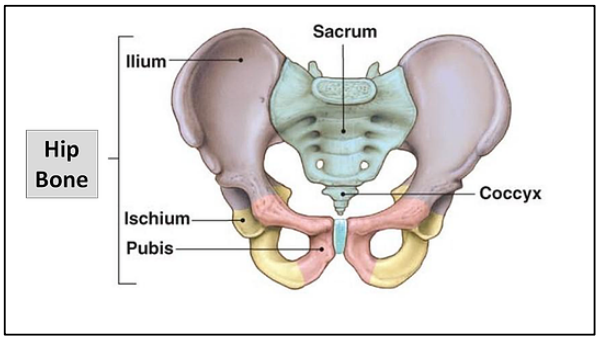


Figure 49: The bones of the pelvis

As stated, the pelvis itself represents a composite of several individual yet interconnecting elements. These include the sacrum (centro-posterior), the coccyx (also centro-posterior), and the left and right innominate bones (*Figure 49*). The innominate bones, themselves, are further sub-divided by the ilia (superior anterior, highlighted in purple), the ischia (inferior posterior, highlighted in yellow), and the pubic bones, or *os pubii* (centro-anterior, highlighted in pink). Where these left and right pubic bones meet at the mid-line is known as the pubic symphysis (highlighted in blue).

1.3.2 The Pubic Symphysis

As previously mentioned, the pubic symphysis is a fibrous, cartilaginous (non-synovial) amphiarthrodial joint. This means that sandwiched between the articular surfaces of the pubic bones (covered by 1 - 3 mm of hyaline cartilage) is a four to five millimeter disc of dense avascular fibro-cartilage, the purpose of which being shock absorption, compression and weight distribution, and the

introduction of limited flexibility (up to 2 mm of "shift" and up to 1° rotation) (Becker et al. 2010)(See *Figure 50*).

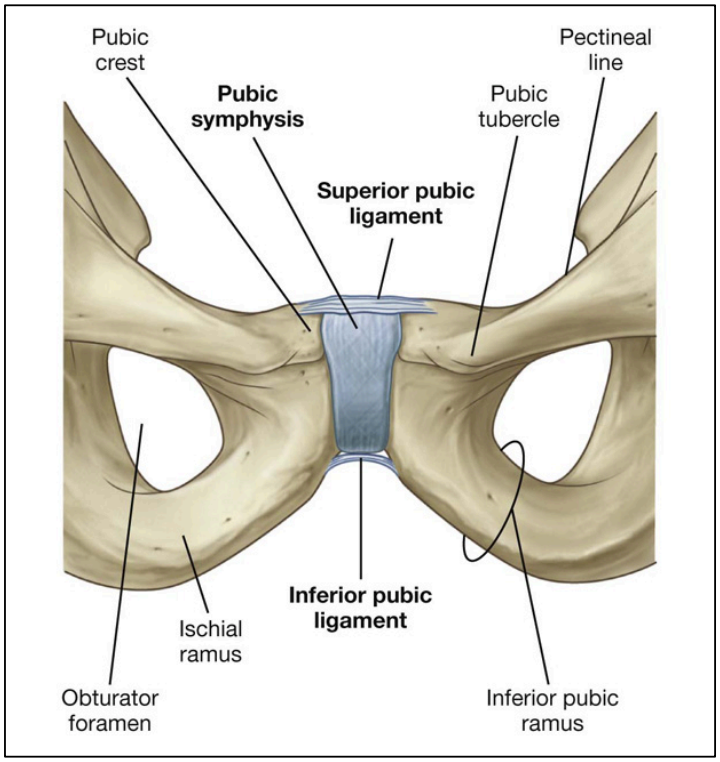


Figure 50: Anatomy and terminology of the pubic symphysis

As a fibrous joint, this cartilage is protected and stabilised by a thick tendinous capsule. Attaching to this capsule and its surrounding bone (the inferior pubic rami, the pubic crest, and the pubic tubercle) are muscles of the abdomen and thigh, as well as the perineum (pelvic floor). The largest of these muscles is the *Rectus Abdominus* (sometimes accompanied by the *pyramidalis*), which attaches directly to the pubic symphysis (and crest) and runs horizontally all the way up to the xyphoid process and the fifth, sixth, and seventh costal cartilages. This muscle is responsible for flexing the lumbar spine, depressing the rib cage, and stabilising the pelvis during walking. Additional abdominal muscles that attach

to the *Linea Terminalis* (via their *aponeuroses* and the *Inguinal Ligament*) are the *Cremaster* (more prominent in males), the *Obliquus Internus Abdominus*, the *Obliquus Externus Abdominus*, the *Obliquus Transversus Abdominus* (all of which compress, contract, and stabilise the abdomen, allowing for the bending and rotation of the trunk).

Just below, attaching to the anterior surface of the pubis and the inferior rami, are the origins of the muscles of the thigh. These include the adductor muscles, which include the *Adductor Magnus*, the *Adductor Brevis*, and the *Adductor Longus* (all of which adduct [or bring towards the body] and flex the hip joint as well as assist in its lateral rotation). Also present in this region are the *Pectineus* (which also flexes and adducts the hip joint) and the *Gracilis* (responsible for the flexing and medial rotation of the knee)(Jarmey and Sharkey 2015) (*Figure 51, below*).

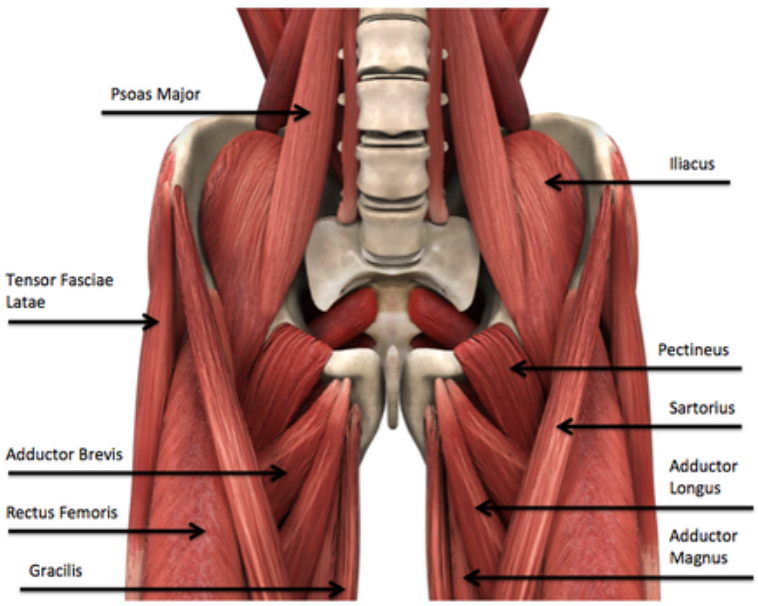


Figure 51: External musculature of the pelvis

Internal attachements include the *Pubococcygeus* and *Puborectalis* (components of the *Levator Ani* complex) and the connecting fascia of the *Urogenital Diaphram,* as well as the *Arcuate Pubic Ligament*, the *Tendinous Arch of the Levator Ani,* and the *Transverse Perineal Ligament* (*See Figure 52, below*).

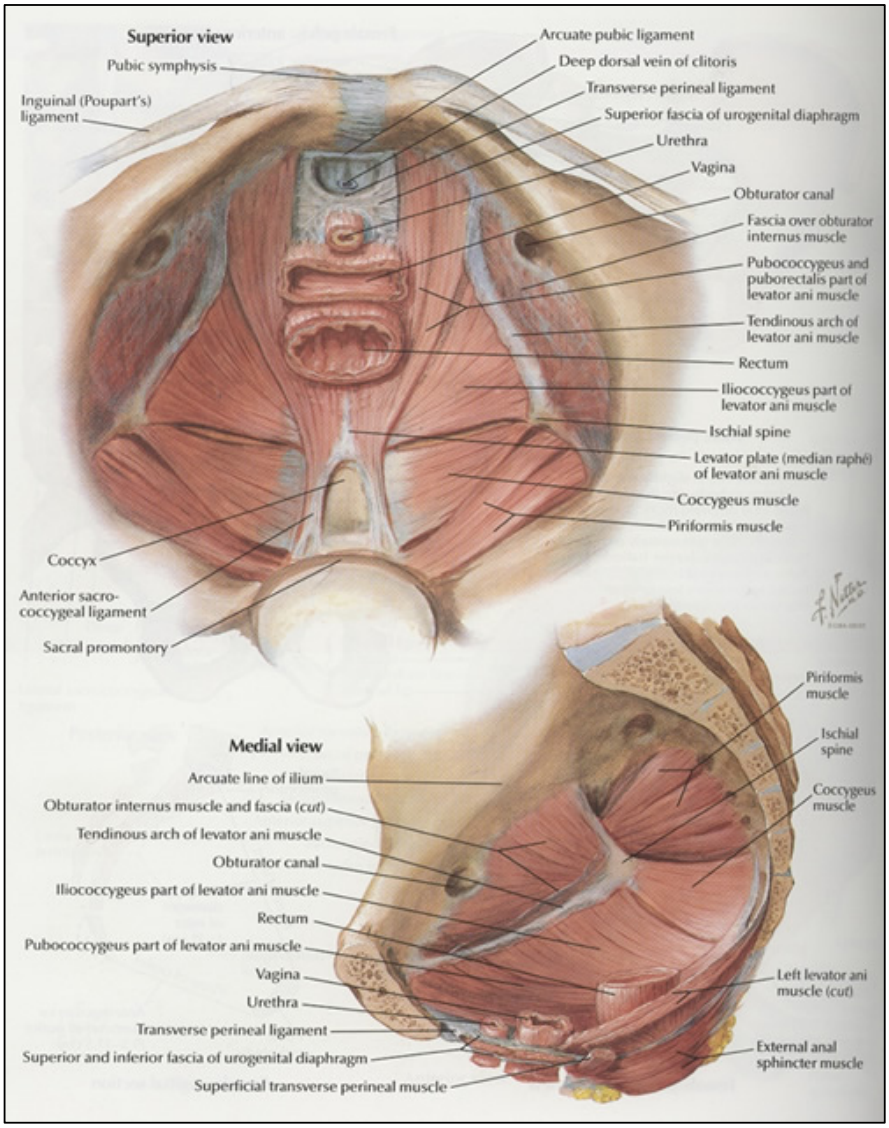


Figure 52: Internal musculature of the (female) pelvis

However, while the various origins of these muscles surround the symphyseal capsule (and, consequently, the joint within), none come into actual contact with the articular facet (*Figure 53*), or "pubic face," itself. This means that while Wolff's Law (which holds that bone will react and adapt to the stresses placed upon it) may apply to the outer edges (potentially leading to abnormal rugosity in the young or to osteophytes in the old), the face – or, the epiphysis from which age is estimated - remains unaffected.

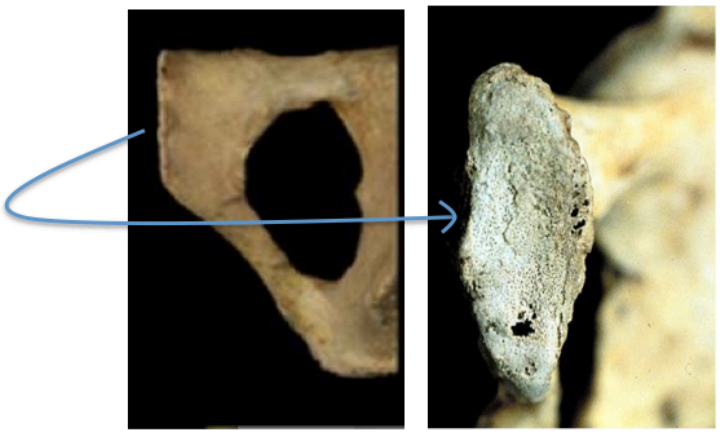


Figure 53: The articular facet of the pubic symphysis

1.3.3 Ageing from the Pubic Symphysis

1.3.3.1 A History of Ageing from the *Os Pubis*

As previously discussed, determining the skeletal age of an individual, or simply "ageing," constitutes one of the four major pillars of the biological profile. For those under the age of 30 years, age may be easily and accurately determined

through the assessment of dental development and cementum striae (Schour and Massler 1941; Gustafson and Koch 1974; Ubelaker 1978; Hillson 1996; Antoine et al. 1999, 2009; AlQahtani et al. 2010), bone size and length (Fozekas and Kosa 1978), and the presence or absence of specifically timed epiphyseal fusions observable throughout generation (Todd 1930; Scheuer and Black 2000; Black *et al*. 2010). These dental eruptions and epiphyseal fusions allow for very concise and confident estimations, with ranges of only two to five years (on either side) age often permitted. For individuals over the age of 45 years, however (when the last fusion completes), this becomes much more problematic. After this "middle adult" threshold, estimation often span multiple decades.

Adult ageing may be determined by a number of techniques employing several elements of the skeleton, often used in combination as a system of "checks and balances" for increased confidence and accuracy. These include both macroscopic methods such as assessing textural differences on the auricular surface (Lovejoy *et al*. 1985; Buckberry and Chamberlain 2002; Igarashi et al. 2005), scoring degradation at the acetabulum (Rouge-Maillart et al. 2004; Rissech et al. 2006; Calce 2012), and change at the costal junctions of the first and fourth rib (Iscan *et al.* 1984; Kunos et al. 1999; DiGangi et al. 2009; Hartnett 2010) as well as microscopic approaches at the histological level such as the counting of osteons (Kerely 1965; Kerely and Ubelaker 1978; Thompson 1979; Stout and Paine 1992; Cho et al. 2002) and acidic racemization (Ohtani and Toshiharu 2005). However, of all these methodologies "the anatomical feature most frequently used for determination of age at death... is the pubic

symphyseal face. In fact... even when used in conjunction with other criteria it is universally considered to be the most... easily interpreted and reliable indicator of age at death in the human skeleton" (Meindl *et al.* 1985).

In 1920, T. Wingate Todd, then an anatomist at the Cleveland Museum of Natural History, published his first of many articles documenting what he saw as a consistent and predictable progression of change to the bony surface of the *os pubis*, or pubic symphysis, over the span of a person's lifetime. Building predominantly upon the observations of Hunter (1762), Aeby (1858), and Cleland (1889), he (with Cox) grouped these "naked eye" changes into 10 distinct phases based upon cadaveric specimens ranging in age from 18 to 88 years (*Figure 54)*. While study surrounding the pubic symphysis had been ongoing since at least 1543, when Vesalius challenged Hippocrates, Todd's publication was the first to introduce a repeatable methodology dealing specifically with the "metamorphosis," as he described it (Todd 1920: 42), of bone as opposed to the soft tissue focus of previous anatomists - making it one of the earliest and most often cited forensic texts.

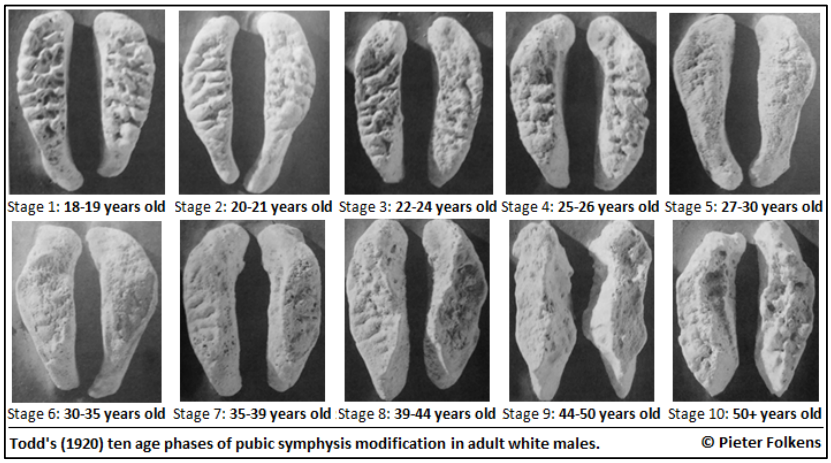


Figure 54: Todd's (1920) ten phase system

However, while still considered one of forensic anthropology's most groundbreaking and influential works, Todd's methodology has long been known to contain several fundamental limitations. First, of the 306 cadavers examined, only 25 specimens could be classified into the early phases of "1," "2," "3," or "4" (combined) and only a further 65 specimens were placed into the "5," "6," or "7" categories - demonstrating a remarkable under-representation of younger individuals in the study sample. In fact, Todd classified the majority of his subjects (approximately 70%) into the fourth decade of life, less than 10 years from the upper limit of his system (as assessment beyond 50 years was deemed fruitless). It is perhaps unsurprising, then, that in her 1955 trial and critique of the method, Sheilagh Brooks found that the individuals in her study set (which included a segment of Todd's own collection) were consistently overaged using the 10 phase technique, a finding echoed by Hanihara (1952), McKern and Stewart (1957), and Katz and Suchey (1986).

Secondly, Katz and Suchey (1986) also asserted that the sample upon which the Todd technique was based (then the "Case Western Reserve Collection," now the "Hamann-Todd Collection") was comprised of too large a proportion of indigents and unclaimed cases for whom pathologists were forced to place into five year estimate groupings (referred to as "lustrums") during preparation for autopsy, casting doubt on the validity of their age documentation. In fact, according to Lovejoy et al. (1985:5), during their examination of Todd's original collection "only three records [out of 3,157] were found to contain legal documentation of birth date" and, of that number, "only about 16% had sufficiently reliable stated ages at death to be included in [their] study." This,

argued Suchey and Katz (though disputed by Meindl *et al.* [1985]), made the collection itself unsuitable for devising a methodology for which individual age must be solid and indisputable (Katz and Suchey 1986; Giesecke 2001.

A third flaw pertained to structure. In ageing his subjects, Todd placed approximately 27% of his specimens as "between" categories (Jackes 1985), citing that in such cases two or more phases appeared to be "superposed" upon one another. This, instead of advocating clear and unambiguous archetypes, introduced the prospect of a continuum of building up and breaking down - that a "grey area" of sorts existed between distinctions. Furthermore, in other instances where specimens did not fit the expected criteria they would be deemed "pathological" and removed from the study all together. This practice of "cherry-picking" data for inclusion led to a complete absence of naturally occurring variation and created the illusion of precision in the resultant age distinctions. It was this final issue that prompted the next chapter in ageing from the symphyseal face. Asserting that Todd's methodology relied upon too much over-simplification for general application, McKern and Stewart developed their own technique - one that replaced Todd's for nearly three decades.

Careful not to incur the same criticism for questionable age documentation, McKern and Stewart's data set (n = 450) consisted solely of fallen US soldiers being returned home as part of an exchange program after the Korean War (1950 - 1953). This, they asserted, ensured irrefutable proof of age in the form birth certificates and military entrance records. In their 1957 publication,

McKern and Stewart proposed a departure from the type of qualitative archetypal system advocated by Todd and introduced a more quantitative tack. In contrast to Todd's comparison matching, this new technique separated the symphyseal face into three distinct "components," with each component then sub-divided into ordinals of zero to five. For example, Component II concerns the ventral rampart *(Figure 55)*:



Fig. 40 Symphyseal face of pubis showing ventral hiatus. (No. 239, 29 years).

The 6 (0-5) stages of Component II are as follows: (Fig. 41)

0. Ventral beveling is absent.
1. Ventral beveling is present only at superior extremity of ventral border.
2. Bevel extends inferiorly along ventral border.
3. The ventral rampart begins by means of bony extensions from either or both of the extremities.
4. The rampart is extensive but gaps are still evident along the earlier ventral border, most evident in the upper two-thirds.
5. The rampart is complete.

Figure 55: Component II of the McKern and Stewart (1957) system

The individual scores for each component were then combined for a total score of 0 - 15. Each aggregate score was then linked to a corresponding age range. This method provided for a possible 125 formula combinations though "only about a fourth of [those] combinations are likely to occur" (McKern and Stewart 1957: 95). By taking a more multivariate approach, McKern and Stewart hoped

their technique would prove more variation inclusive and less subjectively anecdotal. Interestingly, while their system did provide greater "intra" range specificity (that is, it provided a more detailed look at the variations *within* each component), its age ranges did not ultimately differ greatly from Todd's. With the exception of merging scores 11, 12, and 13 for an overall range of 17 years, McKern and Stewart placed each of their individuals into categories comprised of no more than five years - a figure nearly identical to Todd's "lustrums." However, where Todd's method tended toward over-ageing due to a higher proportion of older subjects (Brooks 1955; Krogman 1962), by devising their method exclusively on military personnel McKern and Stewart disproportionately weighted their study toward white males under the age of 25 years and became subject to the same bias as Todd's, but in reverse. In a later effort to amend this, female specific criteria were added (Gilbert and McKern 1973) but all else remained identical.

Despite this, the McKern and Stewart technique remained the standard for skeletal age determination for almost three decades. During that time, several research teams (Nemeskeri *et al.* 1960; Hanihara and Suzuki 1978; Snow 1983; Jackes 1985) introduced updates and modifications by refining the individual component variables and adding the statistical analysis missing from McKern and Stewart's original article. Instead of relying on the practitioners themselves to score and sum the individual components, which could introduce error through subjectivity, these authors devised computational methods of employing multiple regression analysis to predict final age (provided that those ages fell roughly between 18 and 40 years). Jackes (1985) even advocated

discarding pre-defined age ranges all together in favour of these data generated "probability distributions." While this type of analysis offered a greater degree of precision it was also time consuming, required special equipment and training, and was not at all user friendly for the non-statistician. Furthermore, as the end result (final age) rarely differed substantially from the much quicker and more intuitive visual matching system, many practitioners began to question its place and practicality in field-based casework. Finding the entire multivariate paradigm too overly complicated to maintain any level of "inter," or indeed, "intra" observer accuracy, several practitioners continued to work on updating and adapting Todd's original system.

In 1985, Meindl *et al.* published an ambitious compilation of research advocating and supporting a "multifactoral" approach to ageing the skeleton. One facet of this suite (along with assessment of the auricular surface, cranial sutures, dentition, and radiographs of the femur and radius) was the analysis of the pubic symphysis. In order to evaluate the most effective technique for this purpose, the authors performed several "blindfold" tests of accuracy involving all of the methodologies to date - the McKern-Stewart technique, the Gilbert-McKern modification to the McKern-Stewart technique, the Hanihara-Suzuki regression method, and the original Todd ten phase system (with the adjustments Brooks and Ahmed, who had suggested revising certain ranges down by a margin of three years [1955]). After evaluating each independently on a reference sample of 96 individuals, it was concluded that the "relationships between real and estimated age were best for the Todd method" (1986: 31) and that "judged on the criteria of accuracy and bias, the Todd system ... proved

superior" (1986: 32). Based on these results, the authors discarded the poorer performing multivariate methods and concentrated on refining the original.

This refinement came less as a modification but as more of an aid to interpretation. In an effort to simplify and to make the method more accessible, Meindl *et al.* truncated Todd's ten stage seriation into five new "biological phases" based upon what they viewed as the single, over-riding quality of each. Put plainly, what this meant was a merging of the first five phases, the retention (intact) of phases six, seven, and eight, and the further combination of phases nine and ten. Phases one through five, therefore, became "Biological Phase I: Pre-epiphyseal" (ages 20-29), which was characterised by the presence of marked billowing and a lack of ventral rampart formation; phase six became "Biological Phase II: Active epiphyseal" (ages 30-35), characterised by the presence of a ventral rampart; seven became "Biological Phase III: Immediate post-epiphyseal" (ages 35-40) and was hallmarked by changes in texture from uneven to smooth and from granular to dense; eight became "Biological Phase IV: maturing / pre-degenerative" (ages 40-44), recognizable by its absence of activity; and phases nine and ten collapsed to become "Biological Phase V: Degenerative" (ages 45+), characterized by an increase in porosity, erosion, and osteophytic disfigurement.

While not actually producing any new material, the work of Meindl *et al.* nonetheless represents an important contribution to symphyseal ageing as it was the first to formally investigate the accuracy of both the multivariate and archetypal paradigms on the same collection, pitting them against each other. It

was also the first to introduce into the literature a truncation of Todd's phasing system, proposing that certain stages could be combined for greater ease of use without sacrificing efficacy.

Seven months later, though, Suchey and Katz (1986) published their own variation on Todd's theme. In remarkably similar but unrelated scholarship, both research teams evaluated a common data set with both a multivariate technique (McKern-Stewart) and a typological method (Todd), both found that Todd's system (with modification) yielded the greatest accuracy, and both introduced alterations to that system based upon further experimentation. However, while these larger themes were presented by both projects, distinctions soon become evident upon closer inspection.

Of the three major differences between the two studies, the first relates to each team's age demarcations. Where Meindl et al. combined phases I-V (20-29 years) into one broad category, Suchey and Katz maintained phases I-III (15-23 years) and IV-V (19-35 years) as separate entities. Both left phase VI (30-35 years per Meindl *et al*., 22-43 years per Suchey and Katz) intact. However, Suchey and Katz then combined phases VII-VIII (23-59 years) and kept phases IX (28-78 years) and X (36-87 years) distinct, whereas Meindl *et al.* did the reverse (with 36-40 years for phase VII, 40-45 for phase VIII, 45-50 for phase IX, and 50+ years for phase X). These variations are illustrated by *Table 1* (below).

Table 1: Age and phase truncations; Meindl et al. 1985 (L) and Suchey and Katz 1986 (R)

Biological stage	Todd stage
1. Preepiphyseal	I–V
2. Active epiphyseal	VI
3. Immediate postepiphyseal	VII
4. Maturing; predegenerative	VIII
5. Degenerative	IX–X

Todd's phases	N	Mean age	SD	95% range
1, 2, 3	121	18.9	2.3	15–23
4, 5	81	24.7	4.3	19–35
6	43	28.8	5.9	22–43
7, 8	153	36.8	9.6	23–59
9	241	51.0	13.6	28–78
10	100	62.7	12.4	36–87

Furthermore, where Meindl et al. merely collapsed Todd's phases without alteration to his age ranges, Suchey and Katz (with the aid of regression models) dropped the lower threshold from 18 to 15 years and raised the upper boundary from 50 to 87 years - almost doubling Todd's original limit and far outreaching any other method in terms of addressing the identification of older subjects.

The second key difference was Suchey's use of a large and (then) current autopsy sample (available due her role as then Chief Medical Examiner for the city of Los Angeles, CA). This included 739 males and introduced a completely new and updated data set to supplement, as well as juxtapose with, Todd's. Meindl *et al.* had performed their evaluations on Todd's historical sample (1912-1938).

The third and last major divergence stems from which features each team found to be important to the creation of the phases themselves. In their assessments, Meindl *et al.* found billowing (to the exclusion of all else) to be the paramount feature of individuals under the age of 30 years, prompting them to condense Todd's first five phases into their larger "Biological Phase 1." Suchey and Katz, however, maintained that ridges and furrows may persist well into middle age and allowed for its (albeit diminishing) presence in several of their higher

phases. Moreover, where Meindl *et al.* dismissed ossifying nodules as having no importance whatsoever to the prediction of age, Suchey and Katz regarded ossific nodule formation as the absolute hallmark of their second phase. Similarly, the development of a discrete "rim" or "oval outline" (mentioned only briefly by Todd but designated an entire component by McKern and Stewart) also proved much more significant to Suchey and Katz, with its development or breakdown central to all but one of their six phases. Conversely, the advancement of an oval outline is not a deciding factor for any of Meindl *et al.'s* phase distinctions.

Despite these disparities, both articles investigated similar questions with similar approaches and ultimately produced similar outcomes. It is perhaps due, then, to the larger and more modern data set, the farther reaching age ranges, and the exceptional amount of marketing in the years to follow that lead to the eclipse of one over the other. Today, Suchey and Katz's method "is commonly considered to be the best age estimation method and is widely used in forensic anthropology and bioarchaeological contexts" (Rissech *et al.* 2012) while Meindl et al. are most remembered for their work in other areas, namely the auricular surface (Lovejoy *et al.* 1985).

Next, having proven statistically that the new six phase system out-performed all other methods, Suchey paired with Sheilagh Brooks (the first to evaluate Todd back in 1955) to fine-tune the descriptions and illustrations. In 1990, they published a comparison of these refinements - now formally named the "Suchey-Brooks Method for Ageing the Os Pubis," or simply the "Suchey-Brooks

method" - against the multivariate technique of Harsanyi *et al.* (1960). Termed the Acsadi-Nemeskeri method after the pair's 1970 book, it had been developed 30 years earlier on a mixed Hungarian sample and (modeled after McKern and Stewart [1957]) advocated a five point component system, the scores of which were totaled in order to devise a final "summary" age. Finding that this method remained the primary source for European identifications despite their recent contributions to the subject, Suchey and Brooks applied both methods to an historical collection of known age. Once again the archetypal paradigm out-performed the multivariate and the new and improved Suchey-Brooks method officially replaced both the Todd and McKern-Stewart techniques as the field standard in age determination from the pubic symphysis.

That is not to say, however, that the Suchey-Brooks method was then, or continues to be, regarded as foolproof - quite the opposite, in fact. In order to keep their results within a statistically significant margin of accuracy (95%), the age ranges assigned to each new phase had to be expanded dramatically, ballooning them from no greater than five years per phase (Todd) to a span of half a century. Suchey-Brooks's phase IV, for example, assigns a range of 23 to 59 years - a span of three and a half decades - while phases V and VI both span a period of 50 years. Complicating the system further, each of the six phases also overlap. This means that a symphyseal face could belong in several categories at once. These all encompassing ranges, the authors argue, are necessary to accommodate the enormity of human variation exhibited by the pubic symphysis and that the overlap helps to capture transitional movement between phases. Stating that "narrow age ranges help to reduce the number of

possibilities and create the false illusion of efficiency," Suchey cautions that "age is a crucial parameter of the [identification] system, and the anthropologist must take these estimates very seriously" (1986d: 233). However, while these points are certainly valid, in forensic contexts (both for victim confirmation and the narrowing down of missing persons searches) these wide, non-specific estimations are unhelpful. Because of this, and in contrast to the earlier methods wherein age ranges were too limited, many practitioners now agree that "the [Suchey-Brooks] ranges are so broad with such enormous areas of overlap as to be almost meaningless" (Cox and Mays 2000: 69). Additional criticisms cite the fact that only one practitioner performed the observations upon which the methodology was built (as opposed to several to establish inter-observer accuracy) and that the collection is no longer available for reassessment or further study (Hartnett 2010). Nevertheless, along with the assessment of the fourth rib (Iscan *et al.* 1984) and auricular surface (Lovejoy *et al.* 1985), the Suchey-Brooks method for ageing the os pubis is now the most highly regarded and widely applied technique for ageing post-cranial adult remains.

1.3.3.2 The Suchey-Brooks Method for Ageing the *Os Pubis* (1990)

As described above, the "Suchey-Brooks Method of Aging the *Os Pubis*" (or simply the "Suchey-Brooks method" or "Suchey-Brooks") reduced the number of Todd's (1920-1923) traditional phases from ten to six but adhered closely to the recognized archetypal framework found most effective by Meindl *et al.* (1985). With their update to the once ubiquitous standard, Suchey and Brooks

reinstated the simpler, more holistic visual approach deposed three decades earlier by the more quantitative mathematical systems of McKern and Stewart (1957) and Hanihara and Suzuki (1978).

Published in 1990, after a 1986 precursor (Suchey and Katz), the Suchey-Brooks method quickly gained field-wide attention as a result of its meticulous design, extensive sample, and intensive distribution campaign (five articles, two book chapters, myriad conference presentations, and the distribution of technique specific teaching casts within a period of only four years). Quickly outpacing both of the major methodologies that had come before it - Todd (1920) and McKern-Stewart (1957) - the Suchey-Brooks method *(Figure 56, below)* has come to be regarded as the most user-friendly and widely applicable technique currently available to the practitioner for determining ageing the pubis symphysis.

In order to apply the Suchey-Brooks method, the anthropologist must simply look carefully at the symphyseal face of a given specimen and choose the description and / or illustration he or she feels it most closely resembles. The corresponding age range for that "phase" is then listed as that specimen's most likely age.

SUCHEY-BROOKS PUBIC SYMPHYSIS SCORING SYSTEM

The following descriptions define the Suchey-Brooks system for estimating age-at-death, based upon morphology of the pubic symphysis (Brooks and Suchey 1990; Suchey and Katz 1986). While the descriptions can be applied to symphyseal faces from either males or females, visual matches for females should be made in reference to Figure 7. Standards suitable for males are presented in Figure 8. Cast series which further enhance the information presented here are available from Dr. Diane France, at the address noted earlier in this chapter.

Phase 1. Symphyseal face has a billowing surface composed of ridges and furrows which includes the pubic tubercle. The horizontal ridges are well-marked. Ventral beveling may be commencing. Although ossific nodules may occur on the upper extremity, a key feature of this phase is the lack of delimitation for either extremity (upper or lower).

Phase 2. Symphyseal face may still show ridge development. Lower and upper extremities show early stages of delimitation, with or without ossific nodules. Ventral rampart may begin formation as extension from either or both extremities.

Phase 3. Symphyseal face shows lower extremity and ventral rampart in process of completion. Fusing ossific nodules may form upper extremity and extend along ventral border. Symphyseal face may either be smooth or retain distinct ridges. Dorsal plateau is complete. No lipping of symphyseal dorsal margin or bony ligamentous outgrowths.

Phase 4. Symphyseal face is generally fine-grained, although remnants of ridge and furrow system may remain. Oval outline usually complete at this stage, though a hiatus may occur in upper aspect of ventral circumference. Pubic tubercle is fully separated from the symphyseal face through definition of upper extremity. Symphyseal face may have a distinct rim. Ventrally, bony ligamentous outgrowths may occur in inferior portion of pubic bone adjacent to symphyseal face. Slight lipping may appear on dorsal border.

Phase 5. Slight depression of the face relative to a completed rim. Moderate lipping is usually found on the dorsal border with prominent ligamentous outgrowths on the ventral border. Little or no rim erosion, though breakdown possible on superior aspect of ventral border.

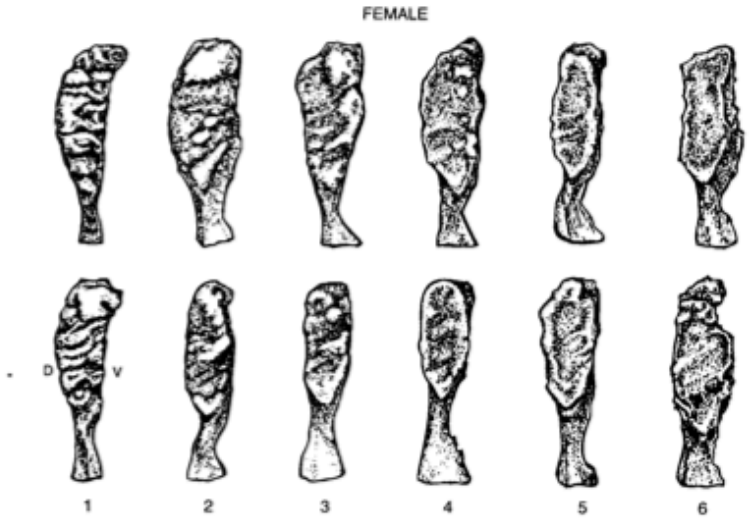


Figure 7. Suchey-Brooks standards for changes in the topography of the female pubic symphysis. D = dorsal; V = ventral. Drawing by Zbigniew Jastrzebski (after Brooks and Suchey 1990).

Figure 56: The Suchey-Brooks Method for Ageing the Os Pubis (from Buikstra and Ubelaker 1994)

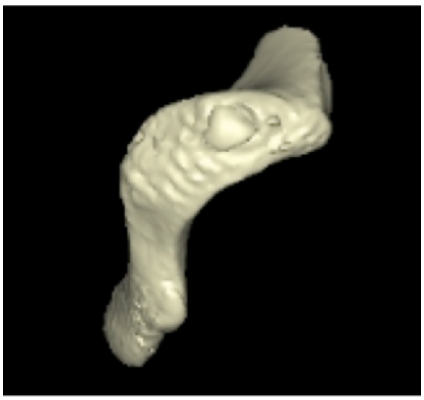


Figure 57: Example of a symphyseal face

For example, suppose the image to the left *(Figure 57)* were to represent the left symphyseal face of a white female of unknown age. By examining the depictions on the previous page, it is clear that this specimen shares the most visual similarity with the bottom illustration for "Phase I." Supported by the description, which lists a billowed (open epiphyseal) appearance and lack of distinction at the lower extremity, it would be reasonable to conclude that this individual does, indeed, belong in Phase I. To estimate age from this, the observer would then consult the table provided by the literature *(Table X, below)*, find Phase I, move across to the "female" data set, and list the corresponding range - in this case, 15-24 years (with a mean age of 19.4 years).[6]

Table 2: Suchey-Brooks Age and phase distinctions

	Female *(n = 273)*			Male *(n = 739)*		
Phase	**Mean**	**Standard Dev.**	**95% Range**	**Mean**	**Standard Dev.**	**95% Range**
1	19.4	2.6	15-24	18.5	2.1	15-23
2	25.0	4.9	19-40	23.4	3.6	19-34
3	30.7	8.1	21-53	28.7	6.5	21-46
4	38.2	10.9	26-70	35.2	9.4	23-57
5	48.1	14.6	25-83	46.6	10.4	27-66
6	60.0	12.4	42-87	61.2	12.2	34-86

As has been stated, the above demonstrated methodology is currently the most widely used, taught, and trusted technique for ageing post-cranial adult remains

[6] The individual represented by *Figure X* was 18 years old at the time of her scan.

despite its limitations and overly broad ranges - especially problematic nearer the latter half of the scale where spans of 44 (phase IV), 58 (phase V), and 45 years (phase VI) become the norm, as stating that an individual has a high statistical probability (95%) of being between 25 and 83 years of age is equally impractical for modern missing persons searches as it is for demographic analyses in archaeological context. For this reason, it has become common practice amongst some practitioners to simply take the mean age listed for an observed phase and add ten years in either direction - though this is formally discouraged by the authors. Alternately, another way practitioners have found to mitigate this imprecision has been to combine multiple phases, or to forgo them altogether in favor of more cautious generic groupings such as early (phases one and two), mid (phase three), or late (phases four and five) adult (Schmitt 2001: 66). While the majority of the work undertaken in this area continues to be methods testing and comparison studies (Sinha and Gupta 1995; Hoppa 2000; Giesecke 2001; Debono *et al.* 2004; Sakaue 2006; Djuric *et al.* 2007; Martrille *et al.* 2007; Kimmerle *et al.* 2008a; Kimmerle *et al.* 2008b; Kimmerle *et al.* 2008c, Konigsberg *et al.* 2008; Konigsberg *et al.* 2009; Lungmus 2009; Warmlander and Sholts 2011; Milner and Boldsen 2012; Rissech *et al.* 2012; Lottering 2013; Fleischman 2013), recent scholarship has increasingly centered around the "older" ranges neglected by the Suchey and Brooks method, leading to the advocacy of an additional seventh phase (Berg 2008; Hartnett 2010a).

1.3.3.3 Berg and Hartnett 7th Phase Modifications (2008 - 2010)

In 2008 (Berg), and then again in 2010 (Hartnett), additions to the Suchey-Brooks method were proposed in the form of the adoption of a seventh phase.

Citing that "very large age ranges are the norm" and that "once an individual breaches ~ 40 years... techniques lose precision, resulting in even wider age ranges" (2008: 569), Berg asked a volunteer to choose a random selection of 85 symphyses over the age of 40 years from The Balkan Sample (ICTY, housed at the University of Tennessee - Knoxville). The volunteer then put them, without any information, into a box. Berg then sorted the contents of that box into three separate groups using the Suchey-Brooks method. He repeated this two more times (for a total of three), each time refining the selection criterion based upon the results of the previous sorting. This was then replicated with an additional 104 individuals from the William Bass Donated collection (University of Tennessee - Knoxville). By this method, he determined that the oldest grouping for each sort and sample exhibited enough distinction to be considered its own phase (based mainly on porosity and bone weight and, therefore, assumed loss of density). With new descriptions and illustrations in hand *(Figure 58)*, three additional observers were then asked to assess two selected "sorts" of the WBD collection (n = 71 in total) and one of the Balkan sample (n = 56).



Figure 58: Berg's (2008) V, VI, and VII categories

With accuracy rates of between 88% and 96% for the author and between 82% (lowest across both samples) and 95% (highest across both samples) for the combined non-author observers, Berg concluded that "the current study produced *r*-values consistently better those reported for the Suchey-Brooks method" (2008: 572). Despite this, however, to remain within the same 95% accuracy margin as did Suchey and Brooks, Berg's phase seven had to maintain an lower bound of 52 years and an upper bound of 95 years - still an interval of over 40 years. Furthermore, as Berg only used women, this investigation failed to narrow its intended target as the parameters for Suchey-Brooks' highest phase (to which Berg's phase seven would belong) is also 40 years. Differences

to the mean ages of the established categories (phases V and VI) were also negligible. It did, however, introduce a new mean age of 78.3 years for its new seventh phase, by far the highest for any method to date as well as a seriation of transitional ages (the age at which subjects "transition" out of one phase and into another) for the Balkan sample (but not the WBD).

Two years later, a second study echoed Berg's call for a seventh phase. But, where Berg sorted only females over the age of 40 years, Hartnett (2010) included both males and females of all ages. While performing a more general evaluation of the Suchey-Brooks method on her newly assembled autopsy sample, Hartnett (with two additional observers) redefined the established phases, effectively halving phases one, two, and six - the latter through the creation of a seventh phase *(Table 3)*.

Table 3: Age comparisons for the Hartnett (2010) and Suchey-Brooks methods; (top) males, (bottom) females

	FSC				Suchey-Brooks*			
Phase	*n*	Mean	SD	Range†	*n*	Mean	SD	Range†
1	14	19.29	1.93	18–22	105	18.5	2.1	15–23
2	14	22.14	1.86	20–26	75	23.4	3.6	19–34
3	36	29.53	6.63	21–44	51	28.7	6.5	21–46
4	69	42.54	8.8	27–61	171	35.2	9.4	23–57
5	90	53.87	8.42	37–72	134	45.6	10.4	27–66
6	34	63.76	8.06	51–83	203	61.2	12.2	34–86
7	96	77	9.33	58–97	–	–	–	–
	FSC				SB*			
Phase	n	mean	SD	range‡	n	mean	SD	range§
1	5	19.8	1.33	18–22	48	19.4	2.6	15–24
2	5	23.2	2.38	20–25	47	25	4.9	19–40
3	25	31.44	5.12	24–44	44	30.7	8.1	21–53
4	35	43.26	6.12	33–58	39	38.2	10.9	26–70
5	32	51.47	3.94	44–60	44	48.1	14.6	25–83
6	35	72.34	7.36	56–86	51	60	12.4	42–87
7	56	82.54	7.41	62–99	–	–	–	–

As did Berg, Hartnett found the most diagnostic features for older specimens to be "loss of integrity" (porosity/degradation) and bone weight. Asserting that "the major deciding factor between [phases] 6 and 7 is bone weight" (2010: 1149), Hartnett concluded that while "often a set of pubic bones will have a younger morphology than what the weight of the bone suggests, the feature of bone weight alone can be used to move a set of specimens up or down a phase" (2010: 1148). Through regression analysis, Hartnett then restructured the entire set of Suchey-Brooks ranges to include her seventh phase (whereas Berg restructured only the last two, plus his seventh). While the ranges remain relatively large to accommodate variation, Hartnett did manage to keep each phase under four decades for both sexes - a marginal improvement over the 50 (males) and 60 (females) year latter ranges of Suchey and Brooks. Also, in addition to new range parameters, Hartnett also provided new phase descriptions to correspond with her updates *Figure 59)*. The combination of these two factors make Hartnett's study the most comprehensive modification to the Suchey-Brooks method since its introduction in 1990.

Phase 1	A clear ridge and furrow system extends from the pubic tubercle onto the inferior ramus. Ridges and furrows are deep and well-defined and do not look worn down. There is no dorsal lipping. Bone is of excellent quality and is firm, heavy, dense, and smooth on the ventral and dorsal body. There is no rim formation. The dorsal plateau is not formed. The ridges and furrows extend to the dorsal edge
Phase 2	The rim is in the process of forming, but mainly consists of a flattening of the ridges on the dorsal aspect of the face and ossific nodules present along the ventral border. Ridges and furrows are still present. The ridges and furrows may appear worn down or flattened, especially on the dorsal aspect of the face. The furrows are becoming shallow. The upper and lower rim edges are not formed. There is no dorsal lipping. The bone quality is very good and the bone is firm, heavy, dense, and smooth on the ventral and dorsal body, with little porosity. The pubic tubercle may appear separate from the face
Phase 3	The lower rim is complete on the dorsal side of the face, and is complete until it ends approximately halfway up the ventral face leaving a medium to fairly large gap between the lower and upper extremities on the ventral face. This enlarged "V" is longer on the dorsal side than the ventral side. Some ridges and shallow furrows are still visible, but appear worn down. In some cases, the face is becoming slightly porous. The rim is forming both on the dorsal aspect of the face and the upper and lower extremities. In some cases, there is a rounded buildup of bone in the gap between the upper and lower extremities above the enlarged "V." Bone quality is good; the bone is firm, heavy, dense, and has little porosity. The dorsal surface of the body is smooth, and there are small bony projections near the medial aspect of the obturator foramen. The ventral aspect of the body is not elaborate. Very slight to no dorsal lipping. Quality of bone and rim completion are important deciding factors. Variant: In some cases, a deep line or epiphysis is visible on the ventral aspect parallel to and adjacent to the face (males only)
Phase 4	In most cases, the rim is complete at this stage, but may have a small ventral hiatus on the superior and ventral aspect of the rim. The face is flattened and not depressed. Remnants of ridges and furrows may be visible on the face, especially on the lower half. The quality of bone is good, but the face is beginning to appear more porous. The dorsal and ventral surfaces of the body are roughened and becoming coarse. There is slight dorsal lipping. In females with parturition pits, dorsal lipping can be more pronounced. The ventral arc may be large and elaborate in females
Phase 5	The face is becoming more porous and is depressed, but maintains an oval shape. The face is not irregularly-shaped or erratic. The rim is complete at this stage. In general, the rim is not irregular. Ridges and furrows are absent on the face. There may be some breakdown of the rim on the ventral border, which appears as irregular bone (not rounded/solid). The ventral surface of the body is roughened and irregular, with some bony excrescences. The dorsal surface of the body is coarse and irregular. Projections are present on the medial aspect of the obturator foramen. Bone quality is good to fair; it is losing density and is not smooth. The bone is moderately light in weight. In females the ventral arc is prominent
Phase 6	The face is losing its oval shape and is becoming irregular. The rim is complete, but breaking down, especially on the ventral border. The rim and face are irregular, porous, and macroporous. Bone quality is fair, and the bone is lighter and more porous, even with bony buildup on the ventral body surface. The rim is eroding. The dorsal surface of the bone is rough and coarse. There are no ridges and furrows. Dorsal lipping is present. Projections are present at the medial aspect of the obturator foramen. Bone weight is a major deciding factor between phases 6 and 7
Phase 7	The face and rim are very irregular in shape and are losing integrity. The rim is complete but is eroding and breaking down, especially on the ventral border. There are no ridges and furrows. The face is porous and macroporous. Dorsal lipping is pronounced. Bone quality is poor, and the bone is very light and brittle. Bone weight is an important deciding factor. The dorsal surface of the bone is roughened. The ventral surface of the body is roughened and elaborate. Projections are present at the medial wall of the obturator foramen. The pubic tubercle is elaborate and proliferative. Bone weight is a major deciding factor between phases 6 and 7
VARIANT	VARIANT: The rim is complete except for a lytic/sclerotic appearing hiatus at the superior ventral margin that extends toward the pubic tubercle and sometimes underneath the ventral rim, which should not be confused with a hiatus

Figure 59: Amended phase descriptions per Hartnett (2010)

1.3.3.4 Chen et al. (2008, 2011) and Dudzik and Langley (2015) Regression Analyses

As has been mentioned, shortly after its introduction by Todd (1920) age determination from the pubic symphysis splintered into two separate methodological camps - the Archetypal branch and the Multivariate branch. Following Todd along the Archetypal line were Brooks (1955), Meindl *et al.* (1985), Suchey, Brooks, and Katz (1986 - 1990), Berg (2008), and Hartnett (2010). Following McKern and Stewart (1957) along the Multivariate line were Gilbert and McKern (1973), Hanihara and Suzuki (1978), Snow (1983), Jackes

(1985), Pasquier (1999), Schmitt (2001), and Chen *et al.* (2008, 2011).

X_1	Ridges and furrows on the symphysial surface	0: Ridges and furrows alternate distinctively 1: The furrows filling in, ridges and furrows alternate indistinctively, 2: Low, blunt ridges and shallow furrows 3: Flatness and more granular 4: Pitted and eroded
X_2	Ridge of pubic tubercle	0: Completed 1: Almost gone 2: Fully disappeared
X_3	Lower extremity	0: No appearance 1: Appearance of dividing line 2: "V" angle forming 3: Atrophy or remaining of "V" angle
X_4	Ventral rampart	0: No formation 1: Local ventral rampart 2: Fully developed 3: Widen or tubercular in superior portion
X_5	Ossific nodules	0: No appearance 1: Appearance 2: Fusion and disappearance
X_6	Dorsal margin	0: No appearance 1: Edged margin without a plateau 2: Plateau and lipping forming 3: Middle destruction or generalized atrophy.
X_7	Ventral beveling	0: No appearance 1: Clear edged- margin 2: Flatness in inferior portion or disappearance
X_8	General macroscopic changes of symphysial surface	0: Prominence 1: Irregular 2: Flatness or fovea inferior with clear periphery
X_9	Bone density of symphysial surface	0: Ridge or no ridge with coarse surface 1: Smooth, dense and solid 2: Concavo-convex or with dense pore 3: Big pits and/or loss of density

Figure 60: Scoring system for the Chen et al (2008) method

Based upon the 1978 work of Hanihara and Suzuki, who split the symphyseal face into seven "variables" which were then factored into regression equations to calculate final age, Chen *et al.* "studied male pubic bones according to the same principle, added two more criteria not mentioned in Hanihara's method but mentioned in Suchey-Brooks', evaluated appropriate scores and deduced four regression analysis equations" (2008: 42)(*Figure 60*). With these modifications, Chen *et al.* claimed to increase predictable accuracy to within one year of an individual's actual age (when evaluating their sample population, the Han Chinese). Independent female data, identical in method but distinct in scoring, were published by the authors in 2011.

To apply the Chen *et al.* method, the symphyseal face must be divided into to nine separate elements and scored on scales of either 0-2, 0-3, or 0-4 (*Figure 60,*

above). After scores are assigned, their numbers are then "plugged in" to one (or all) of four equations - MRA ("multiple regression analysis"), its subsequent GRA ("gradual regression analysis"), QMI ("Quantification Theory Model - I") or its subsequent GRA – depending on preference *(Figure 61).*

In 2013, Fleischman performed a comparison study between this new multivariate method and the archetypal Suchey - Brooks method. For the first time, he was able to report similar accuracy between the two paradigms, though it was noted that the Suchey-Brooks method fared better with younger adults while Chen *et al.* performed better on middle-aged adults. At the same time, Fleischman also introduced adapted equations applicable to American white males.

On October 17, 2001, a resident in Fushun city of Liaoning province, China found a large bag. To his horror, when opening it he found the torso of a dead body in it. He called the police and an investigation was carried out. The following day, somebody reported that a head and several dismembered limbs were found in a trashcan in Dalian station. After the collaboration of several local police forces, it was ascertained that these dismembered body parts were from the same individual. Age identification of the deceased was needed.

The pubic symphysis of the deceased was excised and examined using the method mentioned above. The evaluating score and corresponding coefficients were listed (Table 3). The age deduction was made from MRA and QMI gradual regression equations.

Age determination by MRA gradual regression analysis Equation: $M = 16.79$, $S = 2.14$.
Age of pubic symphysis: $16.79 + 0 + 1.76 \times 2 + 1.71 \times 2 + 2.47 \times 2 + 0 + 1.68 \times 1 + 3.03 \times 2 + 0 + 7.30 \times 1 = 43.71$.
Age determination by QMI gradual regression analysis Equation: $M = 16.45$, $S = 1.97$.
Age of pubic symphysis: $16.45 + 0 + 3.99 + 3.10 + 4.70 + 1.49 + 1.32 + 4.86 + 0 + 5.62 = 41.53$ (The actual age at death of the individual was 42.6 years, birth date: April 21, 1959).

Figure 61: A "case report" detailing the Chen et al. (2008) method

The most recent addition to the regression analysis stream is that of Dudzik and Langley (2015). Similar to Chen et al., this system divides the symphyseal face into multiple individually scored components: 1.) the "pubic tubercle," 2.) the "superior apex," 3.) "billowing," 4.) the "dorsal plateau margin," and 5.) the "ventral rampart margin." However, unlike Chen et al., who then provide the

practitioner with an equation to complete, Dudzik and Langley, uniquely, provide flow charts and a "decision tree" instead (*Figure 62, below*).

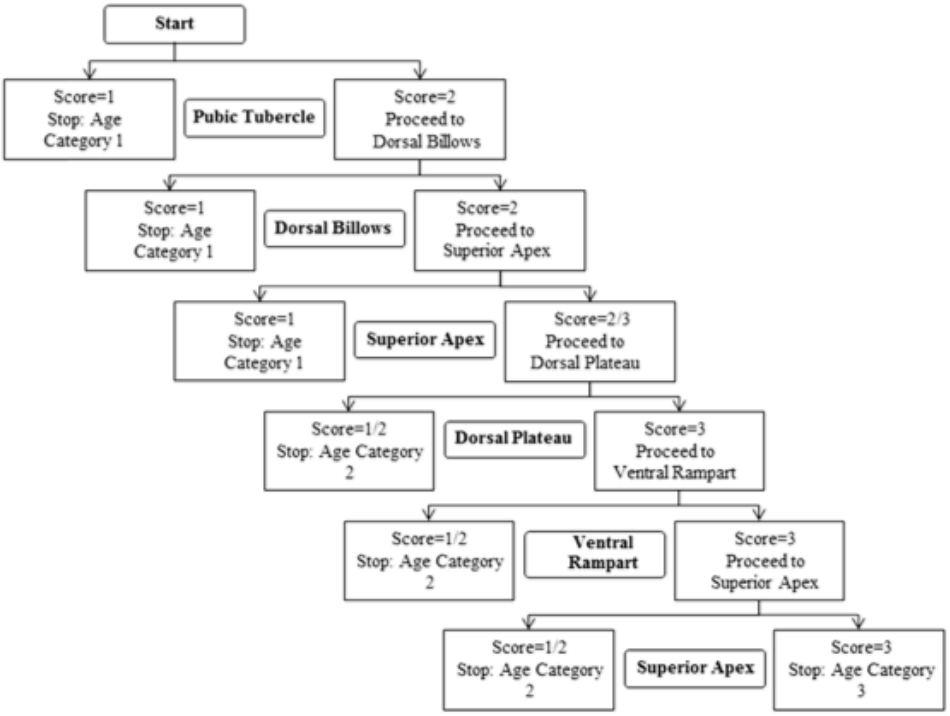


Figure 62: Age assessment "flow-chart" as per Dudzik and Langley (2015)

To implement their system, therefore, the practitioner would look at the bone they wish to age and assign several individual scores based upon the descriptions provided. He or she would then begin at the top of the "tree" and work his or her way down to the bottom, making decisions as he or she goes. Eventually, once a final determination has been made, the practitioner would then consult a table containing the three age categories and their attendant ranges. These include: Category 1, 18 – 26 (years); Category 2: 22- 32 (years); and Category 3, 29 – 40 (years).

With its decision tree and phased ranges, this technique represents a promising compromise between the increased specificity of the multivariate approach and the user-friendliness of non-equation methodologies. Unfortunately, this promise remains somewhat limited for many as, like Hanihara and Suzuki (1978) before them, Dudzik and Langley caution their method may not be used to assess individuals over 40 years of age, stating that "a pubic symphysis that exhibits epiphyseal changes and / or billowing is suitable for this method; a pubic symphsis that exhibits degenerative changes (i.e. porosity and / or rim erosion) is not suitable" (Dudzik and Langley 2015:99).

1.4 The Effect of Sex on Ageing the Os Pubis

The literature remains divided as to whether differences large enough to be statistically relevant exist between the pattern and timing of male and female symphyses. After conducting separate observations, Todd concluded that females tended to exhibit the hallmarks of his phases slightly later than did males (an average of two to five years delay) but that the two sexes did not diverge enough to necessitate separate systems. However, when Brooks tested Todd's methodology in 1955, she found that "the male pubic age seems to be quite accurate, the female pubic age less so" (Brooks 1955: 11). McKern and Stewart, in devising their own technique (1957), also grouped males and females together though later published additional female specific criteria (Gilbert and McKern 1973) stating "the McKern-Stewart male standards [were] not directly applicable to females" (in Suchey 1979:1). Nevertheless, even with these new standards Suchey found that among 23 practitioners asked to "age" a

series of female pubic faces "only 51% of the assessments yielded age ranges which include[d] the known age of the specimen" (Suchey 1979:1).

Seven years later, when amending Todd's original method, Katz and Suchey further concluded that "the male standards presented ... cannot be applied to female pubic bones [as] analysis of 500 female bone pairs has shown that greater variability is present than for the male" (1986). That same year, Suchey (this time working with Angel) also stated that "variability [in females] was so pervasive that the formation of an ageing system [was] virtually impossible" (Angel et al. 1986). In an effort to address this, Suchey (now paired with Brooks) sought to bridge the gap by providing two sets of exemplars - one reference set for males and another for females - but in the end echoed Todd in providing universal phase descriptions for both (1990). As recently as 2010, Hartnett concluded "that females undergo a more regular and predictable pattern of aging in the pubic bone than males, which contradicts much of the known literature. When the entire sample was segregated by sex and evaluated by the author, there were few differences based on sex" (Hartnett 2010). In their publications, Chen et al. (2008, 2011) provide separate scoring criteria and equations for females while Dudzik and Langley (2015) do not. One of the aims of this project will be to try and make sense of what may be causing this variability and such disagreement between practitioners.

1.5 The Problem with Reference Collections

Perhaps one explanation for this discrepancy, or lack of agreement between practitioners, may be the inconsistency and perpetually increasing obsolescence of the reference collections upon which these techniques were developed.

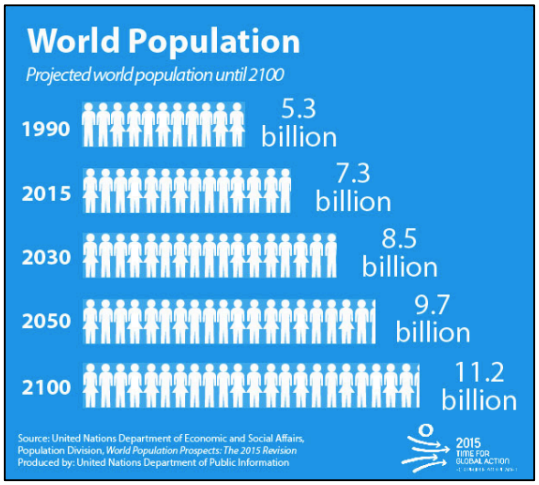


Figure 63: Projected UN world population statistics

According to the United Nations' *Concise Report on the World Population Situation in 2014,* between 2010 and 2014 the global community increased by approximately 1.2% - or the equivalent of approximately 83 million people - per year, a pace set to continue for the next 25 years. At the time this projection presented a monumental leap in growth, with the authors also noting that while "it had taken 123 years for the world's population to grow from 1 billion to 2 billion … only 11 years would be required for the increase from 5 billion to 6 billion" (United Nations 2014). By the time of the next year's conference, however, the world population had already surpassed 7 billion, prompting a revision and upwards adjustment of these projections to reflect a new per annum growth of 87 million (as opposed to the earlier 83 million), constituting a further 4 million people *per year* more than the previous estimate (*Figure 63*). For the anthropologist, who bases his or her profiling opinions and, thus, identification recommendations, upon the

phenotypic appearance of a skeleton ("the observable characteristics of an individual resulting from the interaction of its genotype with the environment," Oxford English Dictionary 2016), in comparison to reference skeletons either assumed or known to be similar in both genotype and environment, this presents a very real problem as, when any population increases, so too does individual variation.

Further complicating this variation will be global migration (with particular relevance to high-income regions such as Europe, North America, and Oceania), a phenomenon already restructuring current population demographics and one poised to play a major role in shaping the skeletal phenotypes of near future generations:

> *From 2000 to 2015, average annual net migration to Europe, Northern America and Oceania averaged 2.8 million persons per year… [with] high-income countries receiv[ing] an average of 4.1 million net migrants annually from lower and middle income countries. In the future, net migration is [therefore] projected to be a major contributor to population growth in many high-income countries. Between 2015 and 2050, total births in the group of high-income countries are projected to exceed deaths by 20 million, while the net gain in migrants is projected to be 91 million. Thus, in the medium [term], net migration is projected to account for 82 per cent of population growth in high-income countries (United Nations 2015:6).*

This increase in population plus international migration means that not only will more skeletal variation exist by simple virtue of more individuals but, in addition, those individuals will also increasingly belong to populations with which the average European, North American, or Oceanic anthropologist may have little to no experience (potentially leading to mistakes and misinterpretations, not due to protocol or error, but unfamiliarity).

At the same time, predictions also indicate that, within the next 35 years, that same global community will also consist of a greater percentage of older adults than ever before (*Figure 64*):

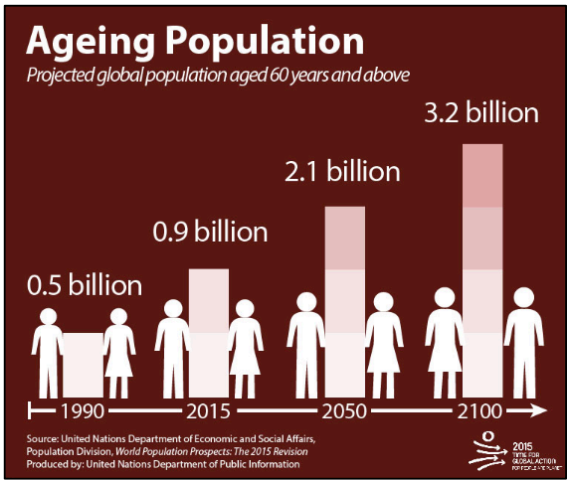


Figure 64: Projected UN population statistics by age

> *In 2015, there [were] 901 million people aged 60 or over, comprising 12 per cent of the global population. The population aged 60 or above is growing at a rate of 3.26 per cent per year. Currently, Europe has the greatest percentage of its population aged 60 or over (24 per cent), but rapid ageing will occur in other parts of the world as well, so that, by 2050, all major areas of the world except Africa will have nearly a quarter or more of their populations aged 60 or over. The number of older persons in the world is projected to be 1.4 billion by 2030 and 2.1 billion by 2050 [more than double the current number], and could rise to 3.2 billion in 2100 [more than triple the current number]. In the short-to-medium term, higher numbers of older population are inevitable, given that the relevant cohorts are already alive (United Nations 2015:7).*

Furthermore, within that group of older adults the number of "extremely old" or "elderly" individuals is set to increase even more sharply:

> *The number of persons aged 80 or over is projected to more than triple by 2050 and to increase more than seven-fold by 2100. Globally, the number of persons aged 80 or over is projected to increase from 125 million in 2015 to 434 million in 2050 and to 944 million in 2100. In 2015, 28 per cent of all persons aged 80 and over lived in Europe, but that share is expected to decline to 16 per cent by 2050 and to 9 per cent by 2100 as the populations of other major areas continue to increase in size and to grow older themselves (United Nations 2015:9).*

Should these predictions prove correct, over the course of the next 15 to 35 years alone these incremental shifts in global demography - increasing number

of individuals, increasing international migration (together resulting in increased variation), and increasing age (especially in the very old) – will have exerted a profound affect upon the skeletal expression of both current and future populations, especially those living in higher-income areas such as Europe, the United States, and Oceania, and all within the span of only one to three generations. By the turn of the next century (2100), therefore, many of these same populations may be virtually unrecognizable.

Despite this shifting skeletal landscape, however, forensic anthropology, a field that prides itself on cutting-edge modernity in the post-*Daubert* age, continues to rely heavily, if not exclusively, on historical reference collections – some only a few years old (the William M. Bass Donated Skeletal Collection; the Maxwell Collection), some a few decades old (The Balkan Sample; the Maricopa County FSC Collection; the William M. Bass Donated Skeletal Collection; the Maxwell Collection), and some over a century old (the Spitalfields Coffin Plate Collection, 1729-1859; the Coimbra Identified Skeletons Collection, 1904-1938; the Hamann-Todd Human Osteological Collection, 1912-1938; the Robert J. Terry Anatomical Skeletal Collection, 1822-1943; and the J.C.B. Grant Collection, 1928-1955).

This incongruity likely stems from the lengthy common history shared by forensic anthropology and its parent field, physical anthropology. Though formally established as its own discipline in 1972 (when "anthropology," originally "physical anthropology," was added as a section of the American Academy of Forensic Sciences), forensic anthropology remains deeply and

inextricably rooted in the ethos of its past. Illustrating this is the fact that, while fully recognized as a distinct field with a distinct purpose, forensic anthropology is still defined by its own members as "the application of physical or biological anthropology to the legal process" (the American Board of Forensic Anthropology 2016), suggesting that the tenets and practices of the earlier paradigm (most notably its devotion to large comparative dry bone assemblages) still hold firm – an unwitting inheritance from parent to child - and continue to shape the direction of forensic anthropology today, though the disciplines are no longer synonymous in either purpose or practice.

This emphasis on large physical assemblages, however, comes at a price. Currently, the most up-to-date research specimens are those obtained through either individual autopsy-based studies (Hartnett 2010, for example) or ongoing body donation programs such as those run by Texas State University, Western Carolina University, Sam Houston University, and the University of New Mexico. Of these, the program that receives the largest number of contributions per year is that of the University of Tennessee – Knoxville, or "UTK" (likely due to the renown and public awareness of its taphonomic research facility, known colloquially as "the body farm"). However, even as the donation leader, UTK's highest yearly intake has only ever been 128 bodies (2009). Generally, these contributions average to approximately 100 bodies per year, though this number is in decline (117 in 2010, 113 in 2011, 90 in 2012, 82 in 2013, 94 in 2014, and 75 in 2015)(Jantz 2016, pers.com).[7]

[7] In the UK, the body governing this, the Human Tissue Authority (or "HTA"), does not retain central metrics regarding donated bodies (one would need to inquire with each medical school

From the standpoint of a collection-builder (UTK openly states that the explicit "goal of the[ir] body donation program is to build [a] collection of known individuals for research purposes"), that annual numbers are small is immaterial - what is important is that they are cumulative ("currently … 1200 individuals and growing" [UTK 2016]). For those interested in current, up-to-date population data, however, small numbers are disastrous. This is because, with each new year, material from the previous year has already begun to "age out" of contemporary relevance – that is, become that much more removed from the population it is meant to represent – and, while this incremental loss may seem small at first, it is far from inconsequential. Imagine, for example, what would happen if someone in the habit of reading the newspaper every morning were to take a vacation or fall subject to a busy week. On Monday, a current, unopened paper would lie on the kitchen table, unread. Tuesday's paper, as the next most recent, would then be placed on top of it, followed by Wednesday's, then Thursday's, then Friday's, then Saturday's. By the time Sunday arrived, therefore, Monday's news will have already been replaced seven times over. Stories and perspectives, accurate at the beginning of the week, will have evolved and moved forward as newer, more updated information became available. In much the same way, with each new years' contributions, donated reference collections can become trapped in a similar cycle of obsolescence.

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in the country, individually, for such information), and no human taphonomic research facilities yet exist (though that may soon change). Because of this, it difficult to ascertain exactly how much modern skeletal material there is available for research in the United Kingdom, yearly or otherwise. However, while they can provide no information on specific numbers or details, according to the HTA a "severe shortage" of body donations is currently in effect and presenting real problems for trainee physicians, many of whom are now leaving medical school without having performed a single dissection, so it may likely be assumed that skeletal donation in the UK remains similarly scarce, if not more so (Human Tissue Authority 2012, pers.com).

At the same time, these low intake levels mean that rarely is an "*n*" suitable for large-scale study attained in any one year. This means that researchers are often forced to combine specimens received over multiple years – thereby mixing current and less current material as if they were equivalent, though that may not be the case. One would not advise the above mentioned reader to catch up with his or her papers by reading them out of order and skipping days in between (starting with Tuesday, then skipping to Saturday, then falling back to Monday, for example) as this would only lead to confusion and to conclusions based upon incomplete or jumbled data. Nevertheless, it is perfectly common practice to skip around through multiple years of a collection – provided all the specimens are from the *same* collection (the assumption being they will all represent the same population and general period). It has been shown, however, that when attempting to fit modern data to past populations, inaccuracy often follows (Wittwer-Backofen et al. 2008), leading many to caution against the tendency "which leads one to superimpose on the mortality structure… the structure of other populations entirely alien to them" (Bocquet-Appel and Masset 1982:321). If contemporary populations may not be applied to past populations, why, then, would past populations be representative of contemporary ones?

Despite this, the combining of multiple years, and multiple decades even, as interchangeable (while, at the same time, acknowledging the dangers of periodic and secular variation in other contexts) appears again and again in the literature both in the testing of established techniques and the development of new ones and is even advocated as a safe-guard against the kinds of false positives

produced when test groups are too similar to each other (Milner and Boldsen 2012) – though the inherent flaws of this practice, which may well account for some degree of repeatability error, bias, and discrepancy, are rarely discussed.

Frequently discussed, however, are the high levels of uncertainty surrounding the personal documentation of those individuals constituting the majority of many historical reference collections, many of whom were indigent, unidentified, or otherwise unclaimed at the time of their deaths and for whom "accurate recording of biological information was not always undertaken" (Blau 2009):

> *"The majority of techniques used by forensic anthropologists today were developed using descriptions and measurements collected either from archaeological collections where age and sex were unknown (e.g., Molleson and Cox 1993) or from anatomical samples (e.g., The Huntington, Terry, and Hamann-Todd Collections) where independent records of these biological attributes did not exist… In the case of archaeological collections, the majority of demographic data are inferred rather than independently known … [and] … in the case of [anatomical samples] … ages were estimated by anatomists on the basis of the external cadaver rather than on known age" (Blau 2009:460).*

While one may be forgiven in assuming that these issues represent "mistakes of the past" – as, surely, the forensic community of today would never accept such ambiguity, especially under the strict accountability of the *Daubert* Standard (Daubert v. Merrell Dow Pharmaceuticals, 509 U.S. 579 1993) – this same issue still plagues modern day collection building, as evidenced by The Balkan Sample (comprised of victims of conflict during the Bosnian War, 1992-1995 [notably post-*Daubert*]), from which biological "data came from cases where identifications (presumptive or positive) were available and from a sample of unidentified cases" (Kimmerle et al. 2008:526). Further criticisms include

"skewed age distributions, disproportionate representation of the sexes and ancestry, and … the specific removal of biological outliers" (Blau 2009), as well as demographic inconsistency with contemporary communities (Komar and Grivas 2008) and incompatibilities with outside populations (Schmitt 2004; Kimmerle et al. 2008; Mansourvar et al. 2014).

Despite these limitations, however (increasing obsolescence, dubious documentation, mixed years and decades, demographic incongruity with the communities they are meant to represent, and inapplicability to populations either of the past or of the present, if dissimilar), historical reference collections are still widely used, and trusted, by forensic anthropologists (so much so that when methods are found to be faulty or inconclusive, or with high degrees of intra or inter observer error, it is often the technique that ends up being viewed as suspect and not the material on which it was developed or verified).

As mentioned, this reliance is partly ideological, but equally culpable is the relative dearth of up-to-date skeletal material upon which to keep current. Because the field still demands physical "dry bone" specimens (a vestige of its shared history with physical anthropology), the only way of acquiring research material is through conflict (which is intermittent, unpredictable, and fraught with ethical concerns), autopsy (which is time consuming, small in scope, and dependent upon the consent of family members during a difficult time), and end-of-life donation (which represents the most sustainable option but suffers from limited yearly contributions). With such limited and infrequent availability, these numbers are much too meager to accurately or responsibly

represent a larger population, current or no. Consequently, for researchers in need of hundreds of specimens it would be impractical, both in terms of time and money, to insist upon remaining current and to not take advantage of the thousands of archaeological specimens easily available and at their immediate disposal. Moreover, this becomes particularly pressing for those in need of study subjects under the age of 45 years as most donated skeletons tend to be those of older individuals (Jantz 2012, pers.com) while autopsy samples and conflict collections, which tend to include younger individuals, remain rare.

This is not to say, however, that large, comparative collections have no benefit. Returning to the analogy of the newspaper, not all stories are linear or chronological. On the contrary, many of the articles are "stand-alone" biographies, editorials, satirical comics, community events, and human interest stories – none of which are tethered to or affected by the passage of time. For this reason, "catching up" on a week's worth of newspapers is still a productive and pleasurable experience, regardless of the timeliness of the headlines. Additionally, while being as currently informed about an unfolding story as possible is certainly important, the ability to trace the evolution of that story, how it changed each day and how its final outcome came to be, is equally valuable. In this way, the relevance and utility of historical collections depends largely upon the emphasis of the researcher. For the physical anthropologist, this might be to follow the twists and turns of a particular feature, documenting its stepwise progression from Monday to Sunday, whereas for the paleo-demographer, it might be for the marriages and obituaries (and perhaps the weather [climate]). For the forensic anthropologist, however, what matters is

the "breaking news" – an aspect that cannot be addressed by backlogs or archives.

With the osteological "status quo" already shifting due to increases in global population and international migration - a combination set to dramatically transform the demographic landscape in as little as 15 years (not to mention the next 35, 50, or 85) – our methods of obtaining representational skeletal material may soon go from woefully inadequate to shamefully so. At the same time, with more people comes more scarcity of resources, leading to increased mortality due to detrimental changes to the environment (famine, natural disaster), epidemic and pandemic disease, and interpersonal violence (Russell and Russell 1984; Urdal 2008; United Nations 2016), which means forensic anthropologists and their up-to-date expertise may also be in greater demand. Given these eventualities, and the time frame projected for them, 100 semi-representative bodies per year will not be sufficient to prepare an entire field for the changes ahead.

"Forensic anthropologists have an ethical responsibility to consider the reliability and acceptability of the techniques [they] employ" (Blau 2009:460). First and foremost, this needs to include a serious look at our inherited dependence on accumulated reference collections. What is needed is a better way to access present day populations - a way to provide bigger, more representational "*n*'s," where detailed demographic, life history, and behavioral information may be documented and verified, and for which more rigorous, universal standards may be applied. This way must be proactive, not reactive –

i.e. looking forward, not back – and must be implemented, with unified purpose, as widely and as expeditiously as possible. If this way is not found, much like the collections it could not break free of, the field of forensic anthropology will find *itself* obsolescing – proving true the words of Iscan, when he warned "..this entity can stagnate or even self-destruct if the direction of future research is not carefully planned" (Iscan 1988:222).

1.6 Computed Tomography (CT)

The direction of that future research - this new way forward – must be the adoption of medical imaging technology, specifically computed tomography (CT), into biological profiling.

The term "medical (or diagnostic) imaging" refers, generally, to any technique or process by which the inner structures or functions of the body may be visualized. This includes ultrasound, or ultrasonography (from "sonar" [Sound Navigation And Ranging], which utilizes radio frequencies), magnetic resonance imaging, or "MRI" (which uses radio frequencies in conjunction with magnets), radiography, or "plain film" radiographs (which utilize "x-ray" frequencies), and computed tomography, or "CT" (which, like radiographs, also utilize "x-ray" frequencies, but digitally and from multiple angles). Also falling under this purview are fluoroscopy (moving radiographs), nuclear medicine (such as single photon emission computed tomography, or SPECT, positron electron therapy, or PET, and scintigraphy), and several experimental modalities such as thermal imaging, thermo- and photo-acoustic imaging, and elastography. Of

these, radiography – or the focused application of "x-rays" - has proven to be most useful in the visualization of bone. The reason for this lies in the differing atomic masses of the body's soft and hard tissues.

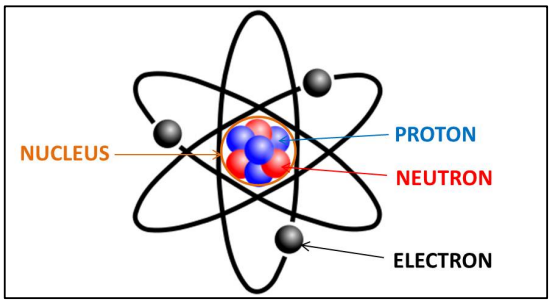


Figure 65: Anatomy of an atom

Like all things, the human body and its tissues are comprised of atoms, which are, themselves, a collection of protons, neutrons, and electrons (*Figure 65*). The weight, or mass, of an atom is measured by the number of protons and neutrons it has in its nucleus (the lower the number of protons and neutrons, the lower the mass; the higher the number of protons and neutrons, the higher the mass). Based on this ratio, then, an atom's mass and an atom's size are directly proportional.

Each element is defined by its own unique weight. Hydrogen, for example, has an atomic mass of one whereas carbon has an atomic mass of 12. This means that an individual carbon atom has more protons and neutrons and is, therefore, larger than an individual hydrogen atom. Larger atoms have more electrons. This distinction is important to radiology as larger atoms, both by virtue of overall size (which translates to more space between electrons) and an increase in the number of electrons themselves, which absorb (or block the flow of) more photons than do smaller ones.

Photons are the zero mass particles by which energy, in the form of light, is transferred. Inside the sun's core, hydrogen atoms under immense gravitational pressure are forced into fusion, forming helium – a reaction that produces intense heat and, consequently, light energy (photons). As the forces within the sun are in constant motion, much of this excess energy is pushed, or radiated, out into space. Once out, this energy (in the form of photons) becomes subject to the push and pull of two opposing forces, the electric field and the magnetic field. This alternating back and forth squeezes the photons forward (towards earth) in the form of waves, with the higher energy particles forming taller, tighter oscillations and the lower energy particles forming shorter, wider ones. The distance between the crests of these oscillations ("wavelength") is used to determine how frequently the wave switches course ("frequency"), denoting its energy potential. This potential may be imagined as a rubber ball in a small room. If it is thrown with tremendous initial force it will bounce furiously, hitting each surface in rapid succession as it rebels against the constraints of the space. If it is not thrown with much initial force, however, its bounces will be fewer, more softly curved, and the time between them will be longer. These differing energy profiles are represented by the "electromagnetic spectrum" (Nova 2012)(*Figure 66*).

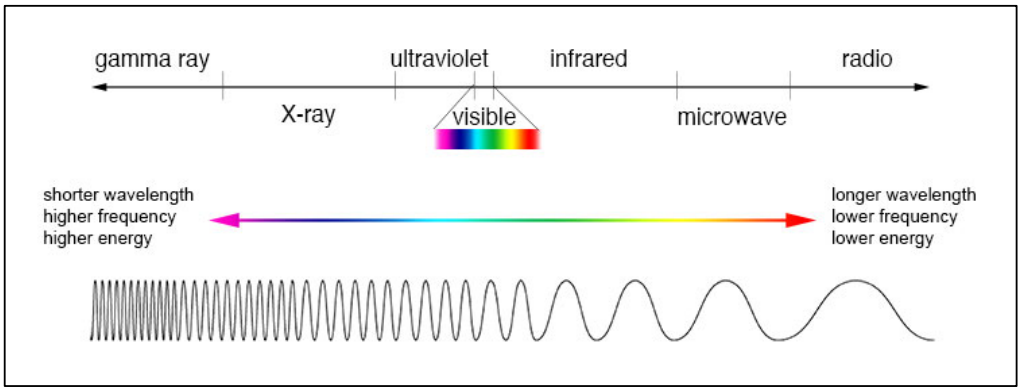


Figure 66: The electromagnetic spectrum

With wavelengths of 10 nanometers or fewer (0.01 to 10nm), frequencies between 30 petahertz and 30 exahertz (3×10^{16} Hz to 3×10^{19} Hz), and quantum electron volts of around 124 and up (120 eV to 120,000 keV), "x-rays" may be found with gamma rays at the high-energy end of the spectrum (Barrie Smith and Webb 2010; Nave 2016) - indicating that its photons are powerful, fast moving, and highly penetrating. As such, they pass right through lower energy material (including atoms with smaller atomic masses) without interruption or effect. Unhelpfully (in terms of imaging), the human body is made up almost entirely of these smaller atoms. For example, approximately 60 to 65% of an adult's body is water, which, as "H_20," is composed of hydrogen (atomic mass: 1) and oxygen (atomic mass: 16). Within that 60 to 65%, furthermore, water accounts for approximately 70%, 73%, and 74% of an individual's liver, heart, and brain (respectively), 80% of an individual's muscle, kidneys and alimentary tract, and approximately 83% of an individual's lungs. In fact, with the exception of skin (65%), bone (32%), and teeth (5%), every tissue in the human body is composed of at least 70% water (Mitchell et al. 1945). By simple virtue of size, both hydrogen and oxygen possess low "radiological densities," which

means that x-rays, being of higher energy, will pass right through them without stopping. This is why "soft" tissue does not appear on radiographs.

The body's "hard" tissues, however - the bones and teeth - are composed primarily of calcium (atomic mass: 40) and phosphorus (atomic mass: 31). As substantially larger atoms with more electrons, calcium and phosphorus are much more "radiopaque." This means that, instead of letting x-rays pass, they are more likely to stop them.

Within the atom are protons, which are positively charged, neutrons, which carry no charge, and electrons, which are negatively charged. Existing outside of the nucleus, these negatively charged electrons are bound to the positively charged protons by electromagnetic force, which compels them to perpetually orbit the nucleus. The multiple paths these electrons take are known as "orbitals" (*Figure 67*). Each of these orbitals, in turn, require differing levels of energy, which is determined by their distance from the nucleus (the closer the orbital, the lower its energy needs to be). In order to drop from a higher energy orbital to a lower energy orbital (i.e. get closer to the nucleus and, therefore, the protons), electrons must give up their excess energy in the form of photons. In this, atom size plays an important role as the farther the orbitals are from each other, the farther the electron has to fall - the longer the drop, the greater the inertia (energy accrued). By this principle,

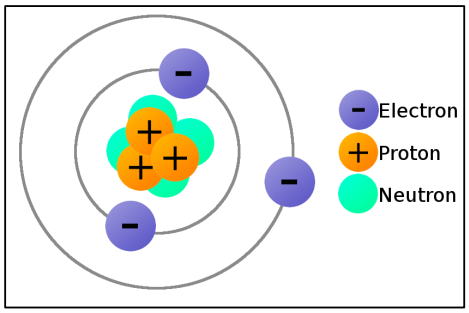


Figure 67: Constituents of an atom

larger atoms like calcium, with its mass of 40, create higher energy photons than do smaller ones like hydrogen (with its mass of one). At these higher energies, these "cast off" photons begin to mimic the high energy electromagnetic profile of x-ray photons. As a result, x-ray photons are much more likely to be absorbed by larger atoms such as calcium and phosphorus as the energy differential between their orbitals more closely matches the energy level of x-ray photons (a case of "like" attracting "like"). As calcium and phosphorus constitute the majority of skeletal tissue, it is this preferential absorption, or "attenuation," of x-ray photons that enable the radiological visualization of bones and teeth.

To produce radiological images, x-ray photons are created artificially by forcing a stream of electrons through a glass vacuum tube, exciting them along the way. At one end of this tube is a (negatively charged) cathode, a heated filament from which the electrons will emanate, and at the other end is a (positively charged) tungsten anode, which attracts them and pull them through the space (remember that electrons are negatively charged and are always trying to get to the positively charged protons in the atomic nucleus, which is what keeps them in orbit – the principle here is the same).

When the filament (cathode) is heated, electrons are generated and pulled to the other side of the tube by the positive charge (the anode), helped along by a pronounced discrepancy in voltage between the cathode (low) and the anode (high). Under the influence of immense pressure, the newly created electrons are hurtled through the tube and smashed against the tungsten anode at the far end. This high-speed collision knocks some of the tungsten electrons out of

their lower orbitals and off into space. This, in turn, causes an electron in a higher orbital to drop into its place. In order to drop to the lower energy level, however, the higher energy electron is forced to release its excess energy in the form of a photon. As the atomic mass of tungsten is 184, this drop between orbitals generates a tremendous amount of energy – enough to create an x-ray photon. Finally, these x-ray photons are aligned to form a focused beam (so as to be targeted only where needed) and filtered to control intensity. This beam is then directed towards an object (*Figure 68, below*).

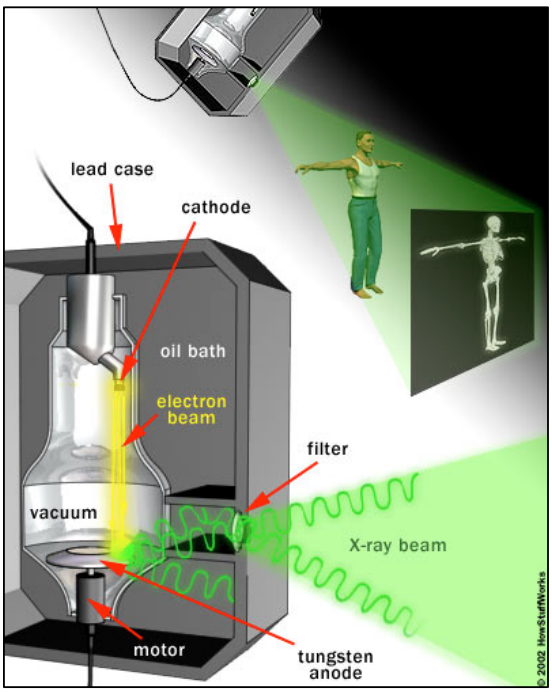


Figure 68: The production of a radiograph

To produce a skeletal image, or "radiograph," this targeted beam of photons (light) is passed through the body and - as x-rays are absorbed by bone (but not by soft tissue) due to the similarity of their energy profiles – a shadow, or void, is created. This is referred to as "attenuation."



Figure 69: Illustration of "attenuation"

This process is very similar to the production of early cave art, and may be imagined that way – pigment is held in an artist's mouth and is, through exhalation, forced towards an object, which either blocks it or lets it pass. This results in a pigment-less impression, or void, where the object used to be (*Figure 69*).

In the case of cave art, this "negative image" is displayed on the stone behind. In radiography, these voids are captured by "detectors." For a conventional radiograph, this detector consists of an imaging plate containing photosensitive film, which is exposed to reveal an image (in much the same way a photograph would be). In digital, or computed, radiography, this film is replaced with digital sensors (*Figure 70, below*), which translate that image into code.

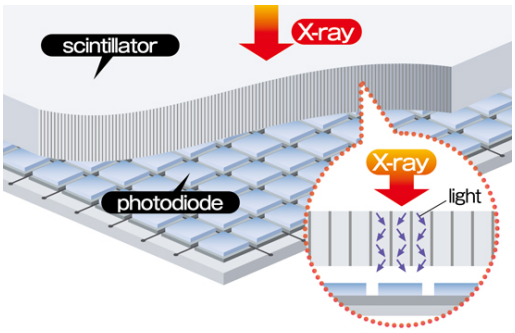


Figure 70: Inner architecture of a digital sensor

Computed (digital) tomography (sectioning), or "CT," from the Greek *tomos* ("slice" or "section"), is simply a series of these single focus radiographs, taken from multiple angles and viewed simultaneously to obtain volume. To accomplish this, the x-ray tube, instead of being fixed in one location, is attached to a circular gantry, which rotates, incrementally, around the object being imaged. This process may be visualized as the face of a clock. If the x-ray tube is positioned at 12 o' clock, its detector will be directly opposite, at 6 o'clock, with the object centered in between. When initiated, the photon beam will pass in a straight line from one to the other, resulting in an image. Once this image has been captured and recorded, the tube will move to 1 o'clock and the detector to 7 o'clock and the process will repeat. Once *that* image is captured and recorded, the tube will move again to 2 o'clock and the detector to 8 o'clock, and so on. In this way, multiple images may be acquired of the same location or structure, increasing clarity. With each complete revolution – or each time the tube returns to 12 o'clock - one cross-section, or "slice," is produced (*Figure 71, below*).

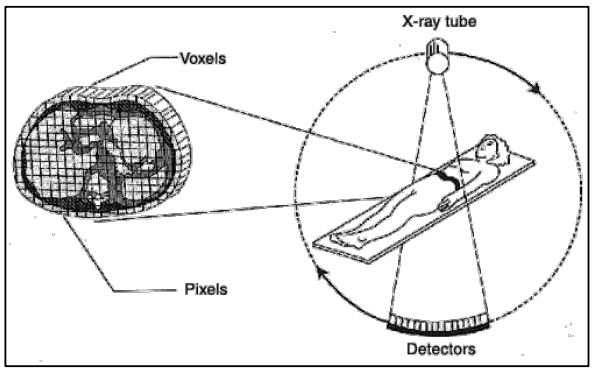


Figure 71: The production of 3D volume through the accumulation and viewing of multiple "slices"

When several 2D slices are "stacked" and viewed together, "pixels" become "voxels" and 3D volume is created.

1.6.1 Computed Tomography in Forensic Research

Over the past two and a half decades, investigators have (slowly) been coming around to CT and its potential impact on the field of forensic anthropology, resulting in a small but growing body of relevant literature. In the early days, when medical imaging technology was in a period of rapid growth and advancement, Reichs (1993) devised a system of quantifying the anterior frontal sinuses by matching them with ante-mortem data (in the same way one would match radiographs taken of a decedent with radiographs taken of him or her during life) while, in 2002, Smith *et al.* sought to identify individuals by cranial features, using the same methodology. As CT technology evolved (for an excellent historical review, see Siemens 2011b), however, so too did its utility in forensic research.

Gradually, thanks in large part to the influence of "The Virtopsy Project," a revolutionary medical imaging facility at the University of Zurich (Bollinger et al. 2008; Verhoff et al. 2008), the use of CT began to broaden from its initial application as a non-destructive method of evaluating mummies (Cesarani *et al*. 2003; Marx and D'Auria 1988; Notman *et al.* 1986) to include the analyses of trauma and pathology (Dedouit *et al.* 2007; Kettner *et al.* 2011; Myers *et al.* 1999; von See *et al.* 2009), the separation of commingled remains (Blau *et al.*

2008; Kahana *et al.* 1997), facial reconstruction (Myers *et al.* 1999; Tyrrell *et al.* 1997; Quatrehomme *et al.* 1997; Wilkinson *et al.* 2006), identification from the frontal sinuses (Reichs 1993; Quatrehomme *et al.* 1996), fetal age estimation (Pommier *et al*. 2009), and age changes to the posterior pelvis, os pubis and rib (Barrier *et al.* 2009; Dedouit *et al*. 2008; Ferrant *et al.* 2009; Telmon *et al.* 2005; Tocheri *et al.* 2002). Now, instead of simply attempting to match the scans with ante-mortem data, investigators were increasingly scanning medical school cadavers, remains from mass disasters, and samples taken from autopsy for the purpose of proactive research.

Unfortunately, while these "proof of concept" studies were technologically progressive, all but two (Pasquier 1999; Schulz *et al*. 2005) presented extremely small sample sizes - with some examining only 5 or 6 skulls (Sholtz *et al.* 2010 and Dedouit *et al.* 2008, respectively) and some only 21 or 22 specimens in total (Telmon *et al*. 2005 and Grabherr *et al.* 2009, respectively). In 2007, Dedouit *et al.* utilised CT in an effort to identify a missing person in an official police inquiry (the first time the technology was used in place of physical bone in a medico-legal capacity) and, while exciting, this too represented only one case, involving only one subject. All told, out of all the investigations prior to 2010, only two (Pasquier 1999; Schulz *et al.* 2005) reported a sample of even 50 individuals. To make matters worse, these studies also scanned (treated) autopsy cadavers, (desiccated) dry bone, or instructional plaster casts (Tocheri et al. 2002), which, due to their density, would be wildly misrepresentative. In addition, most of these cases were further complicated by the presence of unaccounted for variables such as lifestyle differences, substance abuse and

alcohol consumption, multi-ethnic and mixed sex data sets, all of which had been shown to lead to differential ageing as well as discrepancies in bone density, rugosity, and elasticity – raising questions as to the validity of any results (Gilbert 1973; Stewart 1957; Suchey 1979; Suchey and Brooks 1982; Todd 1921; Washburn 1948).

In an effort to remedy this, in 2010, Moskovitch and colleagues published groundbreaking research utilizing the retrospective scans of 160 living individuals to assess the Kunos *et al*. (1999) method of aging the first rib. This was then followed closely by Uthman *et al*. (2011), who used a living sample of 88 individuals (also retrospective) to investigate potentially diagnostically indicators of sexual dimorphism from the maxillary sinus.

"Living" studies since have grown to include Decker *et al.* (2011), who sought to determine sex from the pelvis, Alcaraz (2012), who examined the pubic symphysis (using his own method), Verna *et al.* (2013), who updated age and sex techniques involving the ribs and sternum (as did Oldrini *et al.* 2016), and Wink (2014), who sought to establish the reliability of CT volume renderings when applying the Suchey-Brooks Method for Ageing the Os Pubis.

1.6.2 Computed Tomography and the Os Pubis

Within the published literature, however, only eight investigations to date have involved CT and the os pubis, specifically. The earliest of these was Pasquier *et al.* (1999), which involved scanning the 12 Suchey-Brooks "Male Age

Determination" reference casts (France Casting Trademark, product SA001) in addition to 74 new physical (white male) specimens, collected over a period of four years. The donated specimens were used to create a novel technique, formulated by the measurement of 18 computer generated criteria (or, "invariant descriptors"), leading to various statistical equations to be applied to the symphyseal face to quantify age (a discriminant function analysis much like "FORDISC" [Ousley and Jantz 1993], which quantifies racial variation in the skull). Similar to Hanihara and Suzuki (1978), the authors then applied multiple regression analyses to the data in an attempt to lessen subjectivity. The results of this new methodology were then compared to a Suchey-Brooks analysis of the same sample. Prediction accuracy for the two were similar, however, using their method Pasquier *et al.* claimed the ability to tighten their standard of deviation to 7.3 years, as opposed to the deviation of 10.18 years for Suchey-Brooks.

Despite these results, the Pasquier Method never gained in popularity and is today all but unknown. Perhaps one reason for this lies in its statistical complexity, which can be easily overwhelming for non-statisticians and, therefore, daunting to implement. Another could be its impracticality at the time of its publication. As is still true today, access to CT scanners remains prohibitively expensive and is often accomplished only through direct partnership with a research hospital (which, even then, requires a long and arduous application and approval process). In 1999, it could only have been more so. At the time, it would have been far easier and less time consuming for

an investigator to simply employ the quicker, easier visual techniques already available, bypassing the Pasqueir *et al*. method entirely.

In 2002, Tocheri *et al.* sought not to create their own method but to renew attempts to quantify morphological age change to the os pubis. To do this, however, they did not employ cadaveric specimens as Pasqueir *et al*. (1999) had. Instead they scanned the 24 (12 male and 12 female) Suchey-Brooks "Age Determination" reference casts (France Casting Trademark, products SA001 and SA002) and applied a "water-shed" algorithm for geometric modeling, documenting absolute curvature values from the surface of each cast through region segmentations. In brief, could the ratio of positive and negative space (ridges and furrows, concavities and "build-ups", etc.) at each Suchey-Brooks phase be meaningfully quantified to estimate age? While the specific results of the research were not published (they were, instead, presented at the 71st annual meeting of the American Association of Physical Anthropologists), the authors described them as "successful" and illustrations were provided.

The main issue with this study lies in the fact that the authors scanned the Suchey-Brooks reference casts (France Casting Trademark, sets SA001 and SA002) – not bone - and then based their conclusions on those images. As the casts are made of very heavy, very opaque plaster (which is also uniform throughout), these scans cannot be used to represent bone, and especially not pubic bone, which is mostly trabecular (Wade et al. 2011). That "the models show a high level of surface detail and are practically indistinguishable to the eye from their real world counterparts" (Tocheri *et al.* 2002: 10) is unsurprising

given the radiopacity of plaster and is, therefore, misleading when conflated with actual bone as it establishes a false certainty and a flawed baseline. That being said, if the same methodology could be developed using actual bone, taking density into account, it would undoubtedly prove revolutionary to the estimation of age from the pubic symphysis.[8]

More recently, both Telmon *et al.* (2005) and Grabherr *et al.* (2009) utilized autopsied specimens to perform their respective studies. Through the examination of 21 subjects, Telmon *et al.* (2005) worked to establish that the os pubis could be successfully aged through the application of computed tomography and the Suchey-Brooks method. Based upon the examination of both physical and virtual material by two experienced observers, the authors found that the CT visualisations (at a slice width of 1mm) were equally accurate, though with limitations, concluding "the accuracy of age estimation did not significantly differ between the Suchey-Brooks method applied to bones and the same method applied to CT images. Image analysis and bone analysis thus appeared to be equally reliable" (Telmon *et al*. 2005: 5).

In 2009, Grabbher *et al.* carried out a similar feasibility study but instead of using the more widely accepted Suchey-Brooks Method for Aging the Os Pubis, they employed the work of Ascadi and Nemeskèri (Ascadi and Nemeskèri 1970)

[8] It should be noted that Tocheri *et al.* made use of a portable laser digitiser to collect the skeletal data for their study, not a CT scanner. As an image based investigation using the Suchey-Brooks method to estimate age from the pubic sympysis, however, the research and issues raised are still relevant to the development of this thesis and, as such, have been included here.

and made use of entire skeletons for their estimations. This time, three practitioners were asked to age 22 specimens (with slice widths of 0.63mm) using the "complex" method. Just like Telmon *et al.* (2005), the study undertaken by Grabherr *et al.* suffered from an inexplicably small sample size given its generous funding and scale. Even more baffling, this sample was further compromised by the fact that it comprised solely of specimens who had died from heart failure or drug and alcohol overdose. Due to these oversights, as well as their choosing to employ the controversial Ascadi and Nemeskèri method (though still common in continental Europe), it is perhaps unsurprising that the accuracy rates per observer were 14.3%, 36.3%, and 22.7% (with the samples consistently over-aged).

More recent pubic symphysis studies include Alcaraz (2012), Lottering *et al.* (2013), Villa *et al.* (2013), and Wink (2014). All are methods tests and comparison studies and suffer, again, from small sample size at 167, 195, 12, and 44, respectively. Furthermore, all obtained their scans retrospectively, which means potentially informative demographic and life history information are, by necessity, either absent or limited.

1.7 Aims and Objectives

By utilizing radiography in the form of computed tomography in partnership with living participants, this thesis will seek to address and remedy a number of the issues presented over the course of this chapter.

In order to produce accurate biological profiles, forensic anthropologists must be equipped with the most reliable, up to the date information possible. At present, this is hampered by the perpetuation of adult ageing methodologies with unhelpfully wide ranges (especially for women and older individuals), themselves developed on questionable datasets (ambiguous documentation, current relevance, etc). To begin to remedy this, what is needed is current, verifiable, populationally representative data in quantities sufficient for study – a feat possible only through the incorporation of medical imaging technology.

This thesis will therefore couple bone scans (CT) with a suite of questionnaires, face-to-face interviews, and access to hospital records (if necessary). With these scans, the author will focus on the pubic symphysis - chosen for its continuous, liner change over a person's lifetime (from late teens to late 90's) representing an unbroken spectrum of ageing (as opposed to methods which terminate once fusion is complete, or those that "pick up" afterwards [such as the clavicle, the ageing of which is currently in two halves - one pre-epiphyseal method and one post-epiphyseal]). By examining the pubic symphysis, the technique introduced by this thesis, the Truesdell Composite Method, or "TCM," will be shown to produce a prediction range of no more than 24 years – a better range for law enforcement and far narrower than anything else in the current literature.

While multiple imaging modalities hold promise in this area and work is being done to improve the applicability of MR and Ultrasound, CT is, at present, still the easiest of the three to procure as well as least difficult to "read" as its images look like bone (what practitioners are already used to), making the transition

into virtual profiling more familiar. Conversely, with MR and especially ultrasound, the practitioner must really know what he or she is looking for – as well as what he or she is not looking for – while at the same time having an "eye" for minute shifts in detail, such as subtle colour changes or gaps. If not apt, attuned, or proficient in this, error (and with it, mistrust) is inevitable. Furthermore, MR remains prohibitively time consuming and expensive while ultrasound requires additional training. For these reasons, CT was deemed the best choice for this study. While using this modality in this way has been criticized (i.e. constructing volume renderings to look like "real" bone instead of more quantitative approaches - another manifestation of the visual versus statistics division described earlier), the author would argue one must learn to crawl before he or she can walk, and walk before he or she can run.

At present, as a discipline forensic anthropology is slowly moving forward in this arena but still prefer anonymous retrospective studies (Robinson et al. 2008; Kellinghaus et al. 2010; Decker et al. 2011; Lee et al. 2012; Mestekova et al. 2015; Savall et al. 2015; Bilfeld et al. 2015; Zhang et al. 2015; Lottering et al. 2016; Daumas et al. 2016; Oldrini et al. 2016) or the scanning of autopsy specimens (Boyd et al. 2015; Caple et al. 2016; Lapointe et al. 2016). Indeed, the most recent retrospective studies have gained access to the anonymized medical records of their participants but have had no interaction with them whatsoever. This is essentially the same thing as collection building through donation – basic information, but little to no context. While, within the last year, a handful of interactive studies have taken place (Baillie et al. 2015, 2016 – ultrasound on living volunteers, demographics such as ancestry, age, and BMI

were recorded; Hwang et al. 2015 – consent, demographics, and photo [building upon Lee et al. 2012, same authors]; Ruquet et al. 2015 - questionnaires), all have involved the face or head - none have investigated post cranially. This is likely because dental CT's are small and so are portable and easy to obtain. An illustration of this lies in the fact that for each of the aforementioned studies, all have included a dentist as one of their authors.

Therefore, despite the fact that CT is being used and current data is being collected, no study to date has utilized the technology to its full potential. This means that, while advances are being made, we, as researchers, are only half way there. This is why, as forensic anthropologists, we must consciously break with old habits and embrace not only the present but also the future of our discipline - only then will our techniques and, with them, our estimations, improve.

To that end, this thesis will introduce a new CT specific technique for ageing the os pubis (the "TCM," to be introduced and assessed in future chapters) - made possible only through the active participation of living volunteers - and in doing so will seek to fulfill the following:

Aim: *To improve precision in female age estimation through the utilization of medical imaging technology and personal, face-to-face interaction with living participants.*

0_1 *Developing the technique.* The first objective in accomplishing this aim will be the introduction of a unique, CT-specific technique for the estimation of age from the female os pubis, designed to engender greater clarity and precision and with applicability up to 90 years. This technique, the Truesdell Composite Method, is completely image based so as not to be dependent upon physical reference collections, and thereby opening a new avenue for data gathering to cut a path for future researchers. This technique is built around the pubic symphysis, as the pubic symphysis exhibits the longest rate of continuous change relative to the rest of the body, representing the entire spectrum of adult life. It is also the area most frequently cited, yet it is also the area with most unhelpfully large ranges. Milner and Boldson (2012) stated that, "another limitation of conventional age estimation procedures is not being able to do much, if anything, with the skeletons of old people." This is especially true at the pubic symphysis, where ranges span multiple decades as an individual ages. With its continuum approach, the TCM will seek to address this issue.

0_2 *Testing the technique.* Once this method is established, the second objective in this study must be to test it on a large, representative sample. To acquire this sample, the author will conduct a series of face-to-face interviews with currently living participants involving both study specific questionnaires as well as hospital records, if required. Incorporating living participants through the use of CT not only ensures that any potential changes seen on the bone are the result of age and not

some unknown factor, but it also ensures that the sample on which the technique is being assessed is non-anomolous and fair representation of the larger population.

0_3 *Assessing the technique.* This study's third objective will be that of establishing to statistical satisfaction whether the technique is, indeed, a good predictor of age (on this sample). To do this, the TCM's accuracy and precision will be compared to two existing techniques: the Suchey-Brooks Method for Ageing the Os Pubis (1990) and the Hartnett Method (2010), which will be applied simultaneously. In addition, three independent observers will also assess a subset of images to investigate how well the TCM compares relative to the other techniques.

Milner and Boldsen (2012) also said that, "accuracy and precision are related to one another; when one goes up, the other goes down." With the TCM, this study will seek to prove that need not necessarily be the case. The over-arching research question for this thesis will be, therefore, "can the TCM be considered a good predictor of age?"

The direct steps taken to realize these aims and objectives are detailed in the next chapter – "Materials and Methods."

2

Materials and Methods

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Abstract:

To investigate the effects of lifestyle variables on skeletal ageing reliability, it was first necessary to obtain CT scans, coupled with comprehensive life history information, from a wide cross-section of people. For this, the Oxford University Hospital complex (OUH) was chosen as an ideal location due to their projected intake volume, the variety of patients likely to be seen, and for feasibility and ease of approach (as a teaching hospital, which means that both patients and administration would be familiar with and accustomed to the presence of ongoing studies). This chapter will outline the materials and the methods utilized in this study.

2.0 Ethics Approval and the Release of Data

Approval for this study was granted by "favourable opinion" following a full review by the National Research Ethics Service, or NRES, as well as the Oxford University Hospitals NHS Trust. In order to ensure that the public and / or participating patients would not be harmed during, or as a result of, this study it was necessary for the research and the potential of its outcomes to be considered and cleared in advance by an appropriately qualified, independent committee as convened by the National Health Service, or "NHS." Approval by such a committee is mandatory for all hospital-based research undertaken in the United Kingdom and ensures, among other things, that investigators will be adequately supervised and overseen in (and out of) clinical settings, that studies will be insured (should something go wrong), that detailed risk assessments have been performed, that logistical concerns and data protection laws are upheld, and that a well designed and - most importantly - feasible protocol is proposed and adhered to. Only after these safeguards have been guaranteed (and all ethical considerations have been addressed) may a study go forward and recruitment begin.

Every hospital-based study in the United Kingdom begins with a universal online application through the Integrated Research Ethics System, or "IRAS." This serves as the first and most intensive step of the ethical approval process. Once a profile is created, each proposed investigation is assigned an individual project ID number, which allows for open communication between NRES administrators and the principle investigator (known as the "PI"), in this case the author, and for all changes to be tracked as the application progresses. The project ID number for this study was 119232.

Each project created through IRAS must provide detailed, study-specific information through the completion of a large, comprehensive (80+ page) "Full Project Data Set," which, along with basic administrative details, outlines such things as an overview of the research proposed, its purpose and the fine points of its design, any risks and ethical issues (such as the management of sensitive topics or the treatment of minors and / or vulnerable adults), procedures and protocols, anticipated benefits, recruitment and informed consent, confidentiality and data security, publication and dissemination, scientific and statistical review, and the appropriate management of any results. The credentials and commitment of the author's academic supervisors were also required. Next, as this study was undertaken in partnership with the NHS and was to be carried out within the radiology department of The Churchill Hospital (a specific place, or site, on NHS premises, involving NHS employees), an additional site specific, or "SSI," approval was also necessary. Lastly, because this study sought direct involvement with individual patients, independent approval from the National Health Service (NHS) itself had to also be obtained.

For this project, this meant separate NHS / HSC Research and Development, or "R&D," approval.

Once all three forms were completed to the satisfaction of the Oxford University NHS Trust Clinical Trials and Research Governance, "CTRG," team (a phalanx of the NHS specific to the Oxford hospital complex), insurance for the project was granted and declarations (signatures) were made by the author, the author's two university supervisors, and the study's sponsor (CTRG). The application in its entirety was officially submitted to NRES (Research Ethics Committee, or REC, reference no. 14/SC/0061) through IRAS, with the accompanying documents sent in by post (as required).

After the submission and acceptance of this IRAS application, a review committee was selected and the date for the meeting of that committee was provided (as this study involved patient interaction, the less formal "proportionate review" alternative, for which consideration by a full committee is not needed, was not an option). Assigned to this project was the "South Central - Hampshire A" committee, which met in Southampton on the 11th of February, 2014. Presence of the author was mandatory.

After two revisions (both alterations to the questionnaire), NRES approval to proceed with this study was granted on April 1st, 2014 (Appendix A). "Trust Management" approval (OUH NHS Trust) (Appendix B), together with the "Letter of Access" (LoA) allowing the author full access to the radiology department and to work on NHS premises (Appendix C), was granted

approximately two months later with the completion of an occupational health assessment and the attainment of requisite inoculations. Access to data was granted on June 20th, 2014.

Separately, this project was also assessed by the Oxford University Central University Research Ethics Committee (CUREC), in partnership with the School of Anthropology and Museum Ethnography (SAME). Approval was granted April 11th, 2014 (Appendix D).

In total, the ethical approval process allowing this study to take place took approximately nine months (*Figure 72)*.

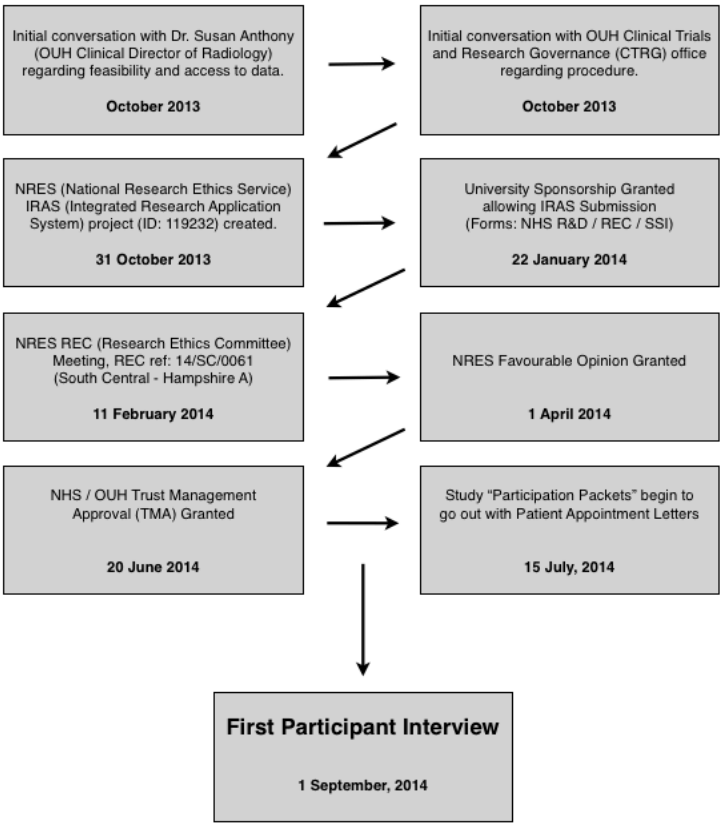


Figure 72: Flowchart detailing the ethical approval process for this study

2.1 Participation Packet

Before interviews could begin, NRES protocol mandates that at least 24 hours must be allowed for patients to consider participation in any trial or study, thus ensuring that sufficient time is given to read and understand any material provided - only after this 24-hour period may consent be considered "informed." Because of this, patients could not be approached to participate for the first time on the day of their exams so, instead, it became necessary to prepare a number of participation "packets" relaying the relevant information (what the study was, what the patient would be asked to do, would his or her information remain anonymous, etc.) to be received *prior* to their scheduled appointments.

The most efficient way to accomplish this was to take advantage of the NHS's already existing appointment notification system. The above-mentioned packets - each containing one invitation to participate, one patient information sheet (PIS), one questionnaire, and one consent form – were therefore posted to potential participants, not by the author, but by the Churchill Radiology Department itself. To facilitate this, the author provided administrative staff with standard, department-approved envelopes pre-stuffed with the above material (3,500 in total) and appointment coordinators would then simply insert their own correspondence and post the combined information as usual.

Not only were these pre-issued packets convenient for the already busy staff but they also served to eliminate any cost to the department. In addition, they also,

inadvertently, aided reception as the envelopes presented by patients when "checking in" became an easy means of recognizing potential study participants (which they would then direct to the author). As per Churchill policy, these appointment notification letters (and, therefore, the study packets with them) were posted approximately six weeks in advance – more than enough time to comply with the 24-hour informed consent requirement. This is why, though Trust Management Approval was granted in June, the first participant interview was not conducted until 1st September.

2.1.1 Invitation to Participate

The first element of this participation packet was its cover letter (Appendix E), which acted to both greet the patient and formally invite him or her to participate in this research study. At the author's request, this letter was composed and signed by Dr. Susan Anthony in her capacity as the Director of Clinical Radiology for the Oxford University Hospitals NHS Trust.

In addition to inviting the patient to participate, this letter also named the study and outlined the materials he or she should have also received. It goes on to assure the patient that it is his or her choice as to whether he or she would like to participate and that, if not, it will in no way affect his or her standard of care. The patient was further informed that he or she may withdraw at any time and that if anything is unclear or any questions should arise, those questions would be fully and freely answered by the author. That a letter of this kind, containing

these assurances, be included was a stipulation of the NRES Research Ethics Committee (REC).

2.1.2 Patient Information Sheet (PIS)

The second element included in the participation packet was the Patient Information Sheet," or "PIS" (Appendix F).

The purpose of this folded leaflet was to provide the actual information regarding the specifics of this study. As can be seen, topics addressed included an overview of the study, the purpose of the study, why the patient was being asked to participate, what he or she would be asked to do, what would happen to the information provided, whether it would be kept confidential, what the benefits of the study were, and whether there were any risks involved should he or she choose to participate.[9]

Who was funding the study and which governing bodies had reviewed and approved it, as well as the author's contact information, were also provided. As with the invitation to participate, these particular headings were also regulated by the NRES research ethics committee (REC) in the form of an approved template. These templates serve to standardize the information given to patients, who may be asked to participate in multiple studies over the course of their treatment, and to reduce ambiguity and potential confusion for those being asked for the first time.

[9] *As can be seen, over time the focus of this project changed; however, approval was not affected*

2.1.3 Questionnaire

Next, in order to obtain the life history information needed to ensure that the study sample for this project was reflective and, therefore, representational of the larger Oxford and British population, a simple six-page questionnaire was created and approved by both the NRES ethic committee and the OUH NHS Trust (Appendix G). The first two pages of this questionnaire solicited demographically based information from both men and women, the third and forth pages requested lifestyle information from both men and women, and the fifth and sixth pages asked for pregnancy information and was for women only.

Throughout the approval process, it was of paramount importance to the South Central Hampshire - A NRES committee that any questionnaire seen by patients be as uniform and as self-explanatory as possible to eliminate any undue confusion or frustration (especially as many of those patients would be elderly and already receiving a large volume of correspondence). It was therefore requested that every effort be made to match the questionnaire as closely as possible to already existing NHS correspondence. To that end, it was stipulated that the questionnaire should conform to a general NHS standard of professional appearance (for example, it must contain both the NHS and Oxford University logos, prominently placed and easily seen), that clear and concise instructions be provided in a prescribed location (top of the first page), and that the questions asked flowed intuitively and be as concise and unambiguous as possible. Furthermore, regarding the questions themselves, it was requested that current UK census categories and phrasing be used wherever applicable.

This, again, was to prevent misinterpretation or uncertainty. The committee felt the more recognizable the question and the more familiar the answer, the less potential there would be for confusion. As a result, all of the main questions (or those posited to be most impactful to this study) such as *"what is your ethnic group?"* were presented categorically and in direct line with census presentation while all "follow-up" questions (or those intended to explain or qualify answers to the main questions) such as *"where were you born?"* were allotted ample space to accommodate hand-written responses.

From the standpoint of the anthropologist, this adherence to rigid, pre-set categories was admittedly reductive and, therefore, problematic[10]; however, given the number of participants, it did help to establish uniformity and curb the tendency to gather the kinds of open-ended, non-repeatable answers that would have made statistical analysis impossible.

It was also suggested that the questionnaire be kept as short as possible, so as not to intimidate the patient, thereby discouraging him or her from participating. To determine an ideal length, a small informal pilot was carried out amongst the author's college peers, which suggested the questionnaire should exceed no more than six pages and take no longer than 10 minutes to

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[10] *While the potential for patient confusion may have been lessened, this limited categorical format presented an ethical dilemma for the author as an anthropologist as, for the most part, nuanced and / or divisive issues such as "sex" and "race" / "ethnicity" could not be accommodated for, elaborated on, or addressed in greater detail. It could be justly argued, therefore, that this framing simply traded one "evil" (ambiguity) for another (perceived insensitivity and enforced conformity). However, this structure was insisted upon (in terms of approval) by the Research Ethics Committee.*

complete (including the reading of instructions). Based upon this, the questionnaire was constructed as follows:

2.1.3.1 Section 1: Demographic Information

Question 1: Are you male or female?

Previous studies (Brooks 1955; Gilbert and McKern 1973, Suchey and Katz 1986, Angel 1986; Berg 2008; Chen et al. 2011) suggest that enough dissimilarity exists between men and women, both in morphology and the timing of transition between phases, to warrant male or female specific criteria when estimating age from the pubic symphysis. Others refute this claim (Todd 1920, Hartnett 2010a, Dudzik and Langley 2015), maintaining that little to no difference exists or, if present, that it is too insignificant to justify disparate techniques. Given this debate, and as this study deals specifically with ageing from the pubic symphysis, it was important to be able to investigate and control for the effect of sex as a confounding variable.

Question 2: What is your current age?

As the purpose of this project was to investigate the efficacy of the Truesdell Composite Method, in relation to the efficacy the Suchey-Brooks (1990) and Hartnett Methods (2010), for the estimation of age, it was first necessary to establish a "known age" the estimated ages could be compared to. The

foundations of this study, therefore, stood upon acquiring confirmed or "known" ages (in years) for each participant.

Question 3: How tall are you (in metres)?

Several recent studies have posited a correlation between an individual's height and differential ageing (Campanacho 2016; Merritt 2015). This question, therefore - to be investigated in conjunction with weight (question 8) and body shape (question 9) - was included to "rule in" or "rule out" the potential impacts of height on the appearance and density of the bones of the pubic symphysis.

Question 4: What is your ethnic group?

Previous studies have shown that race / ethnicity should be taken into account when assessing age from the os pubis and from the human skeleton more broadly (Todd 1920, 1928b; Suchey and Katz 1989; Hoppa 2000; Schmeling et al. 2000; Komar 2003 – see Berg and Ta'ala 2015 for a comprehensive review). This question was, therefore, included to control for "race" (ethnicity) as a confounding variable.

Question 5: Where were you born (City / Country)?

This question, to be considered in conjunction with questions 6 and 7, and as a follow up to question 4, was included to explore the potential role of environmental (such as air or water quality), social, and geographic factors

(such as average standard of living or general access to medical care) on the bones of the pubic symphysis.

Question 6: How long have you lived in the UK?

This question, to be considered in conjunction with questions 5 and 7, was included to explore the effects of potential shifts in environmental and geographic factors on the bones of the pubic symphysis.

Question 7: If less than five years, where did you live before and for how long?

This question, to be considered in conjunction with questions 5 and 6, was included to explore how long it might take for shifts in environmental and geographic factors to affect the bones of the pubic symphysis, if at all.

Question 8: How much do you currently weight?

Recent studies have posited a correlation between weight (as measured by body mass index, or "BMI") and differential ageing (Davis et al. 2006; Moore et al. 2011; Gonçalves et al. 2015; Campanacho 2016; Merritt 2015). This question, therefore, to be taken together with height (question 3), body shape (question 9), was included to investigate the potential impacts of weight, as it directly affects bone density, on the appearance of the bones of the pubic symphysis.

Question 9: Which image best illustrates the shape of your body?

Several studies have posited a correlation between weight (as measured by body mass index, or "BMI") and differential ageing (Davis et al. 2006; Moore et al. 2011; Gonçalves et al. 2015; Campanacho 2016; Merritt 2015). This question, to be investigated in conjunction with height (question 3) and weight (question 8), was included to "rule in" or "rule out" the potential impacts of weight distribution (sometimes categorized into "types" such as "endomorph," "mesomorph," or "endomorph" or the corresponding shapes of apple, hourglass, triangle, rectangle, or pear) which could affect the rate of deterioration due to differential "wear and tear," shock absorption, or differences in gait on the appearance of the bones of the pubic symphysis. In the event that participants were unsure, body shape was selected by the author based on visual assessment.

Question 10: Has your weight fluctuated by more than 3 stones at any point?

This question, a follow-up to questions 8 and 9, was intended to explore the potential impact of large losses or gains on the os pubis (as relates to density) and / or how long it might take, if at all, for large fluctuations in weight to become observable on the bones of the pubic symphysis. Reasons behind large losses or gains were also discussed and noted.

2.1.3.2 Section 2: Lifestyle Information

Question 11: How would you describe your level of activity?

This question was included to investigate any potential differences between the level of activity (Aguirre et al. 2006; Davis et al. 2006; Campanacho et al. 2012) amongst participants, most notably between those self-described as "active" and those self-described as "light" (who would be mostly sedentary). Unfortunately, though hoped for, there were no participants immobile before adulthood, as that may have shed light on the impact of a lack of activity (allowing a view of endocrine function alone) on epiphyseal progression. Additionally, no specific distinction was made between weight bearing exercise (such as running or lifting weights) and non-weight bearing exercise (such as swimming or cycling), but examples of equivalent daily activities were discussed and noted.

Question 12: Do you currently engage in activities that involve twisting or kicking movements such as dance, gymnastics, rugby, or football?

This question was included for two separate but equal reasons. First, clinical studies investigating the prevalence of pubic symphyseal inflammation such as osteitis pubis often cite strenuous, localized shearing forces such as those found in football and dance as the most common cause (Fricker 1991; Read 2016). In fact, Maffey and Emery (2007) list groin injury as one of "the most commonly cited injuries in the sports of ice hockey, soccer, Australian Rules football, calisthenics and cricket." For this study, knowledge of the presence of these

types of forces and their potential underlying effects on the bones of the pubic symphysis was imperative. Second, one of the most persistent anecdotal explanations for why females are considered to be more variable and more difficult to age from the pubic symphysis than males is that, supposedly, during birth, the muscles and ligaments surrounding the pubic symphysis are pulled and strained to such a degree that that force creates pocks or pitting (Suchey et al. 1979; McArthur et al. 2016) which, along with subsequent remodeling, permanently change the appearance (and morphological trajectory) of the bone (Putschar 1976; Mays 2015). It is further posited that this "injury" then results in intensified degradation due to increased susceptibility to degenerative disease such as osteoarthritis, as is seen after injury to other joints like the knee or elbow (Bongiovanni 2015, pers. com). The inclusion of this question, therefore, sought greater understanding into the prevalence of various mechanical forces in and around the pelvic area and their potential effect on ageing accuracy from the bones of the pubic symphysis.

Question 13: Do you currently engage in activities that involve upright stabilization such as horse riding or skating?

As a companion to question 12, this question further explores the potential effects of surrounding muscle and ligament strain on the bones of the pubic symphysis. Stabilization, or the contracting (i.e. "pulling in and holding") of the pelvic and abdominal muscles, introduces similar force but instead of shearing, as in football or dance, the profile is more avulsive. It is unlikely that such movements would lead to anything as traumatic as a fracture; however, as seen

at the mandible (in the case of bisphosphonate-related osteonecrosis of the jaw), even the most minute micro-fracturing and remodeling may still produce substantial impact on the bone involved. This question attempts to investigate whether any association with these types of movements may be linked to the morphological progression of os pubis.

Question 14: Have you ever been treated for a urinary tract infection (UTI) or a condition known as "osteitis pubis" (a joint infection / inflammation)?

An alternative theory for the presence of wider variation at the female pubic symphysis (as compared to males) is that of infection and / or inflammation such as septic arthritis, osteomyelitis pubis, and osteitis pubis (Gamble et al. 1986; Ross et al. 2003; Yax and Cheng 2014; Mays 2015). According to the American College of Obstetricians and Gynecologists (2008), women between the ages of 20 and 50 years are 50% more likely to contract urinary tract infections, or "UTI's," than are men of the same age and that one out of every five women will have suffered at least one UTI in her lifetime (American College of Obstetricians and Gynecologists 2008). In fact, "approximately 62.7 million adults aged 20 years and older have reported at least one episode of a UTI or cystitis, 50.8 million (81%) of whom were women" (American College of Obstetricians and Gynecologists 2008:1). UTI's occur in the kidneys, ureters, and bladder, the latter of which sits directly behind the pubic symphysis, abutting the ventral borders of the os pubes through a thin layer of connective tissue (the "retro-pubic space" or *spatium [or] cavum retzii*). If severe enough, in theory this type of infection could result in increased vascularization and

erratic remodeling around the periphery of the pubic bones which could perhaps alter the appearance of "normal" morphological expression, thereby affecting ageing accuracy (as it is based on that morphology).

As discussed above, another infection often mentioned in this context is osteitis pubis, an inflammation most frequently developed through sports activities (kicking or dancing) or as a result of recent surgery in or around the pelvic area. To complicate matters, pregnancy and menopause - other potential factors examined by this project - are often linked to the increased prevalence of infection (Foxman 2002; American College of Obstetricians and Gynecologists 2008; 2015). To influence boney changes, however, especially to such a degree as to alter morphology, any infection would have to be both chronic and extremely severe - a combination unlikely to be present in societies with access to basic healthcare (except in the case of minority outliers such as poor or high risk populations unwilling or unable to seek adequate care). Additionally, that a uniform pattern of symphyseal change exists at all and that that pattern may be reliably applied to archaeological individuals (who lived before antibiotics) further suggests that infection may not be the primary source of female variation at the pubic symphysis. However, as this remains a commonly held hypothesis, this question was asked in order to gain greater understanding into the role of infection or inflammation on the os pubis.

Question 15: Do you suffer from joint pain or stiffness, or have you been diagnosed with any form of arthritis?

Case studies have recounted the presence of infection, sclerosis, and osteomyelitis due to various forms of arthritis (psoriatic or septic) in a number of patients, citing it is often mistaken for osteitis pubis (Ross et al. 2003; Yax and Cheng 2014; Read 2013). For this reason, it was, therefore, important to document this information and to exclude the participant if surgical measures were taken to correct such an issue. At the same time, this question also documented the presence of arthritis (e.g. osteoarthritis) in other areas of the body, such as the lumbar spine or hips and femora, which may have affected the patient's ambulation. Finally, if arthritis was known to exist elsewhere in the body, synostosis of the pubic bones (primarily a result of outer osteophytic activity) may not be unexpected. Conversely, if synostosis was present at the pubic symphysis with an absence of arthritis elsewhere, the possibility of a potentially excluding pathology would have to be addressed.

As a follow-up question, patients were also asked whether they had ever been diagnosed with either osteopenia or osteoporosis, or if their doctors had ever discussed bone density loss with them. If the answer was "yes," the author noted how long ago that diagnosis or discussion had taken place and whether any treatment, pharmaceutical or otherwise, had been adopted.

Question 16: How would you describe your diet?

Dietary and nutritional status has long been linked with bone health, both in its development and decline. For young adults, poor nutrition (or a diet lacking in calories, vitamins [chiefly D and K], and minerals [iron, magnesium, and

calcium] needed to sustain crucial biological functions) has been known to lead to decreased bone strength and shortened stature, whereas in older adults it can lead to an increased risk of osteoporosis (Frisancho 1995; International Osteoporosis Foundation 2015). As nutritional status is known to be so intimately connected to bone health and density, this question was included to help document participants' dietary intake.

Question 17: Do you smoke or chew tobacco? (How many per day?)

Question 18: If yes, at what age did you begin smoking or chewing tobacco?

Question 19: Do you drink alcohol? (How many units per week?)

Question 20: If yes, at what age did you begin drinking alcohol?

Both tobacco and alcohol consumption have been tied to decreased bone mass and density in young adults (leading to smaller, less mineralized skeletons going into adulthood) as well as earlier menopause in females and an overall increase in the risk of osteoporosis in older adults (Ward and Klesges 2001; Chakkalakal 2005; Wong et al. 2007; Davis 2015). Not only this, but regular tobacco and alcohol intake, even if binge drinking, have also been shown to lead to the inhibition of fracture healing through the interruption of bone building hormones like calcitonin and the destruction of the osteoblasts themselves (Raikin et al. 1998; Hollinger et al. 1999; Turner 2000; Lauing et al. 2008, 2012; Maurel et al. 2011). Hormonal changes such as increased cortisol levels, decreased testosterone levels, and increased prolactin levels, which have also been linked to bone loss, have also been shown to occur with both tobacco and alcohol consumption (Ida et al. 1992; Thayer et al. 2006; Stalder et al. 2010). By

discussing participants' smoking and drinking habits, and by quantifying amounts and duration, this question sought to better understand and document the impact of these substances on ageing from the bones of the pubic symphysis.

2.1.3.3 Section 3: Pregnancy History Information

Question 21: How many times have you been pregnant?

As described in the previous chapter, childbirth has long been assumed to be the primary determinant explaining the morphological differences between male and female pubic bones (Angel 1969; Putschar 1976; Suchey et al. 1979; Ubelaker and La Paz 2012; Mays 2015; McArthur et al. 2016; Bongiovanni 2016). Distinction is rarely made, however, between biological pregnancy and the physical act of giving birth. Generally, as is evident in past literature, "pregnancy" has become synonymous with the physical act of childbirth. This is misleading, however, as this does not take instances of miscarriage, termination, or caesarean section into account, where pregnancies, even carried to full term, occur irrespective of physical birth. As of 2015 (the most recent UK statistics available), an estimated 15-20% (or approximately one in five) of known pregnancies were miscarried (March of Dimes 2016), 16% of pregnancies (per 1,000 residents) were reported as terminated (UK Office of National Statistics 2015), and 26% of births (or approximately one in four) were delivered by caesarean (NHS Digital 2015). Even though these numbers are conservative (as they reflect only those pregnancies known about and documented), they demonstrate clearly that pregnancy and birth are two separate entities, and that

any investigation into the effects of either must recognize them as such. This question, therefore, sought to allow for pregnancies in the absence of birth. Due to the sensitivity surrounding the topics of miscarriage and termination, however, the terms "miscarriage," "termination" or "abortion," could not be used (otherwise, providing informational pamphlets and immediate access to grief counseling would have been required by the NRES committee).

Question 22: How many times have you given birth?

As mentioned above, biological pregnancy and the physical act of giving birth may exhibit differing signatures on the bones of the pubic symphysis. While any effects as a result of the former would be solely hormonal, effects from the latter would be strictly mechanical. As previously mentioned, it has been posited that, during birth, the muscles and ligaments surrounding the pubic symphysis become pulled and strained to such a degree that pocks or pits are created which, along with subsequent remodeling, permanently change the appearance of the bone. This "injury" then results in intensified degradation due to increased susceptibility to degenerative disease such as osteoarthritis, as is seen after injury to other joints like the elbow or knee (Putschar 1976; Bongiovanni 2015, pers. com). This question, therefore, was designed to investigate the mechanical side of birthing and whether, and to what extent, physical strain may inform on the bones of the pubic symphysis and the anthropologist's ability to reliably "age" them.

Question 23: How old were you at the time of your 1st, 2nd, and 3rd births?

As the symphyseal face passes predictably and universally through an established pattern of progression, this question was included to investigate, if birth *is* determined to be a factor, whether the age of a woman at the time of that birth may be influential. After giving birth, does facial remodeling stop or does it continue regardless? If it stops, will that permanently alter that face's appearance? Will it simply skip the phases it missed and continue to degradation, or will the progression reanimate and move through the phases as it originally would have, "catching up" from where it left off? If this is the case, could we trace those alterations back to calculate the timing between multiple births? Or adjust for them, perhaps adding them on as a constant for a more accurate estimated age? If permanent, would determining anything from the face be impossible after a first birth? These are all things potentially answerable by this question. Additionally, while several women will have given birth to more than three children, the reporting limit in this case was capped at three as it was thought that three would be enough to demonstrate any differences that may appear between multiple births while still being a small enough number to allow for interpretation.

Question 24: Did you experience any pain or discomfort (i.e "grinding" or "dislocated" sensations) at the pubic symphysis during your pregnancy?

During pregnancy, production of the hormones Relaxin and Progesterone increases steeply to facilitate the relaxation of the soft tissue structures

(ligaments, cartilage, muscles, etc.) of the pelvis. This causes the female pubic symphysis, usually between 4-5mm in width when not pregnant, to widen and double in size (9-10mm) in preparation for birth (Talmage 1947; Chrishan et al. 1996; Samuel et al. 1998; Zhao et al. 2000; Hsu et al. 2003). When these hormones are produced too soon, however, or in too great a quantity, the targeted soft tissues become too lax and over-stretch, causing pain and instability (and, in severe cases, immobility). Estimates vary but, depending on the criteria used, between one in every five and one in every 300 women will experience "Symphysis Pubis Dysfunction" (SPD), or "Pregnancy-related Pelvic Girdle Pain" (PPGP), during the course of their pregnancy (Jain et al. 2006; Royal College of Obstetricians and Gynaecologists 2015). As this affects mobility, as well as exhibits hyper-laxity of the symphyseal joint due to increased hormonal activity, this question was included to explore any effects pelvic instability may have on the faces of the pubic bones.

Question 25: Did any of these births require an epidural?

Debate continues as to whether the administration of epidural analgesia or anaesthesia increase the risk of instrumental (forceps, ventouse, etc.) or surgical (caesarean) intervention due to a correlated drop of oxytocin, or that that drop in oxytocin results in delayed and/or disrupted (shortened) breastfeeding. However, "despite ongoing controversies, epidural rates have increased; approximately 25% of women in the UK and 66% of women in the USA receive epidural analgesia in labour" (McGrady and Litchfield 2004:114). That the administration of epidural analgesia or anesthesia prolongs the duration of

labour, however, is not disputed (Cheng et al. 2014). Due to the localized numbness introduced by the epidural, in conjunction with the decrease of oxytocin (which facilities the muscle contractions needed for moving the baby down the canal), women in labour can no longer feel when they need to push (creating the need for delivery assistance), nor can they feel how hard they are pushing (which, some have speculated, could lead to damage due to tearing or excess strain as no pain is felt at the time). This question, therefore, sought to document the presence of an epidural during delivery so as to have an awareness of possible circumstantial explanations should significance arise.

Question 26: Were any of these births by caesarean?

As discussed in question 21, delivery by caesarean (or "C") section constitutes a full biological pregnancy without the act of birth through the pelvis. Delivery by caesarean would, therefore, take the pelvis - and the mechanical strain of birth - out of the equation in determining what factors may affect the appearance and morphology of the pubic bones used for the estimation of age. If delivery by caesarean proved significant, any alterations to progression could only have been caused by the hormonal component of pregnancy, not the physical act of birth. Because of this, this question was considered essential to the investigation into the mechanism of morphological change seen on the face of the os pubis and whether it may affect the efficacy of the ageing techniques applied.

Question 27: Were any of these births multiple births (i.e. twins or triplets)?

This question sought to document the presence of multiple births as this could increase labour time as well as the strain associated with it. Additionally, the possibility that multiple births result in higher levels of certain pregnancy related hormones (which may or may not be significant in accelerating morphological change) than do single births has also been raised in the literature and, so, was included as part of this study (Thomas et al. 1998).

Question 28: What were the weights and labour times of your births?

This question was included to document the size (large, average, premature, etc.) of each birth as well as the duration of labour for each delivery (in hours). Additional follow ups for this question included:

1.) *Where did each of your births take place (in hospital, at home, at a birthing center, etc.)? This also differentiated deliveries that took place in other countries.*
2.) *Who assisted the delivery (partner/family, an obstetrician, midwife, etc.)?*
3.) *Was there anything out of the ordinary (breech presentation, transverse lie, nuchal cord, failure to progress, etc.) that necessitated intervention (such as manual rotation)?*
4.) *Were forceps or a ventouse used?*

5.) Were there maternal complications with any of your births (preeclampsia or eclampsia, placental abruption, etc.)?

Again, this question and its follow-ups were incorporated to explore the potential effects of varying degrees of mechanical strain.

Question 29: For which of these births did you breastfeed?

Studies have shown that breastfeeding can often lead to a decrease in maternal bone density and, though temporary, it is not uncommon for a woman to lose up to 5% of her overall bone mass during lactation. This is because of the baby's need for calcium, which it draws from the mother's bones. At the same time, the heightened levels of estrogen produced throughout pregnancy (which act as a buffer, balancing the demands of the baby with the needs of the mother) drop back down to their pre-pregnancy status, taking those protections with them (National Institutes of Health 2015). Though these effects are quickly reversed once breastfeeding ends, as "even if complete restoration in BMD [bone mineral density] was not reached within 5 months of weaning, women with four pregnancies or more had a BMD no lower than women with two pregnancies or fewer" and "neither an extended lactation period nor multiple pregnancies could be used as a risk factor when predicting women at risk for future osteoporosis" (Karlsson et al. 2001), this question was nevertheless included to investigate its temporary effects of breastfeeding on bone density, which is inextricably linked to the accuracy of age estimation from the bones of the pubic symphysis.

Question 30: *Have you ever taken, or are you currently taking, hormone supplements?*

Question 31: *Have you ever taken, or are you currently taking, birth control or contraception?*

Commonly prescribed to relieve the discomfort associated with menopause, hormone replacement therapy, or "HRT," is the artificial continuation of estrogen and progesterone after the body stops making it naturally. Similarly, hormonal contraception uses estrogen and progesterone to stabilize the menstrual cycle to prevent the release and fertilization of an egg (Association of Reproductive Health Professionals 2004). As both prescriptions introduce the pregnancy hormones estrogen and progesterone artificially, it is possible that they may have an effect on the rate at which the os pubis remodels itself. As this remodeling forms the basis of nearly all symphyseal age estimation techniques, this question was included to explore the potential influence of mimicked hormonal activity in the absence of pregnancy.

Question 32: *Have you reached Menopause? At what age?*

As has been discussed over the course of the previous questions, the hormones estrogen, progesterone, and relaxin all play major roles in maintaining the normal endocrine function of the female reproductive system, both in menstruation and then in pregnancy, as well as in influencing the soft tissue structures in and around the pelvis during the fertile years of a woman's life. Bone, as a dynamic living tissue, has been shown to be highly sensitive to these

hormones and their fluctuations, most notably in density response. As density plays a major role in estimating age from the pubic symphysis it was important for the purposes of this study to be aware of when these hormones ceased for each participant.

2.1.4 Consent

In addition to the above questionnaire, each participant packet also included a copy of the consent form patients would be asked to sign should they chose to participate in this study (Appendix H). This consent form would confirm that the patient had read and understood the information provided, including what the study was and what he or she was being asked to do, how his or her data would be used, and for what purpose. It would further confirm each patient had sufficient opportunity to review and consider the information provided, that he or she had been allowed time to ask any questions he or she may have and that those questions were answered to his or her satisfaction before agreeing to participate. By signing, this consent form would also confirm that the patient would not be paid for their participation and that he or she could withdraw at any time and for any reason.

2.2 Data Collection

All data for this project was collected personally by the author in partnership with the Radiology Department of The Churchill Hospital, Oxford, over the course of a seven month period (September 1st, 2014 - March 31st, 2015). With the consent of both Dr. Susan Anthony (Director of Clinical Radiology, Oxford University NHS Trust) and then acting Churchill radiology department manager Tony Mackay, the author was furnished with a dedicated area within the department (a table and 3 chairs in a semi-private alcove) halfway between reception and the joint MRI / CT waiting area for the purpose of conducting interviews. This area contained a wall sized poster describing the study, including example images, as well as an enlarged and laminated copy of the "invitation to participate" cover letter written and as signed by Dr. Anthony (see above). Extra "packet" materials such as patient information sheet (PIS) leaflets, questionnaires, and consent forms were also on hand in case patients had forgotten to bring their materials with them but still wished to participate.

2.2.1 Participant Interviews

Once an eligible patient had arrived for his or her appointment and "checked in" with reception (and it was confirmed that he or she would receive a CT scan that including the pubic symphysis), he or she would be asked to first stop and speak with the author before proceeding to the waiting area. To facilitate this, the patient would then either be given verbal directions as to where to find the author or be escorted to the alcove by a member of staff. Once present, the

author then would greet him or her, introduce herself as the primary investigator (PI), state her affiliation (University of Oxford), and briefly recount the project and what participation would entail. At this time the patient would also be reminded that all data collected as part of this study would be fully anonymized and that in no way would any images or information be identifiable. Sample images were then shown to illustrate this point. If the patient expressed interest in participating, the author would then either go over (if completed beforehand) or complete the study's questionnaire with each patient to make sure that all questions had been answered fully, and that all the information provided was correct (to the best of the patient's knowledge or recollection). Simple follow-up questions were asked where necessary and exclusions were considered in cases where concern may have risen regarding power of consent (such as in cases of mental disability or age related impairment, or where English was not the patient's first language).

After this structured interview, to confirm that the patient was comfortable with his or her information being used as part of this study the consent form was then placed on the table in front of the participant. For added clarity (and to ensure attention), the author moved along the text with a pen as she read each statement aloud, encouraging the patient to follow along. Patients were then asked one last time if there was anything unclear about the purpose of the study, what was being asked of them, and whether they were comfortable with the statements of the consent form. If all was clear and agreeable, participants were then asked to either initial or "tick" the box associated with each statement and to then print, sign, and date the bottom of the form. To witness to this

consent, the form was then also signed and dated by the author. Lastly, each participant was asked whether he or she would like a photocopy of his or her completed consent form (as well as his or her questionnaire, if desired) to act as a receipt for his or her records. At this time it was also confirmed that the patient knew how and where to contact the author, should any future need arise.

Finally, once he or she had been thanked for his or her participation, each patient was either directed or escorted to the joint CT / MRI waiting area to wait to be called for his or her scan. Equally, if participants had been scanned first and had stopped for their interview after the fact, they were given any directions, information, or assistance they might need in order to return to their cars or to public transportation.

2.2.1.1 Data Protection

Once consent was given, each participant's questionnaire was assigned an alphabetic code while his or her consent form was assigned a numeric code. For reference purposes, an electronic primer was created by the author and kept in a secure location (a password protected laptop). The physical documents were then filed and stored in separate, secure locations (i.e. locations with locked entry, known only to the author, and for which the author alone had a key). In this way, all content was, at all times, kept apart, so that even if one of the three elements was somehow compromised, none of others would be. These precautions, coupled with the anonymization of the patients' scans, were

approved by the NRES Research Ethics Committee as satisfactorily fulfilling the obligations as set forth by the Data Protection Act 1998.

2.2.2 CT Scanning

After each patient had completed his or her questionnaire, signed his or her consent, and been given a photocopy for his or her records, he or she was CT scanned as per his or her normal appointment. Following standard NHS procedure, therefore, these scans were performed by one of The Churchill Hospital's staff radiographers, each of whom were professionally trained and fully qualified to produce scans at a clinical level of competency.[11]

2.2.2.1 Instrumentation

Each of the scans utilized for this study were performed on one of two 64 Slice Light Speed Multi-Detector Volumetric Computed Tomography (VCT) machines (manufactured by General Electric Healthcare, program software: 12HW14.6_SP-1-1.V40_H64_G_GTL) located within the Radiology Department of The (OUHS) Churchill Hospital. Each possessed a helical acquisition with a pitch of 0.098, a tube rotation speed of 0.5 seconds, and a tube output of 120 kVp (peak kilovoltage). Slice thickness for each scan was between 0.6 and 0.8 mm.

[11] *To be employed in the UK, radiographers must complete a three to five year degree in medical radiography and maintain registry with the Health and Care Professionals Council (HCPC), a performance based qualification that must be renewed regularly.*

2.2.2.2 Quality Control (Phantom Testing)

To ensure image accuracy, both of the machines involved in this study were subject to yearly, weekly, and daily quality control checks as legally required by the Ionising Radiations Regulations of 1999 (IRR99 No. 3232) and the Ionising Radiation (Medical Exposures) Regulations of 2000 (IRMER No. 1959), both of which prescribe and monitor diagnostic reference levels.

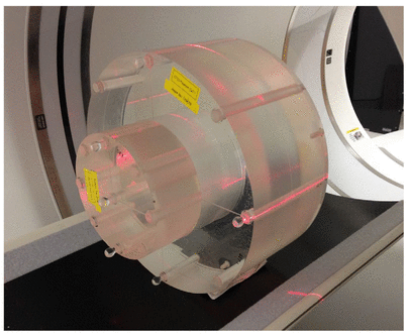


Figure 73: Example of an imaging "phantom"

According to Steven Mutch, the OUH NHS Trust's Principal Physicist, these checks included (but were not limited to) one annual "all in" test to determine if any maintenance, repair, or upgrading was necessary; one weekly operator-assisted check in which a series of "imaging phantoms" (purpose built "dummy" objects of differing attenuations used to test and calibrate medical imaging equipment for things like device accuracy, resolution, contrast, and "signal to noise" ratios - *see Figure 73*, above) were observed and measured, as per the Institute of Physics and Engineering in Medicine's 2007 report, no. 91, "Recommended Standards for the Routine Performance Testing of Diagnostic X-Ray Imaging Systems," an update to the earlier 1981 report, no. 32, "Measurement of the Performance Characteristics of Diagnostic X-Ray Systems used in Medicine" (also still in use); and, finally, daily "warm-up" instrument calibrations, the results of which must be in line with both the machine's manufacturer specifications and national diagnostic

guidelines in order to remain clinically operational (if a machine's daily checks fail, it is illegal to use it until the issue is remedied).

Due to the number and veracity of these already occurring, government regulated quality assurance checks, and that no outside or non-routine material was to be scanned, the author was satisfied that the running of an additional study-specific phantom would be redundant. Had the study included a dry bone element, for example, which would have introduced a medium that would *not* be considered clinically routine (and, thus, likely untested for), the scanning of an independent dry bone phantom would have been imperative. However, as the author was assessing living bone exclusively, and a living bone baseline for comparison had already been well established through daily, weekly, and yearly professional compliance checks, it was determined that the machines used for the purposes of this study could be trusted to produce accurate skeletal images and that the inclusion of an extra phantom would be unnecessary.

2.3 Interpretation of Data

As described in the previous chapter, in order to produce a radiographic image X-Rays are directed towards an object, which, depending upon their atomic energy, either attenuates (absorbs) them or allows them to pass through to the detectors positioned behind. This difference in photon (light) attenuation (absorption), in turn, creates a multi-gradient shadow, or negative impression, of that object. To generate plain-film radiographs, this involves the

development of actual film (such as that used in the everyday camera). To produce computed tomography images, however, this impression is converted (by the photo-sensitive detection plates) into strings of numerical code known as "DICOM" (Digital Image and Communication of Medicine), with each string representing an image.

2.3.1 Digital DICOM Data

After each patient was scanned, his or her DICOM data was automatically uploaded (by the machine itself) to the OUHS's communal "PACS" (or, Picture Archiving and Communication System) storage repository (server). As the OUH NHS Trust contracts with General Electric (GE) Healthcare, this PACS program was that of GE "Centricity."

2.3.2 Image Rendering Software

Once in the system, the DICOM data from each patients' scan was individually retrieved – or, "pushed" from the PACS server onto a dedicated desktop computer - by way of a software package called (GE Healthcare) Advanced Workstation for Diagnostic Imaging (version 4.5), or simply "AW." Finally, on each of these dedicated desktop computers was a nested software called "Volume Viewer" (version 9.5.6), which processed each scan's DICOM information into moveable 3D renderings *(Figure 74, below).*

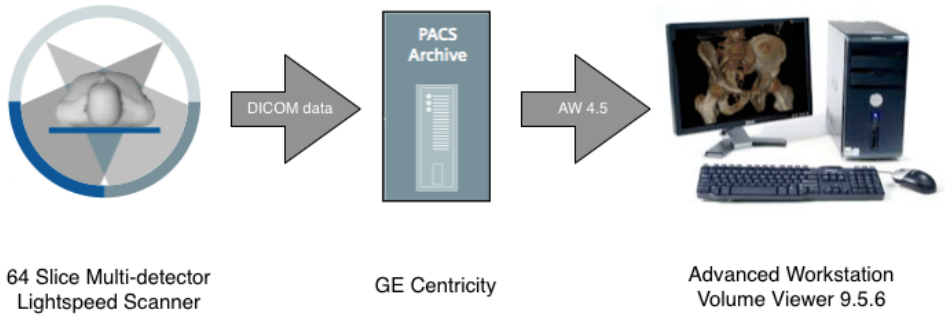


Figure 74: Illustration of the flow of data from scanner to desktop

While several viewing platforms exist (such as Osirix [Prixmeo], MIMICs [Materialise], and 3D Slicer), for this study it was easiest and most time effective to simply use the hospital's Centricity software, as it had been made fully available and the author was in the radiology department all day, everyday, anyway. All "jobs," therefore, were created solely by the author and all analysis was performed through Centricity Volume Viewer.

2.3.3 Imaging Rendering and Segmentation

To retrieve each scan from PACS and push it to an AW workstation, the author simply searched the system for the participant's name. Once found, the author then confirmed the date and protocol (what type of scan) – i.e. "abdopelvis" or "chestabdopelvis" – of that scan to make sure it was indeed that of the participant and, if correct, clicked to open that file. When a file was selected, AW defaulted to a primary screen. This screen was then split into four segments – a coronal view, a sagittal view, an axial view, and a 3D volume view. A second,

adjacent screen magnified any view the author wished to see in more detail *(Figure 75, below)*.



Figure 75: The Centricity Advanced Workstation ("AW"), default screen

The "first glimpse" of this default screen proved invaluable as it not only served to provide overall context but also afforded an initial view of the pubic symphysis as a whole, allowing the author to immediately identify scans with any pathology, fusions, or artifact (disruptions or obstructions) that may exclude them out without having to waste time on further analysis.[12]

While the coronal and sagittal views were beneficial for context, it was the axial and 3D views that were most utilized. As will be discussed in future chapters, axial images were indispensable to the evaluation of density, which, in turn, was

[12] A total of 49 scans were eliminated from this study as "unusable."

indispensable to the estimation of age. However, due to their visual familiarity, it was the 3D renderings that were most impactful to this study.

Bone is isolated from its surrounding tissue through a process known as "thresholding," which is based on the Hounsfield, or "H," Scale (for Sir Godfrey Hounsfield, the inventor of computed tomography), by which tissues are assigned different values, or units, based upon the amount of photon light allowed to pass through them when exposed to an x-ray:

> *"The Hounsfield scale is a calculation from the linear attenuation coefficients of tissues that make up an image slice. [Hounsfield units, or HU's] are relative to the attenuation of water, which is assigned a value of 0 HU. Using water as the reference, the maximum brightness of a pixel is -1000 HU and will appear white on the CT image. The opposite end of the H scale is maximum darkness, which is +1000 HU and the image will be black. Between these extremes are various shades of gray that make a diagnostic CT image" (Joseph 2016).*

As discussed in the previous chapter, bone attenuates, or absorbs, more photon light than any other tissue. Its HU value, therefore, will be high in comparison to the structures around it. Centricity's AW software retained a "standard clinical pre-set" for which the threshold for bone (the open eye) was fixed at just under +1000 (cancelous bone begins a +700)(*Figure 76, below*). As that value was consistent with the demands of this study, the clinical pre-set was not altered.

Tissue	CT Number (HU)
Bone	+1000
Liver	40-60
White mater	-20 to -30
Grey mater	-37 to -45
Blood	40
Muscle	10-40
Kidney	30
CSF	15
Water	0
Fat	-50 to -100
Air	-1000

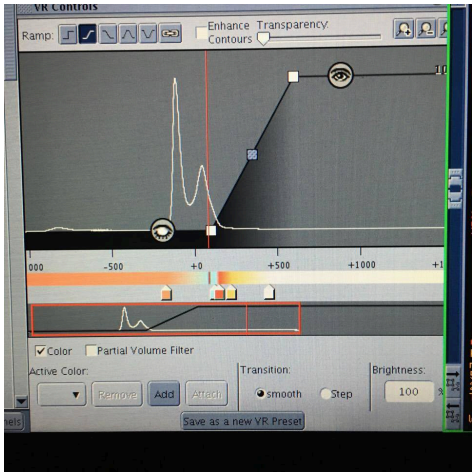


Figure 76: List of comparative Hounsfield units and the Centricity clinical pre-set

Based on those threshold values, bone was then isolated from its surrounding soft tissues through a series of "reconstruction algorithms," resulting in a 3D image (*Figure 77, below*).

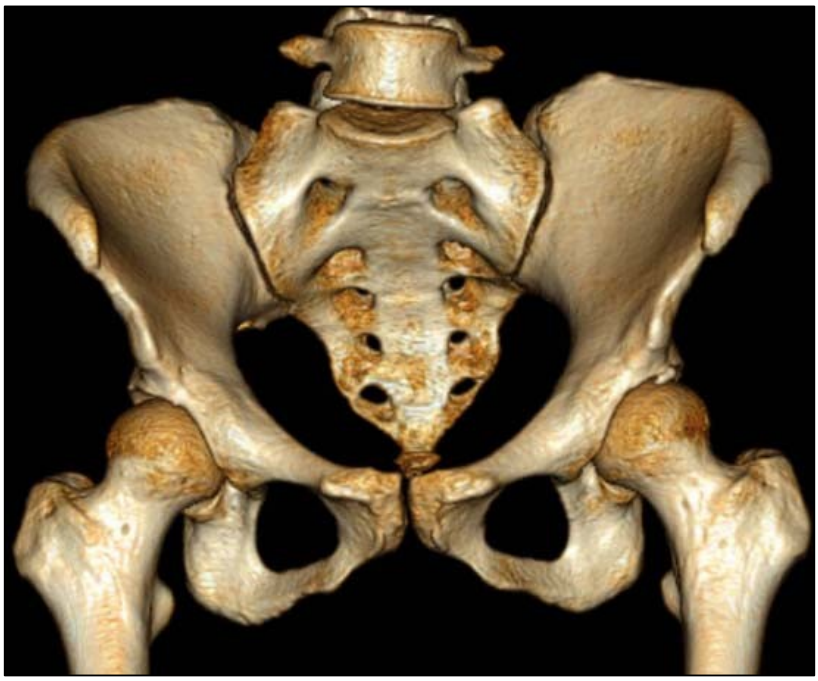


Figure 77: 3D image of the pelvis as created in Centricity

To separate the symphyseal faces and examine them individually, the author then used the software's cutting tool (a small scissor icon that "cut" through the voxels) to "segment" the render. This removed any voxels inside or outside of the author's desired region of interest, or "ROI" (depending on which command was used), allowing for an unobstructed view of either the left or the right symphyseal face. To reverse the deletion of these voxels, the author simply selected the "undo" function, which would return the full image. This cutting procedure was then repeated for the isolation the opposite side (*Figure 78*).

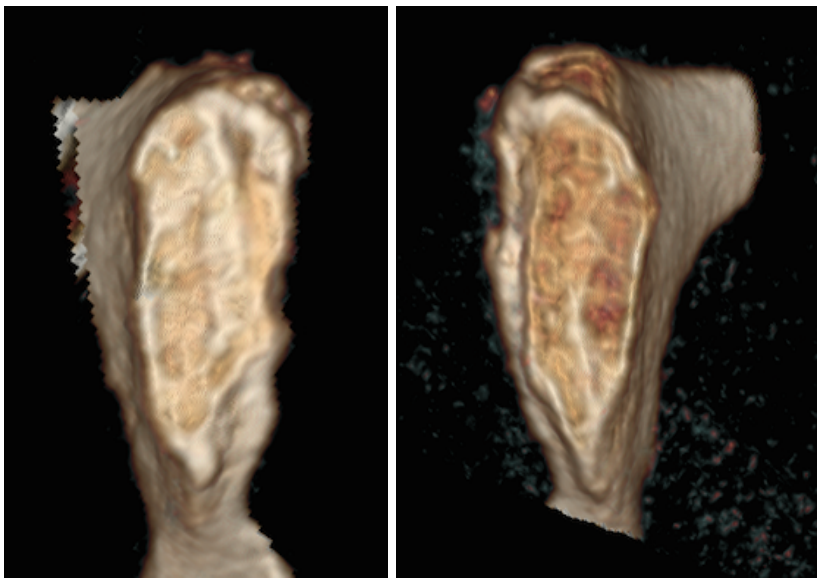


Figure 78: 3D reconstructions of symphyseal faces in Centricity

2.3.4 Image Analysis

As outlined by the previous chapter's aims and objectives, this study sought to establish whether age estimation could be improved by the introduction of a

new, more precise technique. To investigate this, it was therefore necessary to forensically "age" each individual using that technique so that those estimations could be compared with known age.

2.3.4.1 The TCM

This technique – the Truesdell Composite Method, or "TCM" – is described in the following sections.

2.3.4.1.1 A History of Development

The basic structural prototype upon which this technique was built was devised as part of an MSc project undertaken by the author at University College London in 2011 (Truesdell 2011) and arose from the desire for increased transparency in recording differences of opinion amongst observers applying the Suchey-Brooks Method for Ageing the Os Pubis (Brooks and Suchey 1990) to an experimental study sample. That project, which served as a de-facto pilot for this project, sought to establish whether CT images of the pubic symphyses of living individuals (gathered in partnership with University College London Hospital) could be forensically "aged" with a reliability and level of accuracy equal to that of the established mediums of cast or dry bone. For this, 75 anonymous subjects were recruited and evaluated by the author and then, from those 75, the pubic bones of 12 individuals (in accordance with the MSc. monetary allowance) were 3D printed and scored along with 12 of the official

Suchey-Brooks "practice casts" (France Casting - Trademark, product SA005), five screen captured "still frame" images (to mimic evaluation by photograph), and, finally, five "on screen" images which could be moved and manipulated within the software (preloaded onto a laptop). All were scored – or assigned a phase and age range - using the industry standard Suchey-Brooks Method for Ageing the Os Pubis (1990). As discussed previously (chapter 1, "An Introduction and Literature Review," section 1.3.3.2), however, the Suchey-Brooks method has long been acknowledged to be highly subjective, as estimations are often based upon the "feel" (sometimes literally) or general impression the observer gets from the bone in front of them. What makes this problematic is that, as these assessments take place entirely within the observer's head, there is no mechanism for clarification when two separate observers place the same bone into differing phases. Even if the difference of opinion is only one phase, that may still result in the first observer "catching" the actual age of the individual (within their estimation range) and the second, not. As the goal of the project was to establish whether or not medical imaging could present enough detail to produce estimations as accurate as those of dry bone, understanding the root of such discrepancies was of paramount importance - as was the potential for user error, where perhaps an observers' lack of experience (or being unused to working with virtual images) might be the cause of their inaccuracies, not the images themselves. It was for this reason - the effort to document the thought processes of the pilot's observers to clarify what they were seeing or, more importantly, *not* seeing in the images which influenced their phase choices – that a recording sheet, the precursor to the TCM, was created.

2.3.4.1.2 The Suchey-Brooks Phasing Guide

As has been discussed at length, the Suchey-Brooks Method for Ageing the Os Pubis (Brooks and Suchey 1990) provides a separate set of illustrations, to coordinate with sex specific age ranges, for both male and female pubic bones. Because the pilot study recruited only white males (to control for confounding variables such as sex or race), the male image set was used.

Recall also that within the Suchey-Brooks illustrations exist two sets of exemplars differentiating between "early" and "late" stages of the same phase, though they are not formally acknowledged nor are they taken into account in terms of the age ranges. Instead, both images, indistinguishably, represent a larger, overall phase, each labeled I, II, III, IV, V, or VI *(see below, Figure 79)*.



Figure 79: Suchey – Brooks phases I – VI
(from White and Folkens 2005)

For clarity, and to facilitate greater standardization, instead of combining the early and late stages, the images were fanned out and placed as equally weighted along a continuum (with the appropriate phase numbers – i.e. 1.1, 1.2, 2.1, 2.2, etc. – listed beneath each). At the same time, this re-organization enabled clearer, more distinct views of each image while also providing ample space for each to be described individually and in expanded detail. Because of this, more precise descriptions for each of the "half phases" were added.

In addition to restructuring the phases more broadly, the individual images themselves were further segmented into a number of "components" (or, at that point, specific things, areas, or "touch points" upon which the observer was to focus attention). As the goal was transparency through thorough recording, these components had to quickly and completely document the entire face, leaving nothing out, but without being burdensome, overly technical, or (substantially) more time consuming than the Suchey-Brooks method itself. Five areas, or elements, were thusly chosen for this purpose: the top half of the face (labeled then as "tubercle"), the bottom half of the face (labeled then as "apex"), the outline of face (labeled then as "rim shape"), the surface texture of the face (labeled then as "surface morphology"), and, finally, the horizontal contour or "terrain" of the face (labeled then as "concavity," based on the "index finger test" as described by Buikstra and Ubelaker in 1994).

For simplicity, paper recording sheets were printed for each subject, individually, and the observers were asked to score each of the above components separately by physically circling (in ink) whichever columns best

matched whichever specimen they were analyzing. Once all five components had been assessed, observers were then asked to tally their results at the bottom of the last page. For perspective, they were also asked to provide the lowest phase circled, the highest phase circled, and the phase most often circled. This phase (the one most often circled) then served as the most likely phase for that subject. Once a phase was established in this way, the observers were to write it in the box provided, along with the age range for that phase *(see below, Figure 80)*.

APEX:



Indistinct - Face "flows" continuously and uninterrupted onto the ramus	Indistinct - Face "flows" onto the ramus but may contain nodules	Nodule (1+) formation assumes focus, may or may not separate face from ramus	"✓" shape, may be sharply pointed or slightly rounded; face now fully distinct from ramus	Either "V" or backwards "✓" shape, inferior half thickened and raised compared to the rest of the face	May retain backwards "✓" shape, but will more likely round as if forming the bottom of a "C"	Either "V" or "✓" shaped; may exhibit a slight central concavity if rim is raised	May be "V" or "✓" shaped, but may also be a "U"; face may exhibit concavity directly above the apex	Sharply pointed "V" shape, may be wide or narrow	Sharply pointed "V" shape, narrow. May "trail off" or taper to one side more than the other.	Most often a rounded "V" with slightly scalloped edges, but may vary based on degree of degradation	Most often a rounded "V" with scalloped or irregular edges, but may vary based on degree of degradation

SURFACE MORPHOLOGY:



Deep ridge and furrow system evident on entire facial surface, extending out to the ramus and tubercle	Ridge and furrow system still clearly evident; but with depth noticably lessened	Shallow ridges and furrows may still be seen at mid face, but not superior or inferior due to nodule formations	Truncated ridges and furrows may or may not be present on dorsal surface; but now "shorter and fatter"	Truncated ridges and furrows may or may not be present on dorsal surface; but now "shorter and fatter"	Ridge and furrow system largely absent due to dramatic surface changes taking place at this stage	Expanding face may reestablish a shallow ridge and furrow system, or may remain smooth	Final face emerges flat and smooth, but some may retain a few remnant ridges	Ridges and furrows unlikely to be seen at this stage	Ridges and furrows unlikely to be seen at this stage	Ridges and furrows unlikely to be seen at this stage	Ridges and furrows unlikely to be seen at this stage

1.1	*1.2*	*2.1*	*2.2*	*3.1*	*3.2*	*4.1*	*4.2*	*5.1*	*5.2*	*6.1*	*6.2*

RIM SHAPE



No rim formation	No rim formation	No rim formation	Defined apex and ventral rampart begin rim formation; Superior margin becoming increasingly defined by nodules	Defined apex, defined superior margin; dorsal border may be raised or flat; Ventral hiatus breaks up rampart	Defined rim, except at the ventral hiatus (may be lowered to midface); Raised "C" shape (dorsal plateau + apex & sup. nodule)	Defined rim, except at the ventral hiatus where a new surface is "growing over" the gap; Boney "bridges" may be present	Complete rim. Usually oval (rounded apex) or teardropped (pointed apex) in shape.	Complete rim. May have slightly lipped edges. Wide "D" shape.	Complete rim. Dorsal lipping often present, if not pronounced. Pinched "D" shape.	Distinct rim, may exhibit first signs of degradation dorsally. Rim may appear ragged. Narrow oval in shape.	Distinct rim, but may exhibit extensive degradation. Edges may appear wizened. Wide oval in shape.

CONCAVITY (INDEX TEST)

Rounded and convex	Rounded, slightly convex	Flat mid face, swelled at inf. and sup. nodules	Low and flat on dorsal side, raised ventrally (rampart)	Slopes from high (inf.) to low (sup.) due to superior ventral hiatus	Deep central concavity, adjacent to hiatus - middle and outlet of "C" shape	Deep, caverns of concavity continues at hiatus, but under flat boney bridges.	Face is broad and flat	Mostly flat, but may contain a wide, shallow central indent	Deep indentation, often more prominant on dorsal side - face almost "cupped."	Flat face, though edges may become raised, giving the impression of concavity	Flat face, though edges may become raised, giving the impression of concavity

TUBERCLE



Indistinct - Open epiphysis reaches upwards from face uninterrupted	Indistinct - Open epiphysis puncuated by forming nodules, may be several small ones, one large one, or a mix of both	Some distinction Large nodule formation assumes superior focus, but does not separate tubercle from face	Some distinction Large nodule formation assumes superior focus, but does not separate tubercle from face	Distinction Large nodule formation assumes superior focus, sweeps ventrally over hiatus, but without separation	Distinction Large nodule formation assumes superior focus, sweeps ventrally over hiatus, but without separation	Separation Face now completely contained within rim, tubercle has become a visually separate entity	Separation Face now completely contained within rim, tubercle has become a visually separate entity	Recession Face completely contained within the rim, tubercle may begin to receed back from the face	Recession Face completely contained within the rim, tubercle may begin to receed back from the face	Degradation Tubercle may continue to receed back from the face and exhibit irregularities in shape and texture	Degradation May exhibit irregularities in shape and texture; erradic boney outgrowths may result in "knobby" or "craggy" appearance

1.1	*1.2*	*2.1*	*2.2*	*3.1*	*3.2*	*4.1*	*4.2*	*5.1*	*5.2*	*6.1*	*6.2*

Now, please assess which columns have received the most circles and tally your results.
Which phase is this subject most likely to be, based upon these descriptions and images?

Lowest phase circled: _____

Highest phase circled: _____

Phase most circled: _____

Most likely phase: _____

Phase Distinction:

Estimated Age Range:

Figure 80: The author's original Suchey - Brooks phasing guide

As mentioned previously, this guide was created to both elucidate and document the subjective process by which the study's subjects were assigned into one Suchey-Brooks phase over another should differences of opinion arise. At the time it was not intended to be diagnostic or predictive, but instead as a tool for comparing and contrasting the decision-making procedures amongst multiple practitioners.

2.3.4.1.3 Changes to the Suchey-Brooks Phasing Guide

After this pilot proved successful (Truesdell 2011) in establishing that individuals may be forensically aged by virtual imaging with a level of accuracy and reliability equal to that of the more traditional mediums of cast or dry bone, the author broadened its scope for this doctoral project. This time, however, as the project was not Suchey-Brooks specific, the author was free to make changes such "trialing" the addition of the seventh phase advocated first by Berg in 2008 and then again by Hartnett in 2010.

Moreover, as this doctoral project was to include both men and women (whereas the pilot had focused exclusively on men), a new, identical but female specific version of the guide was also created. For this, all of the male illustrations were replaced by female exemplars and entirely new descriptions were devised based upon observable dimorphic differences (see chapter 1, "An Introduction and Review of the Literature," section 1.4). Lastly, for clarity, the names of the five components were also changed to "Upper Boundary," "Lower Boundary," "Outline," "Surface Texture," and "Concavity."

2.3.4.1.4 Addition of Predictive Averaging

After analyzing a number of participants, the author questioned whether weighting the now continuous columns might add some form of predictive element to the guide, similar to that of Megyesi et al.'s (2005) accumulated degree days or Chen et al.'s (2008, 2011) "pinpoint" ageing through regression analyses. The merit of this kind of weighted variable scheme (in which the columns would not be sequential whole numbers, but rather decimals without the benefit of metered regularity) was investigated early in the project; however, it produced only marginal improvements in precision – results too negligible to justify the complication. In an effort to keep things as intuitive and as "user-friendly" as possible, therefore, this predictive element manifested instead as a simple but effective averaging, or "condensing the means," approach. For this, a line of continuous numbers - beginning at three (so as to ensure that 15 – the age at which male and female juveniles begin to noticeably diverge - was the lowest possible outcome) and ending at 16 (to include a seventh phase) - was added along the bottom of each component, with each number representing an individual column. With the addition of these successive numbers, unique to each column, therefore, instead of having to tally the phase distinctions at the end of an assessment (as was necessary for Suchey-Brooks), then looking elsewhere for a corresponding age range, practitioners applying the technique need only add up each column for a sum total, with that total being the estimated mean age for the individual in question.

To illustrate this, if, for the "Upper Boundary" component, a practitioner believes, based on the images and written descriptions, that "Recession" column best resembles the upper boundary of the specimen he or she is assessing, he or she would then circle it and note or remember the number 12 (*Figure 81*).

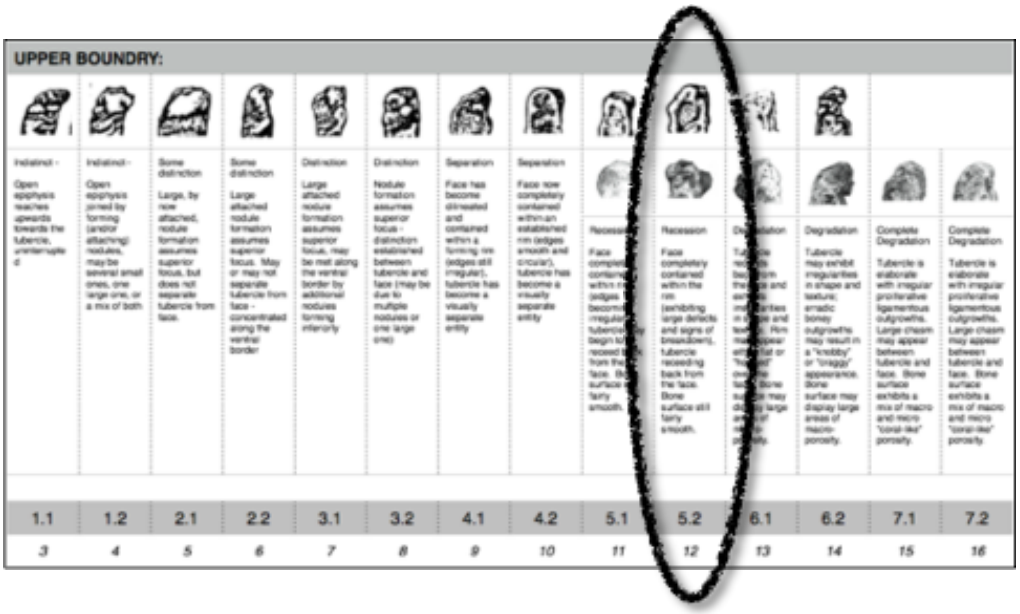


Figure 81: Choosing the 5.2, or 12 point, column

Taking this example further, let us also assume that that specimen most resembles the "12" column for each component thereafter as well, resulting in a total of five 12's overall. 12 x 5 = 60. By this technique, therefore, it may be assumed that the mean age of the individual being assessed is 60 years old (with 10 – 12 years added to either side, depending on the model used – to be explained in chapter 7, "Results"). Had that specimen's best matches been columns 7, 14, 9, 10, and 11, however, the "equation" would be 7 + 14 + 9 + 10 + 11 and the mean age would 51 years (plus or minus 10 – 12 years).

Conveniently, by adding the numbers in this way, the need to multiply by 5 for each component (to determine an overall sum), and then to divide again by 5 (to determine the average) is eliminated - simplifying the process. More importantly, however, it allows for the prediction of a precise age, but without the complicated, lengthy, and time-consuming algebraic equations shown to be off-putting for many practitioners (Meindl 1985).

2.3.4.1.5 Addition of Density Adjustment

After trialing this new technique, and based upon additional experience with the images, it quickly became clear that certain individuals were being consistently, yet predictably (i.e. conforming to an emerging pattern), under-aged, and that those individuals tended to be the ones exhibiting the most obvious loss of density on their axial views. Furthermore, these miscalculations appeared to be stepped in that the individuals exhibiting the greatest amounts of trabecular loss were also the individuals being under-aged most dramatically, while those individuals exhibiting lesser degrees of loss were under-aged less severely. Due to this proportional scaling, which so clearly correlated with density, it was decided that an "accommodation" should be incorporated into the technique - not as a formal a sixth component, necessarily, but as more of an adjustment to the final outcome. For females, this adjustment - based solely on the abundance of participants' trabecular bone as it appeared on their axial view - was divided into three categories: "High Density," which carried a weight of 0; "Medium Density," which carried a weight of 5; and "Low Density," which carried a weight of 10 *(Figure 82, below)*.

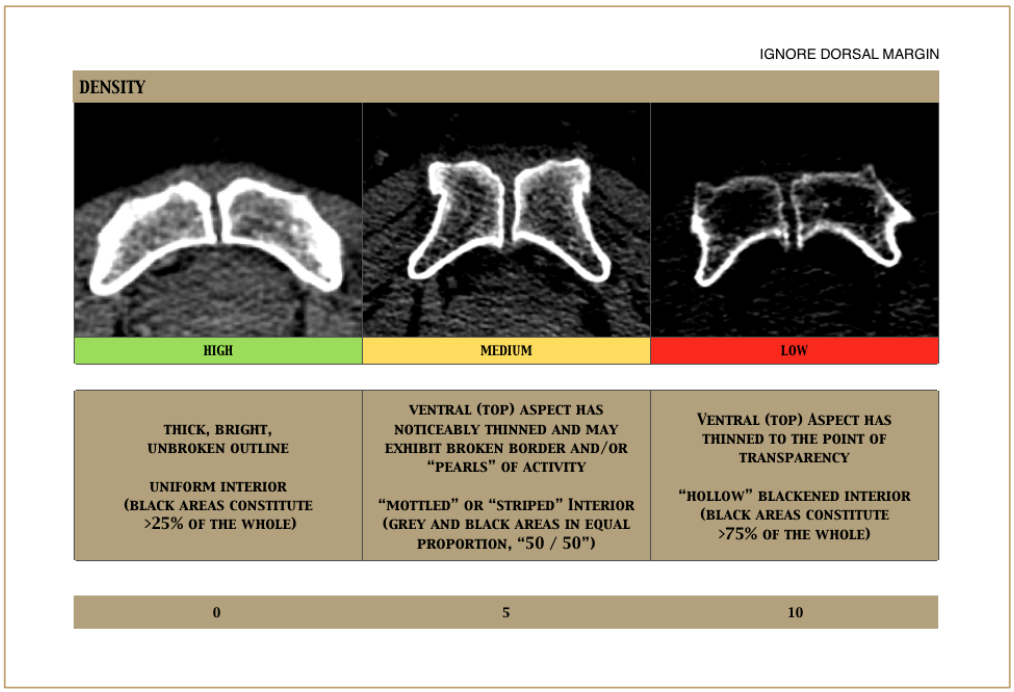
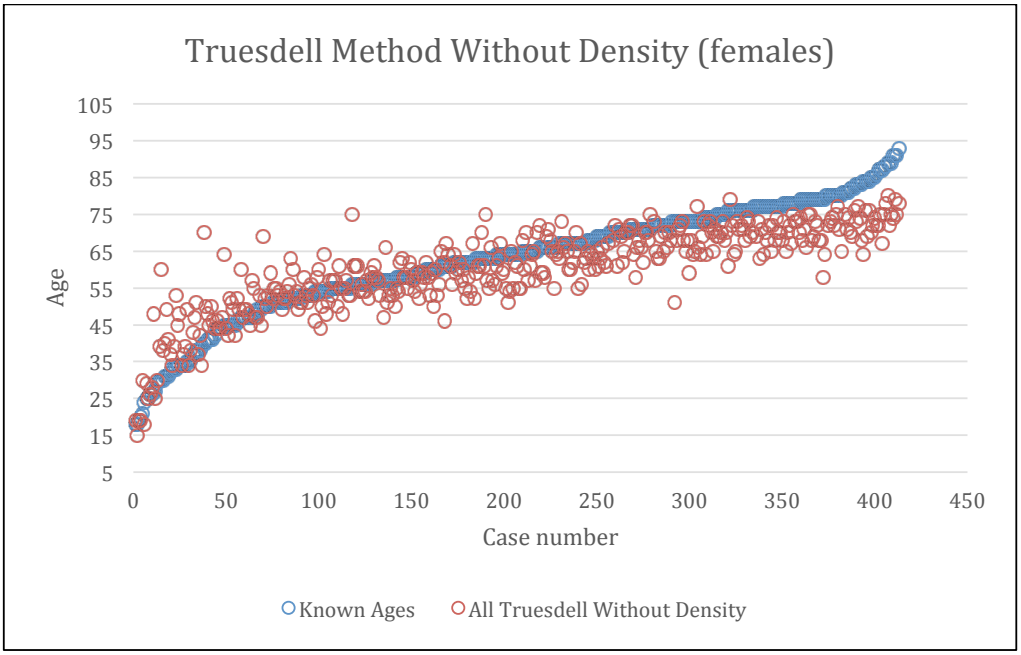


Figure 82: The TCM density adjustment

Much like the components, to apply this adjustment the practitioner need only select the category that best fits the specimen being analyzed then add that category's number to the total score. For example, if, based upon the previous five components, an individual has received a score of 40, with "high" density that score would remain at 40. However, if that individual's density were determined to be either "medium" or "low," that score of 40 would then be "adjusted" up to 45 or 50 years, respectively. The final score, and therefore mean age, for an individual with a component score of 40 and a density adjustment of five would thus be 45 years (plus or minus 10 – 12 years).



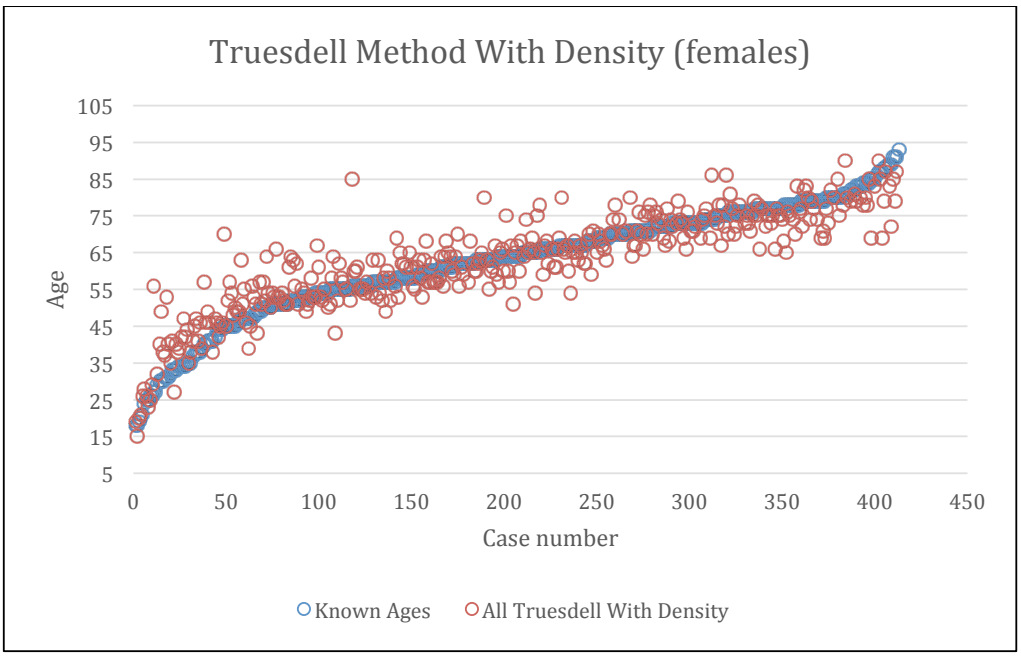


Figure 83: Results before and after applying the density adjustment

As may be seen (*Figures 83, above*), the addition of a "density adjustment" of this kind proved instrumental in solving the problem of pervasive under-ageing.

2.3.4.2 The Technique

As previously mentioned, the TCM combines – or presents a composite of – Todd (1920) and Suchey-Brooks' (1990) system of archetypal visual matching, McKern and Stewart's (1957) components, Hanihara and Suzuki's (1978) and Chen et al.'s (2008, 2011) discrete variables and linear regressions, Berg's (2008) seventh phase, Hartnett's (2010a) density inclusion, and Meindl et al.'s (1985) lack of enthusiasm for fixed or "static" typological phases.

The Truesdell Composite Method (TCM), as introduced here, presents a culmination of the method's evolution to date. That said, however, it is still a work in progress and will therefore continue to improve with use and the incorporation of future work – an example of this being the restructuring of the components into a more "clock-wise" order, as it was found that such a configuration more closely mimics the natural eye track, thereby increasing practitioner speed, memorability, and ease of use (*Figure 84*).



Figure 133: The "watch face" - Beginning at 12 o'clock (the "upper boundary" [1]), move down along the right "arc" to six o'clock (the "lower boundary" [2]), then move back up along the left "arc" to reach 12 o'clock again (closing the circle). This circle is now the "outline" (3). From 12 o'clock, drop directly down to the middle gears for "surface texture" (4), then tilt the watch back (so as to be looking across it horizontally) for "concavity" (5).

As will be seen, the guide page for each component contains a mix of "real world" representative screen captures for each number (column), hand drawn images of those captures with the addition of a blue "highlight" accentuating the most diagnostic or telling feature of that number (column), an explanatory title for each number (column), a written description of the features unique to that number (column), and, lastly, a few key words for that number (column). As stated, to apply the TCM the practitioner must simply chose a number (column) for each of the five components and add them together for an age. All virtual images were taken from the study sample and are the same images used by the author and by the observers to score each participant. The technique, as was employed by this study, is presented on the following pages.

2.3.4.2.1 The Upper Boundary

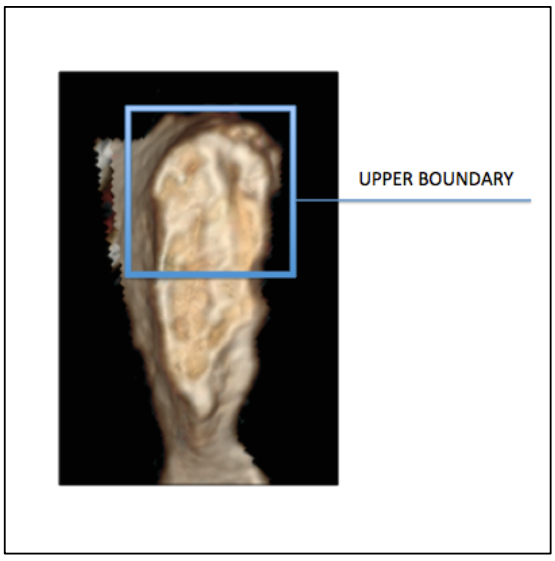


Figure 85: The Upper Boundary

As previously described, for the purposes of the TCM the symphyseal face has been segmented into five discrete, disparate areas. The first of these areas, though they may be taken in any order as they operate independently of each other, is that of the "Upper Boundary" (*Figure 85, left*).

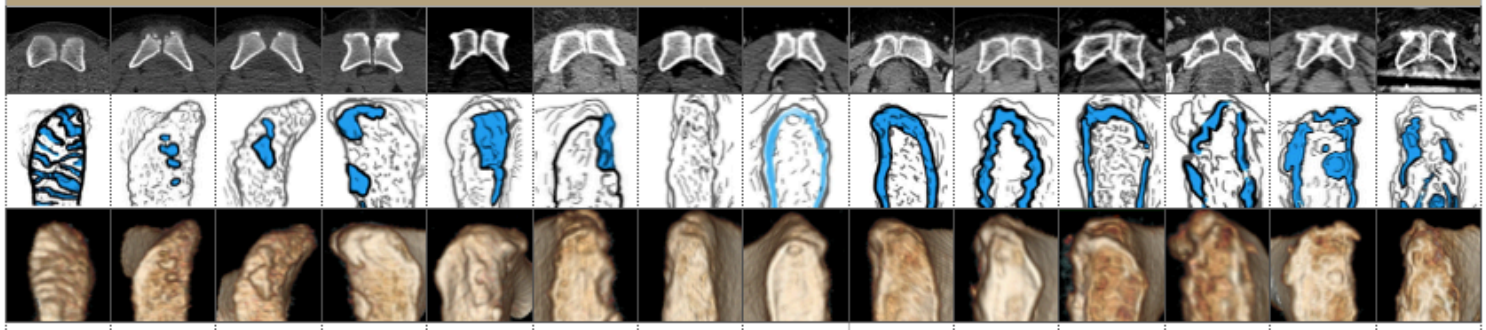
As can be seen, the Upper Boundary consists of the upper half of the face and includes the crest and tubercle behind. In evaluating the Upper Boundary, or "UB," the practitioner should focus primarily on activity, shape, and condition (i.e. whether the epiphysis is open, whether ossific nodules are present, whether the face has flattened, as well as the status [if waxing] or condition [if waning] of the outline). It is important to note that while several of the component elements may appear to overlap, it is what each is doing in each specific area that matters – the outline, for example, exists in multiple locations at once but at the upper boundary it may be broken while at the lower boundary it may remain intact (resulting in two different scores). Austria and Germany both share the Danube but they remain independent countries. In much the same way, certain elements may breach or cross boundaries; however, each component is nonetheless distinct, and must be regarded as such.

In contrast to the other four components, the upper boundary also includes examples of axial images as the author found axial images to be particularly diagnostic in this area. This is because, in this sample, epiphyseal activity was at its most dynamic, as well as its most pronounced, near the upper half of the face. Given this, the author felt it would have been a disservice not to include them, even at the risk of inconsistency.

The guide to the Upper Boundary, in its entirety, may be found on the following page (*Figure 86*). It has also been provided, enlarged, as *Appendix I*.

IGNORE DORSAL MARGIN

UPPER BOUNDARY (UB)



Open Epiphysis Open epiphysis reaches upwards towards the tubercle without interruption Epiphysis may appear triangular or boomerang shaped	**Soft Tissue Nodule Formation** Open epiphysis continues unchecked, though ossific nodules of varying size have begun to appear in the soft tissue	**Nodule Attachment** Ossific nodules have attached to the surface, interrupting the "flow" of the still open epiphysis (similar in appearance to that of rocks in a stream).	**Attachment with "Squaring Off"** Additional nodules have crept up from the midface to create a more distinct, "filled in" UB and "squared off" profile	**Distinction withActivity (Relief)** While nodule activity continues, the UB has flattened and become visually distinct from the tubercle behind	**Distinction with Breach (Recess)** Remodeling at the ventral hiatus takes the form of roughened irregularity, with large variations in surface topography "Mitten" shaped appearance	**Emergence of Outline** The face has flattened and become its own entity through the formation of a faint shadow "rim" or "outline" visible anteriorly but not ventrally	**Established Outline** "Rim" or "outline" has thickened to become a distinct, more permanently established border around the (flat) UB that, although faint, does not disappear ventrally	**Raised or Swelled Outline** "Rim" or "outline" has swelled and raised to create a cupped or "hooded" depression at the centre of the UB *Outline is Thick, Regular*	**Initial Degradation** "Rim" remains raised and thickned but, while still intact and unbroken, it has begun to scallop, becoming more irregular *Outline is Thick, Irregular*	**Continued Degradation** Thinned "rim" has begun to deteriorate and fade, becoming less prominent "Rim" may recede up and back towards the tubercle *Outline is Thin, Regular*	**Degradation with Ventral Breakdown** Tubercle outgrowths have become increasingly prominent Outline has assumed a patchy, scalloped appearance *Outline is Thin, Irregular*	**Partial Obliteration** "Rim" has been nearly obliterated at the UB by deterioration coupled with irregular outgrowth Large, deep macro-pores erode the surface	**Obliteration** Outline has been completely obliterated at the UB by degradation, irregular outgrowth, and macro-pores. Rough "coral- like" texture
Ridges and Furrows	***Nodule Formation***	***Nodule Attachment***	***Containment***	***Squaring Off***	***Ventral Hiatus***	***"Vanishing" Rim***	***"Shadow" Rim***	***Thick - Reguar***	***Thick - Irregular***	***Thin - Regular***	***Thin - Irregular***	***Erosion***	***Obliteration***
3	4	5	6	7	8	9	10	11	12	13	14	15	16

2.3.4.2.2 The Lower Boundary

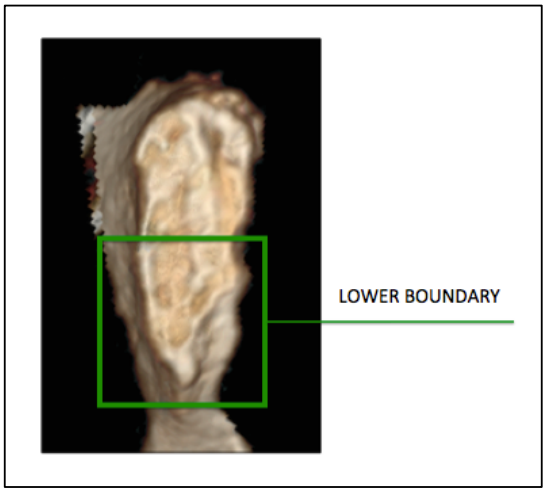
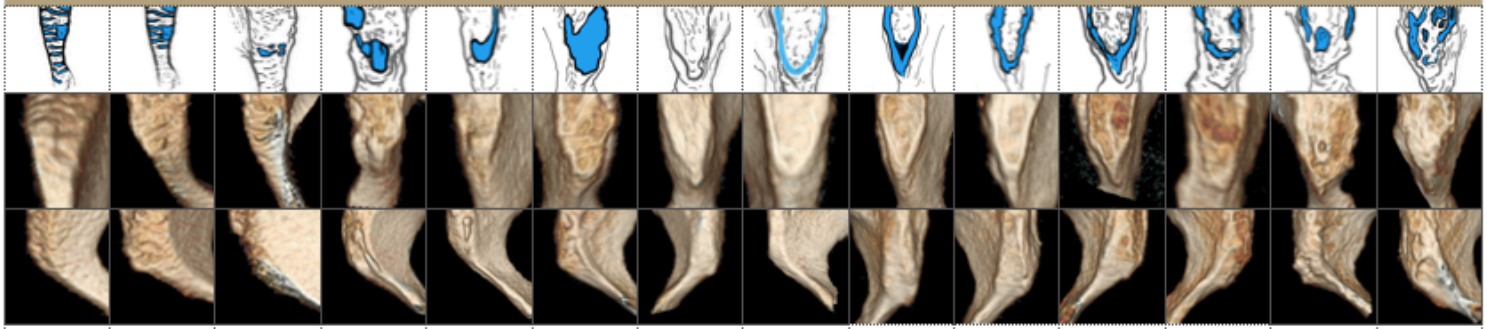


Figure 87: The Lower Boundary

Very similar to the first component, the "Upper Boundary," is the second component, the "Lower Boundary" (*Figure 87, left*) – though, again, they may be taken in any order. Very dissimilar to the Upper Border, however, is that morphological change at the Lower Border, or LB, is much less demonstrative, or "showy," and, instead, may be said to be more of an exercise in subtlety (though more sure-footed discernment comes with repetition). One "trap" this introduces is the temptation to project one component onto the next, the thought being that if one area is one number, they likely all will be. However, this is a habit acquired over years of assessing through the lens of Suchey-Brooks and it will lead the practitioner astray. The UB and LB are often different, as are the other components, and it is not uncommon for both "younger" (pre-10 numbers) and "older" (post-10 numbers) elements to co-exist on the same face (an occurrence discussed in greater detail in following sections). It is, therefore, again, imperative to the efficacy of the method that each component be regarded separately and afforded its own diligence. The guide to the Lower Boundary, in its entirety, may be found on the following page (*Figure 88*). It has also been provided, enlarged, as *Appendix I*.

IGNORE DORSAL MARGIN

LOWER BOUNDARY (LB)



Open Epiphysis Open epiphysis "flows" down the ramus without interruption Sharp, Jagged Surface	**Ramus Distinction** The LB is still open and without nodule formation, but epiphyseal closure moving up the ramus has begun to thicken and contain the "ridges and furrows" to the face	**Nodule Formation** Small ossific nodules have formed and attached, either remaining discrete or creating a raised, overall thickening of the LB	**Attachment with "Squaring Off"** Ossific Nodules have combined to create a thickened separation between the face and ramus Profile "squaring off"	**Initial Activity** Combined nodules begin to move up along the ventral border Widened "V" or "✓" shape	**Continued Activity** Nodule activity and swelling continues and proceeds upwards along the ventral border Widened "✓" shape	**Emergence of Outline** The face has gained distinction through the formation of a faint shadow "rim" or "outline" that now contains it "V" shape *"Vanishing" Rim*	**Established Outline** The thinly edged "rim" or "outline" begun in the previous stage has now thickened to establish a clear and definite border around the LB "Shadow" Rim	**Raised or Swelled Outline** "Rim" becomes raised to create a cupped central depression at the LB Cupped "V" shape	**Outline Degradation** "Rim" begins to degrade through raised, roughened overgrowth Swollen, convex "V" shape	**Continued Degradation** Thinning "rim" has begun to deteriorate and fade while macro-pores become visible Flat "V" shape	**Degradation with Breakdown** "Rim" is still visible but exists within a mix of macro-pores and overgrowth Irregular "V" shape	**Partial Obliteration** "Rim" is nearly obliterated at the LB by deterioration and irregular outgrowth while macro-pores erode and undermine the surface	**Obliteration** "Rim" has been completely obliterated by degradation, irregular overgrowth, macro-pores, and a rough "coral like" texture
No Interruption	***Facial Containment***	***Nodule Formation***	***Nodule Attachment***	***Consolidation***	***Squaring off***	***"Vanishing" Rim***	***"Shadow" Rim***	***Cupped Concavity***	***Swelled Convexity***	***Flat, Level Face***	***Erosion***	***Outgrowth***	***Obliteration***
3	4	5	6	7	8	9	10	11	12	13	14	15	16

2.3.4.2.3 The Outline

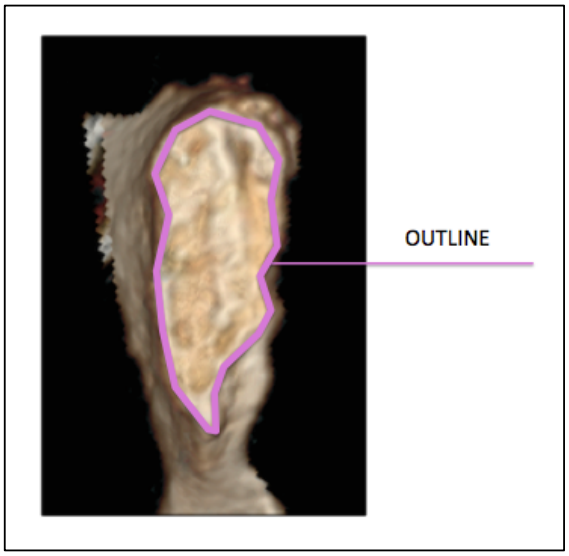


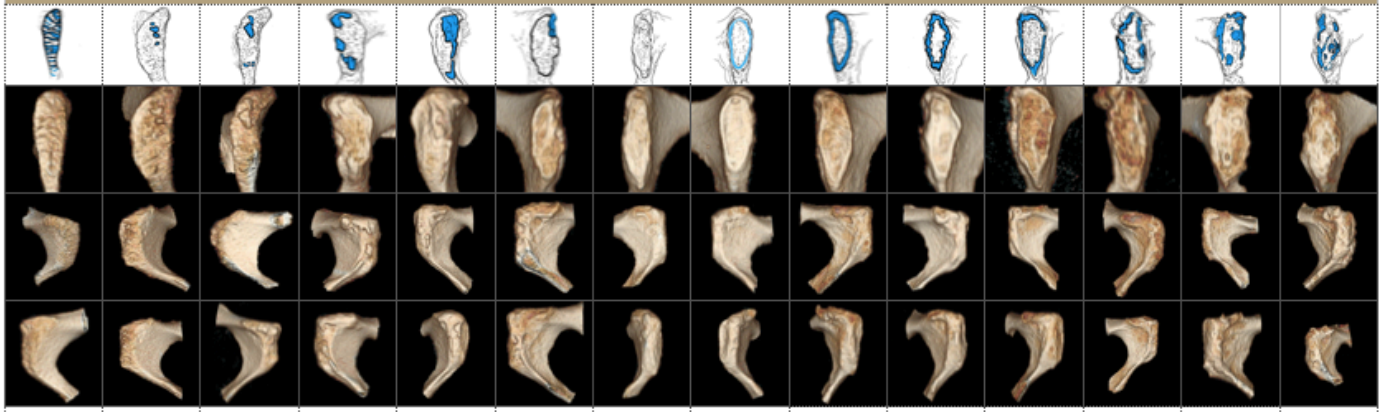
Figure 89: The Outline

Unlike the Upper and Lower Boundaries, for which the practitioner has so far been asked to look at one half of the face and then the other, to assess the third component – the "Outline" (*Figure 89*) – he or she must now "zoom out" and evaluate the shape of the face overall. However, in keeping with the theme of each component being an independent entity, this evaluation pertains to the delineation encircling and enclosing the face, referred to by Suchey and Brooks as the "rim," only. More than any other, this component charts the progression of the face's epiphyseal closure, beginning with its early build-up through the formation, attachment, and activity of ossific nodules (numbers 3-8, or ages 15 to 40), its completion (numbers 9 and 10, ages 45 - 50), and then eventually its breakdown through erosion and deterioration (numbers 11 – 16, ages 55 to 80).

The guide to the Outline, in its entirety, may be found on the following page (*Figure 90*). It has also been provided, enlarged, as *Appendix I.*

IGNORE DORSAL MARGIN

OUTLINE



Open	Open with UB Nodule Formation	Open with UB and LB Nodule Formation	Partial with Central Nodule Formation	Partial with Ventral Nodule Formation	Partial with Ventral Hiatus	Emerging	Established	Pronounced	Initial Degradation	Continued Degradation	Complete Degradation	Partial Obliteration	Obliteration
Open epiphysis reaches upwards towards the tubercle Epiphysis may appear boomerang shaped Edges appear "jagged" on both sides Upper and Lower boundaries rounded in profile	Epiphysis remains open though ossific nodules have begun to appear in the soft tissue Edges "jagged" on both sides	Ossific nodules have fully attached at the UB and have begun forming at the LB Edges remain open but "jagged" appearance has lessened Profile interrupted by nodules at both UB and LB	Nodules from the UB and the LB merge along the ventral border ("rampart") Edges are sharp but no longer "jagged" Profile beginning to "square off" as nodules condense	Nodule activity (building up) is contained to the mid and upper ventral border Dorsal edge remains sharp, ventral edge remains open Profile now square in appearance	Nodule activity (breaking down) is contained to the mid and upper ventral border Dorsal edge remains sharp, the ventral edge remains open, Profile is squared	Both dorsal ("plateau") and ventral ("rampart") borders are now level creating a broad flattened face contained within a faint shadow "rim" Outline may present as an elongated oval shape *"Vanishing" Rim*	Shadow "rim" emergent in the previous stage continues to gain definition and, while faint, does not disappear ventrally Outline may present as an "inverted teardrop" shape *"Shadow" Rim*	"Rim" swells and rounds to create cupped depressions at both the UB and LB "Pointed oval" shape *Outline is Thick, Regular*	Swelled "rim" begins to lose definition taking on a scalloped appearance "Pointed oval" shape *Outline is Thick, Irregular*	Outline continues to degrade as "rim" edges thin "S" or pinched "oval" shape *Outline is Thin, Regular*	"Rim," while still visible, may become confused amid deterioration, irregular outgrowths, and erosion *Outline is Thin, Irregular*	"Rim" is nearly obliterated by deterioration and irregular outgrowth, macro-pores erode and undermine the face Erosion	Outline has been obliterated by degradation, irregular outgrowth, macro-pores, and a rough "coral like" texture Erosion
Ridges and Furrows	***Nodule Formation***	***Nodule Attachment***	***Central Nodules***	***Ventral Activity***	***Ventral Hiatus***	***"Vanishing" Rim***	***"Shadow" Rim***	***Thick - Regular***	***Thick - Irregular***	***Thin - Regular***	***Thin - Irregular***	***Erosive Outgrowth***	***Uniform Destruction***
3	4	5	6	7	8	9	10	11	12	13	14	15	16

2.3.4.2.4 Surface Texture

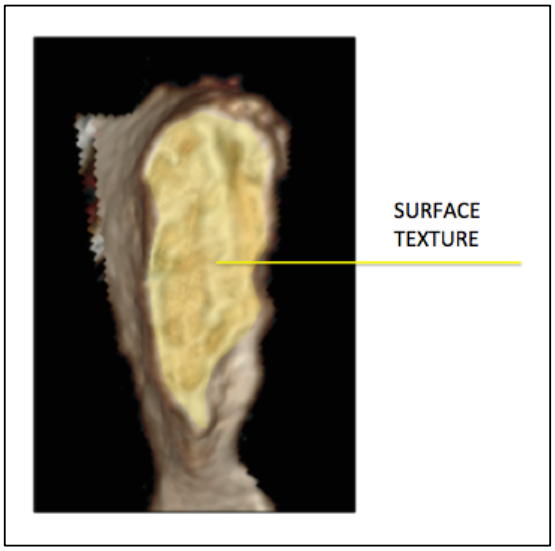
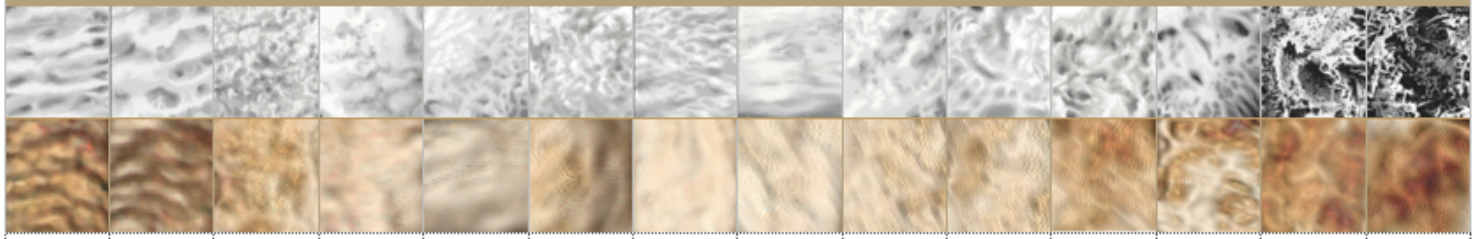


Figure 91: Surface Texture

The fourth component of the TCM – though they may be taken in any order - is that of "Surface Texture" (*Figure 91*). As its name suggests, this component focuses exclusively on the texture and structural integrity of the symphyseal face. Following a similar trajectory as that of the auricular surface, in early life the pubic face is characterized by a smooth, dense solidity which, after the billowing of the "ridges and furrows" (the hallmark of an open epiphysis) resorb and flatten, settles into grainier, more "sandpaper-like" textures before finally being eroded in the form of micro then macro pores which eventually meet, creating large sinkholes and depressions as the face crumbles from below. As this study relied on CT and was, therefore, entirely image based, this component required the most mental "acclimatization" for the observers, as, instead of depending upon tactility, he or she had to depend upon shadow and subtle differences in color (light versus dark) to infer texture. While for some this was difficult at first, with experience it became just another way of interpreting the data. The guide to Surface Texture, in its entirety, may be found on the following page (*Figure 92*). It has also been provided, enlarged, as *Appendix I*.

IGNORE DORSAL MARGIN

SURFACE TEXTURE



Sharp Ridge and Furrow System Sharp, thinly peaked and densely packed ridges and furrows present across the entirety of the open epiphysis	**Ridge and Furrow System with UB Nodule Formation** Swelled, thickening ridges and furrows present across the entirety of the open epiphysis - ossific nodule formation at the UB	**Shallowing Ridge and Furrow System with LB Nodule Formation** Ridges and furrows, while still visible, have begun to "fill in" creating peaks and valleys - like merangue, a mountain range, or choppy water (easily confused w/ porosity) LB nodules	**Shallowed Ridge and Furrow System with Central Activity** Ridges and furrows continue to shallow and may now be sporadic or hardly visible Central nodules	**Mixed Surface with Ventral Activity** Surface is now a mix of smoothness and areas of shallow ridges and furrows Nodule activity (build-up) along the sup. ventral border	**Mixed Surface with Ventral Hiatus** Surface is a mix of smoothness and areas of shallow ridges and furrows Nodule activity (breakdown) along the sup. ventral border	**Smooth - Flat** Ridges and Furrows have now disappeared (remnants may persist) and have been replaced by a smooth, level surface Nodule activity has ceased	**Smooth - Mixed Topography** Surface is smooth (though remnants of ridges and furrows may persist) Face is a mix of raised areas (typically the LB) and depressions (UB)	**Appearance of micro pores** Surface remains smooth but with the addition of micro pores "Sandpaper" appearance	**Appearance of macro pores** Surface remains smooth but macro pores begin to appear below and amongst the micro pores	**Initial Degradation** Surface remains smooth but both micro and macro pores deepen and begin to undermine surface integrity	**Mixed Degradation** Surface is a mixture of smoothness and degradation (50%) as structural integrity is eroded from below "Crumbling" appearance	**Severe Degradation** Surface is now more eroded than it is smooth and intact (75%) "Wasted" or "wizened" appearance Low Density	**Complete Degradation** Surface is now completely eroded "Hollow," or "coral - like" appearance Very low Density
Sharp, Narrow Ridges and (Deep) Furrows	***Thick, Wide Ridges and (Deep) Furrows***	***Irregular Peaks and (Deep) Valleys***	***Rounded Peaks and (Shallow) Valleys***	***Gently Rolling "Surface Waves"***	***Soft "Billowy" Surface***	***Smooth, Flat Surface***	***Smooth, Mixed Surface***	***Micro-Pores***	***Macro-Pores***	***Coalescence Deepening of Macro-Pores - "Sinkholes"***	***50% Degradation***	***75% Degradation***	***≥ 90% Degradation***
3	4	5	6	7	8	9	10	11	12	13	14	15	16

2.3.4.2.5 Topography

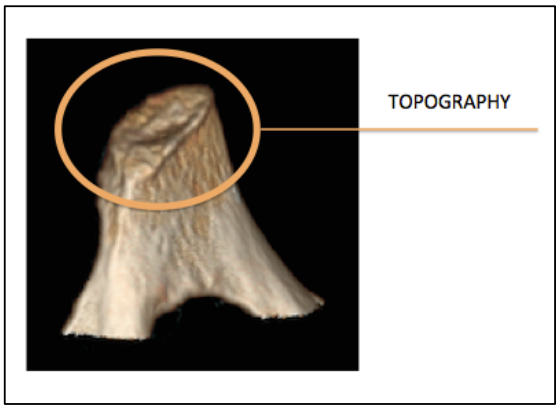


Figure 93: Topography

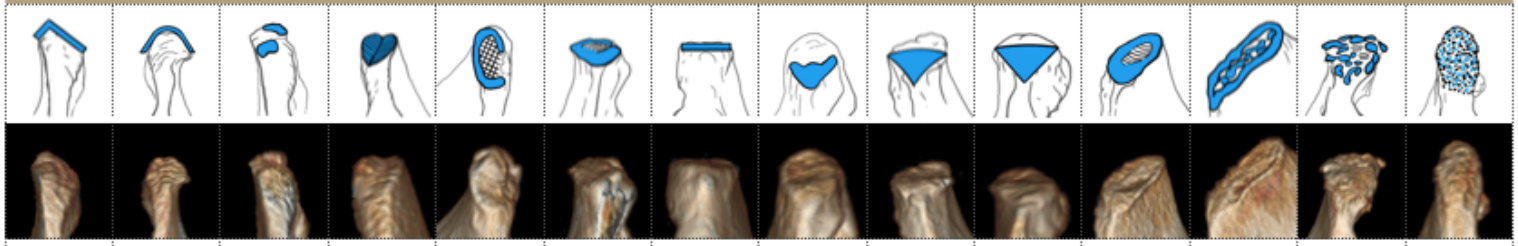
The final component of the TCM is that "Topography" (*Figure 93*) and, like Surface Texture, requires some degree of visual-spatial imagination. As described by the "watch-face" analogy in section 6.1, this component comes into view when the practitioner tilts the face back so as to be looking up from the Lower Boundary up towards the Upper Boundary (inferiorly to superiorly), at a more or less horizontal - though slightly raked - angle.

When positioned in this way, several discernable shapes become evident at the Lower Boundary – the result of the face's continuously shifting morphology. Like Surface Texture, these shapes take some getting used to but once mastered – a product of repetition - they show themselves immediately and become second nature.

The guide to Topography, in its entirety, may be found on the following page (*Figure 94*). It has also been provided, enlarged, as *Appendix I*.

IGNORE DORSAL MARGIN

TOPOGRAPHY



Triangular - Pointed Apex Level but jagged profile raked dorso-ventrally Inferior/ superior view is triangular with sharply pointed apex	**Triangular - Softened Apex** Level but jagged profile raked dorso-ventrally Inferior/ superior view is triangular with softening apex UB nodule visible in the distance	**Convex with Nodules** Mixed profile - raised extremities, flattened centre (lateral edges sharp) Inferior/ superior view is convex as seen behind LB nodule formation	**Valley** Level but slightly scalloped profile Inf/Sup view shows both dorsal and and ventral borders raised forming a long, deep "valley" down the centre of the face	**C-Shape** Level profile raked ventro-dorsally Inferior/ superior view is flat with the exception of a deep central depression on the ventral side (Niagara's) "Horseshoe Falls"	**Filling in or flattened C-Shape** Level profile Inferior/ superior view is vallied but with nodule activity on the (ventral) side	**Plateau** Level profile Inferior/ superior view is flat Tubercle activity may or may not be seen in the distance	**Tulip, or Heart Shaped with depressed background** Profile is level but may contain a dorsal spur at the midface Inferior/ Superior view is tulip or heart shaped with a cupped distal depression	**S-Shape with depressed background** Profile is curved, with an S-Shape Inferior/ Superior view is like a "roller-coaster" or as if looking at an "s" on its side (convex foreground with concave background)	**Shallowed S-Shape with depressed background** Profile is still curved, though less pronounced Inferior/ Superior view is similar to the previous but but rounding has flattened (somewhat like a cake that has fallen after being taken out of the oven)	**Crater** Profile may be flat or slightly curved with a dorsal spur at the midface Rim outline is elevated around the face giving the appearance of a depressed centre Smooth cup or basin	**Filled in Crater** Profile and Inferior/ Superior view remains similar to the previous Central depression becomes obscured by rough erratic outgrowths, or a mix of both Irregular cup or basin, as if filled in with rocks	**Mixed Topography** Profile is a mix of level and concave due to UB and LB degradation Inferior/ Superior view is a mix of textures while the face loses shape and integrity Flat and Irregular	**Coral-Like** Profile is either level or convex due to UB and LB destruction Inferior/ Superior view is convex, porous, and coral like in texture
Sharp Triangle	***Softened Triangle***	***Nodule "Bookends"***	***"V " Shaped Valley***	***"C" Shape, Sloped Interior***	***"C" Shape, Flattened Interior***	***Flat Surface, or "Plateau"***	***Heart (Sometimes Tulip) Shape***	***"S" Shape, High Rounded Curve***	***"S" Shape, Low Flattened Curve***	***Empty "Crater" or "Basin" Shape***	***Filled in "Crater" or "Basin" Shape***	***"Field of Rocks and Boulders," Flat***	***Coral Like Texture, Rounded***
3	4	5	6	7	8	9	10	11	12	13	14	15	16

2.3.5 Documentation

In addition to the TCM, age for each participant was also estimated using the industry standard Suchey-Brooks method (1990) as well as the Hartnett method (2010).

To control for asymmetry (Overbury et al. 2009; Warmlander and Sholts 2011; Beresheim 2015; McCormick and Kenyhercz 2015), both left and right symphyseal faces were assessed independently and recorded separately. If asymmetry was present, whichever side appeared to be "older" was taken as the definitive, or overall, phase for that person. In an attempt to increase specificity, whenever possible Suchey-Brooks designations were recorded by half phases, as illustrated by White and Folkens (2005). For example, instead of phasing a symphyseal face simply as "1," subjects were classified as either "1.1" or "1.2." If this type of half phase distinction could not be made, however, the broader, more encompassing phase distinction would be recorded.

These phase distinctions were then inputted into an excel database already containing the patients' information and questionnaire answers. TCM distinctions (descriptions of the face's "Upper Boundary," "Lower Boundary," "Outline," "Surface Texture," and "Concavity" on a scale of 3 to 16, plus density - to be discussed in later chapters) were placed in clock-wise order (though order is unimportant) and summed – a number then compared with known age and

categorized as “within 5 years,” “within 10 years,” or “more than 10 years” (*Figure 95*).

UpperBoundary Left	LowerBoundary Left	Outline-Left	SurfaceTexture-Left	Concavity-Left	Sum-Left	Density	Sum-Left +Density	ActualAge	Sum+Accurate?
10	11	11	11	11	53	0	53	58	Within5yrs
8	10	8	12	9	47	0	47	48	Within5yrs
9	9	9	11	9	47	0	47	49	Within5yrs
10	10	10	10	12	52	10	62	67	Within5yrs
14	14	13	14	14	69	5	74	70	Within5yrs
12	11	12	11	11	57	10	67	66	Within5yrs
12	12	12	11	12	59	0	59	59	Within5yrs
10	10	10	9	10	49	0	49	50	Within5yrs
14	11	13	13	13	64	10	74	73	Within5yrs
15	15	15	16	15	76	5	81	76	Within5yrs
10	10	10	9	11	50	0	50	52	Within5yrs
13	13	13	13	13	65	10	75	77	Within5yrs
8	9	8	8	8	41	0	41	37	Within5yrs
14	14	14	14	14	70	0	70	68	Within5yrs
12	10	12	11	11	56	0	56	55	Within5yrs
10	9	9	10	10	49	0	49	31	MoreThan10yrs
13	12	13	13	12	63	5	68	68	Within5yrs
13	14	13	14	14	68	5	73	73	Within5yrs
9	11	11	11	10	51	10	61	62	Within5yrs
15	15	14	15	15	74	5	79	73	Within10yrs
14	13	13	15	13	68	5	73	75	Within5yrs
11	11	11	11	12	58	10	68	69	Within5yrs
12	11	12	12	13	60	5	65	58	Within10yrs
13	10	13	9	13	58	5	63	63	Within5yrs
13	13	13	11	13	63	0	63	57	Within5yrs
9	8	8	8	7	40	0	40	30	Within10yrs

Figure 95: Example of TCM recording in Excel

At the same time, the Suchey-Brooks and Hartnett phase determinations for each individual were also placed into the database, followed by their age ranges (and means). These were then also compared with known age. If that known age fell between the end points of the chosen phase’s designated age range, it was noted that the method used was “accurate” (as indicated by “Y” for yes or “N” for no). Additionally, to evaluate the level of precision within that accuracy, distance from known age (in this case, the mean) was categorized into “within 5 years” (green), “within 10 years” (yellow), or “more than 10 years” (red) (*Figure 96*).

SBPhase	SBAge	ActualAge	SBAccurate?	HowFarFromSB Mean?	HartnettPhase	HartnettAge	ActualAge	HartAccurate?	HowFarFrom HartMean?
5	25-83,m48.1	58	Y	Within10yrs	5	44-60,m51.47	58	Y	Within10yrs
4	23-57,m35.2	48	Y	MoreThan10yrs	4	27-61,m42.45	48	Y	Within5yrs
4	23-57,m35.2	49	Y	MoreThan10yrs	4	27-61,m42.45	49	Y	Within10yrs
4	23-57,m35.2	67	N	MoreThan10yrs	4	27-61,m42.45	67	N	MoreThan10yrs
6	42-87,m60.0	70	Y	Within10yrs	6	56-86,m72.34	70	Y	Within5yrs
5	27-66,m45.6	66	Y	MoreThan10yrs	5	37-72,m53.87	66	Y	MoreThan10yrs
5	27-66,m45.6	59	Y	MoreThan10yrs	5	37-72,m53.87	59	Y	Within10yrs
4	23-57,m35.2	50	Y	MoreThan10yrs	4	27-61,m42.45	50	Y	Within10yrs
6	34-86,m61.2	73	Y	Within10yrs	7	58-97,m77.00	73	Y	Within5yrs
6	42-87,m60.0	76	Y	MoreThan10yrs	7	62-99,m82.54	76	Y	Within10yrs
4	23-57,m35.2	52	Y	MoreThan10yrs	4	27-61,m42.45	52	Y	Within10yrs
6	42-87,m60.0	77	Y	MoreThan10yrs	6	56-86,m72.34	77	Y	Within5yrs
3	21-53,m30.7	37	Y	Within10yrs	3	24-44,m31.44	37	Y	Within10yrs
6	34-86,m61.2	68	Y	Within10yrs	6	51-83,m63.76	68	Y	Within5yrs
5	27-66,m45.6	55	Y	Within10yrs	5	37-72,m53.87	55	Y	Within5yrs
5	27-66,m45.6	31	Y	MoreThan10yrs	5	37-72,m53.87	31	N	MoreThan10yrs
6	42-87,m60.0	68	Y	Within10yrs	7	62-99,m82.54	68	Y	MoreThan10yrs
6	42-87,m60.0	73	Y	MoreThan10yrs	6	56-86,m72.34	73	Y	Within5yrs
4	23-57,m35.2	62	N	MoreThan10yrs	4	27-61,m42.45	62	N	MoreThan10yrs
6	42-87,m60.0	73	Y	MoreThan10yrs	6	56-86,m72.34	73	Y	Within5yrs
6	42-87,m60.0	75	Y	MoreThan10yrs	6	56-86,m72.34	75	Y	Within5yrs
6	34-86,m61.2	69	Y	Within10yrs	6	51-83,m63.76	69	Y	Within10yrs
5	25-83,m48.1	58	Y	Within10yrs	5	44-60,m51.47	58	Y	Within10yrs
6	34-86,m61.2	63	Y	Within5yrs	6	51-83,m63.76	63	Y	Within5yrs
6	42-87,m60.0	57	Y	Within5yrs	5	44-60,m51.47	57	Y	Within10yrs
4	26-70,m38.2	30	Y	Within10yrs	4	33-58,m43.26	30	Y	MoreThan10yrs

Figure 96: Example of Suchey-Brooks and Hartnett recording in Excel

Each method was then assessed by calculating the number of entries categorized as "within 5 years," "within 10 years," and "more than 10 years," and dividing that number by the number of participants. Precision levels (the resulting percentages) for each method were then compared.

Lastly, also recorded in the database were notes on the presence of any artifact, which ward had ordered each scan, and the appearance of any interesting, unique, or anomalous features.

2.4 Third Party Observation

Once the author had assessed and documented the entire sample by all three methods, a subset of 75 randomly selected individuals - 50 females (25 parous, 25 nulliparous) and 25 males - was compiled for additional analysis by three independent observers. These observations, as a means of "quality control,"

served not only to establish the author's competence (lending trust to her assessment of the rest of the sample), but also to confirm the presence of any patterns that may arise from the data.

2.4.1 Observation Sample / Subset

Each of the above mentioned categories – parous females ("P"), nulliparous females, ("N"), and males ("M) - were further divided into nine decades: 10's (teens), 20's, 30's, 40's, 50's, 60's, 70's, 80's, and 90's. Between five and seven individuals were placed into each decade (with the exception of the second [teens] and tenth [90's] decades where availability was more limited). When curating this subset, every effort was made to include an even distribution of ages within each category (for example, 40 - 42 - 44 - 46 - 48 as opposed to 40 - 40 - 41 - 48 - 49).

Scans were selected for this subset based solely upon subject age and image clarity. As an extra test of the material, however, some lesser quality scans (i.e. those containing varying levels and types of artifact) were purposely included. For a summary of the final subset, see *Table 4* (below).

Table 4: The Observer's Subset

Observation Number	Subject Number	Pregnancy Status	Decade	Actual Age
1	1076	N	10's	18
2	124	P	80's	88
3	763	P	40's	47
4	603	N	20's	29
5	738	N	70's	77
6	479	P	90's	93
7	855	N	30's	35
8	254	N	10's	19
9	953	P	50's	56
10	446	P	60's	68
11	375	P	40's	42
12	59	N	20's	24
13	491	P	70's	71
14	219	P	50's	58
15	244	N	50's	51
16	190	N	80's	83
17	563	P	30's	39
18	63	N	60's	62
19	460	P	90's	91
20	895	N	70's	74
21	506	N	10's	18
22	952	N	40's	48
23	475	P	60's	66
24	257	N	20's	26
25	838	P	80's	86
26	390	N	30's	38
27	303	P	90's	91
28	102	P	50's	53
29	634	P	70's	79
30	707	N	30's	34
31	227	P	60's	60
32	259	N	10's	18
33	739	P	40's	45
34	8	N	80's	81
35	103	N	20's	25
36	623	P	30's	32
37	639	P	70's	78
38	497	N	50's	52
39	787	P	80's	87

40	552	N	20's	20
41	314	P	60's	63
42	1046	P	40's	40
43	222	N	80's	89
44	1034	N	40's	45
45	225	P	60's	69
46	1075	N	50's	54
47	405	P	70's	70
48	999	N	70's	77
49	525	P	60's	67
50	157	N	80's	84
51	262	M	70's	70
52	31	M	40's	47
53	211	M	80's	80
54	256	M	70's	72
55	171	M	50's	57
56	24	M	60's	60
57	247	M	60's	65
58	106	M	90's	91
59	195	M	80's	82
60	55	M	60's	63
61	270	M	50's	50
62	132	M	80's	85
63	306	M	70's	74
64	134	M	40's	49
65	48	M	80's	89
66	182	M	60's	66
67	105	M	50's	52
68	62	M	70's	75
69	327	M	80's	87
70	121	M	40's	46
71	36	M	50's	59
72	66	M	70's	77
73	217	M	60's	68
74	86	M	50's	54
75	266	M	70's	79

Once the selected scans had been fully anonymized, a group of three independent practitioners were asked to assess them using the TCM, Suchey-

Brooks, and Hartnett methods, exactly as the author had. In addition to extensive professional experience, each observer possessed skeletal training at the doctoral level - observer one received his or her doctorate from the University of Oxford in 2016 (biological anthropology), observer two received his or her doctorate in 2006 from the University of Oxford (biological anthropology/archaeology), and observer three received his or her doctorate in 1990 from the University Tennessee - Knoxville (biological anthropology) - and were all, therefore, well acquainted with skeletal age estimation from the os pubis.

As stated, these observers were asked to provide age estimations for each of the 75 individuals using the three techniques employed by the author (the Suchey-Brooks Method for Ageing the Os Pubis, the Hartnett Method, and the TCM). In an effort to avoid any inadvertent "cross-contamination" of paradigms (variable versus archetype), however, which could potentially bias results, the observers first assessed the entire subset using the Suchey-Brooks and Hartnett methods, then, after a waiting period, assessed the entire subset again using the TCM. Standard reference casts for the Suchey-Brooks method (France Casting, 2015) were provided, as was White and Folken's "Human Bone Manual," as well as a printed copy of the *Journal of Forensic Sciences* article written by Kristen Hartnett (2010), detailing her method. A laminated print of the TCM was also provided.

With the exception of sex (which, in best practice, is determined before age when establishing a biological profile and so would be known), the observers

were given no information prior to their examinations. To remain unbiased, each of the observers carried out their examinations separately and without communication. Observer one and observer two performed their examinations at the study site (Oxford's Churchill Hospital) using the same computer and software (GE's "Centricity") used by the author. Observer three performed his or her examination on a personal desktop computer (Dell) using a different software package ("Mimics" by Materialise, version 18.0). Per NHS data protection regulation, it was required that the author be present at each (in hospital) examination and was, therefore, on hand to provide non-score related guidance or answer any questions the observers had (none had previous experience with medical imaging or assessing age from CT's).

To prevent any confusion or misattributing of results, each observer was given a recording sheet specific to him or her (containing his or her name and the date of each examination). When finished, all results were entered into the master database (described above, section 2.3.4), percentages of accuracy were calculated, and a chi-squared test was run to quantify agreement (see chapter seven, "Results").

By using these materials (invitations to participate, patient information sheets, questionnaires, and consent forms) and by employing this methodology (ethics approval, face-to-face interviews, and CT scan analysis), this study amassed a sample of 1,238 living volunteers over a period of seven months. Details of this sample, including its descriptive statistics, will be discussed in the following chapter – "The Sample (Descriptive Statistics)."

3

The Sample (Descriptive Statistics)

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Abstract:

This chapter will outline the population utilized for this project and discuss its appropriateness for study. As will be shown, as a hospital sample, this group was naturally self-selecting; however, as patients visit the hospital for any number of reasons, it is not anomalous and may, therefore, be trusted to be representative of the wider Oxford and British communities.

At 1,238 individuals, this study constituted the largest image based forensic (anthropological) evaluation ever undertaken (current largest: 556 [417 males and 139 females], Schulz *et al.* 2005). It was also the largest female focused investigation (current largest: 439 females, Schmitt 2001), the largest image based evaluation of the pubic symphysis (current largest: 167 [102 males and 65 females], Alcaraz 2013), the largest to utilize living subjects (current largest: 556 [417 males and 139 females], Schulz *et al.* 2005), and the first to include nulliparous women as an independent data set. Lastly, this study was also the first in the UK to systematically test multiple techniques to investigate age estimation from pubic symphysis.

3.0 Sample Overview

The sample for this study comprised of 1,238 adult individuals (653 males and 585 female) and was a combination of three separate groups - males, nulliparous females (women with no birth history), and parous females (women with a history of at least one birth). Ages ranged from 18 to 101 years and all

ethnic backgrounds were included *(Tables 5a-c, below).* The data for this sample was gathered on-site from within the Radiology Department at Oxford's Churchill Hospital over a period of 7 months (September 1st, 2014 - March 31st, 2015). After initial analysis showed no correlation between ageing inaccuracy and referring departments (Oncology, Urology, Cardiology, etc.), patients from all issuing wards were included.

Table 5 (a): Sample by sex, age, and ethnicity - Males.

Males, *n* = 653							
	White	Asian - South	Asian - East	Black; African, or Caribbean	Arab	Mixed or Multiple Ethnicity[13]	Other Ethnicity[14]
18 - 19yrs	1	1					
20 - 29yrs	10	1					1
30 - 39yrs	19	4	2	1	1	2	1
40 - 49yrs	51	1	1	1		1	
50 - 59yrs	100			1		2	
60 - 69yrs	176	1		1		1	
70 - 79yrs	193	3	1		1		
80 - 89yrs	70						
90 - 99yrs	3						
100 + yrs	1						
n =	624	12	3	4	2	6	2

13 *30-39: One individual self-identified as White mixed with Black*
One individual self-identified as White mixed with East Asian (Hong Kong)
40-49: One individual self-identified as White mixed with Hispanic
50-59: One individual self-identified as White mixed with Black
One individual self-identified as White mixed with Black
60-69: One individual self-identified as White mixed with South Asian (Indian)

14 *20-29: One individual self-identified as "other" - Persian*
30-39: One individual self-identified as "other" - Persian

Table 5 (b): Sample by sex, age, and ethnicity - Parous Females.

Females - Parous, *n* = 496 (one exclusion, one unusable)							
	White	Asian - South	Asian - East	Black; African, or Caribbean	Arab	Mixed or Multiple Ethnicity[15]	Other Ethnicity[16]
18 - 19 yrs							
20 - 29 yrs	2						
30 - 39 yrs	17	1		1			
40 - 49 yrs	36		1		1		
50 - 59 yrs	101	1		3		1	1
60 - 69 yrs	125	1		2		2	2
70 - 79 yrs	149			1		2	
80 - 89 yrs	39	1					
90 - 99 yrs	4						
100 + yrs							
n =	473	4	1	7	1	5	3

Table 5 (c): Sample by sex, age, and ethnicity - Nulliparous Females.

Females - Nulliparous, *n* = 89 (one exclusion)							
	White	Asian - South	Asian - East	Black; African, or Caribbean	Arab	Mixed or Multiple Ethnicity[17]	Other Ethnicity[18]
18 - 19 yrs	3					1	
20 - 29 yrs	10					1	
30 - 39 yrs	14	1					
40 - 49 yrs	8	1					
50 - 59 yrs	16		1	1			
60 - 69 yrs	16						
70 - 79 yrs	8						
80 - 89 yrs	7						
90 - 99 yrs							
100 + yrs							
n =	82	2	1	1	0	2	0

15 *50-59: One individual self-identified as White mixed with South Asian (Indian)*
60-69: One individual self-identified as White mixed South and East Asian (Indian and Malay)
60-69: One individual self-identified as White mixed with South Asian (Indian)
70-79: One individual self-identified as White mixed with Black (St. Helena Island)
70-79: One individual self-identified as White mixed with Black (North African, Tunisia)

16 *50-59: One individual self-identified as "other" - Ashkenazi Jew*
60-69: One individual self-identified as "other" - Ashkenazi Jew
60-69: One individual self-identified as "other" - Brazilian

17 *18-19: One individual self-identified as White mixed with Black*
20-29: One individual self-identified as White mixed with Black

18 *No self-identifications as "other"*

3.1 Demographic Information

This section includes basic physical descriptions such as height, weight, age and ethnicity as well as any changes there to (such as residence and the loss or gain of weight).

3.1.1 Sex

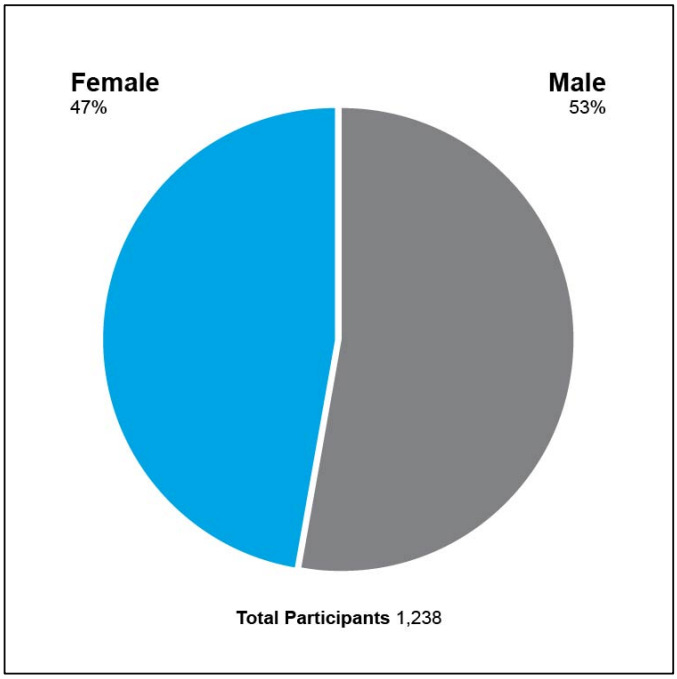
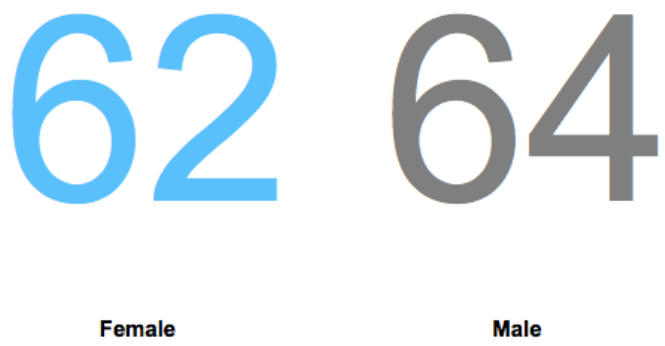


Figure 81: Sample demographics - Sex

Of the 1,238 people who elected to participate in this study, 585 of them were female and 653 of them were male – accounting for 47% and 53% of the sample, respectively (*Figure 81*). Traditionally, men tend to be more frequently represented than women when combined in mixed samples. These percentages, therefore, do not deviate from that norm.

3.1.2 Age



Ages in this sample ranged from 18 to 101 years. According to the Office for National Statistics (2016), the average age for females in the United Kingdom is currently 40 years. For males, that average is 38 years. At an average of 62 years for females and 64 years for males, this sample was approximately 25 years older than the national average for both sexes (*Figure 82*).

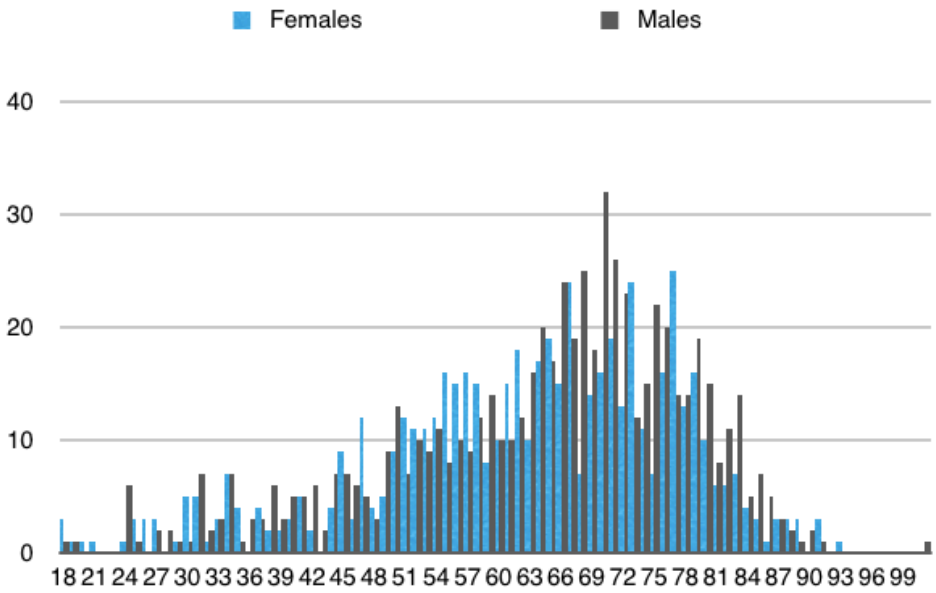


Figure 82: Sample demographics – age distribution by sex

3.1.3 Height

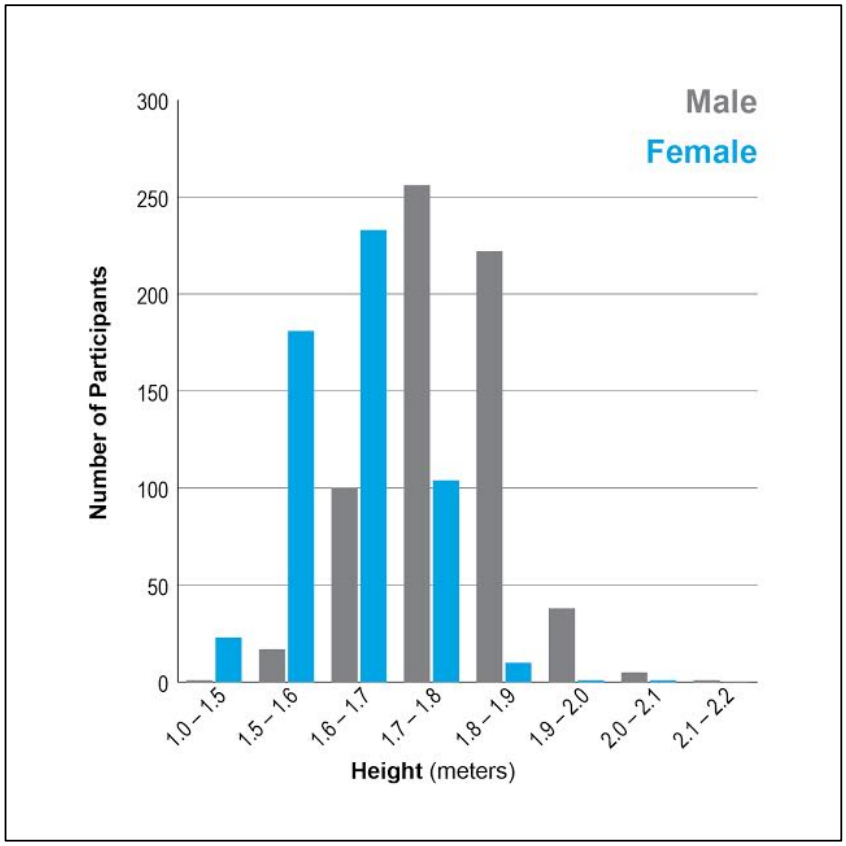


Figure 83: Sample demographics – height

The most commonly reported height for females in this sample was between 1.6 and 1.7 metres, or between 5'2" and 5'6" (the British national average for females is 1.62 meters, or 5'3"), and between 1.7 and 1.8 metres, or between 5'6" – 5'9" for males (the British national average for males is 1.75 meters, or 5'7")(*Figure 83*). Height information was not available for the wider Oxford population; however, based on these responses, this sample was in agreement with the greater British population (Moody 2012, *Health Survey for England*).

3.1.4 Ethnicity

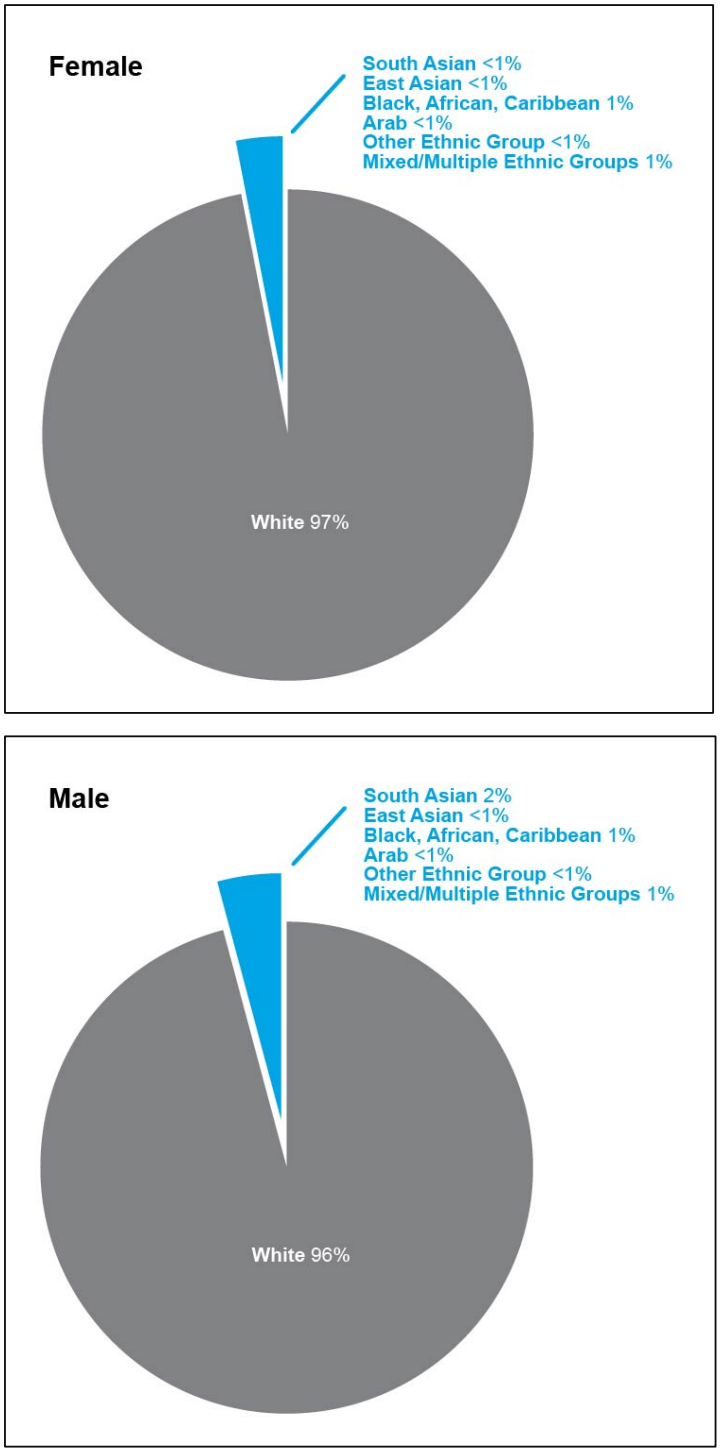


Figure 84: Sample demographics – ethnicity by sex

At 97% (females) and 96% (males), the majority of this sample identified as "white," followed by "South Asian" and "Black, African or Caribbean" (*Figure 84*). According to the most recent UK census, this number was 10 points higher than the national average of 87% (Office of National Statistics 2011) and 18 points higher than the greater Oxford average of 78% (Oxford City Council 2016).

3.1.5 Place of Birth

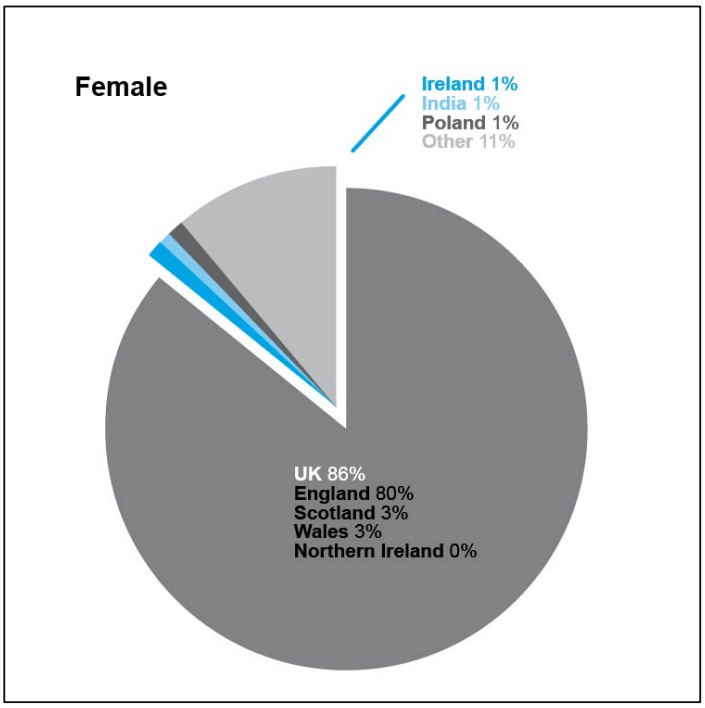


Figure 85: Sample demographics – place of birth, females

At 86%, the majority of females in this sample reported being born in the United Kingdom, equating to the 86.2% of British born respondents according to the latest census (Office for National Statistics 2011). Of those females, 469 (80%) reported being born in England, 17 (3%) in Scotland, 17 (3%) in Wales, 0 (0%)

in Northern Ireland, followed by 7 (1%) in Ireland, 8 (1%) in India, 4 (1%) in Poland, and fewer than 1% each in South Africa, Cyprus, Dominica, Egypt, Germany, Greece, Japan, Iran, Italy, Malaysia, Pakistan, Palestine, Portugal, Trinidad, West Indies, Australia, St. Helen's Island.

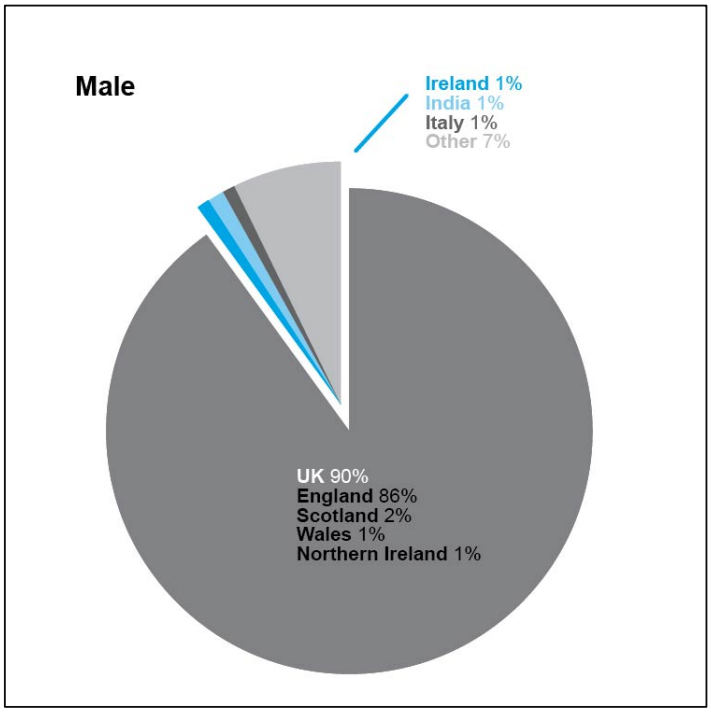


Figure 86: Sample demographics – place of birth, males

At 90%, the majority of males in this sample reported being born in the United Kingdom, approximately 4 points higher than both the females in this sample as well as the national average of 86.2% (Office for National Statistics 2011). 559 (86%) of males reported being born in England, 11 (2%) in Scotland, 9 (1%) in Wales, 7 (1%) in Northern Ireland, followed by 8 (1%) in Ireland, 7 (1%) in India, 4 (1%) in Italy, and fewer than 1% each in Canada, South Africa, China, Cyprus, Dominica, Egypt, Germany, Greece, Iran, Malaysia, Pakistan, Palestine,

Poland, Portugal, Spain, Trinidad, West Indies, Nepal, Libya, USA, Senegal, Iraq, Algeria, Zambia, Jamaica, Hong Kong, South Rhodesia, Zimbabwe, Peru, Philippines, France, Bulgaria, Australia, Belgium, Nigeria, The Netherlands.

3.1.6 Length of Residency in the UK

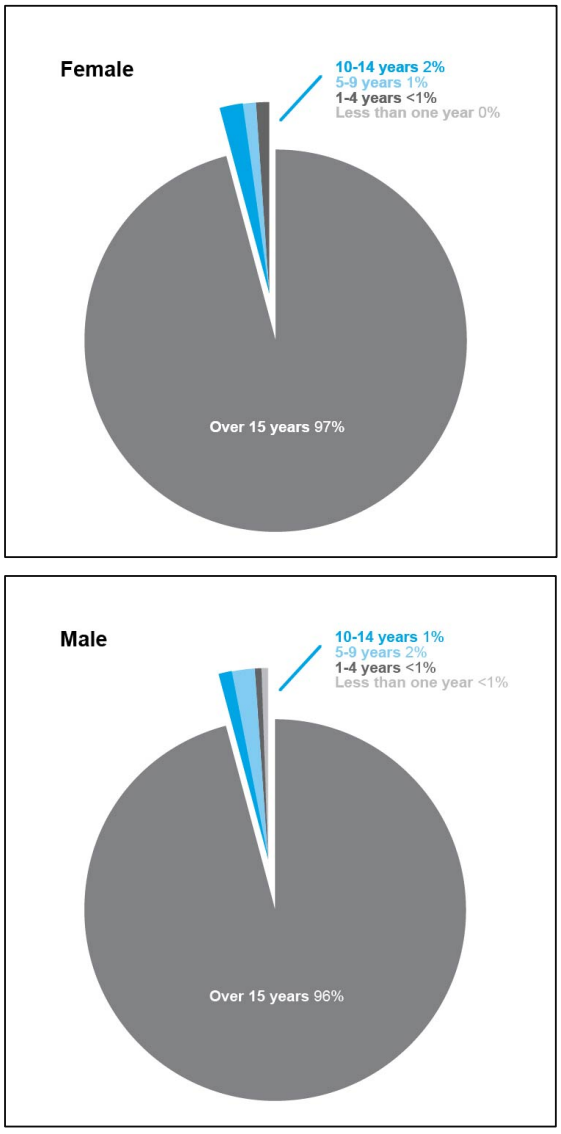


Figure 87: Sample demographics – length of residency by sex

At 97% (females) and 96% (males), the majority of this sample reported living in the United Kingdom for 15 years or more prior to this study (*Figure 87*).

3.1.7 Weight

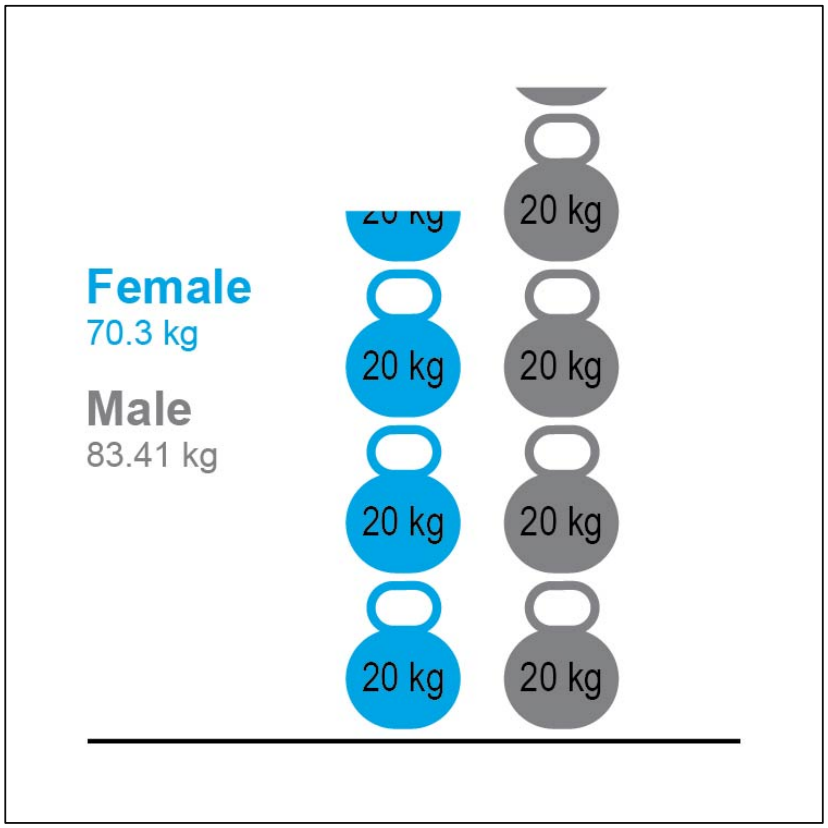


Figure 88: Sample demographic - weight

The most commonly reported weight for females in this sample was 70.3 kilograms, or 11 stone, or 155 pounds (the British national average for females is 70.2 kilograms, or 11 stone, or 155 pounds), and 83.41 kilograms, or 13 stone, or 184 pounds for males (the British national average for males is 83 kilograms, or 13 stone, or 184 pounds)(*Figure 88*). Weight information was not available for the wider Oxford population; however, based on these responses, this

sample was in agreement with the greater British population (Moody 2012, *Health Survey for England*).

3.1.8 Body Shape

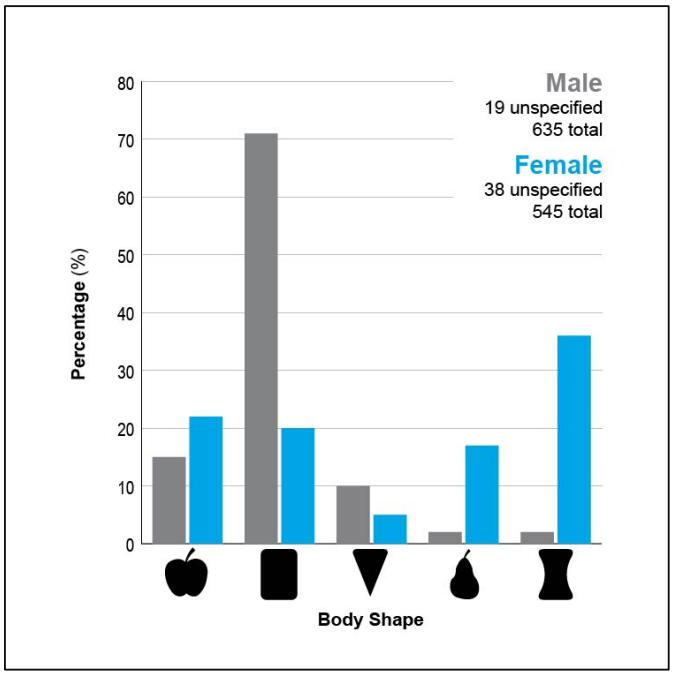


Figure 89: Sample demographics – body shape

At 36% (195 individuals), the most commonly reported body shape for females in this sample was "hourglass" - indicating a waist that was narrower than both the hips and chest (due to higher adipose concentrations in those areas), followed by "apple" (wherein weight was concentrated around the waist). At 71% (451 individuals), the most commonly reported body shape for males was "rectangle" – indicating an evenly diffused adipose distribution (not concentrated in any specific areas), followed by "triangle" (wherein the shoulders were broader than the hips)(*Figure 89*).

3.1.8 Fluctuation

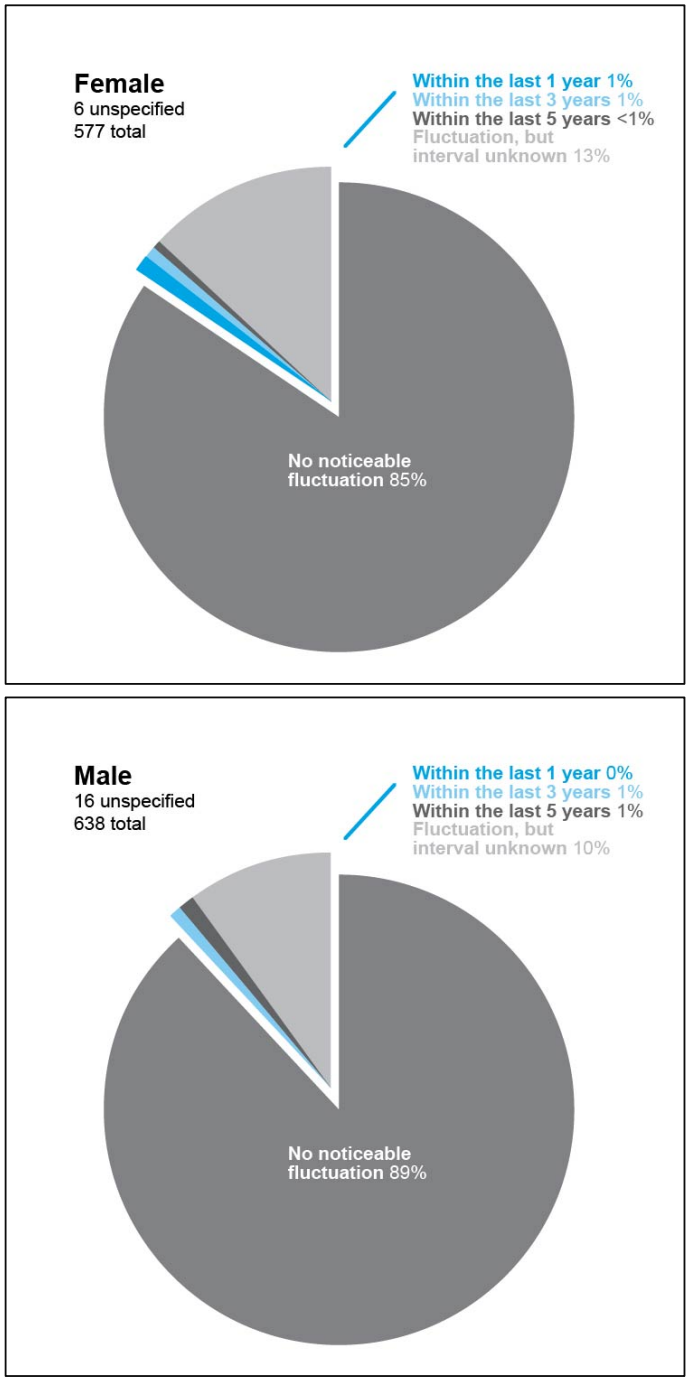


Figure 90: Sample demographics – weight fluctuation

The weights reported by the majority of this sample did not undergo fluctuation; however, data shows that female weight tended to fluctuate more than that of males (*Figure 90*).

3.2 Lifestyle Information

3.2.1 Activity Level

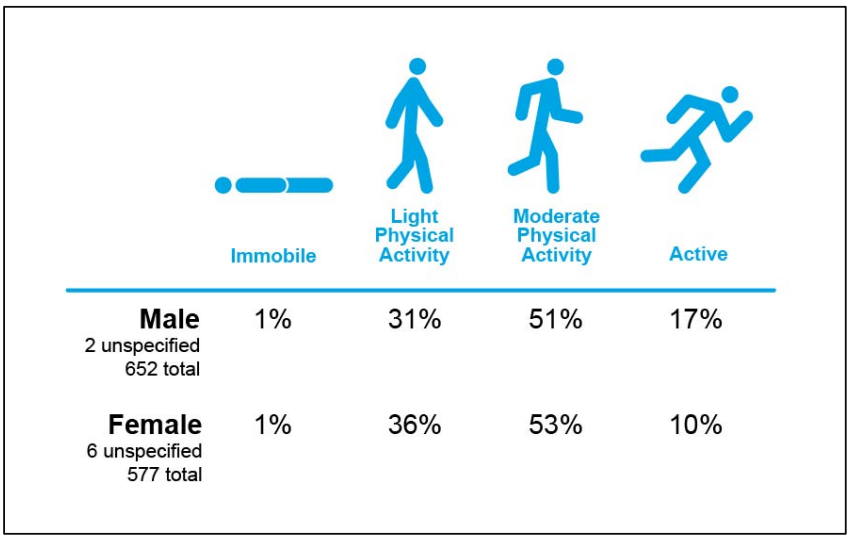


Figure 91: Sample demographics - activity

In this sample, more than half of both males and females self-reported as being "moderately active," which constituted "walking or standing (including commuting) for an hour or more per day, and / or an hour or two of dedicated cardiovascular exercise, dance, or sport per week." This was followed by "lightly active," which was described as "movement in and around the house and garden, light chores and errands." At a combined 68%, males in this sample occupied the higher end of the activity scale ("moderately active" + "active")

while females, at a combined 63% ("moderately active" + "active"), reported slightly less active lifestyles (*Figure 91*). According to the Oxford City Council's "Public Health Profile," from Public Health England (2016), the percentage of physically active adults (as determined by 150 minutes of at least moderate intensity physical activity per week) is 66% for Oxford and 57% for the wider UK. Given these findings, the individuals taking part in this study were entirely representative of greater Oxford, but were more active than the national average.

3.2.2 Activity Type – Twisting

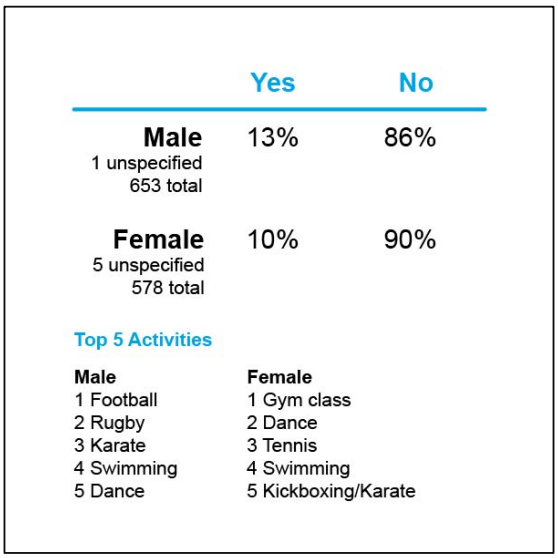


Figure 92: Sample demographics - twisting

The majority of this sample did not report engaging in activities that involved regular kicking or twisting (shearing) such as dancing or football. Of the activities reported, however, football, fitness classes, karate, swimming, and dancing were the most popular answers (*Figure 92*).

3.2.3 Activity Type – Stabilization

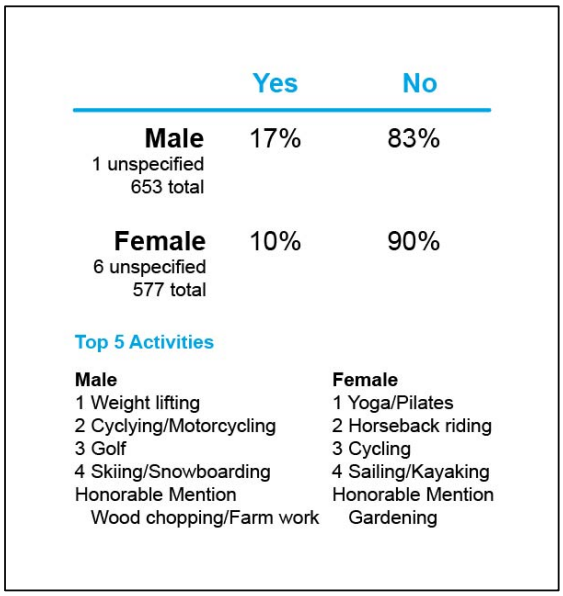


Figure 93: Sample demographics - stabilization

Similarly, the majority of this sample did not report engaging in activities that regularly required the prolonged engagement of their "core muscles" to maintain stability (*Figure 93*).

3.2.4 Pathology

3.2.4.1 Inflammation (Osteitis Pubis)

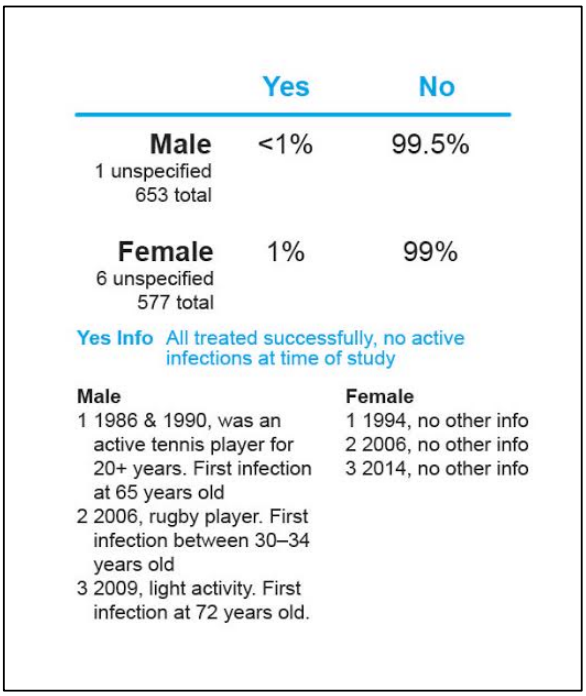


Figure 94: Sample demographics – osteitis pubis

There were no active cases of osteitis pubis in this sample at the time of this study and, of the 1,238 participants, only six reported a known history of this type of inflammation (*Figure 94*). Furthermore, of those, it was unclear as to whether these inflammations were more likely the result of age or activity as inflammation presented in both – i.e. advanced age in the absence of activity as well as activity in the absence of advanced age (and one with both activity and advancing age). Because of this, as well as the small number of applicable cases, it is unlikely that inflammation had any impact on this sample.

3.2.4.2 Infection (UTIs)

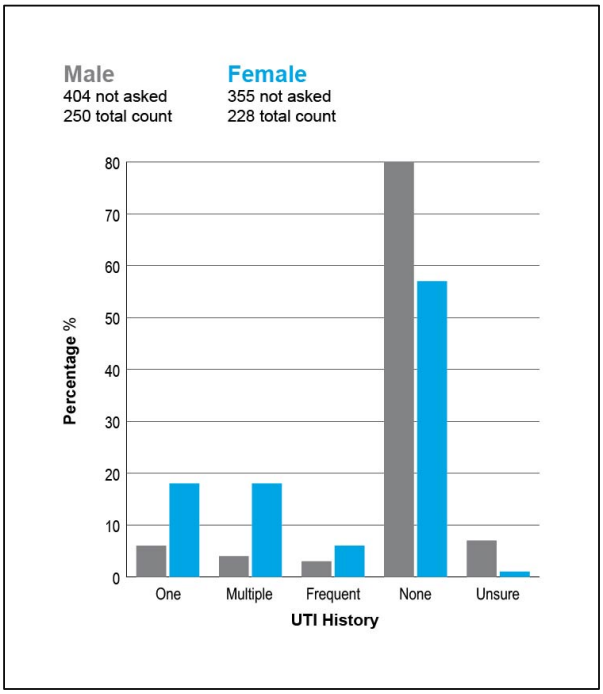


Figure 95: Sample demographics – UTI history

As UTI history was a "follow-up" question it was not formally on the questionnaire. As a result, not all participants were asked. Of those that were, however, the majority reported no known history of urinary tract infections. This was followed by an equal number of respondents reporting either having had one or several (up to three, but infrequently) over the course of their lifetime. Only 7 males and 14 females reported urinary tract infections as being a chronic, or constant, issue (*Figure 95*). That double the amount of females reported frequent UTI's is consistent with the medical literature (American College of Obstetricians and Gynecologists 2008, 2015).

3.2.4.3 Osteopenia / Osteoporosis

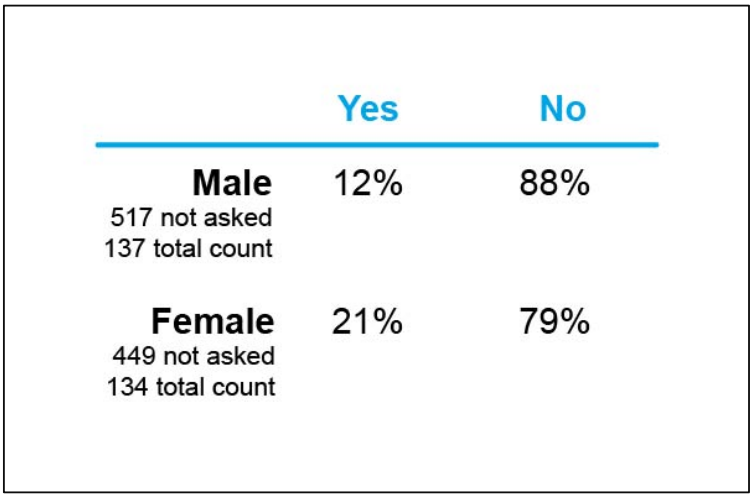


Figure 96: Sample demographics – osteopenia / osteoporosis

Again, as a "follow-up" question, this question was not asked of all participants. However, of those who were asked, the majority of respondents reported no known history of osteopenia or osteoporosis (*Figure 96*). Of those that did report having spoken with their physician about a thinning of their bones, medication for other illnesses was often mentioned as a factor. More females reported a knowledge of osteopenia or osteoporosis than did males (likely due to the prevalence of menopause and, therefore, loss of protective oestrogen, in this older sample), and the most common treatment for osteoporosis in this sample was Alendronic Acid (Fosamax).

3.2.4.4 Arthritis

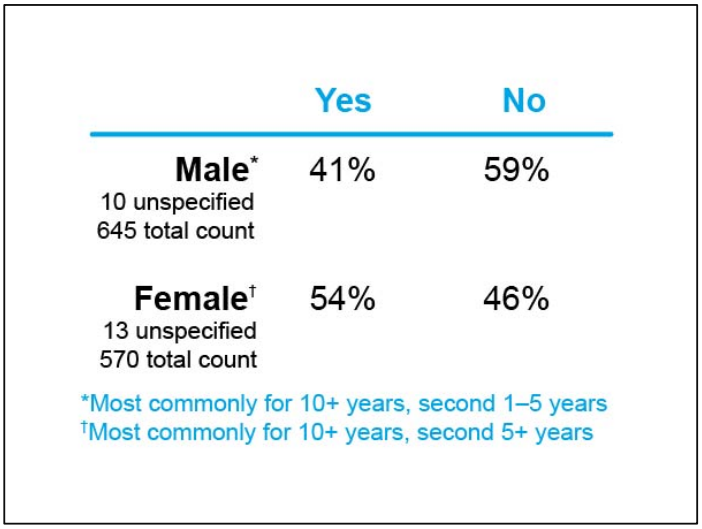


Figure 97: Sample demographics - arthritis

The majority of males in this sample (59%) reported an absence of arthritis while the majority of females (54%) reported a history of joint pain or stiffness. In both sexes, the location of osteoarthritis was highly variable, with no one or two areas occupying the majority (though knees, "hips," and various parts of the hand were popular answers).

3.2.5 Diet

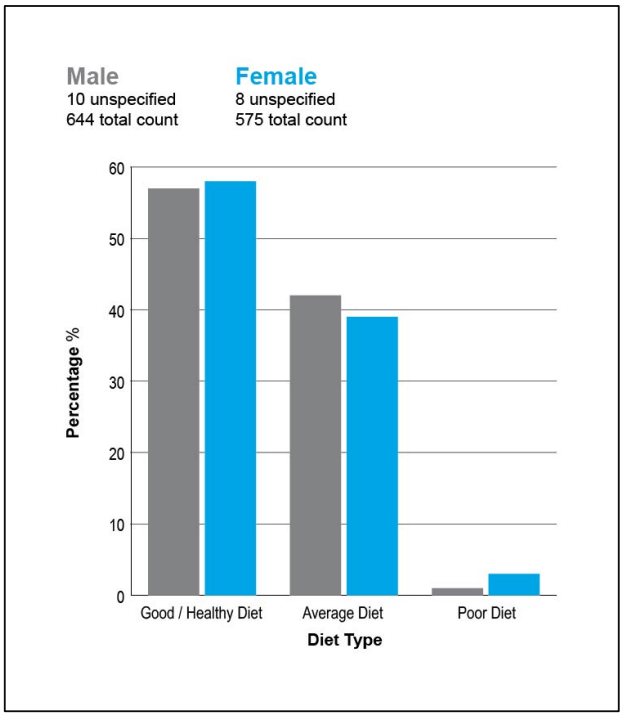


Figure 98: Sample demographics - diet

At 57% (males) and 58% (females), the majority of this sample reported maintaining a "healthy" diet (*Figure 98*). Coming in second, 42% of males and 39% of females reported maintaining an "average" diet. Of those who reported a "poor" diet, loss of appetite (due to medication) presented as the most common cause. According to the Oxford City Council's "Public Health Profile," from Public Health England (2016), excess weight in adults (determined by the number of individuals classified as overweight or obese) ranks at 54% for Oxford and 65% for the wider UK. Based on these findings, this sample may be said to be representative of greater Oxford while being slightly healthier than the national average.

3.2.6 Tobacco Use

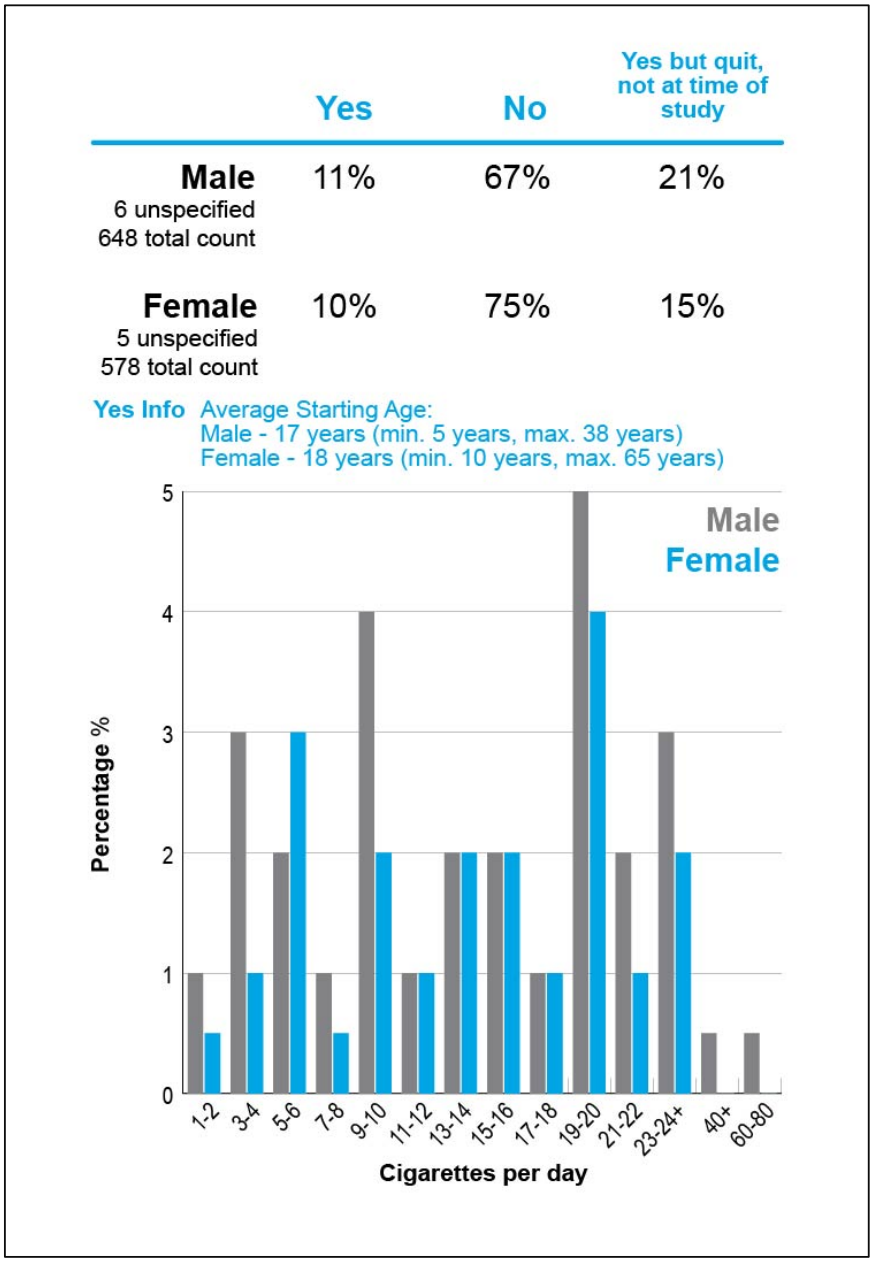


Figure 99: Sample demographics – tobacco use

Regarding the use of tobacco, most of the participants in this study reported either no history of smoking (or chewing) or a history of smoking (or chewing) in the past but not at the time of study (*Figure 99*). Males tended to smoke, or to have smoked and then quit, more than females both in occurrence and cigarettes per day. According to the Oxford City Council's "Public Health Profile," from Public Health England (2016), smoking prevalence in adults is 14% for Oxford and 18% for the wider UK. While "having quit before time of study" makes direct comparison somewhat difficult, the percentage of respondents who identified themselves as active smokers at the time of study was lower for this sample than both the Oxford and wider UK averages - though (informally) taking into account that many of the prior smokers may have quit only days or weeks before, as opposed to years or decades (so as to now be considered non-smokers), this sample is most likely still representative of greater Oxford, but lower than the national average.

Lastly, as it was not on the effects of nicotine, it was beyond the scope of this study to differentiate between tobaccos, i.e. cigarettes (which contain the highest nicotine concentration) versus cigars and pipes (which contain slightly less) versus chewing tobacco versus snuff, etc., which would almost be an entire study unto itself. For the sake of statistics, therefore, all tobacco use was considered as one category and, when mediums other than cigarettes were involved, conversions to cigarette equivalencies were made - 1 pipe roughly equals 2.5 cigarettes, 1 cigar roughly equals 4 cigarettes, etc. (General Practice Notebook 2016).

3.2.7 Alcohol Consumption

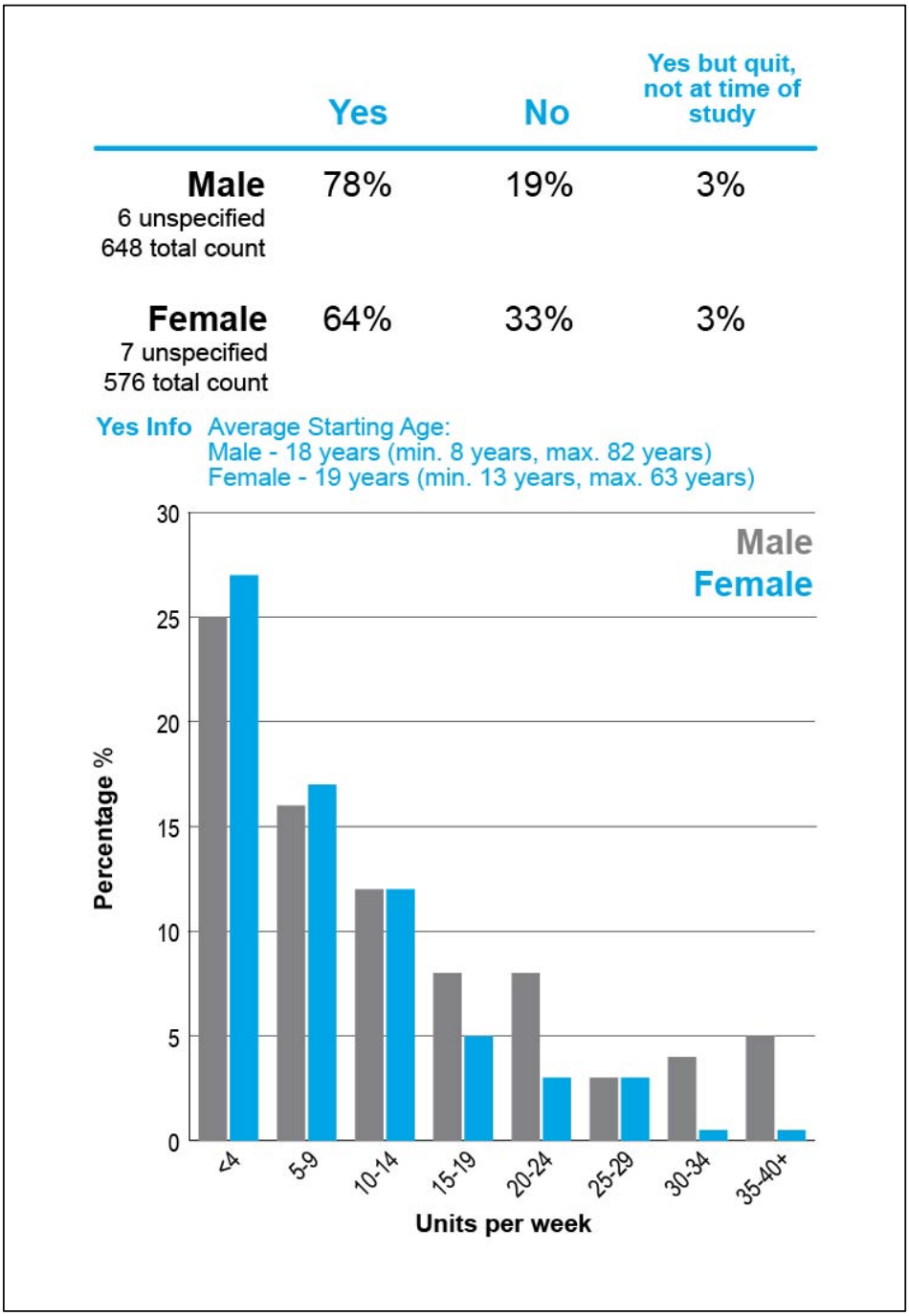


Figure 100: Sample demographics – alcohol consumption

In this sample, most participants reported a current consumption of alcohol or a history of alcohol consumption in the past but not at the time of study (*Figure 100*). Males tended to consume alcohol more than females both in occurrence as well as overall units per week (females more commonly reported consuming fewer than 15 units per week while males more commonly reported consuming more than 15 units per week). While Oxford specific information could not be obtained, according to the UK Department of Health, 81% of British males and 69% of British females (under similar socio-economic conditions) consume alcohol regularly and, for the majority of those drinkers (30% for males, 25% for females), this consumption does not exceed four units (Fuller 2012, *Health Survey for England*). At 78% (males) and 64% (females), this sample presented as slightly under the national average both for overall consumption as well as consumption by units per week.

Just as with tobacco use, it was beyond the scope of this study to differentiate between types of alcohol consumed (i.e. beer versus cider versus wine versus spirits, etc.). Therefore, all alcohol consumption was considered as one category and reported as equally comparable units.

3.3 Mixed Sample (Male and Female) Summary

		Sample	Oxford	UK
Sex	Male	53%	—	49.2%
	Female	47%	—	50.7%
Age	Male	64	—	38
	Female	62	—	40
Height	Male	170-180 cm	—	175 cm
	Female	160-170 cm	—	162 cm
Weight	Male	83.41 kg	—	83.0 kg
	Female	70.3 kg	—	70.2 kg
Ethnicity	White	96%	78%	86%
	Asian - Total	2%	19%	8%
	Asian - South	2%	7%	—
	Asian - East	<1%	12%	—
	Black, African or Caribbean	1%	5%	3.3%
	Arab	<1%	1%	0.4%
	Other	<1%	1%	7.5%
	Mixed / Multiple	1%	4%	2.2%
Country of Origin	Born in UK	88%	72%	87%
	Top 5 non-UK	Poland India Ireland Italy No concensus	Poland India USA Pakistan Germany	Poland India Ireland Pakistan Germany
Activity	Reported Moderate or Active	65.5%	65.9%	57%
Diet	Reported Good or Healthy	58%	—	—
	Obesity Rate	—	13%	57%
Smoking		11%	14%	18%
Alcohol	Male	78%	—	81%
	Female	64%	—	69%
Alcohol per Week	Male	25%	—	30%
	Female	27%	—	25%

Figure 101: Summary statistics – mixed (male and female) sample

3.4 Pregnancy History Information

3.4.1 Number of Pregnancies

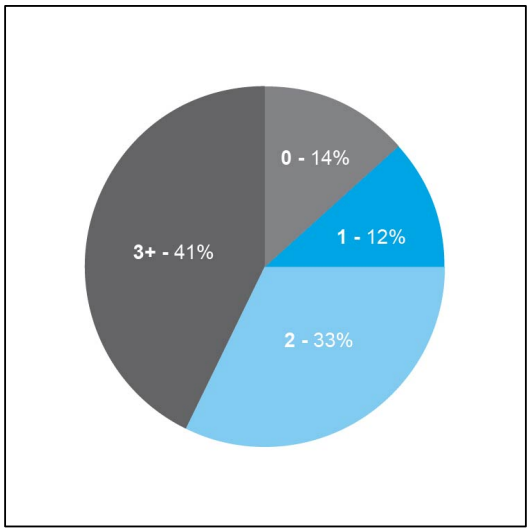


Figure 102: Sample demographics – number of pregnancies

3.4.2 Number of Births

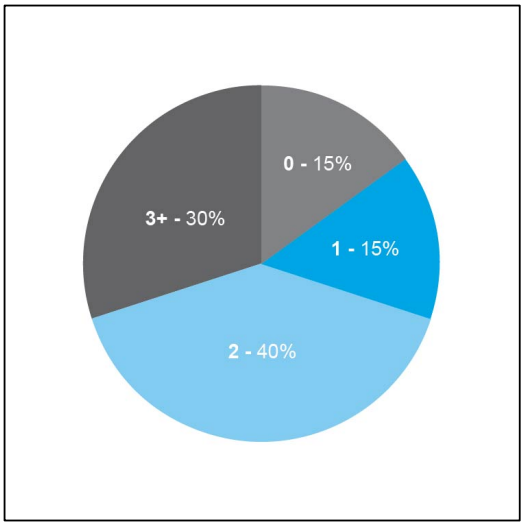


Figure 103: Sample demographics – number of births

For the 585 women represented by this sample, the most commonly reported number of pregnancies per participant was three or more, while the most commonly reported number of births was two (*Figure 102 and 103, above*). This discrepancy would suggest that factors such as miscarriage - an estimated 15-20% (or approximately one in five) of known pregnancies are miscarried (March of Dimes 2016), including at least 12% of first pregnancies (Collier et al. 2006), and terminations - 16% of pregnancies (per 1,000 residents) are terminated (UK Office of National Statistics 2015) – were present and impactful on this sample.

According to the Office for National Statistics (2015), the average number of births per British woman in 2014 was 1.83 (rounded up to 2). This is line with this sample's two births per participant. However, as the majority of these participants were in their 60's and 70's, which would place their childbearing years between 1965 and 1975, fertility rates for those years were consulted as well. Per the Office for National Statistics' 2011 Cohort Fertility Bulletin, which provided data as far back as 1920, the average number of children per woman in 1965 was 1.91 and 1.81 in 1975 (which, rounded up, agree with this sample). This led Whiting

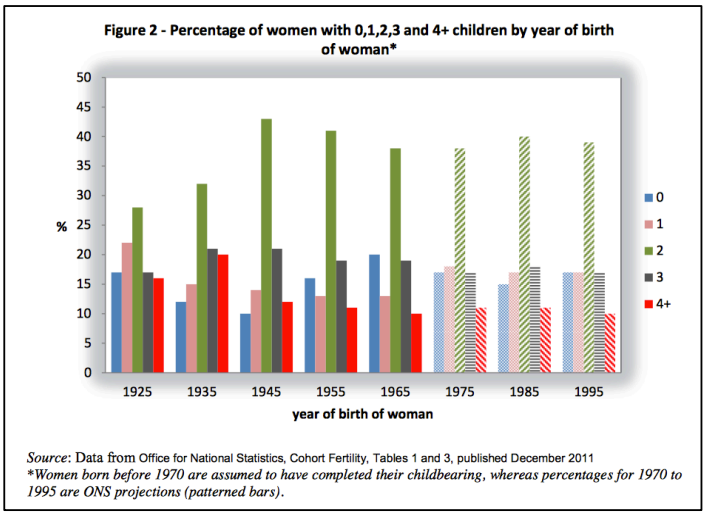


Figure 104: Historical record of birth number per woman (1925-1995)

(2010:1), who synthesized that ONS data, to conclude that "over the last 70 years, the two child family has consistently been the most common family size" (*Figure 104, above*).

3.4.3 Individual Birth Information

The following figure (Figure 105, below) presents participant responses to maternal age at birth, symphysis pubis dysfunction (or "SPD"), epidural, caesarean, multiple births, birth weight, and length of labour.

		1st Birth	2nd Birth	3rd Birth
Age at		26	28	30
SPD	Yes	6%	4%	4%
	No	94%	96%	96%
Epidural	Yes	22%	12%	13%
	No	78%	88%	87%
Caesarean	Yes	11%	11%	12%
	No	89%	89%	88%
Multiple Births	Yes	1%	1%	1%
	No	99%	99%	99%
Birth Weight	< 1 kg	1%	1%	0%
	1-2 kg	4%	2%	2%
	2-3 kg	22%	14%	7%
	3-4 kg	62%	52%	21%
	4-5 kg	10%	14%	7%
	5-6 kg	< 1%	1%	< 1%
Length of Labour	< 5 hr	25%	37%	17%
	6-10 hr	26%	27%	11%
	11-15 hr	19%	9%	3%
	16-20 hr	9%	4%	2%
	21-24 hr	11%	3%	1%
	25+ hr	11%	3%	2%

Figure 105: Summary statistics – parity information by birth order

3.4.3.1 Age at Birth(s)

In this sample, the average maternal age at first birth was 26 years (youngest first birth: 16, oldest first birth: 51), 28 years at second birth (youngest second birth: 18, oldest first birth: 44), and 30 years at third birth (youngest third birth: 20, oldest first birth: 50)(*Figure 105*). As of 2014, the average maternal age in the UK was 28.5 years at first birth (30.2 years overall); however, as stated previously, the majority of the participants involved in this study would have experienced maximum fertility between roughly 1965 and 1975, when average maternal age was 25 and 26 years, respectively (Office for National Statistics 2010, 2011, 2014). This suggests that, though a clear trend towards increasing maternal age has been in effect since the mid-1970's (Whiting 2010; Office for National Statistics 2011), as this sample was predominately older this trend would have begun after the likely interval of the majority of reported pregnancies. While present age at first birth initially makes the responses from this sample appear abnormally low, the average maternal age between 40 and 50 years ago was several years younger (mid-20's). Accounting for this, this sample was, indeed, still representative of the wider UK population regarding age at birth(s). However, while birth-timing intervals for those years could not be found, from 2001 to 2012 the median "between birth" interval was 36 months from first birth to second and 40 months from second birth to third (Office for National Statistics 2014). This represents a difference of approximately three years while in this sample the interval between births was two years.

3.4.3.2 Symphysis Pubis Dysfunction (SPD)

6% (28) of the female participants in this sample reported having experienced Symphysis Pubis Dysfunction, or "SPD," during or after their first birth, while 4% (18) reported experiencing SPD during or after their second birth (*Figure 105*). A further 4% of third time mothers reported experiencing SPD. The remaining 94% to 96% of the sample reported no experience with SPD.

3.4.3.3 Epidural

At 78% (first birth), 87% (second birth), and 87% (third birth), the majority of this sample did not receive epidural during their labours (*Figure 105*). As the prevalence of epidural analgesia is approximately 25% for first time UK mothers (McGrady and Litchfield 2004), the 22% reported by this sample is non-anomalous, if slightly low (likely due to the fact that this is an older sample and epidural analgesia was not in common use until the 1970's).

3.4.3.4 Caesarean Section

At 89% (first birth), 89% (second birth), and 88% (third birth), the majority of this sample delivered their babies vaginally as opposed to caesarean section (*Figure 105*). As Richardson and Mmata (2007:7) state, "Caesarean delivery rates have risen from a level of under 3% in the 1950s, to 9% by 1980, and to 12% by 1990-91. During the 1990s the rate increased more rapidly, reaching

22% by 2001-02. The caesarean rate has since risen more slowly, to about 23% in 2003-04, 2004-05 and 2005-06 (*Figure 106, below*).

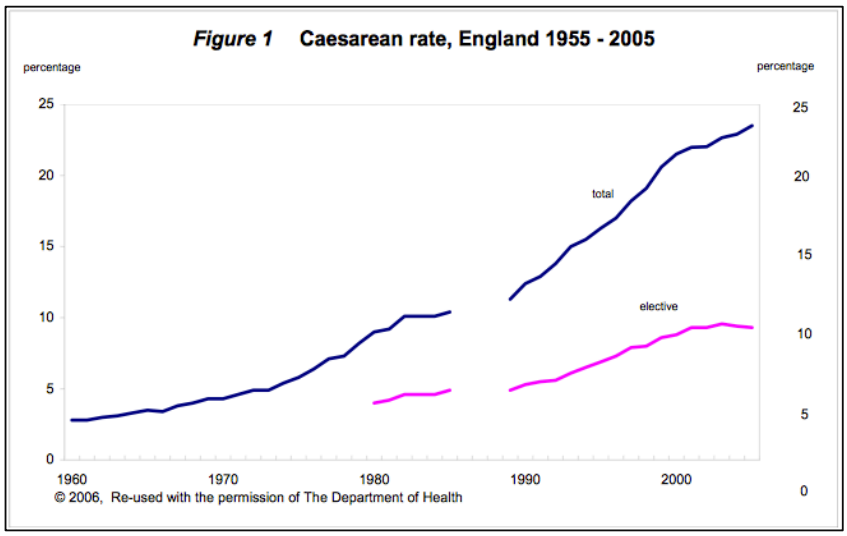


Figure 106: Caesarean rate, England 1955 – 2005 (Department of Health 2006)

As of 2014 (the most recent statistics), the rate of caesareans performed in the United Kingdom was 26.2% - 13.2% of which were elective and 13% of which were emergency (Health and Social Care Information Centre, 2015). As this sample encompassed the births of more recent mothers (for which the higher rates apply) as well as those of much older mothers (for which the lower rates apply), its combined 11% caesarean rate was as would be expected, especially as the latter category represented the majority and would, therefore, be disproportionately impactful on the overall average.

3.4.3.5 Multiple Births

99% of the births in this sample were sole, or "singleton," births (*Figure 105*). During this study, ten individuals reported multiple births – five during their first delivery episode (four incidents of twins, one incident of triplets), three during their second delivery episode (three incidents of twins, zero incidents of triplets), and two during their third delivery episode (two incidents of twins, one incident of triplets). According to the National Health Service, approximately 1.5% (or one in 65 births in the UK) now involves twins or triplets (2016). In 1970, when the majority of the participants in this study would have been at peak fertility, this rate was 1% (or 10 out of every 1000 births)(Pison et al. 2015). At 1%, therefore, this sample was non-anomalous and may be considered representative of the wider British population regarding the incidence of multiple births.

3.4.3.6 Birth Weight

The most common birth weight as reported by the respondents in this study was three to four kilograms (62%), followed by two to three kilograms (22%)(*Figure 105*). The most common birth weight for babies born in the United Kingdom is between 2.7 and 4.1 kilograms, with an average of 3.5 kilograms (Richardson and Mmata 2007; Office of National Statistics 2015; Hicks 2016). This sample was, therefore, non-anomalous and may be considered representative of the wider British population regarding birth weight.

3.4.3.7 Length of Labour

In this sample, length of labour was most commonly less than 10 hours. Additionally, within those 10 hours, first births were accompanied by longer labour times while second and third births became progressively shorter in duration (*Figure 105*). While Oxford specific information could not be obtained, as "normal" labour takes place within 24 hours of the onset of contractions (Collier et al. 2006), with active labour taking approximately eight hours for first time mothers and five hours or fewer for subsequent births (Mehigan 2014), the reported durations of labour for this sample were in line with the national average and, therefore, may be considered representative of the wider UK population.

120 women in this sample reported instrumental assistance (most commonly forceps or ventouse – 13%) due to complications such as breach, posterior position, cord issues, etc. The rate of induction in this sample was 25%. The rate of stillbirth was 4.5%. As of 2014 (the most recent statistics available), the prevalence of instrument-assisted delivery in the United Kingdom was 12.9%, the rate of induction was 25%, and the rate of stillbirth was 4.7% (Health and Social Care Information Centre, 2015; Office for National Statistics 2015).

Hospital births were most common (in keeping with the wider UK), but home births, births at midwife centers, and water births were also reported, as was one birth that took place in a car.

3.4.4 Breastfeeding

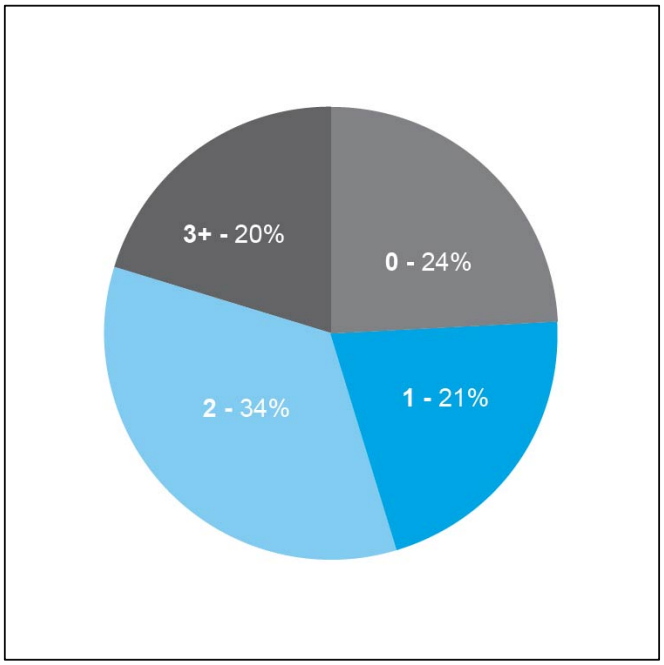


Figure 107: Sample demographics – Breastfeeding (by number of children nursed)

Where breastfeeding was concerned, the majority of this sample most commonly reported "nursing" two births for a duration of six months (the most common response for all births, regardless of number - though this was a recollected estimate for most participants)(*Figure 107*). Breastfeeding for at least six months remains a widely recommended infant care guideline (American Academy of Paediatrics 2016; World Health Organisation 2016; Centres for Disease Control and Prevention 2016).

3.4.5 Hormone Replacement Therapy

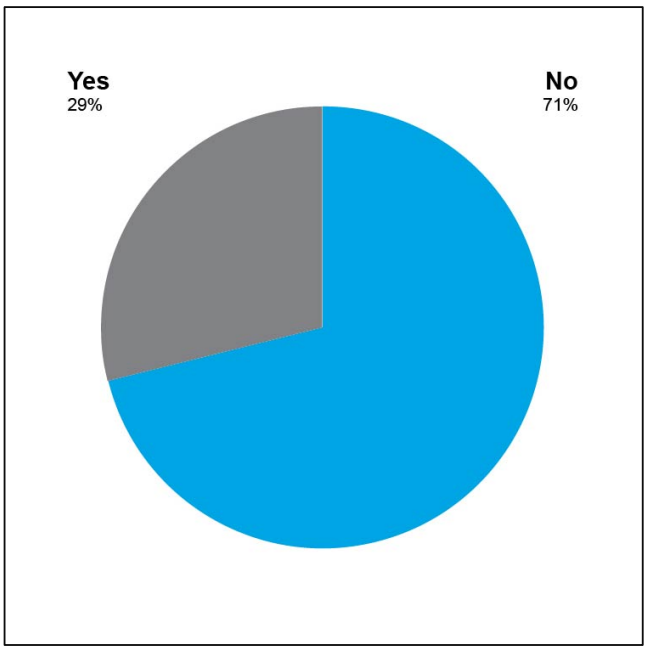


Figure 108: Sample demographics – Hormone Replacement Therapy

Despite the older age of the sample, only approximately three in 10 female participants reported undergoing, or having previously undergone, hormone replacement therapy ("HRT")(*Figure 108)*. Of those that did, however, the most commonly reported duration was five years or fewer. Additionally, several cancer drugs have also been shown to affect hormone levels in women (by blocking them). The most common hormone therapy medications reported by participants in this study included Tamoxifen, Danazol, Letrozole, and Anastrozole.

3.4.6 Contraception

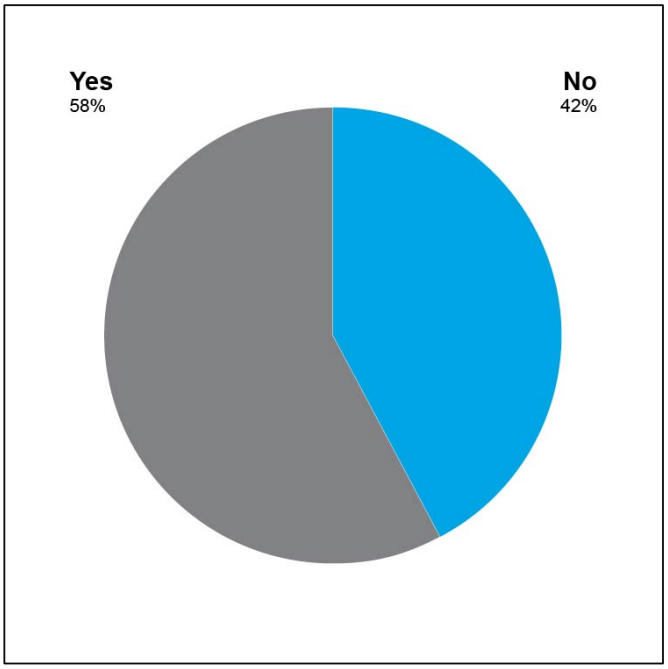


Figure 109: Sample demographics - contraception

By contrast, most female participants in this study (58%) reported currently taking, or having taken, birth control at some point in their lives (*Figure 109*). That more participants reported using birth control than not is in accordance with wider reports for the United Kingdom as "contraception has been free on the NHS since 1974 … [it is believed that] 74% of women of reproductive age use some form of contraception" (Rowlands 2007). The most commonly reported form of contraception was unquestionably "the Pill," though a wide variety of forms were also mentioned (including intra-uterine devices such as ParaGard and Mirena, patches such OrthoEvra, implants such as Implanon and Nexplanon, inserts such as NuvaRing, and injections such as Depo-Provera).

3.4.7 Menopause

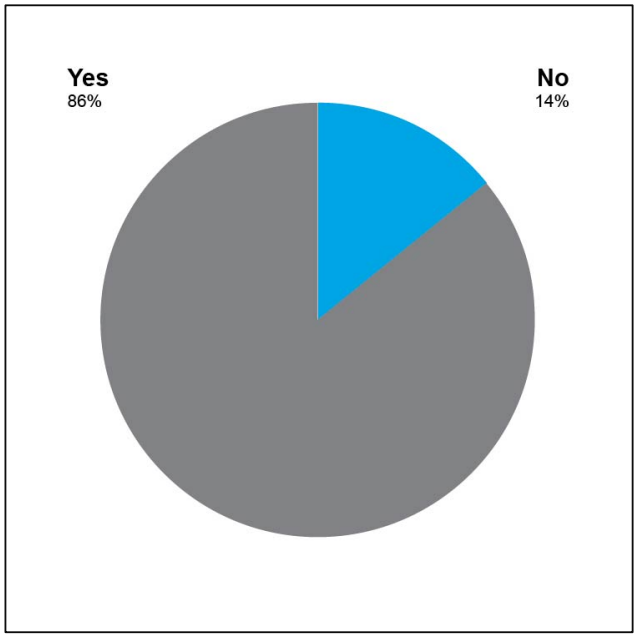


Figure 110: Sample demographics - menopause

As this sample was predominately older, it was no surprise that 86% of the female participants reported having gone through menopause (*Figure 110*). Of these, 63% were 50 years or older while 39% were 49 years or under. The youngest age at menopause was 28 years (hysterectomy, ablation, and sterilisation were chief causes amongst the young) while the oldest was 65 years. The average age of menopause for this sample was 48 while the most commonly reported age at menopause was 50 years. For those aged 49 and under, the majority were between 40 and 49 (15 at age 40; four at age 41; eight at age 42; nine at age 43; seven at age 44; 27 at age 45; 18 at age 46; 16 at age 47; 37 at age 48; 24 at age 49). 12 women reported entering menopause before the age of 40 (*Figure 111, below*).

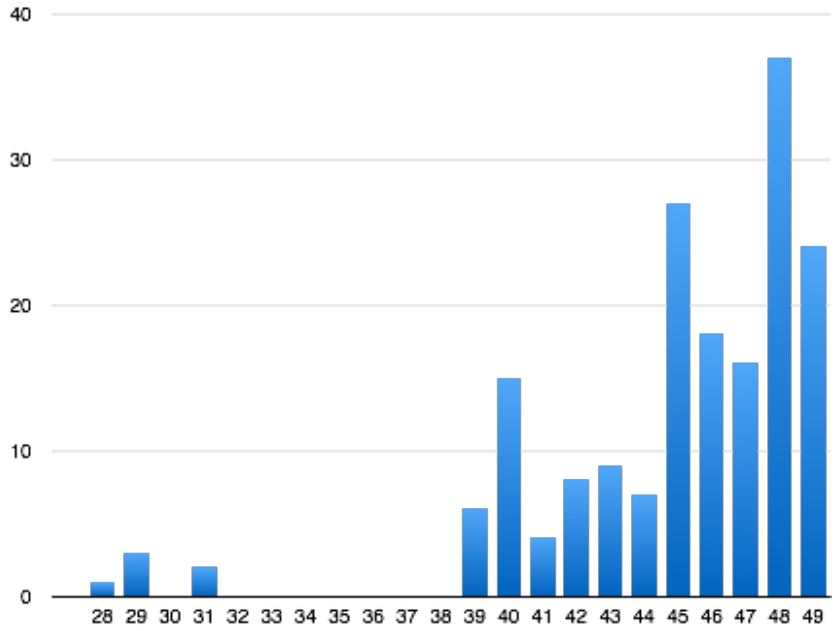


Figure 111: Ages of early menopause as reported by this sample

"Menopause is a natural part of ageing that usually occurs between 45 and 55 years of age, as a woman's oestrogen levels decline. In the UK, the average age for a woman to reach the menopause is 51 [years]. However, around 1 in 100 women experience the menopause before 40 years of age" (National Health Service 2015). Based on these national statistics, as regards to menopause this sample was entirely representative of the wider UK population (with the exception of menopause below the age of 40 years, which was increased in this sample due to higher incidences of medical intervention).

3.5 Ordering department

As this sample was comprised exclusively of hospital patients, the ordering departments (or the specialty that ordered the scan) were also noted. Ordering department could not be obtained for 182 individuals, or 15% of the sample. Of the remaining patients (n=1,056), however, the departments were as follows:

Oncology – 37% (390 individuals)
URO – 25% (266 individuals)
GI – 11% (113 individuals)
GP – 7% (74 individuals)
Chest – 7% (73 individuals)
Haem – 4% (44 individuals)
OPD – 3% (36 individuals)
Wythm – 1% (18 individuals)
NOC Op – 1% (14 individuals)

Less than 1% (each) were ordered by:

OTH
DIABOP
BLHAN
PLOP
RTHERAPY
DAYSURG
DERMOP
POAC
TRANSOP
MII
BAGOT

3.6 Appropriateness for Study

As evidenced over the course of this chapter, the sample employed by this study was older and slightly less ethnically diverse than both the greater Oxford area and the wider United Kingdom (indicating that, while the university is young and multi-cultural, the city and county remain less so). This sample was also

more active and reported healthier lifestyles than the national average (but not the wider Oxford population). This was likely a reflection of the higher overall socio-economic status enjoyed by the city of Oxford in comparison to other parts of the country.[19] Additionally, at 12 individuals, menopause before the age of 40 years was disproportionately high (due to medical intervention, chiefly hysterectomy, in this hospital sample).

In all other lifestyle respects, the sample utilised for this study may be said to be non-anomalous to the greater Oxford community. That being said, the sample remains that of a hospital population and is, therefore, self-selecting to the presence of known disease.[20] As this project sought to improve age estimation in older individuals where this is more common than in the young, however, this contemporary sample of predominately older individuals was still representative and appropriate for use in this study.

[19] *Socio-economic status, or SES, in the form of income or education level, was not included as part of this study due to ethics committee concerns over sensitivity.*

[20] *The presence of "known" disease is stipulated as individuals often live with disease without seeking medical attention, either because they do not know they are ill or because they dislike or fear the clinical experience. Lack of hospitalisation, therefore, should not be assumed to be a verification of health.*

4

Suchey - Brooks Analysis

4.0 **A Review of The Suchey-Brooks Method** 250
4.1 **Applying the Suchey-Brooks Method to this Sample** 254
4.2 **Results of the Suchey-Brooks Analysis on this Sample**..... 259

Abstract:

This chapter will revisit the Suchey – Brooks Method for Ageing the Os Pubis (1990) and will present the results of its application to this sample.

4.0 A Review of The Suchey-Brooks Method

As discussed in previous chapters (chiefly chapter one, section 1.3.3.2), the Suchey - Brooks Method for Aging the Os Pubis resulted from a series of step-wise linear regressions targeting the individual merit of Todd's (1920) original ten phases. From these regressions it was concluded that not all ten categories were needed and new, truncated phases were subsequently developed (Suchey and Katz 1986). Just as with Todd's technique, therefore, to apply the Suchey-Brooks method the appearance and texture of a symphyseal face must be matched to a corresponding "phase" based upon descriptions and illustrations as provided by the authors (*Figures 128 - 130, below*).

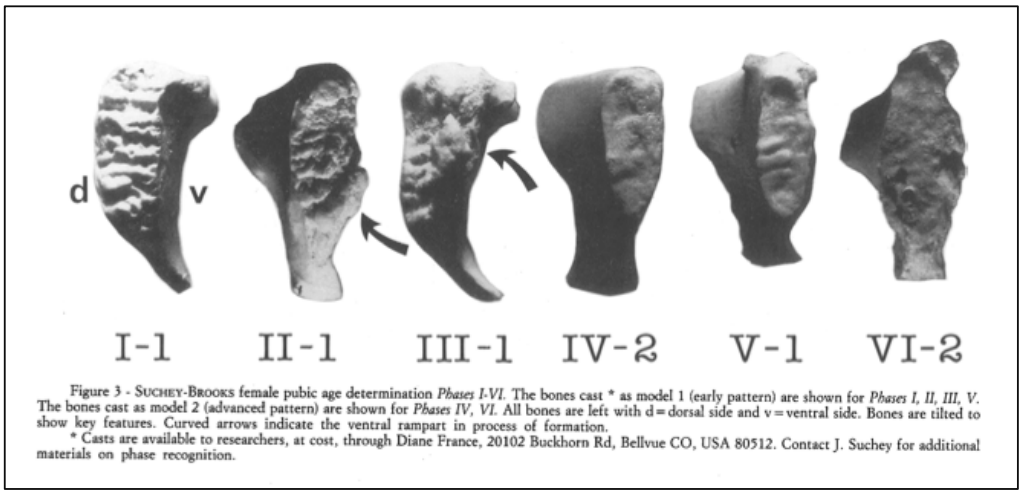


Figure 3 - SUCHEY-BROOKS female pubic age determination *Phases I-VI.* The bones cast * as model 1 (early pattern) are shown for *Phases I, II, III, V.* The bones cast as model 2 (advanced pattern) are shown for *Phases IV, VI.* All bones are left with d = dorsal side and v = ventral side. Bones are tilted to show key features. Curved arrows indicate the ventral rampart in process of formation.

* Casts are available to researchers, at cost, through Diane France, 20102 Buckhorn Rd, Bellvue CO, USA 80512. Contact J. Suchey for additional materials on phase recognition.

Figure 128: Suchey – Brooks phase determination exemplars (from Suchey and Katz 1985)



Figure 129: Illustrations of Suchey – Brooks phases I – VI, male and female (from White and Folkens 2005)

Phase I

Symphyseal face has a billowing surface (ridges and furrows) which usually extends to include the pubic tubercle. The horizontal ridges are well-marked and ventral beveling may be commencing. Although ossific nodules may occur on the upper extremity, *a key to the recognition of this phase is the lack of delimitation of either extremity (upper or lower).*

Phase II

The symphyseal face may still show ridge development. *The face has commencing delimitation of lower and/or upper extremities occurring with or without ossific nodules.* The ventral rampart may be in beginning phases as an extension of the bony activity at either or both extremities.

Phase III

Symphyseal face shows lower extremity and *ventral rampart in process of completion.* There can be a continuation of fusing ossific nodules forming the upper extremity and along the ventral border. Symphyseal face is smooth or can continue to show distinct ridges. Dorsal plateau is complete. Absence of lipping of symphyseal dorsal margin; no bony ligamentous outgrowths.

Phase IV

Symphyseal face is generally fine grained although remnants of the old ridge and furrow system may still remain. *Usually the oval outline is complete at this stage, but a hiatus can occur in upper ventral rim.* Pubic tubercle is fully separated from the symphyseal face by definition of upper extremity. The symphyseal face may have a distinct rim. Ventrally, bony ligamentous outgrowths may occur on inferior portion of pubic bone adjacent to symphyseal face. If any lipping occurs it will be slight and located on the dorsal border.

Phase V

Symphyseal face is completely rimmed with some slight depression of the face itself, relative to the rim. Moderate lipping is usually found on the dorsal border with more prominent ligamentous outgrowths on the ventral border. There is little or no rim erosion. Breakdown may occur on superior ventral border.

Phase VI

Symphyseal face may show ongoing depression as rim erodes. Ventral ligamentous attachments are marked. In many individuals the pubic tubercle appears as a separate bony knob. The face may be pitted or porous, giving an appearance of disfigurement with the ongoing process of erratic ossification. Crenulations may occur. The shape of the face is often irregular at this stage.

Figure 130: Written descriptions of Suchey – Brooks (1990) phases I - VI

Once a phase has been selected from the six available options, the corresponding age range for that phase then becomes the estimated age for that individual (*Table 6, below)*.

Table 6: Suchey – Brooks (1990) age ranges as determined by phase (from White and Folkens 2005)

	Female *(n = 273)*			Male *(n = 739)*		
Phase	**Mean**	**Standard Dev.**	**95% Range**	**Mean**	**Standard Dev.**	**95% Range**
1	19.4	2.6	15-24	18.5	2.1	15-23
2	25.0	4.9	19-40	23.4	3.6	19-34
3	30.7	8.1	21-53	28.7	6.5	21-46
4	38.2	10.9	26-70	35.2	9.4	23-57
5	48.1	14.6	25-83	46.6	10.4	27-66
6	60.0	12.4	42-87	61.2	12.2	34-86

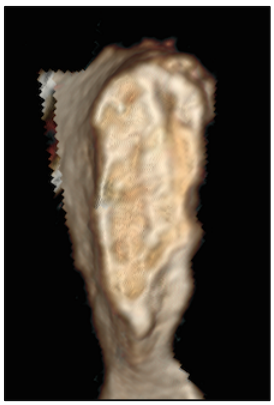


Figure 131: Volume (3D) rendered image of a symphyseal face

To demonstrate this, the image to the left (*Figure 131*) represents the left symphyseal face of one of the female subjects who took part in this study. As may be seen, the face no longer retains any remnants of ridge and furrow morphology and instead displays approximately seven to eight randomly scattered erosions or "pits" (seen virtually as areas where the colour is darker), the result of amalgamating macro-pores on its surface. The face appears flat (as it is uniform in color, with minimal shadow) and a distinct, clearly defined rim may be seen - though this rim has atrophied, creating a sharp and irregular crenulated outline, which remains unbroken (with the exception of perhaps the superior dorsal margin, slightly). The tubercle behind appears to be discrete, with marked enthesic disfigurement, and from the just visible reddish tint (behind the tubercle), a slight (perhaps early, as it is seen no where else) loss of density at the pubic crest may also be inferred.

Based on these characteristics, the sympyseal face pictured above most closely resembles the description and illustrations for Suchey – Brooks' phase VI (and

more specifically, the "early pattern," or VI-I). The estimated age range for this phase (VI) is 42 to 87 years, with a mean of 60 years. Therefore, the estimated age for the individual pictured would be 42 to 87 years. The subject pictured was 66 years old at the time of her scan.

By this procedure, each individual in the sample – both male and female (see Chapter 3, "Sample: Descriptive Statistics," for a summary) – were analysed both by the author and then again by three independent practitioners.

4.1 Applying the Suchey-Brooks Method to this Sample

To determine whether the technique proposed by this thesis (the Truesdell Composite Method, or "TCM") was a good predictor of age, it was first necessary to "age" each individual using an already exisiting technique. As the Suchey – Brooks Method for Aging the Os Pubis was, at the time of writing, the most trusted and most frequently applied technique in the field (Meindl and Lovejoy 1985; Garvin and Passalacqua 2012), it was only logical that the Suchey – Brooks method would serve as that technique and be utilised as part of this study for the purpose of establishing a baseline (against which the TCM would be later compared).

As described in the previous chapter, the sample for this study consisted of 1,238 participants – 653 of which were male and 585 of which were female.

From this overall total there were 75 exclusions (due to obstructive pathology, repeat participation, or unusable scans), which resulted in a final analysis sample of 1,163 individuals (626 males and 537 females). Of those 1,163 participants, 1,030 (or 89%) were aged "accurately" (that is, the known age of the individual fell within the perimeters of the phase chosen) by the Suchey – Brooks Method. 133 individuals (or 11%) were not. Furthermore, with a 98% (527 individuals) rate of accuracy, females were aged "correctly" more often than were their male counterparts, the known ages of whom were captured only 80% of the time (503 individuals).

Within these accurate estimations, however, over half of the time (692 individuals, or 60%) the participant's known age was revealed to be more than 10 years away from the mean and, in many cases, it proved to be significantly more so. This imprecision was more pronounced for males than it was for females, with a total of 66% (412 individuals) of known male ages being greater than 10 years from the phase mean, a difference of 14 points when compared to the same for females (280 individuals, or 52%). This discrepency may be explained by the results of a transition analysis[21], seen below (*Figure 132*), which illustrates that males in this sample tended to exhibit a less predicitable transition trajectory than did their female counterparts.

[21] *Transition analysis is based on the assumption that age related change in any given skeletal feature moves forward (never backwards) in a step-wise progression (i.e. from i to i + 1 but never i + 2 or higher). A general linear model Pr(yj =llaj) =A(a +paj) is then fit, where aj is the age-at-death in the j-th skeleton, a and pare parameters are estimated from the reference sample, and A represents an inverse link function. This model is referred to as "transition analysis" because the intercept and slope of the equation Pr(yj =llaj) =A(a +paj) indicate the timing of the transition from one stage to the next. More specifically, the intercept is the age at which an individual passes from one indicator state to the next, and the slope is the rate of transition (Bethard 2005:17). Please see creators Milner and Boldsen (2002) for the original work. All analysis performed using the VGAM package in R.*

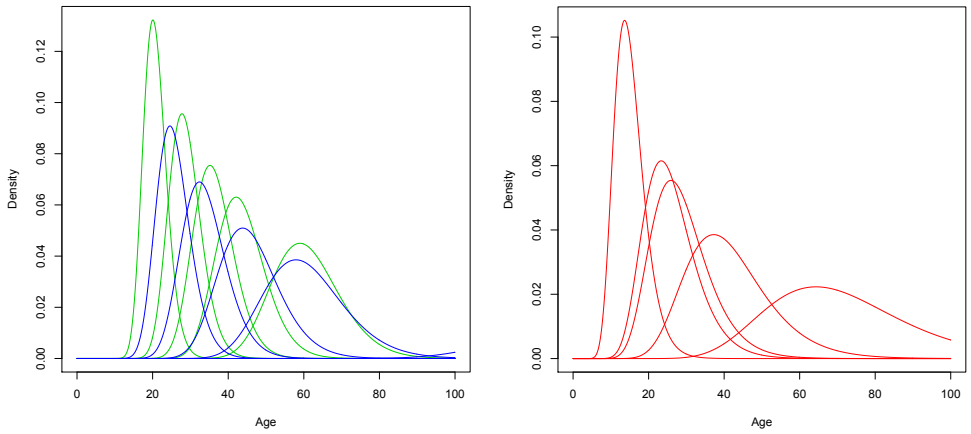


Figure 132: Transition analyses illustrating the timing and regularity of the Suchey – Brooks method (1990) as applied to this sample; females (L) – nulliparous (green), parous (blue), males (R). Note that, as no parous females were categorised as phase I, that peak remains absent.

For the sexes combined, at 48% (558 individuals) the most commonly assigned Suchey-Brooks phase was that of phase VI, followed by phase V (450 individuals, or 39%). For males, phase V was slightly more common than phase VI (300 individuals versus 254 individuals, respectively) whereas for females, phase VI represented the clear majority (304 individuals versus 150 individuals). This distribution (mostly V and VI) is unsurprising given the older skew of the overall sample. Moreover, that more males appear to retain a "younger" appearance further into advanced age is also anectodotally supported and has been largely attributed to the differential (sexually specific) effects of size and oestrogen / menopause (Seeman 2002; Berg 2008; Khosla et al. 2011).

In addition to retaining this "younger" overall appearance at older ages, this same analysis also indicates that males in this sample also transitioned through

the initial Suchey-Brooks phase distinctions earlier (that is, at younger chronological ages) than did either the parous or nulliparous female groups, though not at a faster rate – on the contrary, males generally arrived at each phase before the females did (with the exception of phase VI, where the opposite was true) but then tended to stay in those phases longer, especially in the latter half of life (*Figure 133, below*).

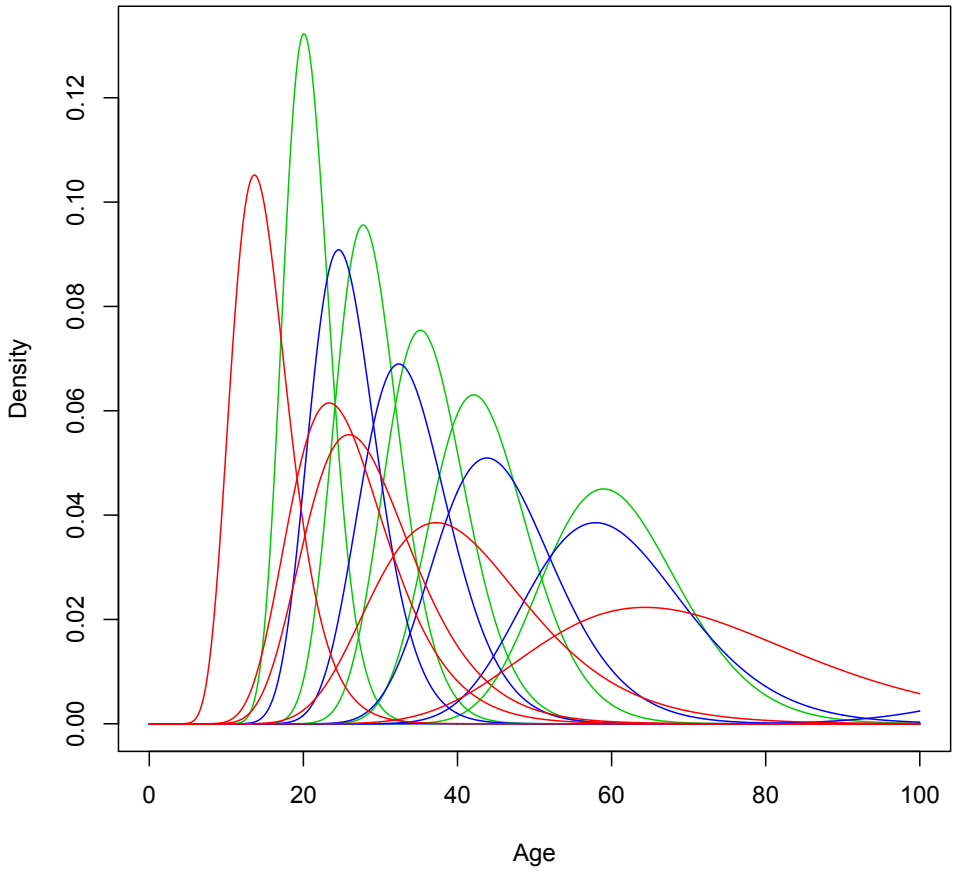
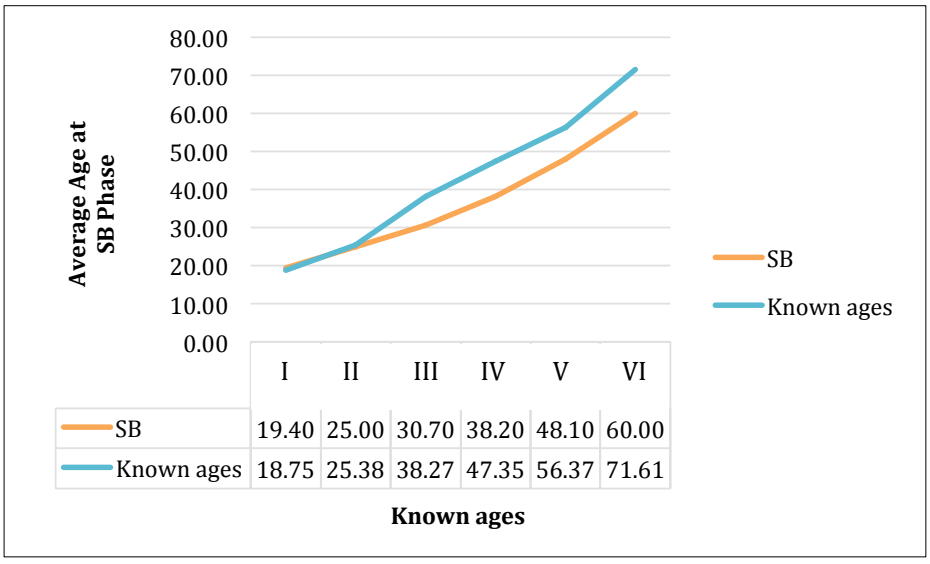


Figure 133: Suchey – Brooks transition analyses, combined sample; nulliparous females (green), parous females (blue), males (red). Note that, as no parous females were categorised as phase I, that peak remains absent.

Lastly, as can be seen, in terms of transitioning the two female groups remained closer to one another (with a difference of only one to three years between them [parous versus nulliparous]) than either did to the males (a difference of five to six years [male versus female]). Additionally, the females in this study were shown to exhibit a more even, regular, and predicitable pattern than were the males, who – in terms of moving through phases – exhibited more erratic and inconsistent behaviour in their transitioning. Finally, in using the Suchey-Brooks method on this sample, females were consistently under-aged by an average of nine to 10 years, while nulliparous women were under-aged by an average of 3.4 years (*Figure 134*). Male under-ageing was negligable.



	I	II	III	IV	V	VI
SB	19.40	25.00	30.70	38.20	48.10	60.00
Known ages	18.75	25.38	38.27	47.35	56.37	71.61

Figure 134: Consistent underageing of females when applying Suchey - Brooks to this sample

Because the divergence between males and females was so pronounced in this sample, both in terms of timing and uniformity, based on this Suchey-Brooks analysis it was the author's opinion that the male and female participants

should be investigated separately and that sex-specific templates were, indeed, warranted. Given this, it would have been beyond the scope – and word count – of this project to adequettely address both in one narrative. Therefore, as the females in this sample appeared to be the more reliabily consistent of the two, as well as the sex in greater need of clarification (see chapter one, section 1.4), they, as opposed to the males, were selected as the primary focus of this thesis.

4.2 Results of the Suchey-Brooks Analysis on this Sample

Moving forward with females only, the estimated age for each subject was then contrasted with her earlier questionnaire answers in an effort to reveal any lifestyle factors that may have played a role regarding the reliability of the Suchey-Brooks analysis. The results of this mixed effects (GLM) "cross-referencing" analysis are provided as Table 7 (below).

Table 7: Significance of questionnaire variables, Suchey – Brooks analysis

Parameter / Variable	P Value	Effect Size
Height	0.756	
Weight	0.071	
Body Shape	0.450	
Race / Ancestry	0.459	
Activity Level	**0.033**	0.69
Twisting Movements	0.977	
Stabilising Movements	0.487	
Osteitis Pubis	0.063	
UTI History	0.910	
Arthritis	0.441	
Osteoporosis	0.479	
Diet	0.645	
Tobacco	**0.010**	1.85
Alcohol	0.482	

Pregnancy Status	0.062	
- Times Pregnant	0.846	
- Times Given Birth	0.895	
- Age at First Birth	0.994	
- SPD	0.151	
- Epidural	0.193	
- Caesarean Section	0.233	
- Multiple Births	0.171	
- Birth Weight	0.614	
- Length of Labour	0.796	
- Births Breast Fed	0.519	
Hormone Replacement	0.720	
Contraception	0.247	
Menopause	**< 0.001**	7.69
Age at Menopause	0.261	

As can be seen, the female participants' reported level of activity (which made individuals look younger than their actual age), whether or not they had smoked tobacco (which made individuals look older than their actual age), and whether or not they had experienced menopause, regardless of age (which, again, made individuals look older than their actual age) were all statistically significant at the 5% level to the estimation of age from the pubic symphysis using the Suchey-Brooks method in this sample. As of the time of writing, there was no way to control or adjust for the presence of these factors within the confines of the Suchey-Brooks method; however, by virtue of its purposeful "vagueness," for lack of better description, the Suchey-Brooks method essentially encompasses all potential variables already and, while that means improvements within the system (such as increases in precision) are rendered impossible, such factors should not effect the efficacy, or overall accuracy and reliability, of the method as traditionally applied.

Finally, as this sample was predominately older (i.e. 45+ years of age and, therefore, "post-epiphyseal"), the Suchey-Brooks method did not prove itself to be an ideal technique for estimating age from the participants in this study (*Figure 135, below*).

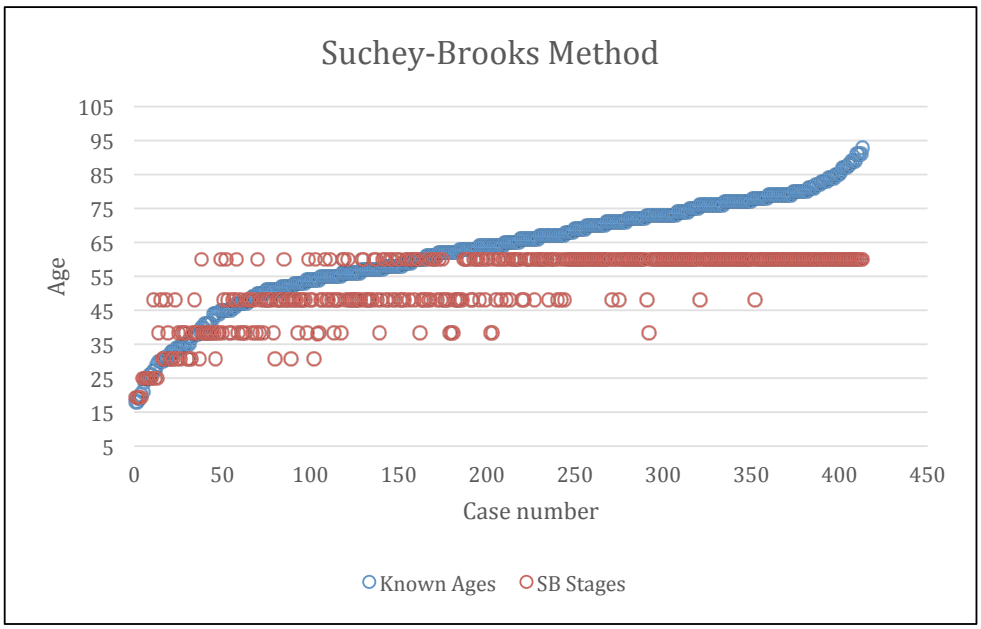


Figure 135: Inappropriateness of the Suchey – Brooks method (1990) in addressing older individuals in this study sample

This stemmed from the fact that the Suchey-Brooks phases as presented were simply too limited when addressing the second half of life, a flaw that became especially and overwhelmingly problematic when applied to this sample, where the majority of individuals were well beyond the terminal mean of 60 years. As a result, while general "accuracy" did not suffer due to the overly expansive age ranges for phases V and VI (25 to 83 [a 58 year span] and 42 to 87 years [a 45 year span], respectively), any hope for meaningful precision was forfeited for over half of the sample.

The next chapter – Chapter 5, "The Hartnett Method" - will examine the Hartnett method (2010a), a technique that borrows extensively from the Suchey-Brooks method but with the inclusion of both a seventh phase (first advocated by Berg 2008) and a formal accounting for density (in the form of bone weight). As both of these additions played a major role in the formation of the TCM, an evaluation and assessment of this method served as an important intermediary step on the path to its development.

5

Hartnett Analysis

5.0 **A Review of The Hartnett Method** 263
5.1 **Applying the Hartnett Method to this Sample** 269
5.2 **Results of Applying the Hartnett Method to this Sample**..... 273

Abstract:

This chapter will revisit the Hartnett Method (2010) and will present the results of its application to this sample.

5.0 A Review of The Hartnett Method

As stated in the previous chapter, just as the Suchey-Brooks Method for Aging the Os Pubis (Brooks and Suchey 1990) was an updated version of Todd's original technique (1920), the Hartnett method (2010) is an updated version of the Suchey-Brooks method. By keeping many of the same phases and phase descriptions, Hartnett retained a sense of familiarity while at the same time introducing new elements – chief among them being projections into the obturator foramen, a seventh phase, and a formal accounting of "bone weight," or density. By keeping the old while suggesting additions, the Hartnett method "eases" the practitioner into the regime without major upset or confusion. Like

Suchey-Brooks, the method is still archetypal in that pubic bones to be evaluated are still sorted into representative phases and then regressed age ranges are provided for those phases. Where Hartnett departs from the Suchey-Brooks method, however, is in her introduction of a floating variable – density – which can "push" a phase determination up or down, depending on severity.

To apply the Hartnett method, therefore, the practitioner employs the same matching technique as he or she would when applying the Suchey-Brooks method, though this time by written description only. These descriptions and their corresponding ages are as follows (*Figures 136 and 137*):

Phase 1	A clear ridge and furrow system extends from the pubic tubercle onto the inferior ramus. Ridges and furrows are deep and well-defined and do not look worn down. There is no dorsal lipping. Bone is of excellent quality and is firm, heavy, dense, and smooth on the ventral and dorsal body. There is no rim formation. The dorsal plateau is not formed. The ridges and furrows extend to the dorsal edge
Phase 2	The rim is in the process of forming, but mainly consists of a flattening of the ridges on the dorsal aspect of the face and ossific nodules present along the ventral border. Ridges and furrows are still present. The ridges and furrows may appear worn down or flattened, especially on the dorsal aspect of the face. The furrows are becoming shallow. The upper and lower rim edges are not formed. There is no dorsal lipping. The bone quality is very good and the bone is firm, heavy, dense, and smooth on the ventral and dorsal body, with little porosity. The pubic tubercle may appear separate from the face
Phase 3	The lower rim is complete on the dorsal side of the face, and is complete until it ends approximately halfway up the ventral face leaving a medium to fairly large gap between the lower and upper extremities on the ventral face. This enlarged "V" is longer on the dorsal side than the ventral side. Some ridges and shallow furrows are still visible, but appear worn down. In some cases, the face is becoming slightly porous. The rim is forming both on the dorsal aspect of the face and the upper and lower extremities. In some cases, there is a rounded buildup of bone in the gap between the upper and lower extremities above the enlarged "V." Bone quality is good; the bone is firm, heavy, dense, and has little porosity. The dorsal surface of the body is smooth, and there are small bony projections near the medial aspect of the obturator foramen. The ventral aspect of the body is not elaborate. Very slight to no dorsal lipping. Quality of bone and rim completion are important deciding factors. Variant: In some cases, a deep line or epiphysis is visible on the ventral aspect parallel to and adjacent to the face (males only)
Phase 4	In most cases, the rim is complete at this stage, but may have a small ventral hiatus on the superior and ventral aspect of the rim. The face is flattened and not depressed. Remnants of ridges and furrows may be visible on the face, especially on the lower half. The quality of bone is good, but the face is beginning to appear more porous. The dorsal and ventral surfaces of the body are roughened and becoming coarse. There is slight dorsal lipping. In females with parturition pits, dorsal lipping can be more pronounced. The ventral arc may be large and elaborate in females
Phase 5	The face is becoming more porous and is depressed, but maintains an oval shape. The face is not irregularly-shaped or erratic. The rim is complete at this stage. In general, the rim is not irregular. Ridges and furrows are absent on the face. There may be some breakdown of the rim on the ventral border, which appears as irregular bone (not rounded/solid). The ventral surface of the body is roughened and irregular, with some bony excrescences. The dorsal surface of the body is coarse and irregular. Projections are present on the medial aspect of the obturator foramen. Bone quality is good to fair; it is losing density and is not smooth. The bone is moderately light in weight. In females the ventral arc is prominent
Phase 6	The face is losing its oval shape and is becoming irregular. The rim is complete, but breaking down, especially on the ventral border. The rim and face are irregular, porous, and macroporous. Bone quality is fair, and the bone is lighter and more porous, even with bony buildup on the ventral body surface. The rim is eroding. The dorsal surface of the bone is rough and coarse. There are no ridges and furrows. Dorsal lipping is present. Projections are present at the medial aspect of the obturator foramen. Bone weight is a major deciding factor between phases 6 and 7
Phase 7	The face and rim are very irregular in shape and are losing integrity. The rim is complete but is eroding and breaking down, especially on the ventral border. There are no ridges and furrows. The face is porous and macroporous. Dorsal lipping is pronounced. Bone quality is poor, and the bone is very light and brittle. Bone weight is an important deciding factor. The dorsal surface of the bone is roughened. The ventral surface of the body is roughened and elaborate. Projections are present at the medial wall of the obturator foramen. The pubic tubercle is elaborate and proliferative. Bone weight is a major deciding factor between phases 6 and 7
VARIANT	VARIANT: The rim is complete except for a lytic/sclerotic appearing hiatus at the superior ventral margin that extends toward the pubic tubercle and sometimes underneath the ventral rim, which should not be confused with a hiatus

Figure 136: Hartnett phase descriptions

	FSC				SB*			
Phase	n	mean	SD	range†	n	mean	SD	range§
1	5	19.8	1.33	18–22	48	19.4	2.6	15–24
2	5	23.2	2.38	20–25	47	25	4.9	19–40
3	25	31.44	5.12	24–44	44	30.7	8.1	21–53
4	35	43.26	6.12	33–58	39	38.2	10.9	26–70
5	32	51.47	3.94	44–60	44	48.1	14.6	25–83
6	35	72.34	7.36	56–86	51	60	12.4	42–87
7	56	82.54	7.41	62–99	–	–	–	–

Figure 137: Hartnett age range designations according to phase, contrasted with the same for Suchey - Brooks

As can be seen, the descriptions for Hartnett's phases I through V remain nearly interchangeable with those of Suchey-Brooks (and Todd before them) save for the occasional notation of projections into the obturator foramen (this is not a slight on Hartnett, rather this lack of distinction between methods in describing the younger phases stems from the fixed epiphyseal formation / fusion trajectory described in chapter one, section 1.2.1, of this thesis). As can also be

seen, however, Suchey-Brooks' terminal phase VI has been split, resulting in a phase VI of lessened degradation and a phase VII for more extensive decline (likely an adoption and adaptation of Berg's 2008 work). When differentiating between these two phases, "bone weight is a major deciding factor." For use in this study, which was exclusively image based and therefore devoid of tactility, density was substituted for weight with the permission of Dr. Hartnett (Hartnett pers. com. 2015).

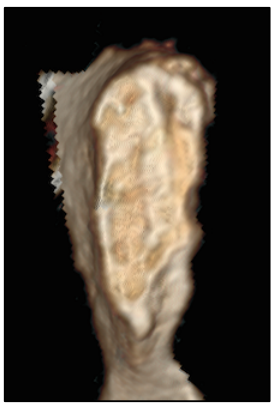


Figure 138: Volume (3D) rendered image of a symphyseal face

By recalling the image used to illustrate the Suchey-Brooks method in the previous chapter (*Figure 138),* the Hartnett method may be demonstrated in much the same way. As with Suchey-Brooks, phases 1 through 3 may be discounted immediately as a completed "rim," or outline, is clearly visible (the chief developmental benchmark for phase 4). Moving down the descriptions, it is quickly clear that phases 4 and 5 may be discounted as well as that same rim has lost its oval shape and is, in opposition to the phase 5 descriptions, both irregularly-shaped and erratic. This assessment leaves phases 6 and 7 as the only viable options for this individual (in keeping with the same photograph being placed into the terminal Suchey-Brooks phase VI). Of the two, this symphyseal face appears to be more consistent with Hartnett's phase 6 than phase 7, simply due to the fact that while degenerative changes such as erosion and porosity are indeed present, their severity could not be represented accurately by words such as "elaborate" or "proliferative."

Once an initial phase has been chosen based on morphology, density (taking the place of bone weight in this study) must then be consulted to determine whether phase 6 will remain as the final phase distinction or whether 5 or 7 might be more appropriate (*Figure 139, below*).

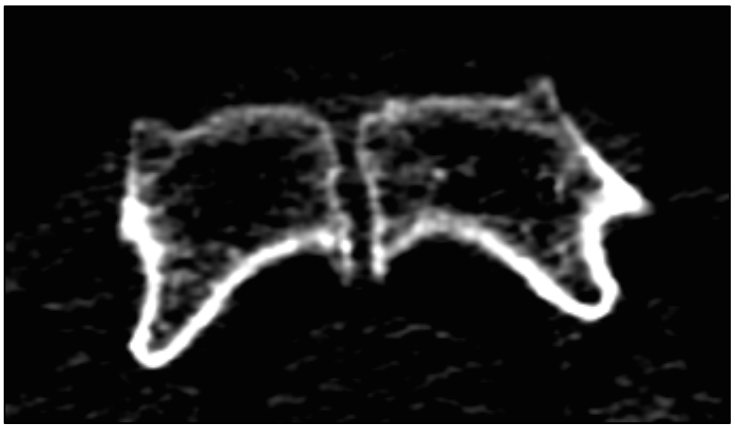


Figure 139: Axial view of a symphysis exhibiting low density

In this axial view, large "pockets" of little to no density (black areas) can be easily seen occupying at least 80% of the space inside both pubic bones (as discussed in chapter two, section 1.6, due to the differential attenuation of x-rays, in radiographic images air appears black, fat appears grey, soft tissue and water appear as varying lighter shades of grey, and bone appears white). Additionally, as the denser the bone the brighter it appears, a severe lack of density is also present on the ventral margin of the pubic outline as well. If this image were representational of the subject being assessed, based on the density displayed – which would translate to very light bone weight - there would be no choice but to "shift" the morphological phase 6 assignment up, making phase 7 the final phase for that individual.

Conversely, if the scan to the right were representational (*Figure 140*), with its thick, bright, uniform density – which would translate physically to a "high," or heavy bone weight – the individual in the screen capture would be shifted down a level to phase 5.



Figure 140: Axial view of a symphysis exhibiting high density

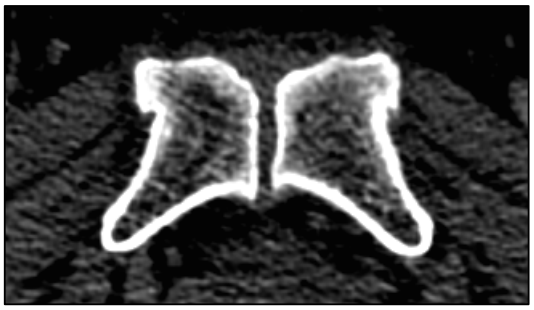


Figure 141: Axial view of a symphysis exhibiting moderate density

However, as the scan to the left (*Figure 141*) is the actual scan for the individual in the screen capture, with its density ratio a more or less equal mix of the two (a "50 / 50" balance between black and white), according to the Hartnett method the original assignment of phase 6 may be allowed to stand. This distinction carries with it an age range of 56 to 86 years, with a mean age of 72.34. As revealed in the previous chapter, the actual age of this individual was 66 years.

In her 2014 evaluation of the Hartnett method on a (physical) modern sample, Merritt surmised that "although the Suchey-Brooks… method w[as] correct more often in assigning individuals to the appropriate age phase, the reliability of Hartnett's revised method [wa]s far superior, especially for the pubic symphysis… also, Hartnett's revision of the female Phase 7 and addition of male

a Phase 7 to the pubic symphysis method improved the accuracy for determining age at death of older individuals.." (Merritt 2014:710). Additionally, Merritt also felt that Hartnett's revised method had "much clearer written phase descriptions compared with the Suchey-Brooks method" and that "taking into account the texture and weight of the bone ma[d]e it much easier to classify skeletal elements into age phases even without casts" (Merritt 2014:710).

These conclusions, without exception, were supported by the results of the present study. One area in which the Hartnett method suffered with this sample, however, was with the gap in means between her fifth and sixth phases (as evidenced by the above example). From phase 2 onwards, the mean age for each accompanying range followed a roughly ten year interval – that is, except for the interval between phases 5 and 6 when the mean skips from 51 to 72 years. As the majority of the sample utilized by this study were in their 60's (with the average age for men being 64 years and the average age for females being 62 years), this meant that the many individuals with ages in this area were often classified as further from the mean (regarding precision) than they would have been had that (approximately) 60 year mean not been absent.

5.1 Applying the Hartnett Method to this Sample

As stated in the previous chapter, the sample for this study consisted of 1,238 participants – 653 of which were male and 585 of which were female. From this

overall total there were 75 exclusions (due to obstructive pathology, repeat participation, or unusable scans), which resulted in a final analysis sample of 1,163 individuals (626 males and 537 females). Of those 1,163 participants, 1,080 (or 93%) were aged "accurately" (that is, the known age of the individual fell within the perimeters of the phase chosen) by the Hartnett method. 83 individuals, or 7%, were not. In contradiction with the Suchey-Brooks analysis, however, with a 94% (591 individuals) rate of accuracy, males were aged "correctly" more often than were their female counterparts, the known ages of whom were captured only 91% of the time (488 individuals).

Furthermore, and again in contrast to the Suchey-Brooks findings, within this accuracy it was revealed that, when employing the Hartnett method, the participant's known age was estimated to within 10 years of the mean of the chosen phase 77% of the time (899) and more than 10 years away from the mean of the chosen phase only 23% of the time (264 individuals). Imprecision, however, stayed in keeping with the Suchey-Brooks analysis and was once again more pronounced in males than it was in females, with a total of 27% (172 individuals) of known male ages being estimated to more than 10 years from the mean of the chosen phase - a difference of 10 percentage points when compared to the same metric for females (92 individuals, or 17%).

For the sexes combined, as with Suchey-Brooks, the most commonly assigned Hartnett phase was that of phase 6 (37%, 391 individuals), followed closely by phase 5 (31%, 365 individuals). Also echoing Suchey-Brooks, for males, phase 5

was slightly more common than phase 6 (220 individuals versus 181 individuals, respectively) – presenting a younger appearance in later life - whereas for females, phase 6 represented the majority (210 individuals versus 145 individuals). Like Suchey-Brooks, this distribution (mostly phases 5 and 6) was again unsurprising given a sample composed of subjects predominately in their seventh and eighth decades of life. Moreover, further reflecting this older sample was the fact that after phases 5 and 6, phase 7 ranked as the third most common designation in all categories – male (24%, 152 individuals), female (16%, 88 individuals), and overall (21%, 240 individuals).

Regarding precision, in this sample the estimated age of each male participant fell within five years of the actual age 43% of the time (268 individuals) and within 10 years of the actual age 30% of the time (186 individuals). In females, estimated age fell within five years of the participant's known age 57% of the time (305 individuals) and within 10 years of the actual age 26% of the time (140 individuals). While imprecision appeared to be greater amongst the males in this sample regardless of method, the gulf between techniques was no less striking – when using the Suchey-Brooks method, 66% of the males in this study were estimated to be more than 10 years away from the mean whereas with Hartnett this number was 27% (a 39 point difference); at the same time, 52% of the females in this study were estimated to be more than 10 years away from the mean using the Suchey-Brooks method while only 17% were similarly classified when using Hartnett (a 35 point difference).

Overall, the Hartnett method, with its added seventh phase, seemed to regulate, or stabilise, the Suchey-Brooks method when applied to this sample, especially for the males at the older end of the aging spectrum. Essentially, the seventh phase, in this case, acted as a counter-weight to bring the males into greater balance with the two female groups, which were already quite similar themselves – resulting in the three disparate categories behaving more or less identically, with the exception of males between the ages of approximately 25 and 40 years (*Figures 142 and 143, below*).

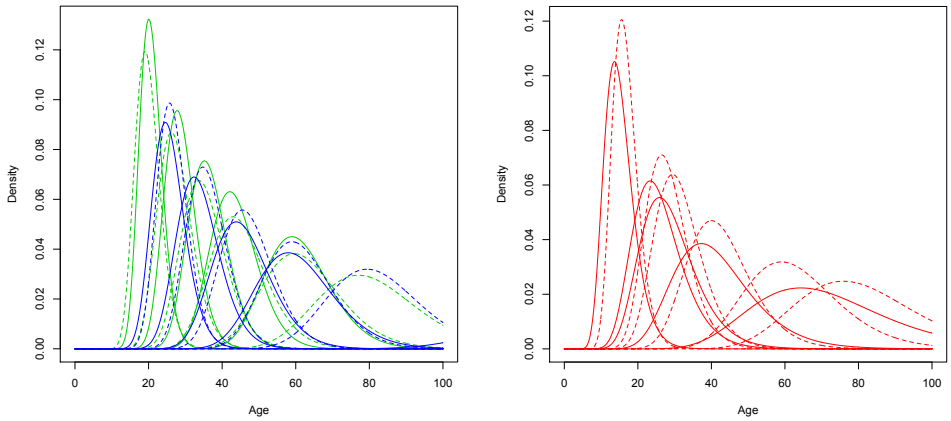


Figure 142: Transition analysis comparison of the Hartnett (dashed) and Suchey – Brooks (solid) methods; females (L) – nulliparous females (green), parous females (blue), males (red). Note that, as no parous females were categorised as phase 1 in either technique, that peak remains absent.

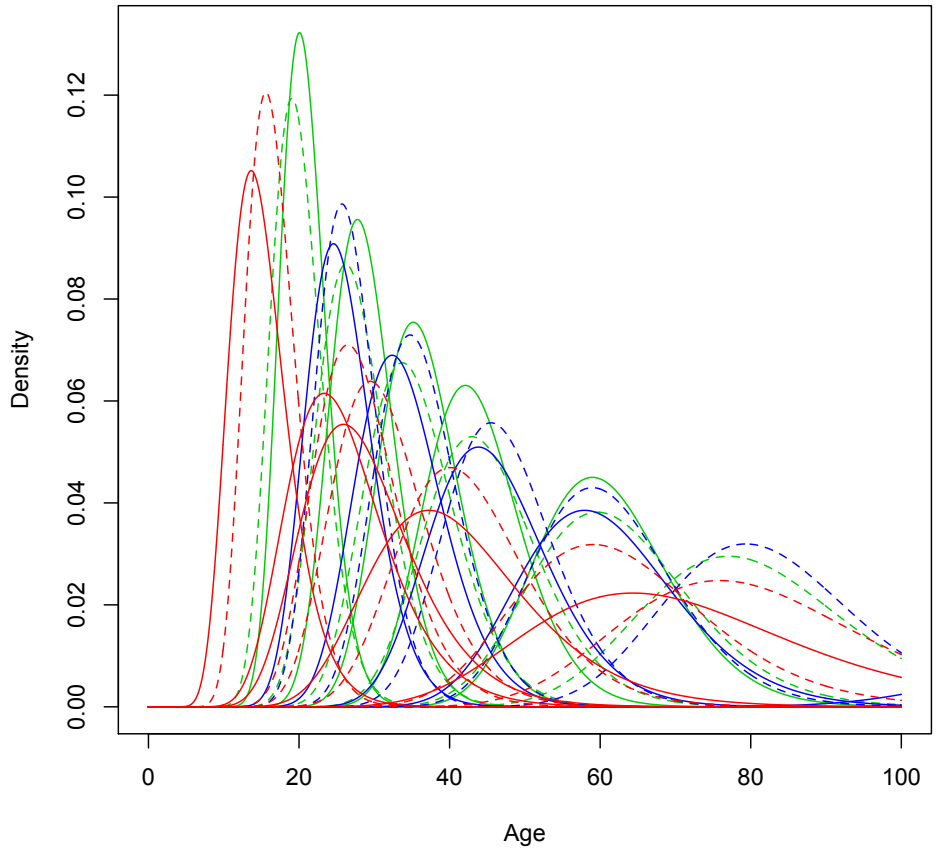


Figure 143: Transition analysis comparison of the Hartnett (dashed) and Suchey – Brooks (solid) methods – combined sample; nulliparous females (green), parous females (blue), males (red). Note that, as no parous females were categorised as phase 1 by either technique, that peak remains absent.

5.2 Results of Applying the Hartnett Method to this Sample

As was determined by the Suchey-Brooks assessment of the previous chapter, females only were taken forward through further stages of analysis in this thesis. Therefore, as with Suchey-Brooks, the estimated age for each subject was contrasted with her questionnaire answers in an effort to reveal any lifestyle factors that may have played a role regarding the reliability of this Hartnett

evaluation. The results of this mixed effects (GLM) "cross-referencing" are provided below (*Table 8*).

Table 8: Significance of questionnaire variables, Hartnett analysis

Parameter / Variable	P Value	Effect Size
Height	0.734	
Weight	0.067	
Body Shape	0.486	
Race / Ancestry	0.496	
Activity Level	**0.047**	0.73
Twisting Movements	0.892	
Stabilising Movements	0.486	
Osteitis Pubis	0.083	
UTI History	0.720	
Arthritis	0.404	
Osteoporosis	0.559	
Diet	0.846	
Tobacco	**0.002**	1.33
Alcohol	0.537	
Pregnancy Status	0.631	
- Times Pregnant	0.772	
- Times Given Birth	0.552	
- Age at First Birth	0.999	
- SPD	0.143	
- Epidural	0.165	
- Caesarean Section	0.084	
- Multiple Births	0.493	
- Birth Weight	0.796	
- Length of Labour	0.267	
- Births Breast Fed	0.448	
Hormone Replacement	0.762	
Contraception	0.259	
Menopause	**< 0.0001**	7.89
Age at Menopause	0.240	

Once again, in accordance with the Suchey-Brooks analysis, participants' level of activity (which made individuals look younger than their actual age), whether or not they had smoked tobacco (which made individuals look older than their

actual age), and whether or not they had experienced menopause, regardless of age (which, again, made individuals look older than their actual age) were all statistically significant at the 5% level to the estimation of age from the pubic symphysis using the Hartnett method. There was no way to control or adjust for the presence of these factors within the confines of the Hartnett method; however, by not controlling for them in the original design, the method inherently encompassed them already and, while that means improvements within the system (such as increases in precision) cannot be made at this time, such factors should not have effected the efficacy, or overall accuracy and reliability, of the method as it was applied in this case.

Due to the addition of its seventh phase, the Hartnett method compellingly out-performed the Suchey-Brooks method in this study. This was largely because the sample utilised was predominately older (i.e. 45+ years of age and up), a demographic for which the Hartnett method, with its additional phase and accounting for density, could accommodate (where the Suchey-Brooks method could not).

The next chapter, Chapter 6: "The Truesdell Composite Method," will introduce the Truesdell Composite Method, or "TCM," - a novel technique which combines the visual matching of Suchey-Brooks, the density adjustment and seventh phase of the Hartnett method, components like those of McKern and Stewart (1957), and variable based regressions like those of Chen et al. (2010) - and will examine its performance and reliability as a predictor of age.

6

Truesdell Composite Method (TCM) Analysis

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6.2 **Applying the TCM to this Sample** 280
6.3 **Results of Applying the TCM to this Sample** 287

Abstract:

This chapter will revisit the Truesdell Composite Method and will present the results of its application to this sample.

6.0 A Review of the Truesdell Composite Method

As discussed, and as its name would suggest, the Truesdell Composite Method represents a compilation of several preceeding methods and concepts, including Todd (1920) and Suchey-Brooks' (1990) system of archetypal visual matching, McKern and Stewart's (1957) components, Hanihara and Suzuki's (1978) and Chen et al.'s (2008, 2011) discrete variables and linear regressions, Berg's (2008) seventh phase, Hartnett's (2010a) density inclusion, and Meindl et al.'s (1985) lack of enthusiasm for fixed or "static" typological phases. To apply the TCM to a specimen in question, however, the practitioner need only choose one of 14 numbered columns for each of its five discrete components ("Upper Boundary," "Lower Boundary," "Outline," "Surface Texture," and "Topography")

and then add the appropriate adjustment for density (see "Materials and Methods" – sections 2.3.4.1.5 and 2.3.4.2 – for a complete tutorial).

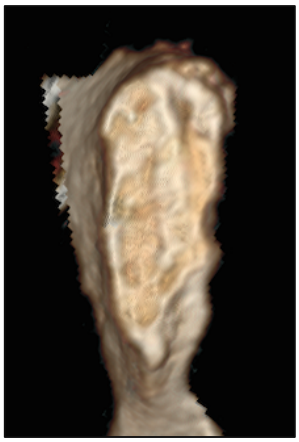


Figure 144: Volume (3D) rendered image of a symphyseal face

Using the image to the left (*Figure 144*) as an example once again, the TCM may be illustrated here in much the same way as the Suchey-Brooks and Hartnett methods were before it. As mentioned previously, it is the author's preference to begin with Density and, therefore, the axial image for the individual in question will be consulted first (*Figure 145, below)*.

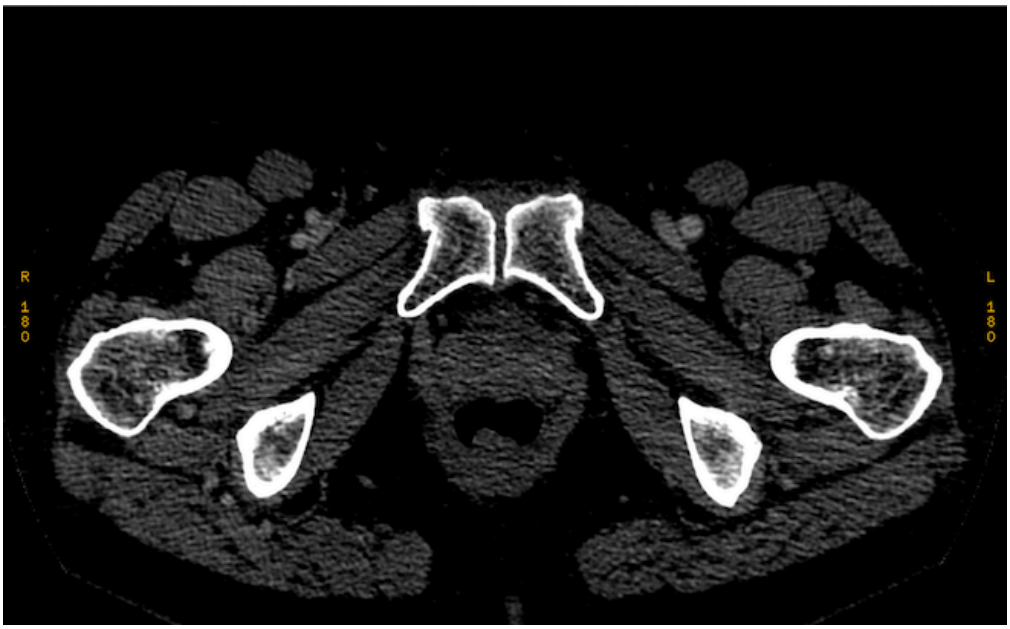


Figure 145: Axial view demonstrating the bones of the pelvis

As is evident, overall, the cortical bone surrounding the pubic bones appears bright and uniform, though noticeably thinned (a trait confirmed by the ischia and femora, also in view). In addition, no pathology or artifact is exhibited (which could obscured the image or rendered it unusable). This would initially suggest that this individual is not likely to be a very young person (40 years or under), but neither are he or she likely to be very old (70 or above).

Within the bone, a closer inspection of the pubic symphysis (*Figure 146*) reveals a mottled, or "tiger striped" appearance to the inner trabeculae, with a relatively equal amount of visible black and grey. This 50% / 50% ratio, along with the intensified (disproportionate) thinning of the cortical bone along the ventral aspect, indicates a "medium" level of density. A score of 5 should therefore be noted.

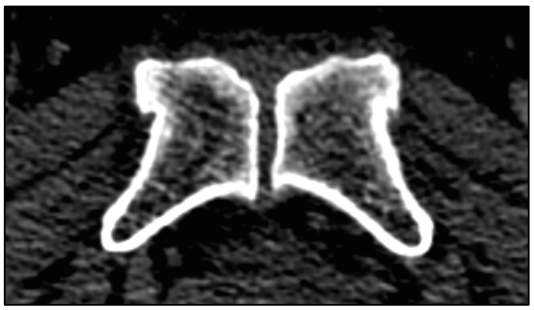


Figure 146: Axial view of a symphysis exhibiting a mottled, or "tiger-striped" appearance

Moving next to the Upper Boundary, it is apparent from the above image that the UB has "squared off" (i.e. the wide, softly curving "V" shape that existed between the two bones has pinched in to create more of a "Y" or "T" shape), reflecting a completion of fusion at that area. This means that anything below a 7 may be immediately discounted. Next, looking at the rendered (non-axial) image, it may be seen that the outline at the UB is not swelled or smooth but has, instead, thinned quite severely in some places while retaining thickness in

others. It is also evident that the face and tubercle have become two distinct entities and that large macro-pores have begun to erode the surface. However, while the outline has thinned and one or two small perforations have begun to appear, it has not yet lost it uniformity and maintains its continuity overall. This means that anything 14 or over may also be discounted. For the Upper Boundary, therefore, it is the author's opinion that column 13 (with its key words of "thin and regular") is most representative of this individual.

The same process may be applied to the Lower Boundary, where a slight convexity exists and the outline remains thicker, more rounded, and regular in appearance. Because of this, it is the author's opinion that column 12 is the best fit for the LB in this case (though a 13 would also be supported). Moving through to the next component, because the Outline has thinned but remained intact, it is the author's opinion that 13 most resembles the individual in question. The same assignment, 13, is also the author's choice as the best match Surface Texture (though 12 would not be argued with) and Topography as well.

This means that the numbers to be summed for the individual represented by the picture will be 5 (Density), 13 (UB), 12 (LB), 13 (Outline), 13 (Surface Texture), and 13 (Topography). As 5 + 13 + 12 + 13 + 13 + 13 = 69, the estimated mean age for this individual is, therefore, 69 years. As previously revealed, the actual age of the woman represented by the image at the time of her scan was 66 years.

6.1 Applying the TCM to this Sample

As stated in previous chapters, the sample for this study consisted of 1,238 participants – 653 of which were male and 585 of which were female. From this overall total there were 75 exclusions (due to obstructive pathology, repeat participation, or unusable scans), which resulted in a final analysis sample of 1,163 individuals (626 males and 537 females). Of those 1,163 participants, 1,086 (or 93%) were aged "accurately" (that is, the known age of the individual fell within the age range predicted) by the Truesdell Composite method. 77 individuals, or 7% of those assessed, were not. Furthermore, of those accurately aged, 939 individuals, or 86%, were aged to within five years of his or her actual (known) age while the remaining 147 individuals, or 14%, were aged within 10. Using the TCM on this sample, females were aged correctly more often than were their male counterparts, though only slightly, with a 95% (510 out of 537 individuals) rate of accuracy for women versus a rate of only 92% (576 out of 626 individuals) for men.

Furthermore, nested within this accuracy it was revealed that, when employing the Truesdell Composite Method, the participant's known age was estimated to be between zero and five years from his or her actual age a total of 81% of the time (939 individuals), to within six and 10 years of his or her actual age a total of 13% of the time (147 individuals), and more than 10 years (11+) from his or her actual age only 7% of the time (80 individuals). 80% of the male sample (501 individuals) were aged to with five years of known age, 12% (72

individuals) to within 10 years, and 8% (53 individual) were estimated to be more than a decade away from his actual age. For females (parous and nulliparous combined), this varied only slightly with 81% of the sample (435 individuals) being aged to within five years of her actual age, 13% (72 individuals) to within 10 years, and 6% (30 individuals) more than 10 years from actual age.

When contrasted with Suchey-Brooks, by which 60% of the sample (695 individuals) were estimated to be more than a decade away from their actual ages, and Hartnett, by which this number was 23% (264 individuals), that only 7% (80 individuals) of the sample were estimated to be more than 10 years from actual age when using the TCM – a narrowing of 53 percentage points when compared with Suchey-Brooks as well as 16 percentage points when compared with Hartnett - represents a marked improvement in overall precision when estimating age from the pubic symphysis. Of those 80 individuals, however, the TCM stayed in keeping with Hartnett (though not Suchey-Brooks) in that males, rather than females, were more likely to be placed in this "10+" category. Using the Suchey-Brooks method on this sample, a total of 48% of females were aged more than a decade from their actual age while the same applied to only 34% for males. For Hartnett, this ratio was reversed. Indeed, Dr. Hartnett makes mention of this in her 2010 publication, stating "in general, correlation values [we]re higher for females than for males, suggesting that there was less interobserver error between observers for females than for males… This may suggest that females undergo a more regular

and predictable pattern of aging in the pubic bone than males, which contradicts much of the known literature" (Hartnett 2010:1149). When using the Hartnett method on this sample, males were estimated to be over 10 years from actual age a total of 27% of the time while females were aged similarly only 17% of the time. When using the TCM, this number was 8% for males and 6% for females.

For males, the most commonly assigned category for the Upper Boundary was 10 (36%, 227 individuals), followed by 11 (18%, 114 individuals); the most commonly assigned category for the Lower Boundary was 10 (34%, 210 individuals), followed again by 11 (26%, 162 individuals); for the Outline, the most commonly assigned category was 10 (35%, 221 individuals), followed by 11 (21%, 133 individuals); for Surface Texture, the most commonly assigned category was 12 (33%, 207 individuals), followed by 11 (26%, 165 individuals); and, finally, the most commonly assigned category for Topography was 11 (35%, 218 individuals), followed again by 10 (23%, 144 individuals). The most common Density adjustment for males was that of 15 (28%, 175 individuals), followed closely by 10 (26%, 161 individuals), and then 0 (24%, 152 individuals). [22] Based on these numbers, therefore, the "average" or "stereotypical" male face for this sample would contain an established, non-"vanishing" though not pronounced, "shadow" rim and a surface with a mix of micropores and emerging macropores.

[22] In order to "neutralise" the age differential due to their (deceptively) younger appearance and bring them more into line with the females, for men, the Density Adjustment was expanded from three categories to five - "Good," which carried a weight of 0; "Fair," which carried a weight of 5; "Medium," which carried a weight of 10; "Poor," which carried a weight of 15; and "Very Poor," which carried a weight of 20.

For nulliparous females, the most commonly assigned category for the Upper Boundary was 14 (13%, 11 individuals), followed by 13 (11%, 10 individuals); the most commonly assigned category for the Lower Boundary was 11 (15%, 12 individuals), followed by 10 (13%, 11 individuals), then 9 (12%, 10 individuals); for the Outline, the most commonly assigned category was 13 (12%, 10 individuals); for Surface Texture, the most commonly assigned category was 12 (16%, 13 individuals); and the most commonly assigned category for Topography was 9 (20%, 16 individuals), followed equally by 10 (12%, 10 individuals), and 14 (12%, 10 individuals). The most common Density adjustment for nulliparous females was that of 0 (51%, 42 individuals), followed by 5 (33%, 27 individuals), then 10 (15%, 12 individuals). Based on these numbers, therefore, the "average" or "stereotypical" nulliparous female face for this sample would contain a thin, somewhat irregular outline displaying varying degrees of degradation (more pronounced at the Upper Boundary than at the Lower Boundary, with the overall outline somewhere between the two) and a surface beset by an increasing number of macropores, plentiful enough now (appearing over perhaps 20 – 40% of the face) that they begin to coalesce, deepening together as large depressions or "sinkholes" as structural integrity begins to erode from below.

For parous females, the most commonly assigned category for the Upper Boundary was 14 (21%, 97 individuals), followed by 13 (17%, 79 individuals); the most commonly assigned category for the Lower Boundary was 13 (21%, 96 individuals), followed by 12 (18%, 84 individuals), and then 11 (16%, 72

individuals); for the Outline, the commonly assigned category was 14 (24%, 107 individuals), followed by 13 (18%, 83 individuals); for Surface Texture, the commonly assigned category was 13 (26%, 117 individuals), followed by 12 (20%, 92 individuals); and, finally, the most commonly assigned category for Topography was 10 (17%, 76 individuals), followed by 12 (15%, 67 individuals). The most common Density adjustment was 5 (48%, 219 indiduals), followed by 0 (36%, 164 individuals). As a result, the "average" or "stereotypical" face of a parous female in this sample would contain a thin, irregular outline with a fair amount of perforation and degradation (slightly more pronounced at the Upper Boundary than at the Lower Boundary, but consistent overall) and a surface beginning to erode through a number of established macropores coalescing and deepening together to form large depressions or "sinkholes" across perhaps 20 - 40% of the face.

Given this information, it would appear that, on average, the male face maintains the "youngest" appearance of the three (10/10/10/12/11), followed by the nulliparous females (14/11/13/12/9) and, finally, by the parous females (14/13/14/13/10) – further confirming the earlier transition analyses of both the Suchey-Brooks and Hartnett methods (chapters 4 and 5, respectively). Also reaffirmed by this TCM analysis is the closeness of the two female groups, who never differed in any area (component) by an interval greater than two years (too small to be significant). Between the male and female groups, however, that number doubled, with differences of three and four years in several areas. These findings are presented graphically on the following page (*Figure 147*).

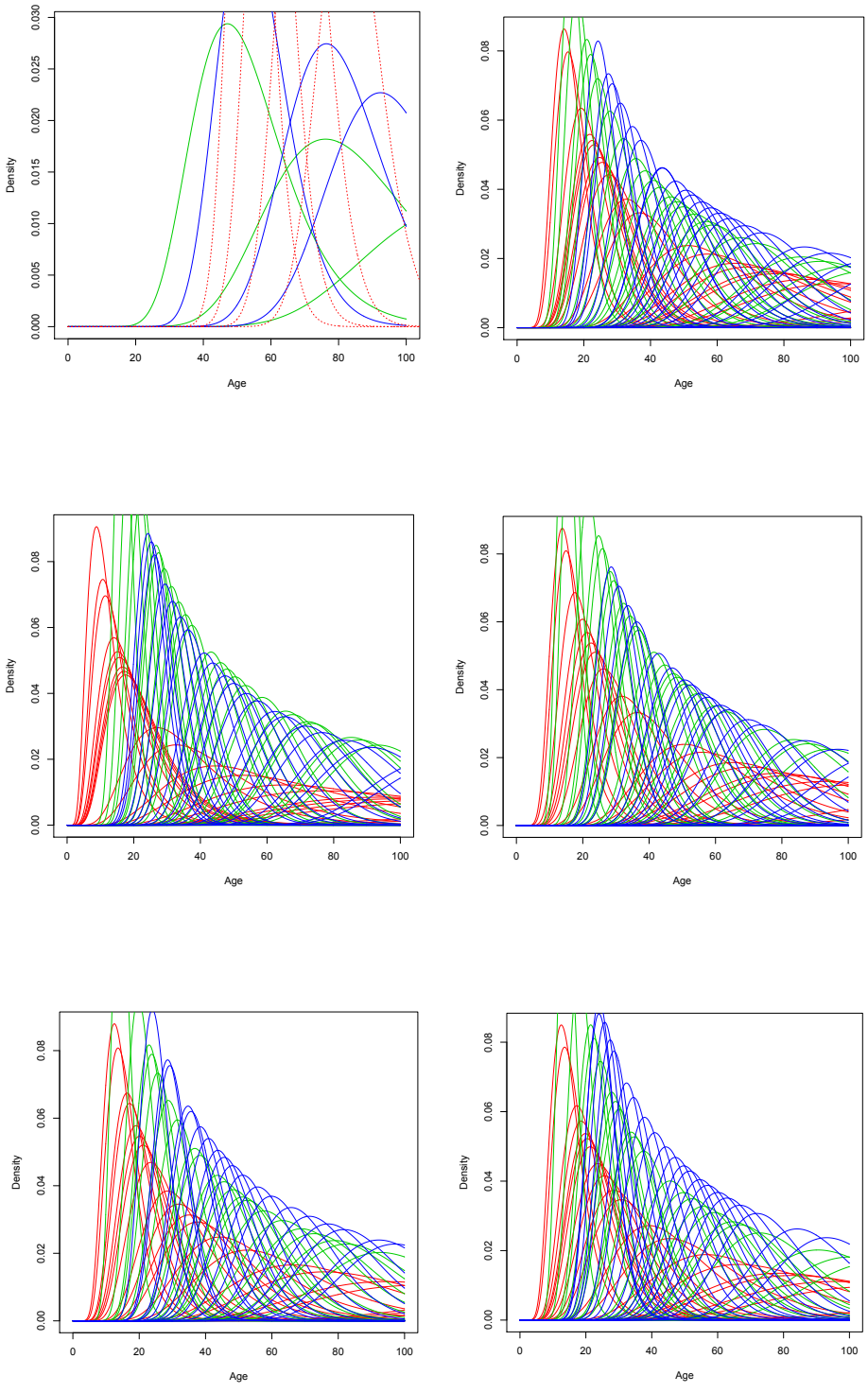


Figure 147: Transition analysis of each of the TCM components – Density (top left), Upper Boundary (top right), Lower Boundary (center left), Outline (center right), Surface Texture (bottom left), Topography (bottom right); nulliparous females (green), parous females (blue), males (red). Note that, as no parous females were categorised as phase 1 by either technique, that peak remains absent.

As with the Suchey-Brooks and Hartnett transition analyses, the above TCM analysis illustrates, yet again, how much more regemented and uniform female symphyseal progression was in this sample when compared to that of the males, who, as a group, exhibited large, precipitous breaks in transition early in life followed by sweeping, expansive ones later. Furthermore, in addition to this overall regularity, the two female groups appeared to maintain this consistency in all areas - meaning the face was shown to advance as one homogeneuos unit, with each component transitioning more or less simultaneously, with only one or two years discerepancy at any given time. For the males, this was less so, which may indicate that men may be more variable depending on the area being analysed. Regrading both sexes, however, there seems to be something of note taking place in and around the fourth decade of life that, while present for both, appears to be especially pronounced in men. This is as yet unexplained and would undoubtedly benefit from future work. Lastly, it would also appear that loss of density (considered here to be category five and up) begins to affect age estimation at the pubic symphysis as early as the late thirties in nulliparous females, while, in parous females, that effect is delayed by several years. Moreover, as men tended to look older than females when assessed by axial image but younger when assessed by 3D rendering, it may also be posited that density, though equally affected in both, may exert less of an influence on the appearance of the male face than it does on that of the female.

6.2 Results of Applying the TCM to this Sample

As determined by the Suchey-Brooks assessment, females only were taken forward through further stages of analysis for this thesis. Therefore, as with Suchey-Brooks and Hartnett, the estimated age for each subject was contrasted with her questionnaire answers in an effort to reveal any lifestyle factors that may have played a role regarding the reliability of the TCM evaluation. The results of this mixed effects (GLM) "cross-referencing" are provided below as *Table 9*.

Table 9: The effect of lifestyle variables on the study sample, TCM analysis

Parameter / Variable	P Value	Effect Size
Height	0.733	
Weight	0.067	
Body Shape	0.495	
Race / Ancestry	0.432	
Activity Level	**0.028**	0.72
Twisting Movements	0.886	
Stabilising Movements	0.486	
Osteitis Pubis	0.083	
UTI History	0.766	
Arthritis	0.413	
Osteoporosis	0.566	
Diet	0.838	
Tobacco	**0.002**	1.33
Alcohol	0.556	
Pregnancy Status	0.684	
- Times Pregnant	0.686	
- Times Given Birth	0.677	
- Age at First Birth	0.562	
- SPD	0.296	
- Epidural	0.292	
- Caesarean Section	0.647	
- Multiple Births	0.224	
- Birth Weight	0.558	

- Length of Labour	0.631	
- Births Breast Fed	0.833	
Hormone Replacement	0.667	
Contraception	0.142	
Menopause	**< 0.0001**	7.69
Age at Menopause	0.251	

Once again, participants' level of activity, whether they had or had not smoked tobacco, and whether they had or had not experienced menopause, were all statistically significant at the 5% level - echoing the results gained by both the Suchey-Brooks and Hartnett analyses of previous chapters.

When using the Suchey-Brooks method, parous women in this sample were under-aged by an average of nine to 10 years, while nulliparous were under-aged by an average of three to four years. By applying the TCM, however, this tendency was completely corrected (see *Figure 132*, page 263 of this chapter) - likely due to the "equalizing" effect of the density adjustment, which made the TCM more representative and, therefore, more effective on this older sample. Additionally, in discussing the benefit of adopting their component system, McKern and Stewart (1957:64) wrote "… component system[s are] flexible to the point where slight deviations in observation will not necessarily produce grave errors in age estimation." As it relies on averages, the same is true of the TCM. With its multiple components and variables, the usual source of error associated with archetypal techniques such as Suchey-Brooks - that individual variation is compressed into a narrowly applicable set of typological exemplars -

is drastically reduced as, even if one or two categories are scored incorrectly, the overall average may still lessen, or "absorb," the inconsistency.

By establishing a standard scoring system for all observers, it was originally hoped that subjectivity in phasing would be reduced or, if differing category decisions were made, they would be documented along the way, leading to a better understanding of where and how practitioners varied. However, though rough and in its infancy, over the course of this chapter the restructured and repurposed Truesdell Composite Method has been shown to be at least as effective as two of the field's established techniques - the Suchey-Brooks Method for Ageing the Os Pubis (1990) and the Hartnett method (2010) - for the purposes of estimating age from the pubic bones of the human skeleton.

It will be further demonstrated that the application of the TCM on this sample lead to a sevenfold increase in precision in ageing from the pubic symphysis, including improvements of 34.5% regarding estimations to within 10 years of actual age and 40.7% to within 5 years of actual age. This increased precision, in turn, allowed for more precision in the study's statistical analysis. These analyses will be detailed in the following chapter - "Results (Statistical Analysis)."

7

Results (Statistical Analysis)

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Abstract:

This chapter will present the results of various statistical analyses as applied to this sample. All analyses were performed using either the "R" open source computational program (version R-3.2.2) or the SAS statistical software package (2015 University Edition).

7.0 Proving the Model (Method)

In order to investigate any "interactions," or the potential effects of certain variables (in this case the questionnaire answers) on estimation accuracy, the TCM must first to be proven to be a good indicator of age. To do this, regression analysis was applied in the form of a basic general linear model (or "GLM") comparing the independent TCM variables (Density, Upper Boundary, Lower Boundary, Outline, Surface Texture, and Topography) with the response variable of age.

7.0.1 Diagnostic Checks for Normality

Before this was possible, however, checks had to be performed to confirm that each variable followed what is known as a "normal" distribution. Establishing normality ensures that all points of data are more or less equally spaced, which allows them to be compared more effectively (apples are more easily compared to other apples than they are to oranges). To test for normality, quantile-quantile, or "Q-Q," plots were produced for each.

7.0.1.1 Density

The first variable tested was that of density, which differed slightly from the other variables in that it was categorical rather than continuous in nature. For illustrative purposes, a normality line was inserted with the intercept (*Mu*, the mean) set at 10 and the slope (*sigma*, the standard deviation) at 2. Results of this analysis are presented as Figure 148 *(below)*.

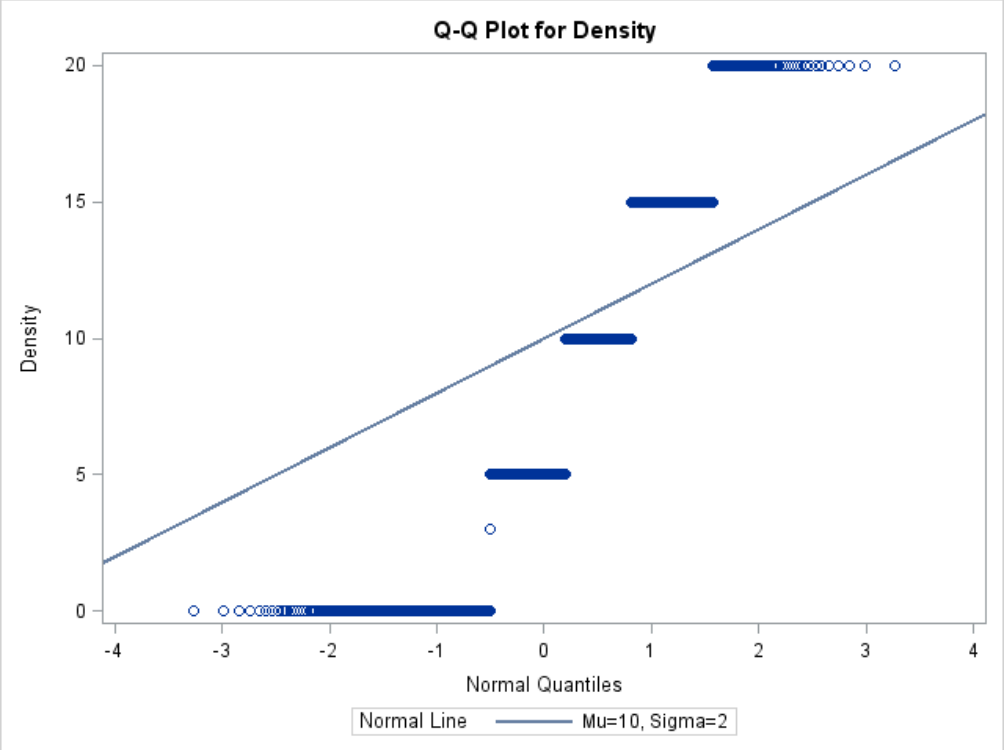


Figure 148: Q – Q Plot for Density

7.0.1.2 Upper Boundary

The second variable tested for normality was the "Upper Boundary." Again, for illustrative purposes, a normality line was inserted with the intercept (*Mu*, the mean) set at 10 and the slope (*sigma*, the standard deviation) set at 2. The results of this analysis are presented as Figure 149 *(below)*.

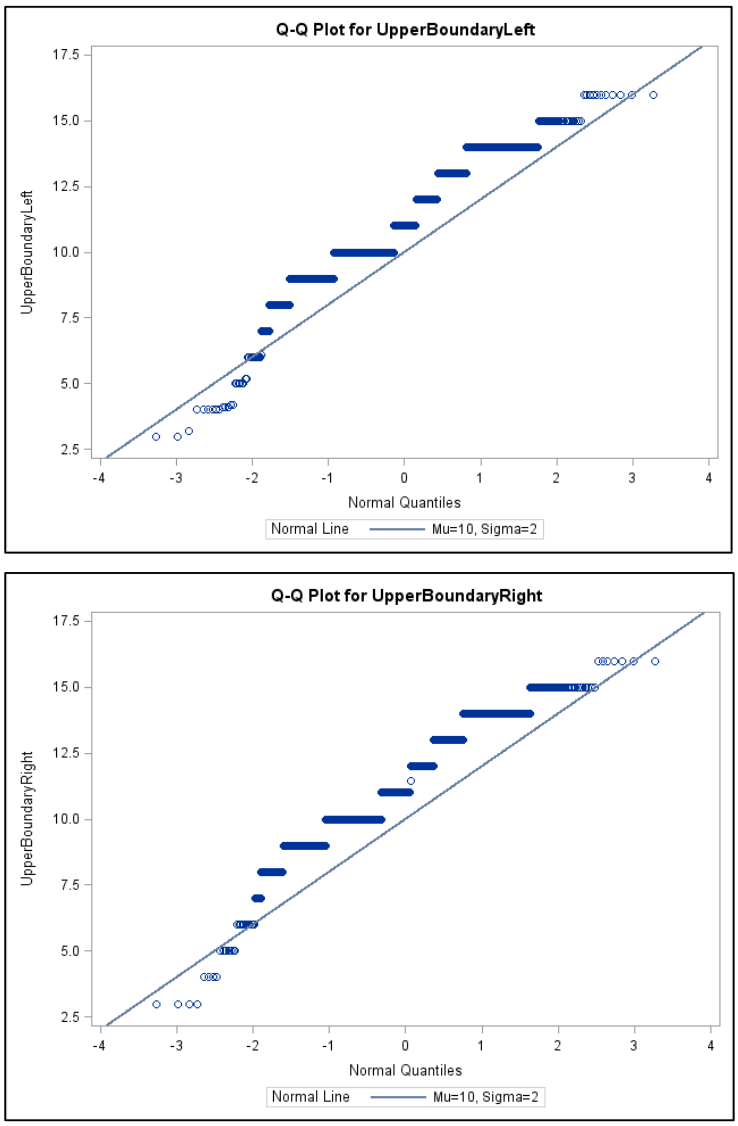


Figure 149: Q – Q Plots for Upper Boundary, Left (top) and Right (bottom)

7.0.1.3 Lower Boundary

The "Lower Boundary" component was third to be tested for normality. Once again, a normality line was inserted with the intercept (*Mu*, the mean) set at 10 and the slope (*sigma*, the standard deviation) set at 2. The results of this analysis are presented below as Figure 150.

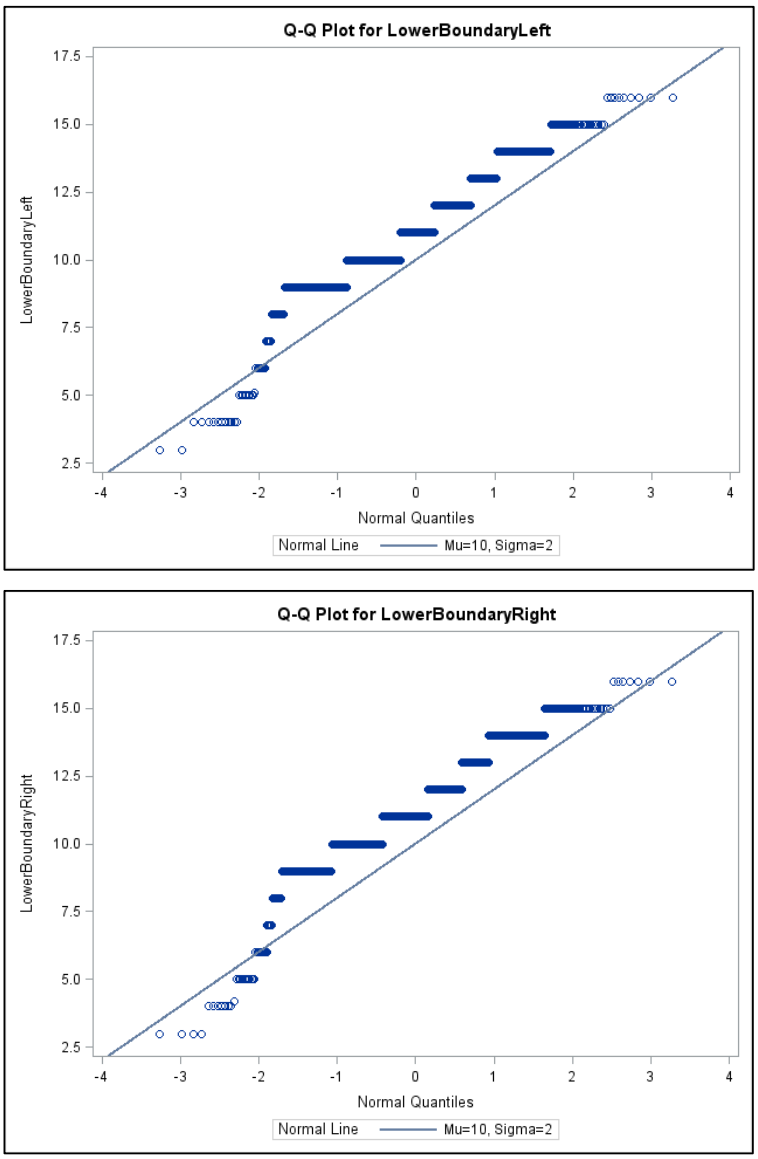


Figure 150: Q – Q Plot for Lower Boundary, Left (top) and Right (bottom)

7.0.1.4 The Outline

The fourth variable tested for normality was that of the "Outline." For clarity, a normality line was inserted with the intercept (*Mu*, the mean) set at 10 and the slope (*sigma*, the standard deviation) set at 2. The results of this analysis are presented below as Figure 151.

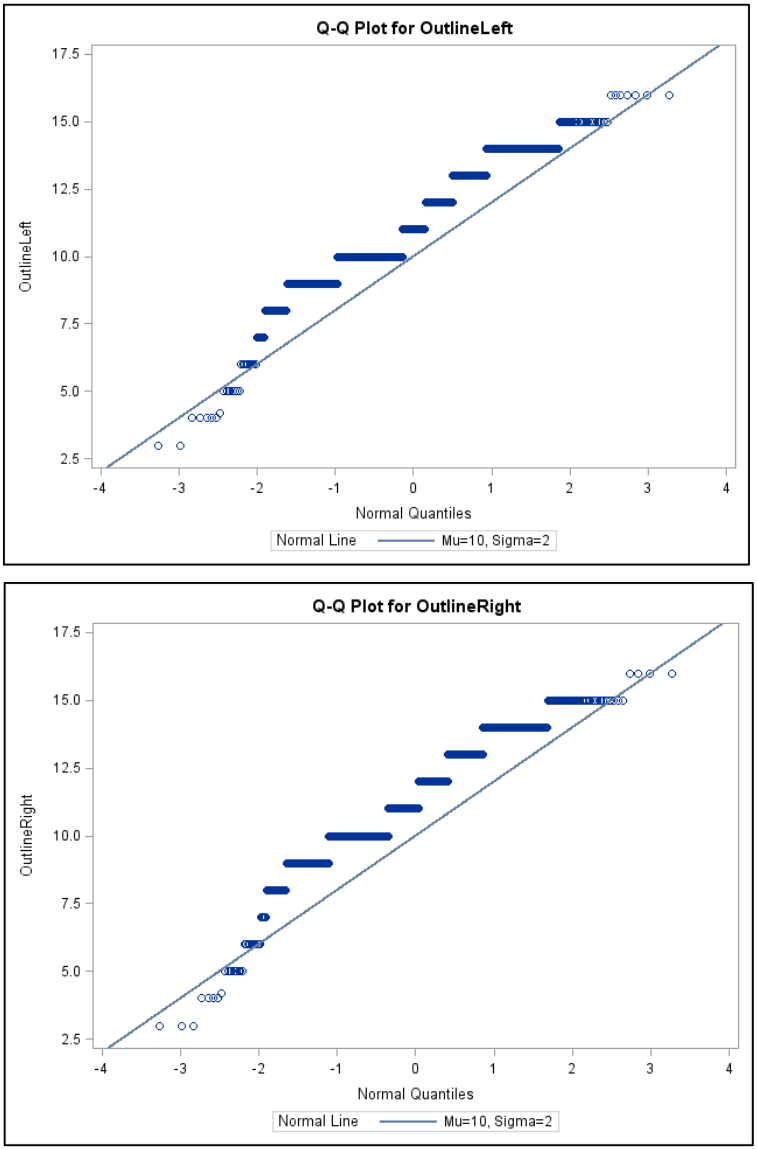


Figure 151: Q – Q Plots for the Outline, Left (top) and Right (bottom)

7.0.1.5 Surface Texture

"Surface Texture" was the fifth variable tested for normality in this study. As with the previous variables, a normality line was inserted with the intercept (*Mu*, the mean) set at 10 and the slope (*sigma*, the standard deviation) set at 2. The results of this analysis are presented as Figure 152 *(below)*.

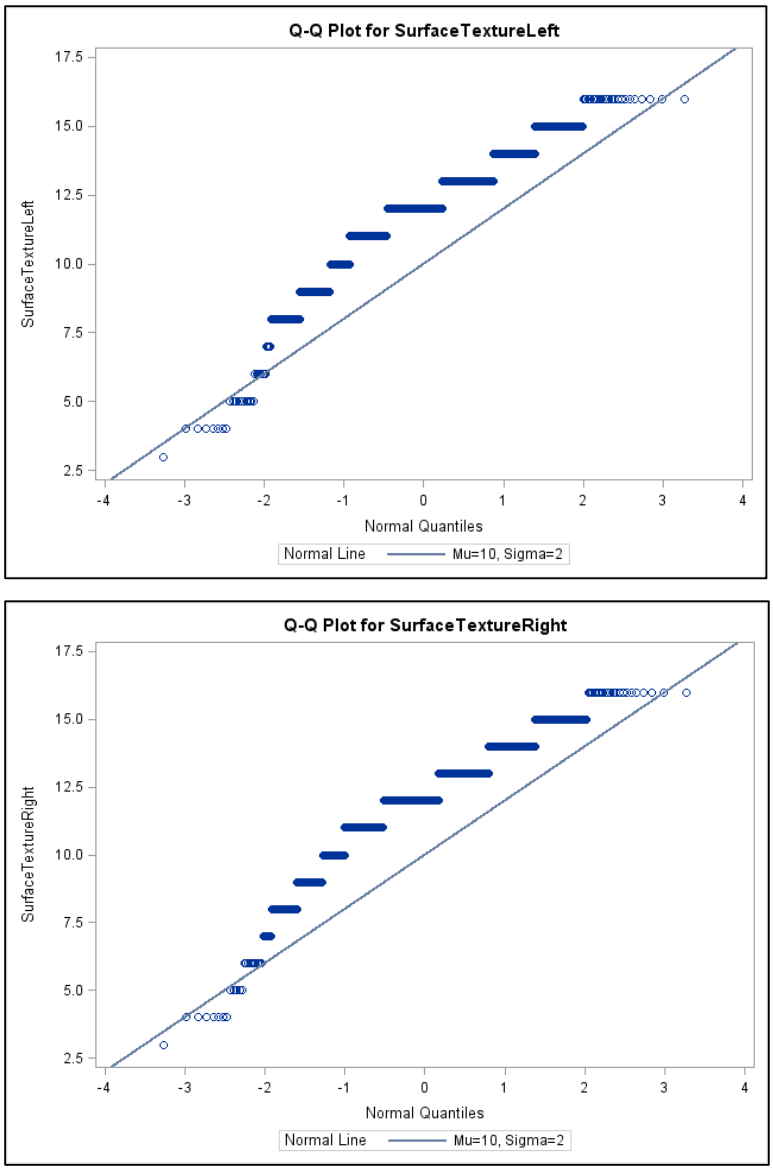


Figure 152: Q – Q Plot for Surface Texture, Left (top) and Right (bottom)

7.0.1.6 Topography

The last variable tested for normality was that of "Topography." For illustrative purposes, a normality line was again inserted with the intercept (*Mu*, the mean) set at 10 and the slope (*sigma*, the standard deviation) set at 2. Results of this analysis are presented below as Figure 153.

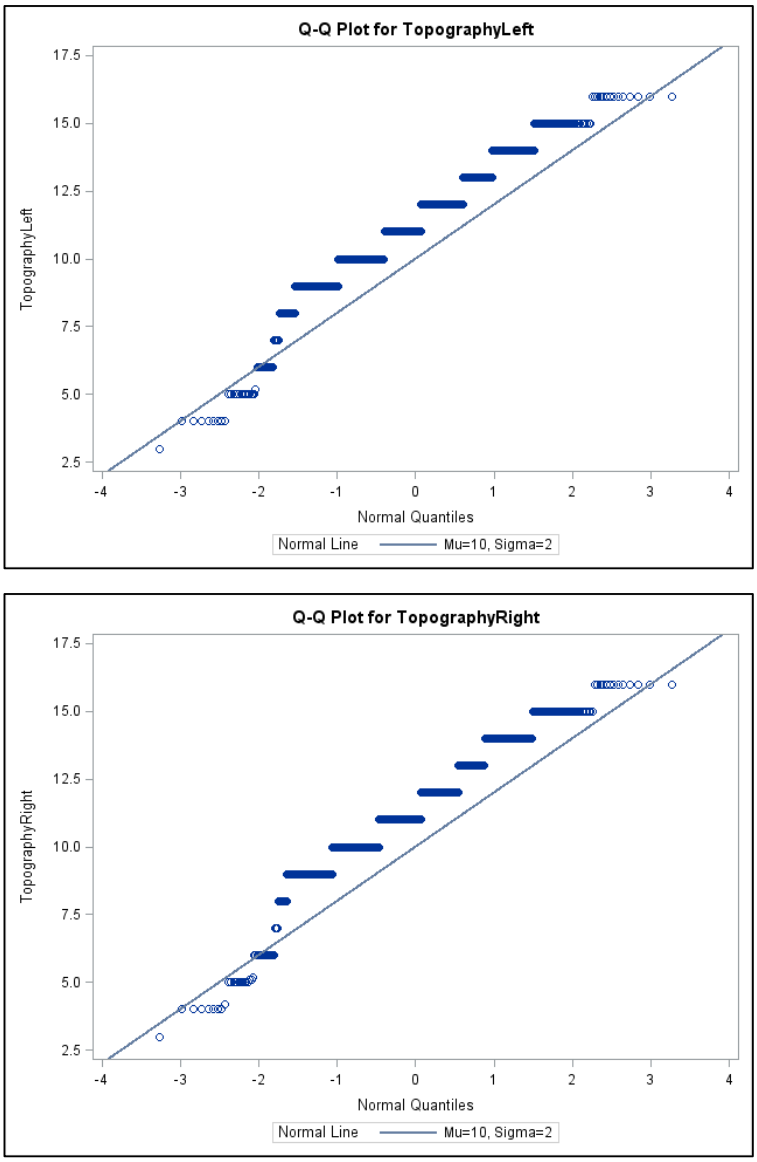


Figure 153: Q – Q Plot for Topography, Left (top) and Right (bottom)

7.0.1.7 Transformation of Density

After a comparison of the "Q-Q" plots for each component, it was concluded that Density was the only non-normal variable in need of transformation. This was likely due to its categorical nature, which skewed the distribution of the data. In order to transform the data to a distribution more in line with the other components, then, that categorical data had to be transformed into something more continuous. To do this, square roots were employed. Taking the square root of each density score, instead of the scores themselves, decreased the awkwardness of the data by narrowing the gaps, or intervals, between each point – thereby making them appear more continuous. The results of this transformation are presented below (Figure 154). As before, a normality line was added for better visualisation, and the parameters were adjusted accordingly to account for the smaller numbers (*Mu* to 2 and *sigma* to 1).

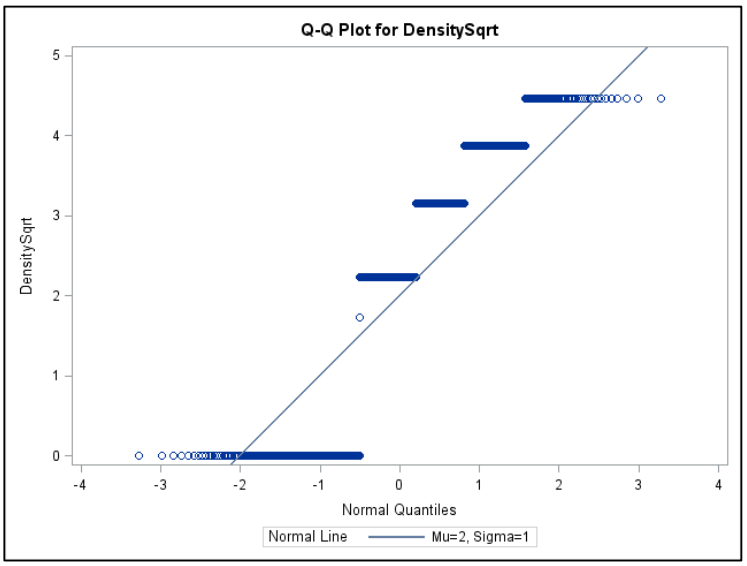


Figure 154: Q – Q Plot for Density Squared

As can be seen by juxtaposing the new plot against the original, the transformation of Density by square rooting exhibited a normalising effect by bringing things "into line" and allowing for more equal comparison with the other variables of the TCM.

7.0.1.8 Running the Regression

Once all the predictive variables had been normalised, the author fit a general linear model (or "GLM") to compare the independent TCM variables of "Density" (dens.sqrt), "Upper Boundary" (ub), "Lower Boundary" (lb), "Outline" (outl) "Surface Texture" (surftext), and "Topography" (top) against the response variable of "age." The resulting model is presented below (*Figure 155*).

```
> guess <- read.csv("Desktop/Dr. Lunn 5.csv", header = T)
> mod1 <- lm(Age ~ dens.sqrt + ub + lb + outl + surftext + top, data =
guess)
> summary(mod1)

Call:
lm(formula = Age ~ dens.sqrt + ub + lb + outl + surftext + top,
    data = guess)

Residuals:
    Min      1Q  Median      3Q     Max
-28.522  -2.741   0.337   3.401  21.934

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)   0.0379     1.1521   0.033   0.9738
dens.sqrt     4.8989     0.1251  39.165  < 2e-16 ***
ub            1.1249     0.2349   4.789 1.90e-06 ***
lb            0.7974     0.2004   3.979 7.35e-05 ***
outl          0.7058     0.2923   2.415   0.0159 *
surftext      1.1313     0.1640   6.897 8.82e-12 ***
top           0.8318     0.1585   5.247 1.84e-07 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 5.914 on 1122 degrees of freedom
  (106 observations deleted due to missingness)
Multiple R-squared:  0.8316, Adjusted R-squared:  0.8307
F-statistic: 923.7 on 6 and 1122 DF,  p-value: < 2.2e-16
```

Figure 155: The original TCM general linear model (model 1)

Noticeably, this model does not distinguish between the left and right sides for any given parameter. This is because in preliminary testing, asymmetry was taken into account but returned no meaningful significance. For some values, the left proved more beneficial but for others it was the right (*Table 10, below*). For this reason it was determined that there was not enough evidence to justify keeping the two sides separate and the left and right pubic bones were combined to increase the power of the overall analysis.

Table 10: Results for Asymmetry exhibiting mixed values

Parameter	Estimate	Standard Error	t Value	Pr > |t|
Intercept	-0.149850842	1.14507623	-0.13	0.8959
UpperBoundaryLeft	0.333472184	0.17991569	1.85	0.0641
UpperBoundaryRight	0.890910550	0.22916995	3.89	0.0001
LowerBoundaryLeft	0.173741112	0.17985646	0.97	0.3343 (NS)
LowerBoundaryRight	0.458261943	0.18395446	2.49	0.0129
OutlineLeft	0.481077017	0.23406880	2.06	0.0401
OutlineRight	0.239713776	0.26333128	0.91	0.3629
SurfaceTextureLeft	0.308770811	0.18914975	1.63	0.1029
SurfaceTextureRight	0.886351022	0.19812280	4.47	<.0001
TopographyLeft	0.262263065	0.13647252	1.92	0.0549
TopographyRight	0.562191920	0.13643045	4.12	<.0001
DensitySqrt	4.870890312	0.12473169	39.05	<.0001

Based on this regression (with sides combined), each of the six variables were found to be significant to the model's (and, therefore, the method's) ability to estimate age from the os pubis. Because of this, no single variable could be eliminated - though, surprisingly, "Outline" proved least diagnostic relative to the others. This is surprising as the current industry standard methods – chiefly the Suchey-Brooks and Hartnett methods - are based almost entirely upon outline.

7.0.1.8.1 Standard Diagnostics

Once this combined model had been established, routine diagnostic checks were applied to assess its efficacy. These included a "Box-Cox" test (at a power of 4/3) to determine homoscedasticity (or that variability is the same on both sides of the regression line), as well as a "Cook's Distance" test to look for any outliers exerting undue influence. The results of these analyses are presented below as Figure 156 (*below*).

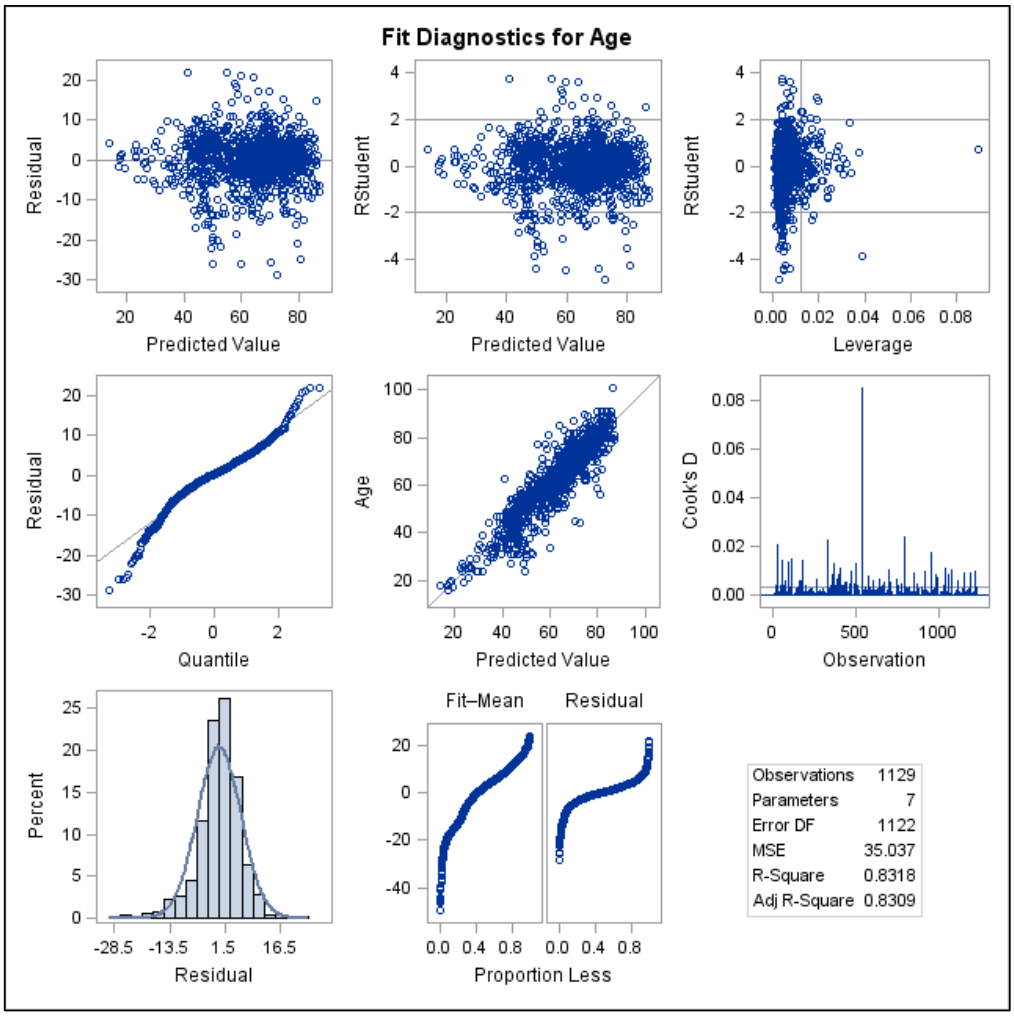


Figure 156: Routine Diagnostic Checks for TCM model 1

As can be seen, homoscedasticity (top left) was acceptable, all data followed normal distribution, and all points fit the regression lines nicely (if a bit "heavy tailed"). In running these diagnostics, however, "Cook's Distance" flagged up an outlier exerting too great an influence, potentially throwing off the model (preventing it from being as efficient as it could be). This outlier proved to be individual 537 and it was debated whether to eliminate him or her. As an obvious outlier, he or she was likely to be unrepresentative of the sample as a whole which would render his or her influence on the model unwarranted. There could also be an error at 537, making the interference equally as unjustified. The alternative was to leave 537 in, but with a note of caution. Ultimately, it was decided that individual 537 should be taken out of the data set. New diagnostics were run to incorporate this change. The adjusted results are presented as Figure 157 *(below)*.

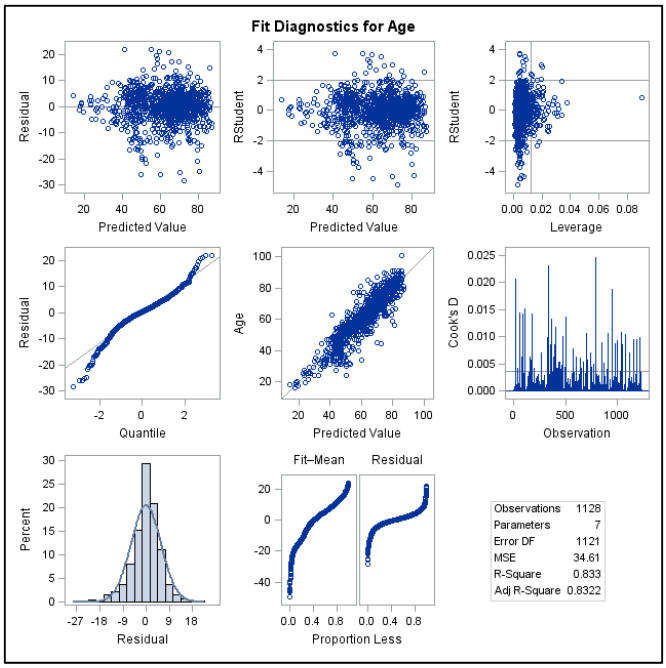


Figure 157: Adjusted diagnostic checks for TCM model 1

As can be seen, all information remained identical to the previous application with the exception of "Cook's Distance" which, through this exclusion, became unexceptional. The adjusted R-Squared value (which quantifies how much of the data's variation can be explained by a given model) increased marginally from 0.8308 to 0.8322 as a result of this change, but remained 83% overall.

Lastly, age – as the response variable – was tested as final check for normality. The results of this test are provided below (*Figure 158*).

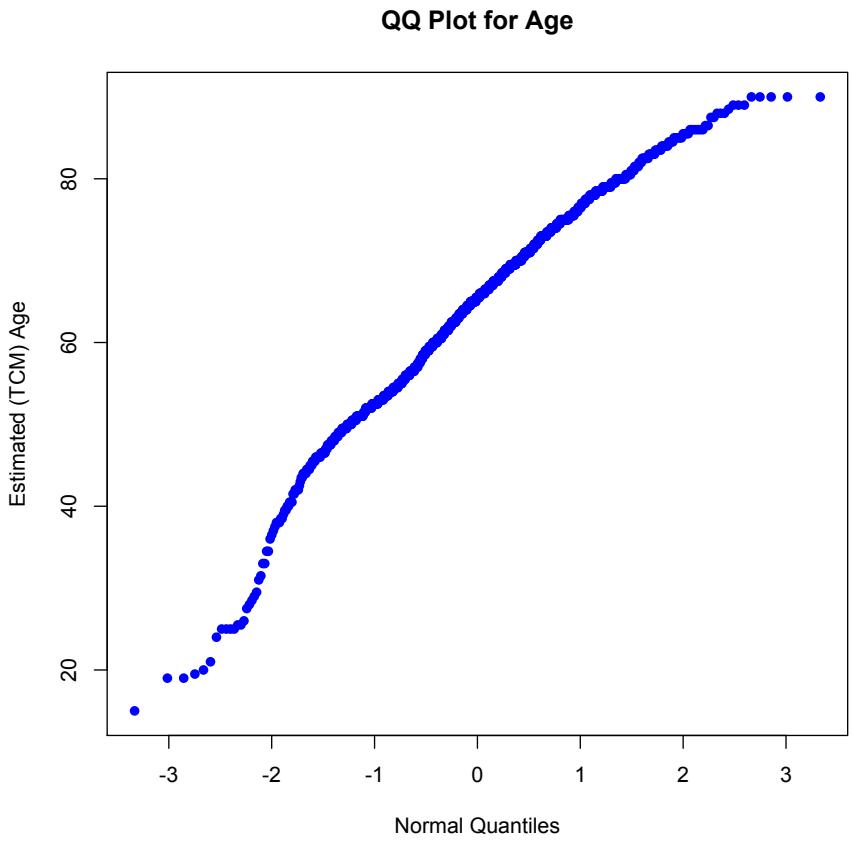


Figure 158: Q-Q Plot for Age

With all relevant diagnostic checks for normality and homoscedasticity performed and adjusted for where necessary, and with this resulting in an overall R-value of 83%, this model (and therefore the Truesdell Composite Method) was proven, statistically, to be a good indicator of age for this sample.

7.1 Linear Effects

Once the TCM had been proven a reliable predictor of age, the author was then able to "add in" additional variables to ascertain whether any outside factors could influence how well the method worked. This was done by performing a series of "linear effects," a process by which each "unknown" (a variables such as height or weight) is pitted against the proven model, one by one, to establish statistical significance.

7.1.1 First Tier Testing

Because there were so many questions and follow-up questions asked of each patient to ensure as much explanatory detail as possible (see Materials and Methods, "Questionnaire"), when performing these linear effects the author first limited the investigation to a series of broad but representative groupings. Before blindly and exhaustively testing each and every pregnancy related variable (of which there were nearly 100), for example, a more efficient initial step was to establish whether or not pregnancy had any impact at all. In other words, if pregnancy as a whole evidenced no significant impact on estimation

accuracy, it would have been inefficacious to spend time assessing differences in sub-variables such as duration of labour for second versus third deliveries, or the administration of epidural for single versus multiple births.

With this in mind, the following variables were tested during the first tier:

To test for associations regarding body composition;

1.) *Height (Questionnaire, question 3)*
2.) *Weight (Questionnaire, question 8)*
3.) *Body Shape (Questionnaire, question 9)*

To test for an associations regarding Race or Ethnicity;

4.) *Self-Identified Ethnicity (Questionnaire, question 4)*

To test for associations regarding physical / mechanical activity;

5.) *Activity Level (Questionnaire, question 11)*
6.) *Twisting Movements (Questionnaire, question 12)*
7.) *Stabilisation (Questionnaire, question 13)*

To test for associations regarding inflammation / infection;

8.) *Osteitis Pubis (Questionnaire, question 14)*

9.) UTI history (Follow-up, question 14)

To test for associations regarding bone mass and / or age related change;

10.) Presence of Osteoarthritis (Questionnaire, question 15)

11.) Osteoporosis or Osteopenia (Follow-up, question 15)

12.) Menopause (Questionnaire, question 32)

To test for associations regarding nutritional history and status;

13.) Diet (Questionnaire, question 16)

To test for associations regarding substance use;

14.) Tobacco Use (Questionnaire, question 17)

15.) Alcohol Consumption (Questionnaire, question 19)

To test for associations regarding the supplementation of artificial hormones;

16.) HRT or other hormone supplementation (Questionnaire, question 30)

17.) Use of hormonal Contraception (Questionnaire, question 31)

To test for associations regarding pregnancy and/or pregnancy status;

18.) History of Pregnancy (Questionnaire, question 21)

These questions were chosen as, while broad enough to envelope several sub-questions each, still carried enough specificity to be immediately diagnostic in either including or excluding relatively large swaths of data. The results of these linear effects are presented as Table 11 *(below).*

Table 11: Results of "first tier" significance testing (TCM)

Parameter / Variable	Significance (Effect Size)
Height	0.733
Weight	0.067
Body Shape	0.495
Race / Ethnicity	0.432
Activity Level	**0.028 (**0.72)
Twisting Movements	0.886
Stabilising Movements	0.486
Osteitis Pubis	0.083
UTI History	0.766
Arthritis	0.413
Osteoporosis	0.566
Diet	0.838
Tobacco	**0.002 (**1.33)
Alcohol	0.556
Pregnancy Status	**< 0.0001** (6.41)
Hormone Replacement	0.667
Contraception	0.142
Menopause	**< 0.0001 (**7.69)
Age at Menopause	0.251

Based upon this first tier, or round, of analysis, all but four of the variables tested proved to be statistically insignificant when applied to the model and could, therefore, be eliminated or "ruled out" as impactful. The four variables that did prove significant, and therefore warrant further investigation, were those of "Activity Level," "Tobacco Use," "Pregnancy Status," and "Menopause."

7.1.2 Second Tier Testing

During the first round of linear effects testing, four variables (or four potential influences to the efficacy of the model), were found to be significant. Because of this, these variables – "Activity Level," Tobacco Use," "Pregnancy Status," "Menopause" - were explored in greater detail.

As the most sensitive of the three methods (in terms of precision of estimation accuracy), first tier testing had been performed using the TCM alone (this was also because it was not necessary to prove already existing models / methods). For these variables, however, testing against all three methods (the TCM, Suchey-Brooks, and Hartnett) was also included to confirm continuity.

7.1.2.1 Pregnancy Status (Parity)

The first variable to be looked into in greater depth was that of parity, or pregnancy status. In creating the data set, males, parous females (those with a history of at least one pregnancy), and nulliparous females (those with no pregnancy history) were recorded as either "M," "P," or "N," respectively. This allowed for simultaneous comparisons between the sexes (males and females) as well as within sex (pregnancy history categories).

As "Pregnancy Status" had been established as highly significant with a p-value of <0.0001 (TCM), the following explanatory variables were also investigated in

an attempt to determine exactly what *about* pregnancy, or the lack there of, was proving significant to the model, and therefore, age estimation. For reasons previously detailed, for this initial exploration data was limited to first births only. As before, should significance have arisen in any area, second and third births would then have also been compared. Results of this inquiry are presented below (*Table 12*).

Table 12: Significance testing for parity related variables (all methods)

Parameter / Variable	Suchey-Brooks	Hartnett	TCM
Times Pregnant	0.846	0.772	0.686
Times Given Birth	0.895	0.552	0.677
Age at First Birth	0.994	0.999	0.562
SPD / PPGP	0.151	0.143	0.296
Epidural	0.193	0.165	0.292
Caesarean Section	0.233	0.084	0.647
Multiple Births	0.171	0.493	0.224
Birth Weight	0.614	0.796	0.558
Length of Labour	0.796	0.267	0.631
Births Breast Fed	0.519	0.448	0.833

As can be seen, none of these explanatory questions returned p-values small enough to be considered significant, though SPD / PPGP ("Symphysis Pubis Dysfunction / Pregnancy related Pelvic Girdle Pain") for the Suchey-Brooks method did present as borderline. Reasons for this remain unclear.

As no pregnancy related variables returned significant findings for any of the three methods, it was determined that pregnancy itself was likely *not* the causative agent in this variable's significance to the model and, therefore, to the accuracy of age estimation from the pubic bones - effectively eliminating both the hormonal impact of pregnancy as well as the localised physical or

mechanical strain of labour (the first study to do so). Given these values, the significance exhibited by "Pregnancy Status" (recorded as "M," "N," and "P") is more likely due to the sex of the individual, and not parity status at all. Indeed, when parity status is uncoupled from sex, values change to the following:

Table 13: Second tier significance testing (all methods)

Parameter / Variable	Suchey-Brooks	Hartnett	TCM
Height	0.756	0.734	0.733
Weight	0.071	0.067	0.067
Body Shape	0.450	0.486	0.495
Race / Ancestry	0.459	0.496	0.432
Activity Level	**0.033** (0.69)	**0.047** (0.73)	**0.028** (0.72)
Twisting Movements	0.977	0.892	0.886
Stabilising Movements	0.487	0.486	0.486
Osteitis Pubis	0.063	0.083	0.083
UTI History	0.910	0.720	0.766
Arthritis	0.441	0.404	0.413
Osteoporosis	0.479	0.559	0.566
Diet	0.645	0.846	0.838
Tobacco	**0.010** (1.85)	**0.002** (1.33)	**0.002** (1.33)
Alcohol	0.482	0.537	0.556
Pregnancy Status	0.062	0.631	0.684
- Times Pregnant	0.846	0.772	0.686
- Times Given Birth	0.895	0.552	0.677
- Age at First Birth	0.994	0.999	0.562
- SPD	0.151	0.143	0.296
- Epidural	0.193	0.165	0.292
- Caesarean Section	0.233	0.084	0.647
- Multiple Births	0.171	0.493	0.224
- Birth Weight	0.614	0.796	0.558
- Length of Labour	0.796	0.267	0.631
- Births Breast Fed	0.519	0.448	0.833
Hormone Replacement	0.720	0.762	0.667
Contraception	0.247	0.259	0.142
Menopause	**< 0.0001** (7.69)	**< 0.0001** (7.89)	**< 0.0001** (7.69)
Age at Menopause	0.261	0.240	0.251

7.1.2.2 Activity Level

At significances of 0.033 (Suchey-Brooks), 0.047 (Hartnett), and 0.028 (TCM), the second variable to be investigated in further detail was that of "Activity Level." This effect was seen across the entirity of sample and did not depend on sex or method. Regarding activity, participants in this study were asked to choose between four categories – immobile, light, moderate, and active (for descriptions of each, see chapter 2 – "Materials and Methods"). As only 12 participants identified as "immobile," for this assessment they were collapsed into the next lowest category, "light." This combined category was then set as the reference level (*Table 14*).

Table 14: Significance - Activity Level

Category	p - value
Immobile	Reference Level
Light	
Moderate	0.091
Active	0.020

As can be seen, the difference between the light / immobile and active categories is statistically significant. It is, therefore, this difference that prompted the low p-value for Activity Level in the optimum model.

Incidentally, while not itself significant, the moderate category nevertheless "trends" towards significance. This makes sense, as activity then becomes "stepped," with less activity being less significant and more activity being more significant.

7.1.2.3 Tobacco Use

With p-values of 0.010 (Suchey-Brooks), 0.002 (Hartnett), and 0.002 (TCM), the third variable flagged up as significant by the first round of linear effects testing was that of "Tobacco Use." This effect was seen across the entirity of the sample and was not male or female dependent.

Unfortunately, despite its high significance, the author was advised against pursuing tobacco use as part of this study as to do so would mean cutting the sample in half (as only "yes" would be relevant), then further dissecting that already smaller sample into even smaller segments to assess each individual variable. This would not only mean reformulating an already working model, but would also lead to weakened, less powerful results. For this reason it was decided that further investigation into the effects of nicotine on ageing from the os pubis could not receive the justice it deserved at this time and should therefore be considered future work, as a purposefully recruited study with more controls and specificity would be more effective.

7.1.2.4 Menopause

Of the three significant factors given closer looks as a result of first tier testing, Menopause was, by far, most influential (with p-values of < 0.0001 in each method). Additionally, of the three factors, menopause also returned the largest effect size across all methods - 7.69, 7.69, and 7.89 (followed by Tobacco,

then Activity). The only follow-up question regarding menopause, however, was "age at menopause." When tested, this returned a p-value of 0.251 and was, consequently, not significant. Furthermore, as the potential influence of hormone replacement therapy, or "HRT" (commonly prescribed to alleviate discomfort during menopause), had already been eliminated during the first round, it was determined that the significance of menopause came down to whether a woman had or had not experienced it. This does not appear to be a direct influence, however, but rather an indirect one – the mechanism of menopause appears to be its effect on density.

Lastly, that menopause carried such a high significance for this sample may also be linked to its demographics in that over half of the participants in this study were over 50 years of age.

7.2 Interactions

Once the initial "linear effects" had been completed (by which all but "activity," "menopause," and "tobacco use" were systematically eliminated as non – significant to the model), the next step regarding interpretation was that of investigating "interactions" – which may perhaps best be described as determining circumstantial relationships between individual variables under various conditions. Often exemplified by the idea of "Fischer's cats," a more accessible example might be that of a growing seedling.

For a plant to grow, it may be hypothesized that soil, water, and sunlight are all required. Indeed, during initial testing the three do form a working model (meaning that under the tested conditions, in the presence of soil [variable one], water [variable two], and sunlight [variable three], seedlings did, in fact, grow). What this initial test does not establish, however, is whether all three variables were equally important to that growth or whether one or more of them may have exhibited more influence than the others. In other words, if sunlight (or soil or water) had been left out, would the seedling have grown equally well (meaning the missing variable had no significant effect on the growth of the seedling and could, therefore, be eliminated from the process) or would its success have been compromised? Further to this, would it have grown equally well in the presence of sunlight and soil, but in the absence of water, as it would have if water had been present, but not soil? Alternately, would the seedling have failed to grow unless all three were present? Does an optimal combination exist to ensure that a seed will germinate to its full potential every time?

Similarly, to establish whether any variables could be pruned from the TCM without compromising its effectiveness, tests for interactions were performed.

7.2.1 The Baseline

As previously presented ("Running the Regression" - section 7.0.1.8), preliminary modeling indicated that, of the TCM variables tested - "Density" (dens.sqrt), "Upper Boundary" (ub), "Lower Boundary" (lb), "Outline" (outl) "Surface Texture" (surftext), and "Topography" (top) - all were significant to the

success of the ageing outcome and, therefore, none could be eliminated *(Figure 159, below)*.

```
> mod1 <- lm(Age ~ dens.sqrt + ub + lb + outl + surftext + top, data =
guess)
> summary(mod1)

Call:
lm(formula = Age ~ dens.sqrt + ub + lb + outl + surftext + top,
    data = guess)

Residuals:
    Min      1Q  Median      3Q     Max
-28.522  -2.741   0.337   3.401  21.934

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)   0.0379     1.1521   0.033   0.9738
dens.sqrt     4.8989     0.1251  39.165  < 2e-16 ***
ub            1.1249     0.2349   4.789 1.90e-06 ***
lb            0.7974     0.2004   3.979 7.35e-05 ***
outl          0.7058     0.2923   2.415   0.0159 *
surftext      1.1313     0.1640   6.897 8.82e-12 ***
top           0.8318     0.1585   5.247 1.84e-07 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 5.914 on 1122 degrees of freedom
  (106 observations deleted due to missingness)
Multiple R-squared:  0.8316, Adjusted R-squared:  0.8307
F-statistic: 923.7 on 6 and 1122 DF,  p-value: < 2.2e-16
```

Figure 159: Regression results for the basic TCM (model 1)

These variables produced an "Adjusted R - Squared" value of 0.8308, which means they can be used to explain 83% of the variation seen in this data set (*Figure 160)*. In this study, variation was based on the accuracy or inaccuracy of individual estimations. Therefore, it may reasonably be concluded that approximately 1,030 of the 1,238 participants in this study were aged accurately using these six variables alone (the TCM).

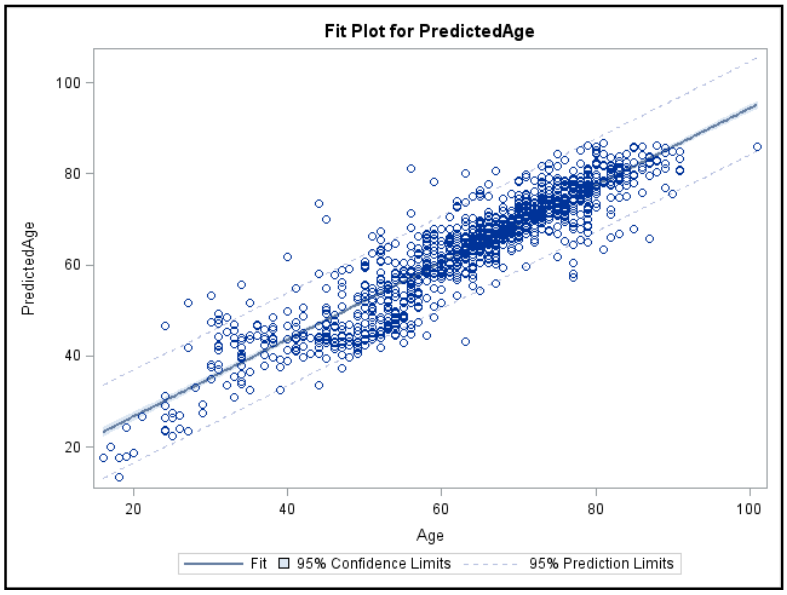


Figure 160: Fit plot - basic TCM (model 1)

Once the efficacy of the six variable method (the TCM) had been established, the author could then work to improve estimation accuracy for the 17% of participants for which the basic TCM was not correct. This was done by adding additional variables to the model to increase specificity.

Recall the analogy of the growing seedling and assume that, like the model above, all three variables – water, soil, and sunlight - contributed equally to the success of the plant. How will the outcome be effected when additions to the optimum model, such as the use of fertiliser or the playing of music, are added? Similarly, what will happen to the age estimation model when sex is accounted for and the significant variables of "Activity," "Menopause," and "Tobacco Use" are added?

7.2.2 Adding One Known Variable (Sex)

As “sex” flagged up as significant during the first round of linear effects testing (under the guise of “Pregnancy Status”), it was added to the TCM model in the hope that increased specificity would decrease unexplained variation. The results are presented as Figures 161 and 162 *(below)*.

As can be seen, with this change the adjusted R - Squared value of this second model increased from 83% (.8307) to 84% (0.8445) – a precision increase of 1%.

```
> mod2 <- lm(Age ~ Sex*(dens.sqrt + top) + ub + lb + outl + surftext, data =
guess)
> summary(mod2)

Call:
lm(formula = Age ~ Sex * (dens.sqrt + top) + ub + lb + outl +
    surftext, data = guess)

Residuals:
     Min       1Q   Median       3Q      Max
-29.4109  -2.4201   0.3368   3.0984  21.2911

Coefficients:
              Estimate Std. Error t value Pr(>|t|)
(Intercept)    -1.5574     1.3874  -1.123   0.2619
SexM            5.1534     2.1248   2.425   0.0155 *
dens.sqrt       3.2858     0.2324  14.136  < 2e-16 ***
top             1.3610     0.1710   7.957 4.29e-15 ***
ub              0.9885     0.2260   4.374 1.33e-05 ***
lb              0.8410     0.1963   4.285 1.98e-05 ***
outl            0.6949     0.2805   2.477   0.0134 *
surftext        1.1044     0.1593   6.932 7.01e-12 ***
SexM:dens.sqrt  2.6813     0.2804   9.562  < 2e-16 ***
SexM:top       -1.0040     0.2011  -4.994 6.87e-07 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 5.67 on 1119 degrees of freedom
  (106 observations deleted due to missingness)
Multiple R-squared:  0.8457, Adjusted R-squared:  0.8445
F-statistic: 681.5 on 9 and 1119 DF,  p-value: < 2.2e-16
```

Figure 161: Regression results for the intermediate TCM (model 2)

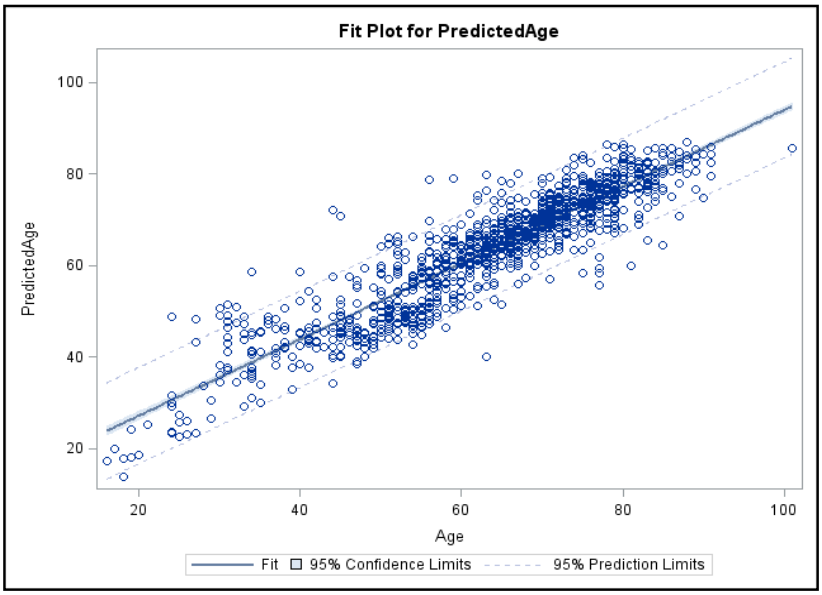


Figure 162: Fit plot - intermediate TCM (model 2)

7.2.3 Adding All Known Variables (Parity + Activity + Menopause + Tobacco Use)

The second, third, and fourth variables found to be significant by linear effects testing were those of "Activity," "Tobacco Use," and "Menopause." In the interest of increasing specificity, they, too, were added to the model, as was parity status (which defines sex at the same time). The results of those additions are presented below as *Figures 163 and 164*.

```
> mod3 <- lm(Age ~ Menopause*(dens.sqrt + top) + ub + lb + outl + surftext +
Tobacco + Action + Pregnancy.Status, data = guess)
> summary(mod3)

Call:
lm(formula = Age ~ Menopause * (dens.sqrt + top) + ub + lb +
    outl + surftext + Tobacco + Action + Pregnancy.Status, data = guess)

Residuals:
     Min       1Q   Median       3Q      Max
-27.7225  -2.6582   0.2223   3.0584  21.5713

Coefficients:
                    Estimate Std. Error t value Pr(>|t|)
(Intercept)           7.7071     1.8121   4.253 2.29e-05 ***
MenopauseN           -3.3301     3.6305  -0.917 0.359212
MenopauseY           -4.3619     2.7916  -1.562 0.118461
dens.sqrt             5.9581     0.1576  37.809  < 2e-16 ***
top                   0.5449     0.1946   2.800 0.005203 **
ub                    1.0058     0.2203   4.566 5.53e-06 ***
lb                    0.6835     0.1918   3.563 0.000383 ***
outl                  0.5962     0.2716   2.195 0.028380 *
surftext              0.8747     0.1625   5.383 8.95e-08 ***
TobaccoY             -1.6351     0.4131  -3.958 8.04e-05 ***
ActionA              -1.2178     0.5336  -2.282 0.022680 *
ActionM              -0.7019     0.3721  -1.886 0.059508 .
Pregnancy.StatusN     2.0967     1.6260   1.290 0.197493
Pregnancy.StatusP     4.1134     1.6848   2.441 0.014785 *
MenopauseN:dens.sqrt -1.5545     0.9487  -1.639 0.101580
MenopauseY:dens.sqrt -3.2098     0.2835 -11.324  < 2e-16 ***
MenopauseN:top       -0.2745     0.3739  -0.734 0.462910
MenopauseY:top        0.7707     0.2069   3.726 0.000205 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 5.44 on 1098 degrees of freedom
  (119 observations deleted due to missingness)
Multiple R-squared:  0.8591, Adjusted R-squared:  0.8569
F-statistic: 393.7 on 17 and 1098 DF,  p-value: < 2.2e-16
```

Figure 163: Regression results for the optimum TCM (model 3)

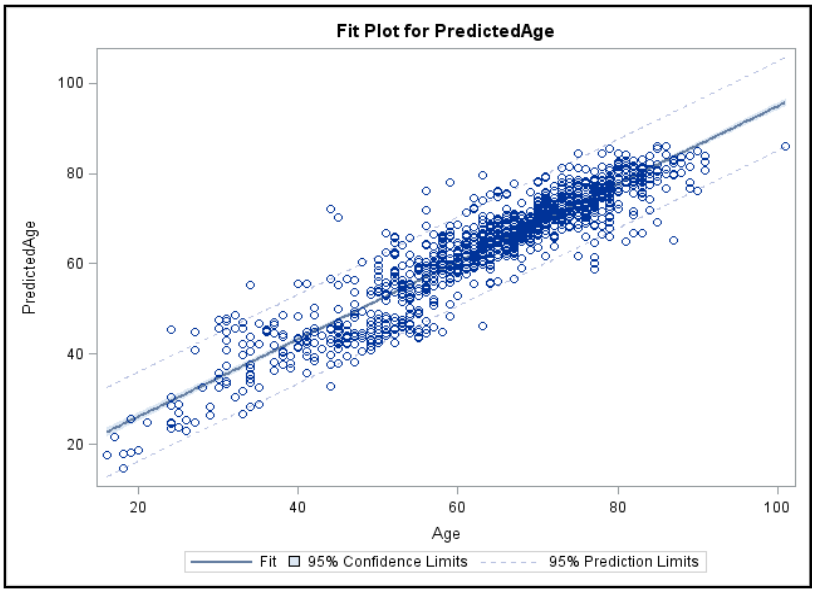


Figure 164: Fit plot - optimum TCM (model 3)

As evidenced by this last model, at which point all of the variables found significant by this study had been included, the final (and therefore best) adjusted R - Squared value had risen to 0.856, or 86% - representing a 3% increase over the basic TCM model's 83%. This means that, by including the additional information of sex, activity, tobacco use, and menopause, the percentage of unexplained variation in this sample fell from 17% to 14%.

7.3 Life History and Method Accuracy

The importance of this type of life history information may be further demonstrated by the additional step of including actual as well as estimated age into the model. By doing so, the role of context and its effect on the precision of the model itself may be investigated (*Figure 165, below*).

```
Call:
lm(formula = TCMAge ~ ActualAge + Menopause * (dens.sqrt + top) +
    ub + lb + outl + surftext + Tobacco + Action + Pregnancy.Status,
    data = guess)

Residuals:
    Min      1Q  Median      3Q     Max
-10.597  -1.042   0.012   0.738  37.285

Coefficients:
                    Estimate Std. Error t value Pr(>|t|)
(Intercept)          0.74572    0.70405   1.059 0.289750
ActualAge            0.07606    0.01163   6.541 9.37e-11 ***
MenopauseN           0.83702    1.39942   0.598 0.549883
MenopauseY           0.07544    1.07757   0.070 0.944198
dens.sqrt            3.50019    0.09215  37.982  < 2e-16 ***
top                  0.80015    0.07543  10.608  < 2e-16 ***
ub                   1.01098    0.08569  11.799  < 2e-16 ***
lb                   0.99779    0.07436  13.418  < 2e-16 ***
outl                 0.84348    0.10493   8.038 2.34e-15 ***
surftext             0.90660    0.06362  14.249  < 2e-16 ***
TobaccoY            -0.03124    0.16056  -0.195 0.845764
ActionA             -0.49396    0.20610  -2.397 0.016709 *
ActionM             -0.33878    0.14366  -2.358 0.018537 *
Pregnancy.StatusN   -1.36610    0.62696  -2.179 0.029550 *
Pregnancy.StatusP   -1.35000    0.65091  -2.074 0.038312 *
MenopauseN:dens.sqrt -1.37506    0.36597  -3.757 0.000181 ***
MenopauseY:dens.sqrt -1.08966    0.11547  -9.437  < 2e-16 ***
MenopauseN:top       0.12031    0.14410   0.835 0.403974
MenopauseY:top       0.11816    0.08031   1.471 0.141494
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 2.096 on 1096 degrees of freedom
  (120 observations deleted due to missingness)
Multiple R-squared:  0.9713,  Adjusted R-squared:  0.9709
F-statistic:  2062 on 18 and 1096 DF,  p-value: < 2.2e-16
```

Figure 165: The optimum model including both actual and estimated age

By eliminating the variable of actual age, significant contextual variables may be isolated and examined. In this way, two people of the same age may be compared with equivalency, or with “all things being equal.” By doing this, it can be seen that lifestyle factors accounted for approximately 3% of variation in this sample (as, by controlling for age, the R-Squared increased to 97%). Within that 3%, it appears that density exerts the most influence over the variables in question. For example, in the case of menopause, the higher the density level (i.e. the less dense the trabecular bone), the larger the residual - meaning the “older” a bone looks, the more error is introduced when estimating its age (as would be expected). Density is, therefore, proportionately linked with precision

in this model. This is significant to this study as several biological and lifestyle factors – tobacco, level of activity, parity status, and menopause - have been shown to directly affect density, again highlighting the importance of taking life history into account when estimating age from the human skeleton. Also verified by this model was the slightly "younger" facial appearance of nulliparous females when compared to parous females, corroborating the findings discussed in section 6.2 of the previous chapter, while maintaining the nearly identical status of parous and nulliparous females when compared with males, corroborating the earlier finding of the two female catergories grouping closer to each other than either is to males (supporting this thesis's advocation of separate templates).

Additionally, this type of investigation also allows the practitioner to make predictions about the differential influences of lifestyle. For example, according to this model, those individuals who reported smoking tobacco appeared to be slightly "older" in terms of age estimation when compared with those who did not. The same may be said for activity (again, likely due to the increased osteoclastic activity of the older sample), as well as sex (with females appearing "older" than males, as expected). The utility of these predicitions will be further illustrated in the following section.

7.4 Predictions

In addition to exhibiting the relationship between variables and their effects on overall efficacy, each of the above models may also be made predictive, meaning that they may also be used to estimate age.

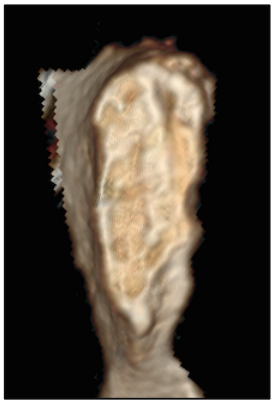


Figure 166: Volume (3D) rendered image of a symphyseal face

In the previous chapter, the individual to the left *(Figure 166*) received scores of 5 + 13 + 12 + 13 + 13 + 13. Assuming that each had equal influence, an age of 69 years was estimated. Prediction equations work by assigning "weight," or how much each variable is worth in relation to the others, to each individual variable. Those weights are then either added or subtracted from a "reference." To illustrate this, the basic five component + density adjustment TCM model (model 1 - see above, section 7.3.1) will again be used, but instead of keeping the variables unweighted for ease of use and simply adding them as whole numbers (the TCM without intervention), these same scores will be weighted and computed via statistical equation. For the above individual, this translates to:

0.04 (as the intercept) + (4.90 x density squared) + (1.12 x Upper Boundary score) + (0.80 x Lower Boundary Score) + (0.71 x Outline Score) + (1.13 x Surface Texture Score) + (0.83 x Topography Score)

For TCM scores of 5 for Density, 13 for Upper Boundary, 12 for Lower Boundary, 13 for Outline, 13 for Surface Texture, and 13 for Topography, this equation became the following:

0.04 + (4.90 x 2.24) + (1.12 x 13) + (0.80 x 12) + (0.71 x 13) + (1.13 x 13) + (0.83 x 13)

0.04 + 10.97 + 14.56 + 9.60 + 9.23 + 14.69 + 10.79

0.04 + 10.97 + 14.56 + 9.60 + 9.23 + 14.69 + 10.79 = 69.88

In the program generating the model, that equation presented as the following:

```
> predict(mod1, newdata = list(dens.sqrt = sqrt(5), ub = 13, lb = 12, outl =
13, surftext = 13, top = 13), interval = "confidence")
       fit      lwr      upr
1 69.88029 69.32405 70.43654
```

```
> predict(mod1, newdata = list(dens.sqrt = sqrt(5), ub = 13, lb = 12, outl =
13, surftext = 13, top = 13), interval = "prediction")
       fit      lwr     upr
1 69.88029 58.26248 81.4981
```

As the above example was done manually and incorporates rounding for simplicity, its sums will not be as precise as when automatically computed. However, the outcomes remain the same - both estimate an age of 69 years (rounded to 70 years). The benefit of computing age statistically, as opposed to simply adding it manually, is that a prediction envelope may be generated. In this case, the equation above predicts a 95% confidence interval of 1 year and a 95% prediction envelope of 23 years, which translates to a range of 58 - 81 years (with 70 as the mean). As revealed in previous chapters, the actual age of the individual in question was 66 years old at the time of her scan).

While, by using this model alone, the individual's actual age differs by only three to four years from her actual age and, therefore, falls within the predicted range, it may still be possible to increase this precision by including a series of known variables. When the additional variable of sex is added (model 2 - see above, section 7.3.2), for example, the same procedure applies:

-1.56 (as the intercept) + 0 (Female, already the reference level) + (3.29 x density squared) + (0.99 x Upper Boundary score) + (0.84 x Lower Boundary Score) + (0.69 x Outline Score) + (1.10 x Surface Texture Score) + (1.36 x Topography Score)

Assuming the same scores (5, 13, 12, 13, 13, 13), this equation becomes:

-1.56 + 0 + (3.29 x 2.24) + (0.99 x 13) + (0.84 x 12) + (0.69 x 13) + (1.10 x 13) + (1.36 x 13)

-1.56 + 0 + 7.37 + 12.87 + 10.08 + 8.97 + 14.30 + 17.68

-1.56 + 0 + 7.37 + 12.87 + 10.08 + 8.97 + 14.30 + 17.68 = 69.71

With a prediction interval of 22 years, this becomes 59 – 81 years:

```
> predict(mod2, newdata = list(Sex = "F", dens.sqrt = sqrt(5), ub = 13, lb =
12, outl = 13, surftext = 13, top = 13), interval = "confidence")
       fit      lwr      upr
1 69.81657 69.09337 70.53978
```

```
> predict(mod2, newdata = list(Sex = "F", dens.sqrt = sqrt(5), ub = 13, lb =
12, outl = 13, surftext = 13, top = 13), interval = "prediction")
       fit     lwr      upr
1 69.81657 58.6688 80.96435
```

This procedure may then be further repeated for the variables of "Activity," "Menopause," and "Tobacco Use" (as well as "Pregnancy Status," if known):

7.71 (as the intercept) + 4.11 (Parous) – 1.22 (Activity "Active") - 1.64 (Tobacco "Yes") – 4.36 (Menopause "Yes") + (5.96 – 3.21 x density score, squared) + (1.01 x Upper Boundary score) + (0.68 x Lower Boundary Score) + (0.60 x Outline Score) + (0.87 x Surface Texture Score) + (0.55 + 0.77 x Topography Score)

Assuming the same TCM scores (5, 13, 12, 13, 13, 13), this equation then becomes:

7.71 + 4.11 – 1.22 - 1.64 – 4.36 + (2.75 x 2.24) + (1.01 x 13) + (0.68 x 12) + (0.60 x 13) + (0.87 x 13) + (1.32 x 13)

7.37 +4.11 – 1.22 -1.64 – 4.36+ 6.16 + 13.13 + 8.16 + 7.80 + 11.31 + 17.16

7.37 + 4.11 – 1.22 - 1.64 – 4.36 + 6.16 + 13.13 + 8.16 + 7.80 + 11.31 + 17.16 = 67.98

With a prediction interval of 22 years, this becomes 57 – 79 years:

```
> predict(mod3, newdata = list(Pregnancy.Status = "P", Action = "A", Tobacco
= "Y", Menopause = "Y", dens.sqrt = sqrt(5), ub = 13, lb = 12, outl = 13,
surftext = 13, top = 13), interval = "confidence")
       fit      lwr      upr
1 68.25322 66.91348 69.59296
```

```
> predict(mod3, newdata = list(Pregnancy.Status = "P", Action = "A", Tobacco
= "Y", Menopause = "Y", dens.sqrt = sqrt(5), ub = 13, lb = 12, outl = 13,
surftext = 13, top = 13), interval = "prediction")
       fit      lwr      upr
1 68.25322 57.49541 79.01103
```

While each additional variable increases the statistical efficacy of the overall model, when estimating age from a unknown skeleton it is often unlikely that

information regarding an individual's parity, menopause status, activity level, or smoking habits will be available – however, if female remains are estimated to be over a certain age, 60 years or above for example, it may be argued that menopause may be reasonably assumed. Similarly, it could also be argued that the presence of secondary indicators such as stained fingernails, dental impressions of a clay pipe (for older remains), or more circumstantial indicators such as a lighter or cigarette pack in a pocket may also point to tobacco use. Before any given examination, an investigator may know next to nothing about an individual, may have access to an extensive network of information, or may possess a level of knowledge falling anywhere in between. Given that this spectrum of information exists, a series of applicable models with increasing levels of specificity may prove most sensible, as well as practical.

Based upon both the increasing R-Squared values of the models as well as the narrowing ages they predict, an improvement may be said to exist between model one (the basic TCM, for which no information need be known) and the additional models (containing various levels of known information). As exhibited above, model one produced an age of 70 years while, with the addition of sex and additional lifestyle factors such as parity, activity level, smoking, and menopause, that age was narrowed to 68 years in model three – only two years away from the individual's actual age of 66 years. Results of this final "optimum" model (model 3) are presented as Figures 167 – 171 (*below*).

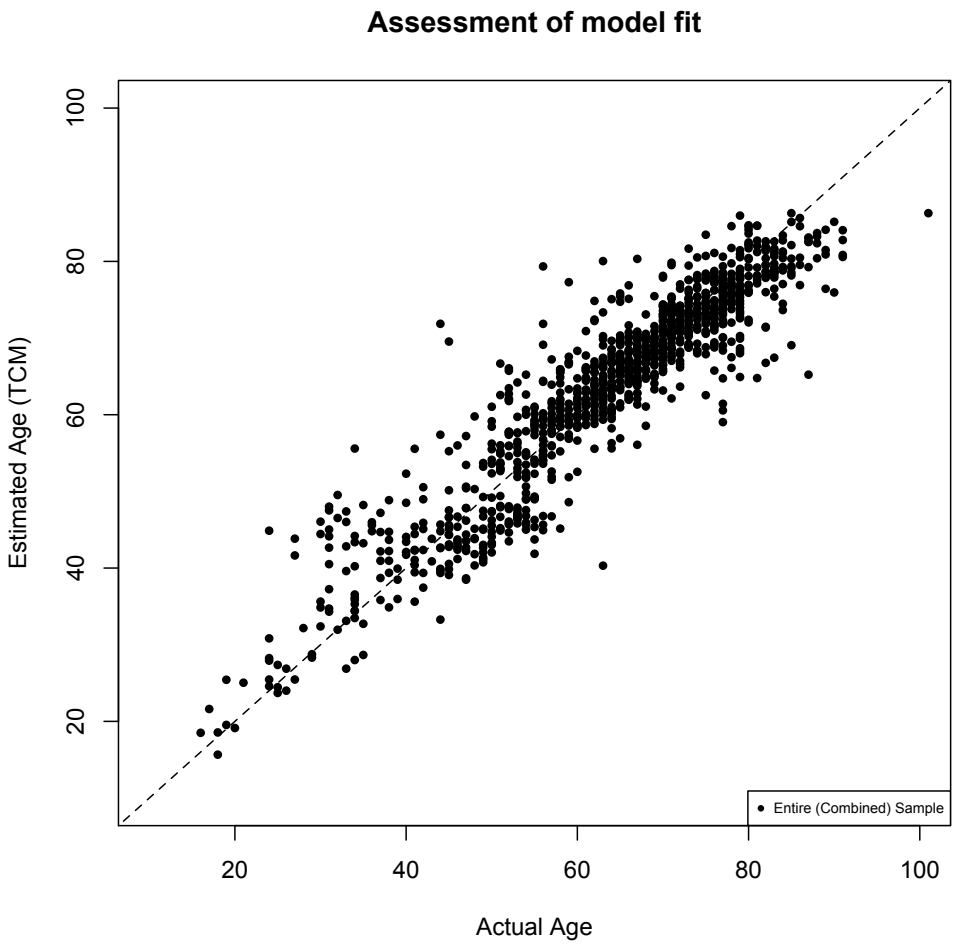


Figure 167: Assessment of fit (optimum model), overview

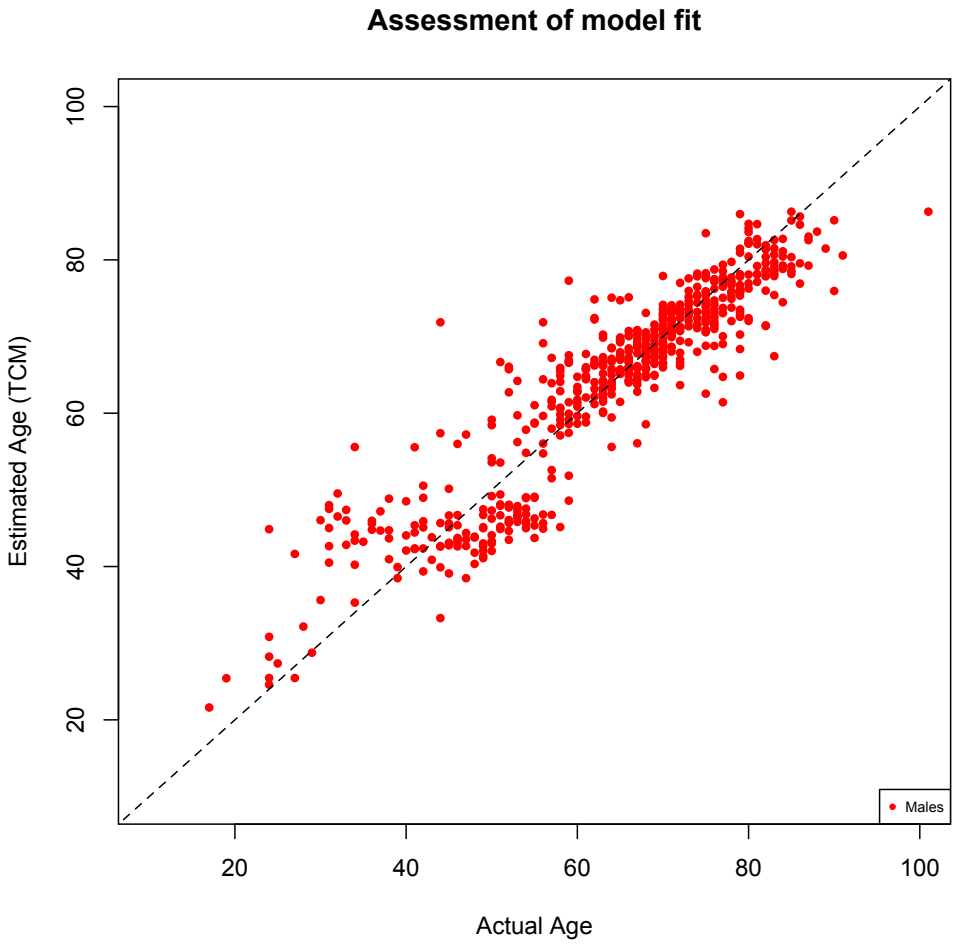


Figure 168: Assessment of fit (optimum model), males only

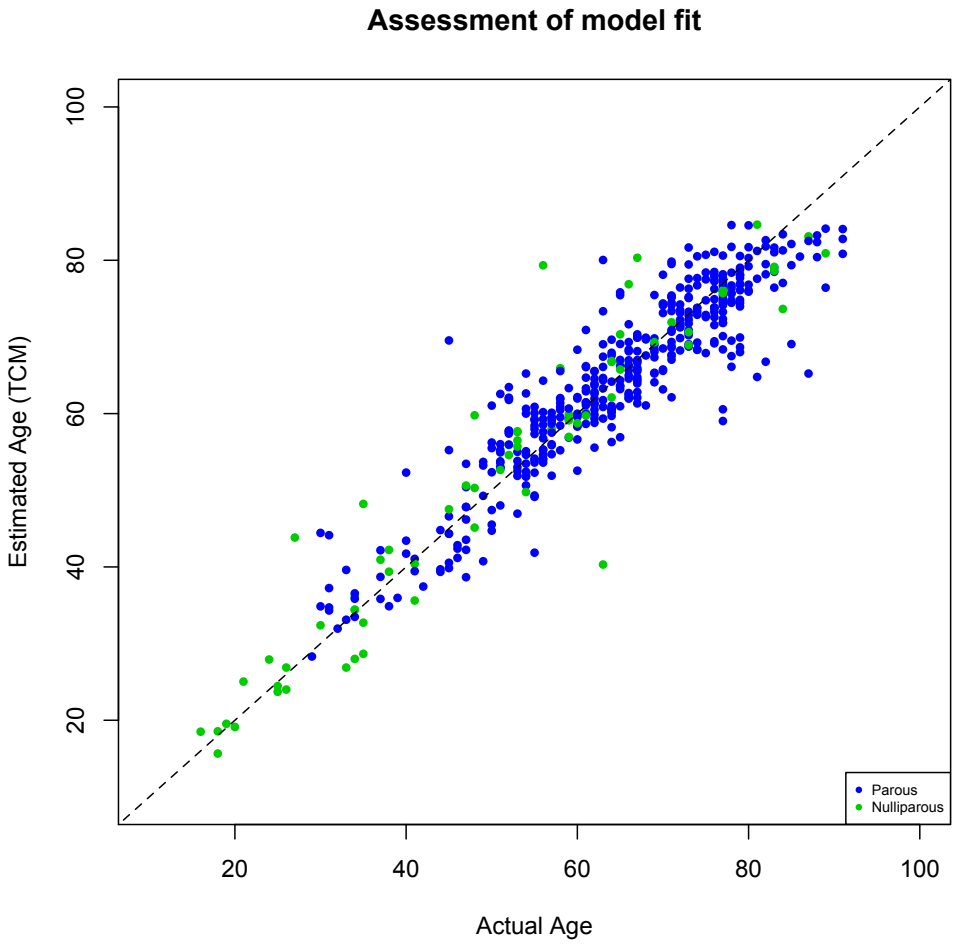


Figure 169: Assessment of fit (optimum model), females only

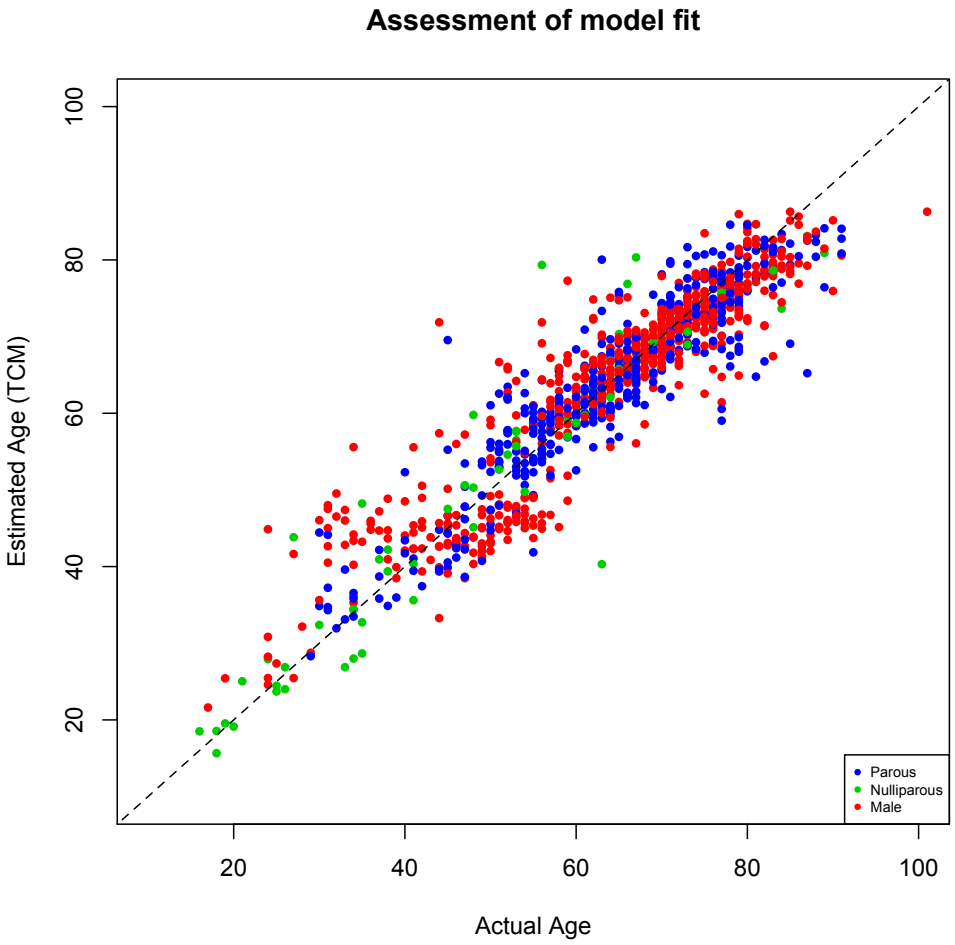


Figure 170: Assessment of fit (optimum model), parity status

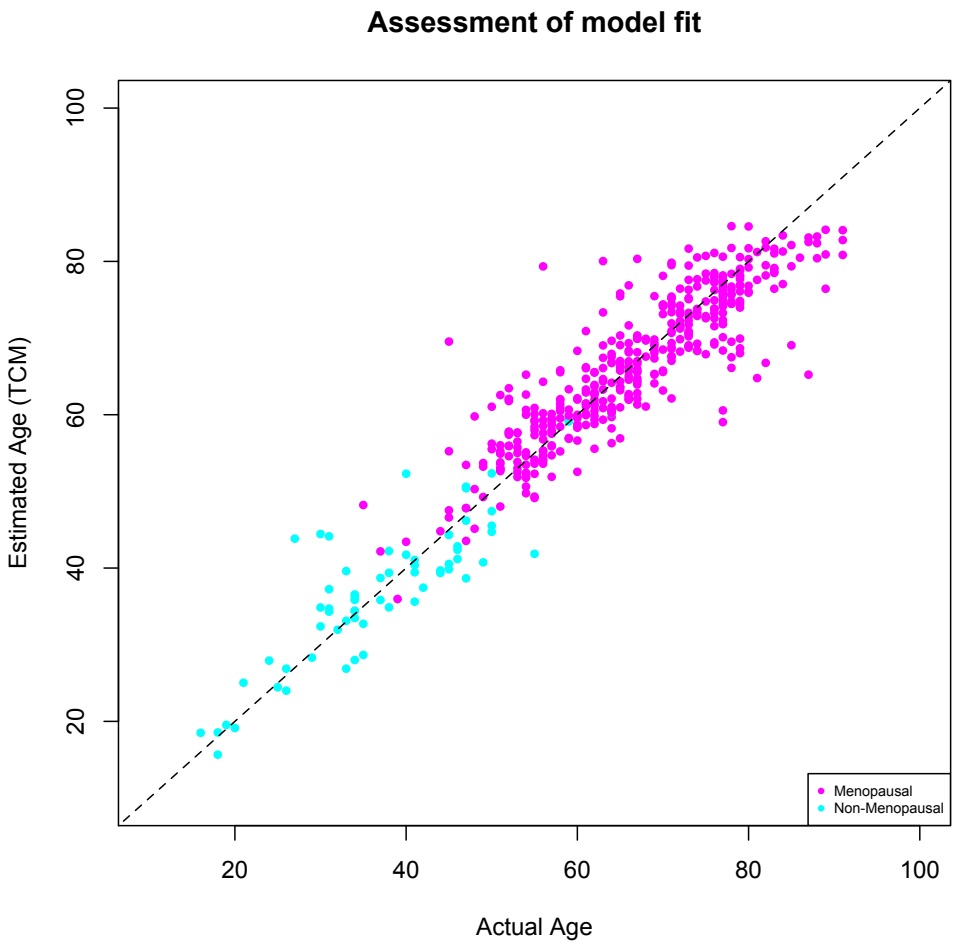


Figure 171: Assessment of fit (optimum model), menopausal status

7.5 Cross-Validation Testing

To investigate the validity and robusticity of the model's predictive element, a small section of the sample was eliminated from the dataset (this was the observers' subset - see chapter 2, "Materials and Methods," section 2.4.1, for more information) and the models were re-fitted without them. Those models were then used to predict the ages of the newly "unknown" subjects. These results were then plotted as a graph of "predicted age" versus "true (or actual) age" for a visual assessment of how well the model performed. For this analysis, the most specific model (the optimum model - see above) was used as sex, parity, activity level, tobacco use, and menopausal status were all known *(Figure 172)*.

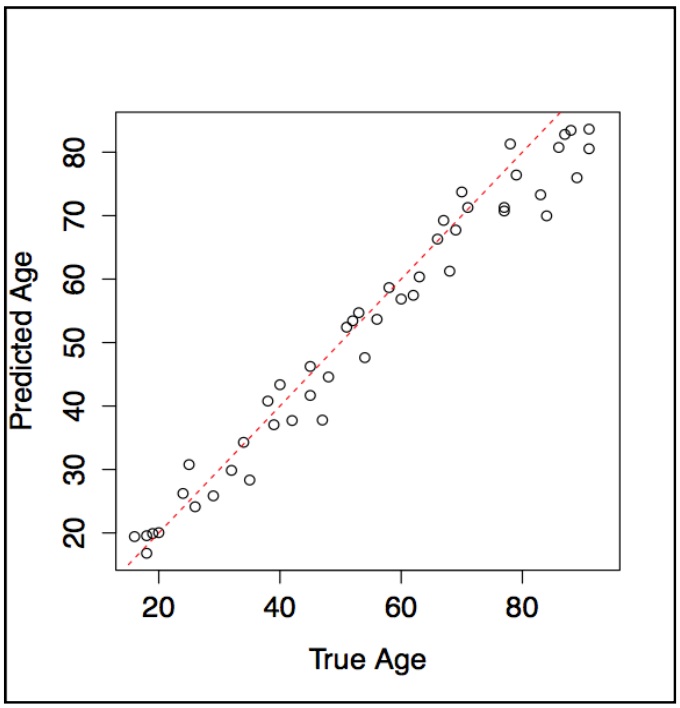


Figure 172: Results of Cross Validation testing

By using the TCM predictively, as above, each of the 50 "unknown" individuals were estimated to within an exceptable margin of actual age.

Based on these results, it is therefore the author's opinion that the Truesdell Composite Method, as introduced and described by this thesis, has been effectively shown to be an acceptable predictor of age when estimating from the pubic symphysis.

7.6 Independent Observations

Once the method had been proven effective, in order to demonstrate that the author's proficiency in estimating age could be trusted (and, by extension, that the results and conclusions based upon that proficiency could also be relied upon), three independent observers were invited to evaluate a subset of the sample.

As outlined in the "Materials and Methods" chapter of this thesis, each observer performed his or her examination separately, blindly, on different days, and with no communication between sessions. Each performed his or her examination on a desktop computer and looked at each of the 50 scans in succession with access to multiple views of the skelton – including axial, coronal, sagittal, and moveable 3D images. The author and two of the observers performed their examinations with the aid of General Electric's ("GE") "Centricity" software while the last employed Materialise's "Mimics" software.

Each observer was asked to estimate age for each subject using the Suchey-Brooks Method for Ageing the Os Pubis (1990), the Hartnett method (2010), as well as the Truesdell Composite Method, or "TCM."

The outcomes of the observers' individual examinations are detailed by the following sections.

7.6.1 The Author

As stated above, to establish estimation competency and to investigate the veracity and repeatability of the Truesdell Composite Method relative to existing techniques, the author examined a test sample of 50 individuals employing the Suchey-Brooks Method for Ageing the Os Pubis, the Hartnett method, and the Truesdell Composite Method, or TCM.

The results of this examination are presented below *(Figure 173*), with green indicating an estimation to within five years of actual age, yellow indicating an estimation to within 10 years of actual age, and red indicating an estimation of more than a decade from an individual's actual age.

SB Phase	SB Range	Actual Age	Accuracy	Precision	Hart. Phase	Hart. Range	Actual Age	Accuracy	Precision	TCM Score	TCM Range	Actual Age	Accuracy	Precision
6	42-87, 60	81	Y	21 years +	7	62-99,m82.54	81	Y	2 year -	78	66-90	81	Y	3 year -
2	19-40, 25	24	Y	1 year -	2	20-25,m23.20	24	Y	1 year +	25	13-37	24	Y	1 year +
6	42-87, 60	62	Y	2 years +	6	56-86,m72.34	62	Y	10 years -	61	49-73	62	Y	1 year +
5	25-83, 48	53	Y	5 year +	5	44-60,m51.47	53	Y	2 year +	53	41-65	53	Y	Exact Age
2	19-40, 25	25	Y	Exact Age	2	20-25,m23.20	25	Y	2 year +	24	12-36	25	Y	1 year -
6	42-87, 60	88	Y	28 years +	7	62-99,m82.54	88	Y	5 year +	87	75-99	88	Y	1 year -
6	42-87, 60	84	Y	24 years +	6	56-86,m72.34	84	Y	12 years +	76	64-88	84	Y	8 years -
6	42-87, 60	83	Y	23 years +	7	62-99,m82.54	83	Y	Exact Age	79	67-91	83	Y	4 year -
5	25-83, 48	58	Y	10 years +	5	44-60,m51.47	58	Y	7 years +	59	47-71	58	Y	1 year +
6	42-87, 60	89	Y	29 years +	7	62-99,m82.54	89	Y	6 years +	82	70-94	89	Y	7 years -
6	42-87, 60	69	Y	29 years +	6	56-86,m72.34	69	Y	3 year -	68	56-80	69	Y	1 year -
5	25-83, 48	60	Y	12 years +	5	44-60,m51.47	60	Y	9 years +	57	45-69	60	Y	3 year -
5	25-83, 48	51	Y	3 years +	5	44-60,m51.47	51	Y	Exact Age	54	42-66	51	Y	3 year +
1	15-24, 19	19	Y	Exact Age	1	18-22,m19.80	19	Y	Exact Age	19	07-31	19	Y	Exact Age
2	19-40, 25	26	Y	1 year +	2	20-25,m23.20	26	Y	3 year +	25	13-37	26	Y	1 year -
1	15-24, 19	18	Y	1 year -	1	18-22,m19.80	18	Y	2 year -	19	07- 31	18	Y	1 year +
6	42-87, 60	91	Y	31 years +	7	62-99,m82.54	91	Y	8 years +	84	72-96	91	Y	7 years -
5	25-83, 48	63	Y	15 years +	5	44-60,m51.47	63	N	12 years +	59	47-71	63	Y	4 year -
4	26-79, 38	42	Y	5 years +	4	33-58,m43.26	42	Y	1 year -	46	34-58	42	Y	4 year +
4	26-79, 38	38	Y	Exact Age	4	33-58,m43.26	38	Y	5 year -	41	29-53	38	Y	3 year +
6	42-87, 60	70	Y	10 years +	6	56-86,m72.34	70	Y	2 year -	75	63-87	70	Y	5 year +
6	42-87, 60	68	Y	8 years +	6	56-86,m72.34	68	Y	4 year -	61	49-73	68	Y	7 years -
6	42-87, 60	91	Y	31 years +	7	62-99,m82.54	91	Y	8 years +	86	74-98	91	Y	5 year -
6	42-87, 60	66	Y	6 years +	6	56-86,m72.34	66	Y	6 years -	66	54-78	66	Y	Exact Age
6	42-87, 60	93	Y	33 years +	7	62-99,m82.54	93	Y	10 years +	88	76-100	93	Y	5 year -
6	42-87, 60	71	Y	11 years +	6	56-86,m72.34	71	Y	1 year -	70	58-82	71	Y	1 year +
5	25-83, 48	52	Y	4 year +	5	44-60,m51.47	52	Y	1 year -	54	42-66	52	Y	2 year +
1	15-24, 19	18	Y	1 year -	1	18-22,m19.80	18	Y	1 year -	15	03-27	18	Y	3 year +
6	42-87, 60	67	Y	7 years +	6	56-86,m72.34	67	Y	5 year -	68	56-80	67	Y	1 year +
1	15-24, 19	20	Y	1 year +	1	18-22,m19.80	20	Y	Exact Age	20	08-32	20	Y	Exact Age
3	21-53, 31	39	Y	8 years +	3	24-44,m31.44	39	Y	8 years +	36	24-48	39	Y	3 year -
2	19-40, 25	29	Y	4 years +	2	20-25,m23.20	29	N	6 years +	31	19-43	29	Y	2 year +
3	21-53, 31	32	Y	1 years +	3	24-44,m31.44	32	Y	1 year +	36	24-48	32	Y	4 year +
6	42-87, 60	79	Y	19 years +	6	56-86,m72.34	79	Y	7 years +	75	63-87	79	Y	4 year -
6	42-87, 60	78	Y	18 years +	7	62-99,m82.54	78	Y	5 year -	83	71-95	78	Y	5 years +
3	21-53, 31	34	Y	3 years +	3	24-44,m31.44	34	Y	3 year +	38	26-50	34	Y	4 years +
6	42-87, 60	77	Y	17 years +	6	56-86,m72.34	77	Y	5 year +	76	64-88	77	Y	1 year -
4	26-79, 38	45	Y	7 years +	4	33-58,m43.26	45	Y	2 year +	48	36-57	45	Y	3 years +
4	26-79, 38	47	Y	9 years +	4	33-58,m43.26	47	Y	4 year +	45	33-57	47	Y	2 years -
6	42-87, 60	87	Y	27 years +	7	62-99,m82.54	87	Y	4 year +	85	73-97	87	Y	2 years -
6	42-87, 60	86	Y	26 years +	7	62-99,m82.54	86	Y	3 year +	82	70-94	86	Y	4 years -
3	21-53, 31	35	Y	4 years +	3	24-44,m31.44	35	Y	4 year +	34	22-46	35	Y	1 year -
6	42-87, 60	74	Y	14 years +	7	62-99,m82.54	74	Y	9 years -	75	63-87	74	Y	1 year +
4	26-79, 38	48	Y	10 years +	4	33-58,m43.26	48	Y	5 year +	46	34-58	48	Y	2 years -
5	25-83, 48	56	Y	8 years +	5	44-60,m51.47	56	Y	5 year +	54	42-66	56	Y	2 years -
6	42-87, 60	77	Y	17 years +	6	56-86,m72.34	77	Y	5 year +	75	63-87	77	Y	2 years -
5	25-83, 48	45	Y	3 years -	4	33-58,m43.26	45	Y	2 year +	45	33-57	45	Y	Exact Age
4	26-79, 38	40	Y	2 years +	4	33-58,m43.26	40	Y	3 year -	40	28-52	40	Y	Exact Age
4	26-79, 38	54	Y	16 years +	4	33-58,m43.26	54	Y	11 years +	53	41-65	54	Y	1 year -
1	15-24, 19	18	Y	3 years -	1	18-22,m19.80	18	Y	1 year -	19	07-31	18	Y	1 year +

	Suchey-Brooks	Hartnett	TCM
Actual Age Captured within Prediction Range	(50 of 50) 100%	(48 of 50) 96%	(50 of 50) 100%
Precision to within 5 Years of Actual Age	(20 of 50) 40%	(35 of 50) 70%	(46 of 50) 92%
Precision to within 10 Years of Actual Age	(10 of 50) 20%	(12 of 50) 24%	(4 of 50) 8%
Precision to more than 10 Years from Actual Age	(20 of 50) 40%	(3 of 50) 6%	(0 of 50) 0%

Figure 173: Observation results – the author

As is clearly visible, precision to within five years of the subjects' actual age (green) increased by 30% between the Suchey-Brooks and Hartnett methods, a further 22% between the Hartnett and the TCM, and a 52% increase between the Suchey-Brooks method and the TCM. This was a direct reversal of the "more than 10 years from the Actual Age" category (red), which dropped by 34%

between the Suchey-Brooks and Hartnett methods, 6% between the Hartnett and TCM, and 40% between the Suchey-Brooks and TCM. At 4%, the "within 10 years" category (yellow) saw a slight increase between the Suchey-Brooks and Hartnett methods, while a 16% decrease was indicated between the Hartnett method and TCM, as well as a 12% decrease between the Suchey-Brooks method and the TCM.

As the author had both developed the TCM *and* had recently used it to assess over 1,000 individuals, it is perhaps unsurprising that she was able to age the majority of individuals to within five or 10 years of their actual age. The author also possessed extensive experience (approximately six years) with ageing from computed tomography (CT). This was not the case for the other observers, however, as participation in this study served as their first exposure.

During the author's examination, participants were aged above the Suchey-Brooks mean a total of 84% of the time, above the Hartnett mean a total of 58% of the time, and above the TCM score a total of 38% of the time. Conversly, participants were aged below the Suchey-Brooks mean a total of 10% of the time, below the Hatnett mean a total of 34% of the time, and below the TCM score a total of 50% of the time. Exact age was estimated a total of 6% of the time using the Suchey-Brooks method, 8% of the time using the Hartnett method, and 12% of the time when employing the TCM.

7.6.2 Observer One

The results of Observer One's examination are presented as Figure 174 (*below*).

SB Phase	SB Range	Actual Age	Accuracy	Precision	Hart. Phase	Hart. Range	Actual Age	Accuracy	Precision	TCM Phase	TCM Range	Actual Age	Accuracy	Precision
5	25-83, 48	81	Y	33 years +	5	44-60,m51.47	81	N	30 years +	75	63-87	81	Y	6 years -
3	21-53, 31	24	Y	7 years -	3	24-44,m31.44	24	Y	7 years -	34	22-46	24	Y	10 years +
5	25-83, 48	62	Y	14 years +	5	44-60,m51.47	62	Y	11 years +	70	58-82	62	Y	8 years +
4	26-79, 38	53	Y	15 years +	4	33-58,m43.26	53	Y	10 years -	54	42-66	53	Y	1 year +
3	21-53, 31	25	Y	6 years -	3	24-44,m31.44	25	Y	7 years -	32	20-44	25	Y	7 years +
6	42-87, 60	88	Y	28 years +	7	62-99,m82.54	88	Y	5 years +	85	73-97	88	Y	3 years -
6	42-87, 60	84	Y	24 years +	6	56-86,m72.34	84	Y	12 years +	76	64-88	84	Y	8 years -
6	42-87, 60	83	Y	23 years +	7	62-99,m82.54	83	Y	Exact Age	90	78-102	83	Y	7 years +
6	42-87, 60	58	Y	2 years -	7	62-99,m82.54	58	N	25 years -	51	39-63	58	Y	7 years -
6	42-87, 60	89	Y	29 years +	7	62-99,m82.54	89	Y	6 years +	85	73-97	89	Y	4 years -
6	42-87, 60	69	Y	9 years +	7	62-99,m82.54	69	Y	7 years -	51	39-63	69	Y	18 years -
6	42-87, 60	60	Y	Exact Age	6	56-86,m72.34	60	Y	14 years -	65	53-77	60	Y	5 years +
6	42-87, 60	51	Y	9 years -	7	62-99,m82.54	51	N	32 years -	78	66-90	51	N	27 years +
1	15-24, 19	19	Y	Exact Age	1	18-22,m19.80	19	Y	Exact Age	20	08-32	19	Y	1 year +
2	19-40, 25	26	Y	1 year +	2	20-25,m23.20	26	N	3 years +	24	12-36	26	Y	2 years -
2	19-40, 25	18	Y	7 years -	2	20-25,m23.20	18	N	5 years -	21	09-33	18	Y	3 years +
6	42-87, 60	91	Y	31 years +	7	62-99,m82.54	91	Y	8 years +	73	61-85	91	N	13 years -
5	25-83, 48	63	Y	15 years +	5	44-60,m51.47	63	N	12 years +	52	40-64	63	Y	11 years -
3	21-53, 31	42	Y	11 years +	3	24-44,m31.44	42	Y	11 years +	47	35-59	42	Y	5 years +
5	25-83, 48	38	Y	10 years -	5	44-60,m51.47	38	N	13 years -	54	42-66	38	N	16 years +
6	42-87, 60	70	Y	10 years +	7	62-99,m82.54	70	Y	13 years -	79	67-91	70	Y	9 years +
6	42-87, 60	68	Y	8 years +	7	62-99,m82.54	68	Y	15 years -	72	60-84	68	Y	4 years +
6	42-87, 60	91	Y	31 years +	7	62-99,m82.54	91	Y	8 years +	90	78-102	91	Y	1 year -
6	42-87, 60	66	Y	6 years +	6	56-86,m72.34	66	Y	6 years -	52	40-64	66	N	14 years -
6	42-87, 60	93	Y	33 years +	7	62-99,m82.54	93	Y	10 years +	90	78-102	93	Y	3 years -
6	42-87, 60	71	Y	11 years +	7	62-99,m82.54	71	Y	12 years -	73	61-85	71	Y	2 years +
3	21-53, 31	52	Y	21 years +	3	24-44,m31.44	52	N	21 years +	74	62-86	52	N	22 years +
1	15-24, 19	18	Y	1 year -	1	18-22,m19.80	18	Y	1 year -	15	03-27	18	Y	3 years -
6	42-87, 60	67	Y	7 years +	7	62-99,m82.54	67	Y	16 years -	70	58-82	67	Y	3 years +
1	15-24, 19	20	Y	1 year +	1	18-22,m19.80	20	Y	Exact Age	21	09-33	20	Y	1 year +
2	19-40, 25	39	Y	14 years +	2	20-25,m23.20	39	N	16 years +	21	09-33	39	N	18 years -
2	19-40, 25	29	Y	4 years +	2	20-25,m23.20	29	N	6 years +	39	27-51	29	Y	10 years +
5	25-83, 48	32	Y	16 years -	5	44-60,m51.47	32	N	19 years -	44	32-56	32	Y	12 years +
6	42-87, 60	79	Y	19 years +	7	62-99,m82.54	79	Y	4 years -	80	68-92	79	Y	1 year -
6	42-87, 60	78	Y	18 years +	7	62-99,m82.54	78	Y	5 years -	84	72-96	78	Y	6 years +
4	26-79, 38	34	Y	4 years -	4	33-58,m43.26	34	Y	9 years -	35	23-47	34	Y	1 year +
6	42-87, 60	77	Y	17 years +	7	62-99,m82.54	77	Y	6 years -	69	57-81	77	Y	8 years -
3	21-53, 31	45	Y	14 years +	3	24-44,m31.44	45	N	14 years +	48	36-57	45	Y	3 years +
5	25-83, 48	47	Y	1 year -	5	44-60,m51.47	47	Y	4 years -	52	40-64	47	Y	5 years +
6	42-87, 60	87	Y	27 years +	7	62-99,m82.54	87	Y	4 years +	86	74-98	87	Y	1 year -
6	42-87, 60	86	Y	26 years +	7	62-99,m82.54	86	Y	3 years +	90	78-102	86	Y	4 years +
2	19-40, 25	35	Y	10 years +	2	20-25,m23.20	35	N	12 years +	35	23-47	35	Y	Exact Age
5	25-83, 48	74	Y	26 years +	5	44-60,m51.47	74	N	23 years +	74	62-86	74	Y	Exact Age
3	21-53, 31	48	Y	17 years +	3	24-44,m31.44	48	N	17 years +	42	30-54	48	Y	6 years -
5	25-83, 48	56	Y	8 years +	5	44-60,m51.47	56	Y	5 years +	50	38-62	56	Y	6 years -
6	42-87, 60	77	Y	17 years +	6	56-86,m72.34	77	Y	5 years +	74	62-86	77	Y	3 years -
5	25-83, 48	45	Y	3 years -	5	44-60,m51.47	45	Y	6 years -	49	37-61	45	Y	4 years +
4	26-79, 38	40	Y	2 years +	4	33-58m,43.26	40	Y	3 years -	37	25-49	40	Y	3 years -
3	21-53, 31	54	N	23 years +	3	24-44,m31.44	54	N	23 years +	50	38-62	54	Y	4 years -
1	15-24, 19	18	Y	1 year -	1	18-22,m19.80	18	Y	1 year -	20	08-32	18	Y	2 years -

	Suchey-Brooks	Hartnett	TCM
Actual Age Captured within Prediction Range	(49 of 50) 98%	(34 of 50) 68%	(44 of 50) 88%
Precision to within 5 Years of Actual Age	(12 of 50) 24%	(16 of 50) 32%	(28 of 50) 56%
Precision to within 10 Years of Actual Age	(12 of 50) 24%	(13 of 50) 26%	(13 of 50) 26%
Precision to more than 10 Years from Actual Age	(26 of 50) 52%	(21 of 50) 42%	(9 of 50) 18%

Figure 174: Observer results – observer one

For Observer One, precision to within five years of the subjects' actual age increased by 8% between the Suchey-Brooks and Hartnett methods, 24% between the Hartnett and the TCM, and 32% between the Suchey-Brooks method and the TCM. Contrastingly, estimations placing participants in the "more than 10 years from the Actual Age" category dropped by 10% between the Suchey-Brooks and Hartnett methods, dropped 24% between the Hartnett and TCM, and decreased by 34% between the Suchey-Brooks and TCM. The "within 10 years" category saw a 2% increase between Suchey-Brooks and Hartnett, with no change between Hartnett and the TCM. There was a 2% increase between Suchey-Brooks method and the TCM.

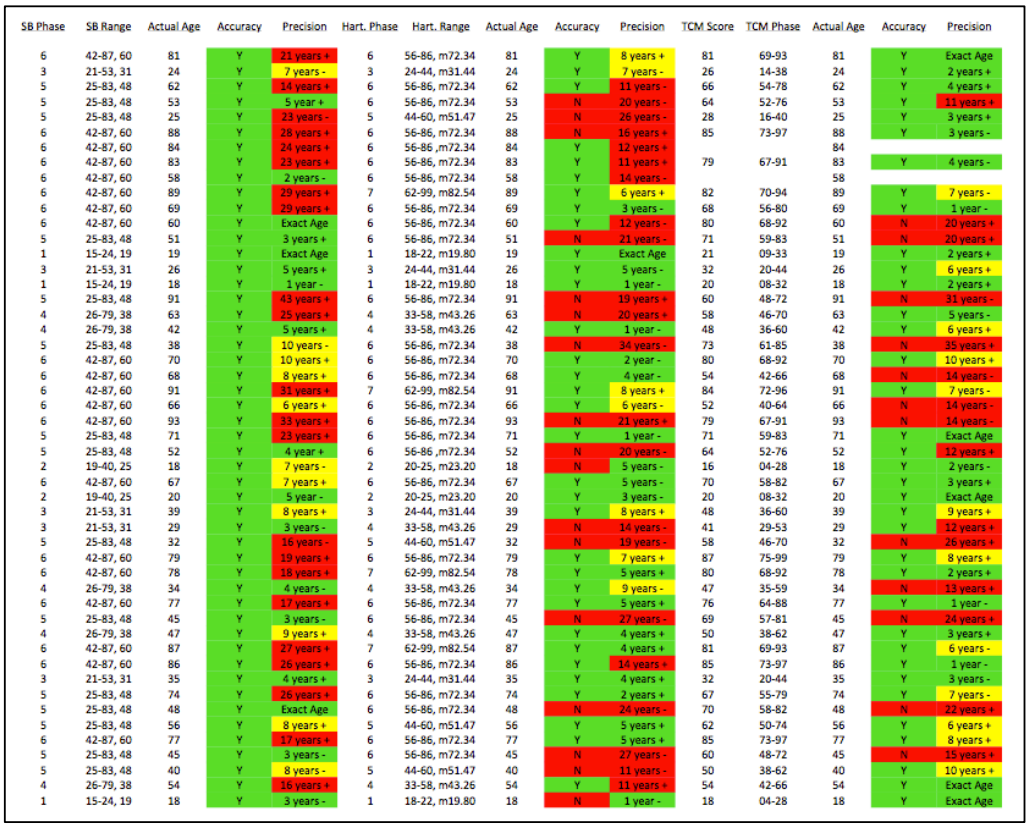
During Observer One's examination, participants were aged above the Suchey-Brooks mean a total of 72% of the time, above the Hartnett mean a total of 46% of the time, and above the TCM score a total of 50% of the time. Participants were aged below the Suchey-Brooks mean a total of 24% of the time, below the Hatnett mean a total of 48% of the time, and below the TCM score a total of 46% of the time. Exact age was estimated a total of 4% of the time using the Suchey-Brooks method, 6% of the time using the Hartnett method, and 4% of the time when employing the TCM.

7.6.3 Observer Two

For Observer Two, precision to within five years of the subjects' actual age increased by 6% between the Suchey-Brooks and Hartnett methods, a further 4% between the Hartnett and the TCM, and 10% between the Suchey-Brooks method and the TCM. Estimations placing participants in the "more than 10 years from the Actual Age" category remained even between the Suchey-Brooks and Hartnett methods (both 44%), while there was a decrease of 13% between the Hartnett and TCM and a 13% decrease between the Suchey-Brooks and TCM. The "within 10 years" category saw a decrease of 6% between Suchey-Brooks and Hartnett, a 9% increase between Hartnett and the TCM, and a 3% increase between Suchey-Brooks and the TCM.

During Observer Two's examination, participants were aged above the Suchey-Brooks mean a total of 66% of the time, above the Hartnett mean a total of 42% of the time, and above the TCM score a total of 56% of the time. Participants were aged below the Suchey-Brooks mean a total of 28% of the time, below the Hatnett mean a total of 56% of the time, and below the TCM score a total of 33% of the time. Exact age was estimated a total of 6% of the time using the Suchey-Brooks method, a total of 2% of the time using the Hartnett method, and a total of 10% of the time when employing the TCM.

The results of this examination are presented below as *Figure 175*.



SB Phase	SB Range	Actual Age	Accuracy	Precision	Hart. Phase	Hart. Range	Actual Age	Accuracy	Precision	TCM Score	TCM Phase	Actual Age	Accuracy	Precision
6	42-87, 60	81	Y	21 years +	6	56-86, m72.34	81	Y	8 years +	81	69-93	81	Y	Exact Age
3	21-53, 31	24	Y	7 years -	3	24-44, m31.44	24	Y	7 years -	26	14-38	24	Y	2 years +
5	25-83, 48	62	Y	14 years +	6	56-86, m72.34	62	Y	11 years -	66	54-78	62	Y	4 years +
5	25-83, 48	53	Y	5 year +	6	56-86, m72.34	53	N	20 years -	64	52-76	53	Y	11 years +
5	25-83, 48	25	Y	23 years -	5	44-60, m51.47	25	N	26 years -	28	16-40	25	Y	3 years +
6	42-87, 60	88	Y	28 years +	6	56-86, m72.34	88	N	16 years +	85	73-97	88	Y	3 years -
6	42-87, 60	84	Y	24 years +	6	56-86 ,m72.34	84	Y	12 years +			84		
6	42-87, 60	83	Y	23 years +	6	56-86, m72.34	83	Y	11 years +	79	67-91	83	Y	4 years -
6	42-87, 60	58	Y	2 years -	6	56-86, m72.34	58	Y	14 years -			58		
6	42-87, 60	89	Y	29 years +	7	62-99, m82.54	89	Y	6 years +	82	70-94	89	Y	7 years -
6	42-87, 60	69	Y	29 years +	6	56-86, m72.34	69	Y	3 years -	68	56-80	69	Y	1 year -
6	42-87, 60	60	Y	Exact Age	6	56-86, m72.34	60	Y	12 years -	80	68-92	60	N	20 years +
5	25-83, 48	51	Y	3 years +	6	56-86, m72.34	51	N	21 years -	71	59-83	51	N	20 years +
1	15-24, 19	19	Y	Exact Age	1	18-22, m19.80	19	Y	Exact Age	21	09-33	19	Y	2 years +
3	21-53, 31	26	Y	5 years +	3	24-44, m31.44	26	Y	5 years -	32	20-44	26	Y	6 years +
1	15-24, 19	18	Y	1 year -	1	18-22, m19.80	18	Y	1 year -	20	08-32	18	Y	2 years +
5	25-83, 48	91	Y	43 years +	6	56-86, m72.34	91	N	19 years +	60	48-72	91	N	31 years -
4	26-79, 38	63	Y	25 years +	4	33-58, m43.26	63	N	20 years +	58	46-70	63	Y	5 years -
4	26-79, 38	42	Y	5 years +	4	33-58, m43.26	42	Y	1 year -	48	36-60	42	Y	6 years +
5	25-83, 48	38	Y	10 years -	6	56-86, m72.34	38	N	34 years -	73	61-85	38	N	35 years +
6	42-87, 60	70	Y	10 years +	6	56-86, m72.34	70	Y	2 year -	80	68-92	70	Y	10 years +
6	42-87, 60	68	Y	8 years +	6	56-86, m72.34	68	Y	4 year -	54	42-66	68	N	14 years -
6	42-87, 60	91	Y	31 years +	7	62-99, m82.54	91	Y	8 years +	84	72-96	91	Y	7 years -
6	42-87, 60	66	Y	6 years +	6	56-86, m72.34	66	Y	6 years -	52	40-64	66	N	14 years -
6	42-87, 60	93	Y	33 years +	6	56-86, m72.34	93	N	21 years +	79	67-91	93	N	14 years -
5	25-83, 48	71	Y	23 years +	6	56-86, m72.34	71	Y	1 year -	71	59-83	71	Y	Exact Age
5	25-83, 48	52	Y	4 year +	6	56-86 ,m72.34	52	N	20 years -	64	52-76	52	Y	12 years +
2	19-40, 25	18	Y	7 years -	2	20-25, m23.20	18	N	5 years -	16	04-28	18	Y	2 years -
6	42-87, 60	67	Y	7 years +	6	56-86, m72.34	67	Y	5 years -	70	58-82	67	Y	3 years +
2	19-40, 25	20	Y	5 year -	2	20-25, m23.20	20	Y	3 years -	20	08-32	20	Y	Exact Age
3	21-53, 31	39	Y	8 years +	3	24-44, m31.44	39	Y	8 years +	48	36-60	39	Y	9 years +
3	21-53, 31	29	Y	3 years -	4	33-58, m43.26	29	N	14 years -	41	29-53	29	Y	12 years +
5	25-83, 48	32	Y	16 years -	5	44-60, m51.47	32	N	19 years -	58	46-70	32	N	26 years +
6	42-87, 60	79	Y	19 years +	6	56-86, m72.34	79	Y	7 years +	87	75-99	79	Y	8 years +
6	42-87, 60	78	Y	18 years +	7	62-99, m82.54	78	Y	5 years +	80	68-92	78	Y	2 years +
4	26-79, 38	34	Y	4 years -	4	33-58, m43.26	34	Y	9 years -	47	35-59	34	N	13 years +
6	42-87, 60	77	Y	17 years +	6	56-86, m72.34	77	Y	5 years +	76	64-88	77	Y	1 year -
5	25-83, 48	45	Y	3 years -	6	56-86, m72.34	45	N	27 years -	69	57-81	45	N	24 years +
4	26-79, 38	47	Y	9 years +	4	33-58, m43.26	47	Y	4 years +	50	38-62	47	Y	3 years +
6	42-87, 60	87	Y	27 years +	7	62-99, m82.54	87	Y	4 years +	81	69-93	87	Y	6 years -
6	42-87, 60	86	Y	26 years +	6	56-86, m72.34	86	Y	14 years +	85	73-97	86	Y	1 year -
3	21-53, 31	35	Y	4 years +	3	24-44, m31.44	35	Y	4 years +	32	20-44	35	Y	3 years -
5	25-83, 48	74	Y	26 years +	6	56-86, m72.34	74	Y	2 years +	67	55-79	74	Y	7 years -
5	25-83, 48	48	Y	Exact Age	6	56-86, m72.34	48	N	24 years -	70	58-82	48	N	22 years +
5	25-83, 48	56	Y	8 years +	5	44-60, m51.47	56	Y	5 years +	62	50-74	56	Y	6 years +
6	42-87, 60	77	Y	17 years +	6	56-86, m72.34	77	Y	5 years +	85	73-97	77	Y	8 years +
5	25-83, 48	45	Y	3 years -	6	56-86, m72.34	45	N	27 years -	60	48-72	45	N	15 years +
5	25-83, 48	40	Y	8 years -	5	44-60, m51.47	40	N	11 years -	50	38-62	40	Y	10 years +
4	26-79, 38	54	Y	16 years +	4	33-58, m43.26	54	Y	11 years +	54	42-66	54	Y	Exact Age
1	15-24, 19	18	Y	3 years -	1	18-22, m19.80	18	N	1 year -	18	04-28	18	Y	Exact Age

	Suchey-Brooks	Hartnett	TCM
Actual Age Captured within Prediction Range	(50 of 50) 100%	(33 of 50) 66%	(36 of 48) 75%
Precision to within 5 Years of Actual Age	(17 of 50) 34%	(20 of 50) 40%	(21 of 48) 44%
Precision to within 10 Years of Actual Age	(11 of 50) 22%	(8 of 50) 16%	(12 of 48) 25%
Precision to more than 10 Years from Actual Age	(22 of 50) 44%	(22 of 50) 44%	(15 of 48) 31%

Figure 175: Observer results – observer two

7.6.4 Observer Three

The results of Observer Three's examination are presented as *Figure 176*.

SB Phase	SB Range	Actual Age	Accuracy	Precision	Hart. Phase	Hart. Range	Actual Age	Accuracy	Precision	TCM Score	TCM Range	Actual Age	Accuracy	Precision
6	42-87, 60	81	Y	21 years +	7	62-99, m82.54	81	Y	2 years -	78	66-90	81	Y	3 years -
3	21-53, 31	24	Y	7 years -	3	24-44, m31.44	24	Y	7 years -	30	18-42	24	Y	6 years +
5	25-83, 48	62	Y	14 years +	6	56-86, m72.34	62	Y	10 years -	51	39-63	62	Y	11 years +
4	26-79, 38	53	Y	15 years +	4	33-58, m43.26	53	Y	10 years +	53	41-65	53	Y	Exact Age
2	19-40, 25	25	Y	Exact Age	2	20-25, m23.20	25	Y	2 years +	25	13-37	25	Y	Exact Age
6	42-87, 60	88	Y	28 years +	7	62-99, m82.54	88	Y	5 years +	85	73-97	88	Y	3 years -
		84					84					84		
6	42-87, 60	83	Y	23 years +	7	62-99, m82.54	83	Y	Exact Age	83	71-95	83	Y	Exact Age
5	25-83, 48	58	Y	10 years +	5	44-60, m51.47	58	Y	7 years +	53	41-65	58	Y	5 years -
6	42-87, 60	89	Y	29 years +	7	62-99, m82.54	89	Y	6 years +	90	78-102	89	Y	1 year +
6	42-87, 60	69	Y	29 years +	6	56-86, m72.34	69	Y	3 years -	65	53-77	69	Y	4 years -
5	25-83, 48	60	Y	12 years +	5	44-60, m51.47	60	Y	9 years +	56	44-68	60	Y	4 years -
5	25-83, 48	51	Y	3 years +	5	44-60, m51.47	51	Y	Exact Age	60	48-72	51	Y	9 years +
1	15-24, 19	19	Y	Exact Age	1	18-22, m19.80	19	Y	Exact Age	20	08-32	19	Y	Exact Age
2	19-40, 25	26	Y	1 year +	2	20-25, m23.20	26	N	3 years +	26	14-38	26	Y	Exact Age
1	15-24, 19	18	Y	1 year -	1	18-22, m19.80	18	Y	1 year -	19	07-31	18	Y	1 year -
6	42-87, 60	91	Y	31 years +	7	62-99, m82.54	91	Y	9 years +	90	78-102	91	Y	1 year +
5	25-83, 48	63	Y	15 years +	5	44-60, m51.47	63	N	12 years +	53	41-65	63	Y	10 years -
5	25-83, 48	42	Y	6 years -	5	44-60, m51.47	42	N	9 years -	58	46-70	42	N	16 years +
2	19-40, 25	38	Y	13 years +	2	20-25, m23.20	38	N	15 years +	62	50-74	38	N	24 years +
5	25-83, 48	70	Y	22 years +	5	44-60, m51.47	70	N	19 years +	66	54-78	70	Y	4 years -
6	42-87, 60	68	Y	8 years +	7	62-99, m82.54	68	Y	14 years -	56	44-68	68	Y	12 years -
6	42-87, 60	91	Y	31 years +	7	62-99, m82.54	91	Y	9 years +	85	73-97	91	Y	6 years -
5	25-83, 48	66	Y	18 years +	6	56-86, m72.34	66	Y	6 years -	67	55-79	66	Y	1 year +
6	42-87, 60	93	Y	33 years +	7	62-99, m82.54	93	Y	10 years +			93		
6	42-87, 60	71	Y	11 years +	7	62-99, m82.54	71	Y	12 years -	75	63-87	71	Y	4 years +
5	25-83, 48	52	Y	4 year +	6	56-86, m72.34	52	N	20 years -	58	46-70	52	Y	6 years +
1	15-24, 19	18	Y	1 year -	1	18-22, m19.80	18	Y	1 year -	16	04-28	18	Y	2 year -
5	25-83, 48	67	Y	19 year +	6	56-86, m72.34	67	Y	5 years -	78	66-90	67	Y	11 year +
2	19-40, 25	20	Y	5 year -	2	20-25, m23.20	20	Y	3 years -	22	10-34	20	Y	2 years +
2	19-40, 25	39	Y	14 years +	2	20-25, m23.20	39	N	16 years +	30	18-42	39	Y	9 years -
3	21-53, 31	29	Y	3 years -	3	24-44, m31.44	29	Y	2 years -	38	26-50	29	Y	9 years +
4	26-79, 38	32	Y	6 years -	4	33-58, m43.26	32	N	11 years -	48	36-60	32	N	16 years +
6	42-87, 60	79	Y	19 years +	7	62-99, m82.54	79	Y	4 years -	89	77-101	79	Y	10 years +
6	42-87, 60	78	Y	18 years +	7	62-99, m82.54	78	Y	4 years -			78		
2	19-40, 25	34	Y	9 years +	2	20-25, m23.20	34	N	11 years +	45	33-57	34	Y	11 years +
6	42-87, 60	77	Y	17 years +	7	62-99, m82.54	77	Y	6 years -	68	56-80	77	Y	9 years -
4	26-79, 38	45	Y	7 years +	4	33-58, m43.26	45	Y	2 years +	57	45-69	45	Y	12 years +
4	26-79, 38	47	Y	9 years +	4	33-58, m43.26	47	Y	4 years +	51	39-63	47	Y	4 years +
6	42-87, 60	87	Y	27 years +	7	62-99, m82.54	87	Y	4 years +	90	78-102	87	Y	3 years -
6	42-87, 60	86	Y	26 years +	7	62-99, m82.54	86	Y	3 years +	89	77-101	86	Y	3 years +
2	19-40, 25	35	Y	10 years +	2	20-25, m23.20	35	N	12 years +	32	20-44	35	Y	3 years -
6	42-87, 60	74	Y	14 years +	7	62-99, m82.54	74	Y	9 years -			74		
		48					48					48		
6	42-87, 60	56	Y	4 years -	6	56-86, m72.34	56	Y	16 years -	65	53-77	56	Y	9 years +
6	42-87, 60	77	Y	17 years +	7	62-99, m82.54	77	Y	6 years -	81	69-93	77	Y	4 years +
4	26-79, 38	45	Y	7 years +	4	33-58, m43.26	45	Y	2 years +	42	30-54	45	Y	3 years -
3	21-53, 31	40	Y	9 years +	3	24-44, m31.44	40	Y	9 years +	34	22-46	40	Y	6 years -
4	26-79, 38	54	Y	16 years +	4	33-58, m43.26	54	Y	11 years +	41	29-53	54	N	13 years -
1	15-24, 19	18	Y	3 years -	1	18-22, m19.80	18	Y	1 year -	17	03-27	18	Y	1 year -

	Suchey-Brooks	Hartnett	TCM
Actual Age Captured within Prediction Range	(48 of 48) 100%	(38 of 48) 79%	(41 of 45) 91%
Precision to within 5 Years of Actual Age	(11 of 48) 23%	(21 of 48) 44%	(25 of 45) 56%
Precision to within 10 Years of Actual Age	(11 of 48) 23%	(15 of 48) 31%	(11 of 45) 24%
Precision to more than 10 Years from Actual Age	(26 of 48) 54%	(12 of 48) 25%	(9 of 45) 20%

Figure 176: Observer results – observer three

For Observer Three, precision to within five years of the subjects' actual age increased by 21% between the Suchey-Brooks and Hartnett methods, 12% between the Hartnett and the TCM, and 33% between the Suchey-Brooks method and the TCM. This was a direct reversal of the "more than 10 years from the Actual Age" category, which dropped by 29% between the Suchey-

Brooks and Hartnett methods, 5% between the Hartnett and TCM, and 34% between the Suchey-Brooks and TCM. The "within 10 years" category saw an increase of 8% between the Suchey-Brooks and Hartnett methods, a 7% decrease between Hartnett and the TCM, and a 1% increase between Suchey-Brooks and the TCM.

During Observer Three's examination, participants were aged above the Suchey-Brooks mean a total of 77% of the time, above the Hartnett mean a total of 48% of the time, and above the TCM score a total of 44% of the time. Participants were aged below the Suchey-Brooks mean a total of 19% of the time, below the Hatnett mean a total of 46% of the time, and below the TCM score a total of 44% of the time. Exact age was estimated a total of 4% of the time using the Suchey-Brooks method, a total of 6% of the time using the Hartnett method, and a total of 11% of the time when employing the TCM.

7.7 Observer Comparisons

In the following sections, observers' results (including the author) will be juxtaposed to determine larger patterns.

7.7.1 Over and Under Ageing

With the exception of the Hartnett method, which exhibited the highest degree of variation amongst observers, an overall tendency to over age (or provide an

estimate above the mean for any given technique) was seen, both at the individual level and with observers combined.

This over-estimation was most pronounced when applying the Suchey-Brooks method - with the author estimating an age above the mean 84% of the time, Observer One estimating age above the mean 72% of the time, Observer Two estimating age above the mean 66% of the time, and Observer Three estimating age above the mean 77% of the time. This pattern continued with the TCM (though to a lesser degree), where Observers One and Two estimated above actual age 4% and 23%, respectively, the author *under* aged 12% more often than she over aged, and Observer Three estimated equally for both *(Table 15).*

Table 15: Observer over versus under ageing (all methods)

Observer Over Versus Under Ageing				
		Suchey-Brooks	**Hartnett**	**TCM**
Author	Over Aged	(42 of 50) 84%	(29 of 50) 58%	(19 of 50) 38%
	Under Aged	(5 of 50) 10%	(17 of 50) 34%	(25 of 50) 50%
	Exact Age	(3 of 50) 6%	(4 of 50) 8%	(6 of 50) 12%
Observer 1	Over Aged	(36 of 50) 72%	(23 of 50) 46%	(25 of 50) 50%
	Under Aged	(12 of 50) 24%	(24 of 50) 48%	(23 of 50) 46%
	Exact Age	(2 of 50) 4%	(3 of 50) 6%	(2 of 50) 4%
Observer 2	Over Aged	(33 of 50) 66%	(21 of 50) 42%	(27 of 48) 56%
	Under Aged	(14 of 50) 28%	(28 of 50) 56%	(16 of 48) 33%
	Exact Age	(3 of 50) 6%	(1 of 50) 2%	(10 of 48) 10%
Observer 3	Over Aged	(37 of 48) 77%	(23 of 48) 48%	(20 of 45) 44%
	Under Aged	(9 of 48) 19%	(22 of 48) 46%	(20 of 45) 44%
	Exact Age	(2 of 48) 4%	(3 of 48) 6%	(5 of 45) 11%

While over-estimations remained most pervasive (both by method and observer), as a general trend over-ageing decreased between the Suchey-Brooks

method and the TCM while, at the same time, under-ageing increased - as did the percentage of times the observers' estimations matched the exact age of the participant. This juxtaposition is presented as Figure 177 and 178 (*below*).

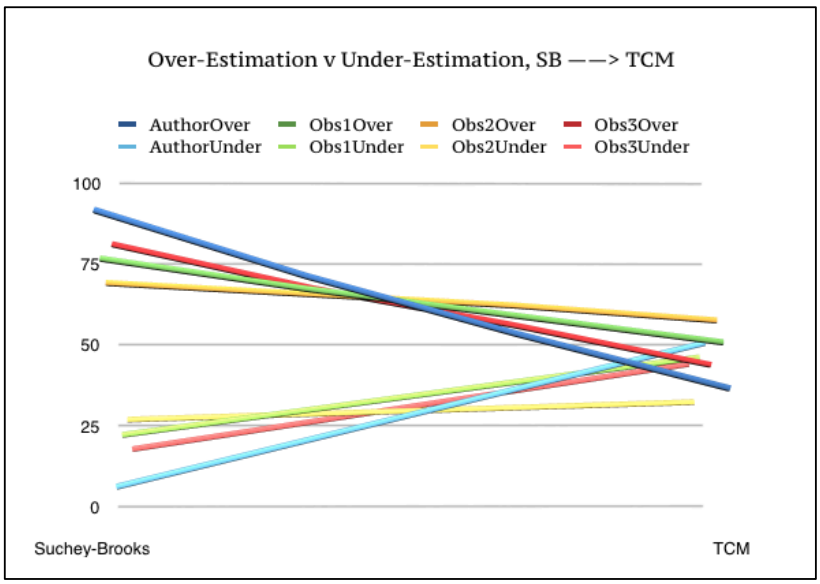


Figure 177: Comparison of over-estimation versus under-estimation between Suchey – Brooks and the TCM

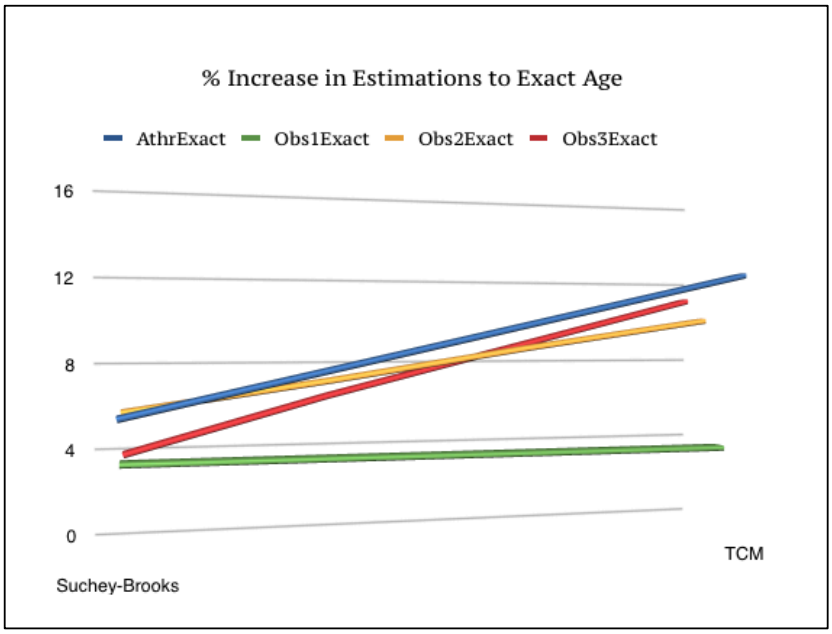


Figure 178: Percentage increase in exact age estimations between Suchey – Brooks and the TCM

7.7.2 Agreement

The table below lists the p-values for the 18 Chi-Squared analyses comparing the accuracy of the observers for the Suchey-Brooks, Hartnett, and TCM techniques. Here the test is for no agreement between the observers; hence, a statistically significant p-value (at the 5% level - shown below in bold) indicates that there is some degree of correlation between observers indicated *(Table 16)*.

Table 16: Chi-squared results detailing observer agreement

Chi-Squared Results Indicating Observer Agreement		
Method	**Test**	**P-Value**
Suchey-Brooks	Observer 1 v Observer 2	**0.000**
Suchey-Brooks	Observer 1 v Observer 3	**0.000**
Suchey-Brooks	Observer 1 v the Author	**0.000**
Suchey-Brooks	Observer 2 v Observer 3	**0.015**
Suchey-Brooks	Observer 2 v the Author	**0.000**
Suchey-Brooks	Observer 3 v the Author	**0.005**
Hartnett	Observer 1 v Observer 2	0.912
Hartnett	Observer 1 v Observer 3	0.925
Hartnett	Observer 1 v the Author	0.035
Hartnett	Observer 2 v Observer 3	0.261
Hartnett	Observer 2 v the Author	0.392
Hartnett	Observer 3 v the Author	0.229
TCM	Observer 1 v Observer 2	0.197
TCM	Observer 1 v Observer 3	**0.017**
TCM	Observer 2 v Observer 3	0.053

It can be seen that for the Suchey-brooks method, all of the observers' results agreed, whereas none did when using the Hartnett method. There was agreement between Observer One and Observer Two using the TCM, while there was borderline significance between Observer Two and Observer Three.

These results perhaps best illustrate the importance of familiarity and practitioner experience on the effectiveness of estimating age from the pubic symphysis. The Suchey-Brooks Method for Ageing the Os Pubis has been the "gold standard" in age estimation since its introduction in 1990 and has, consequently, been the most widely taught and cited ageing technique over the past 25 years (Garvin and Passalacqua 2012). In the field of forensic anthropology, the Suchey-Brooks method has become all but ubiquitous. Additionally, several of the predictive age ranges for the Suchey-Brooks method are quite wide - a woman placed into phase four, for example, would be expected to fall within 26 and 70 years of age. Given these factors, it is perhaps unsurprising that each of the observers exhibited significant agreement for this method.

The Hartnett method, on the other hand, was introduced only six years ago (2010) and has not been as widely circulated. In fact, prior to their examinations, none of the observers had used, or in two of the three cases even heard of, the Hartnett method. This being so, it has not benefited from the advange of extensive multi-media training and reference materials afforded to Suchey-Brooks. This may perhaps explain why each of the observers reported difficulty and a distinct lack of confidence in applying the Hartnett technique - a concern arguably substantiated by their variable results and total lack of agreement.

Lack of experience may also have served as a hinderence regarding the implementation of the TCM. As it is a product of this doctoral project, the

observers had never seen the technique before being asked to apply it.[23] Moreover, the reference materials for the TCM were still prototypical and are hand drawn - by no means the polished illustrations contained in the books and published articles with which the observers were accustomed to working. That being said, though somewhat crude, the technique nevertheless provided visual illustrations to supplement its written descriptions – engendering a degree of familiarity with the Suchey-Brooks method. This may account for the increased observer agreement over the Hartnett method, given both were equally unfamiliar to the observers.

7.7.3 Increases in Precision

While the observers' results returned mixed statistical agreement when subjected to chi-squared testing, certain overall patterns in the data nevertheless presented themselves.

The individual observers' results, combined, are provided below as *Table 17*.

[23] This is also why the author chose not to include herself in the chi-square testing for the TCM portion of the observations. As its creator, the author would naturally have much more experience and would be infinitely more familiar with the technique. Given this unfair advantage, it would be unlikely for agreement to occur. The author felt, therefore, that it would be more beneficial to compare the independent observers alone.

Table 17: Increases in Precision (all methods, all observers)

Increases in Precision: Suchey-Brooks — —> Hartnett — —> TCM				
		Suchey-Brooks	Hartnett	TCM
Author	Actual Age Captured within Prediction Range	(50 of 50) 100%	(48 of 50) 96%	(50 of 50) 100%
	Precision to within 5 Years of Actual Age	(20 of 50) 40%	(35 of 50) 70%	(46 of 50) 92%
	Precision to within 10 Years of Actual Age	(10 of 50) 20%	(12 of 50) 24%	(4 of 50) 8%
	Precision to more than 10 Years from Actual Age	(20 of 50) 40%	(3 of 50) 6%	(0 of 50) 0%
Observer 1	Actual Age Captured within Prediction Range	(49 of 50) 98%	(34 of 50) 68%	(44 of 50) 88%
	Precision to within 5 Years of Actual Age	(12 of 50) 24%	(16 of 50) 32%	(28 of 50) 56%
	Precision to within 10 Years of Actual Age	(12 of 50) 24%	(13 of 50) 26%	(13 of 50) 26%
	Precision to more than 10 Years from Actual Age	(26 of 50) 52%	(21 of 50) 42%	(9 of 50) 18%
Observer 2	Actual Age Captured within Prediction Range	(50 of 50) 100%	(33 of 50) 66%	(36 of 48) 75%
	Precision to within 5 Years of Actual Age	(17 of 50) 34%	(20 of 50) 40%	(21 of 48) 44%
	Precision to within 10 Years of Actual Age	(11 of 50) 22%	(8 of 50) 16%	(12 of 48) 25%
	Precision to more than 10 Years from Actual Age	(22 of 50) 44%	(22 of 50) 44%	(15 of 48) 31%
Observer 3	Actual Age Captured within Prediction Range	(48 of 48) 100%	(38 of 48) 79%	(41 of 45) 91%
	Precision to within 5 Years of Actual Age	(11 of 48) 23%	(21 of 48) 44%	(25 of 45) 56%
	Precision to within 10 Years of Actual Age	(11 of 48) 23%	(15 of 48) 31%	(11 of 45) 24%
	Precision to more than 10 Years from Actual Age	(26 of 48) 54%	(12 of 48) 25%	(9 of 45) 20%

As evidenced above, when estimating age using the Suchey-Brooks Method for Ageing the Os Pubis, each of the observers placed the majority of individuals into the "more than 10 years from actual age" category (red) while placing the least amount of individuals into the "within five years of the actual age" category (green). In direct contrast, when estimating age using the Truesdell Composite Method, all observers placed the majority of individuals into the "within five

years of actual age" category and the least amount of individuals into the "more than 10 years from the actual age" category. This juxtaposition is visualised as *Figure 179* (below).

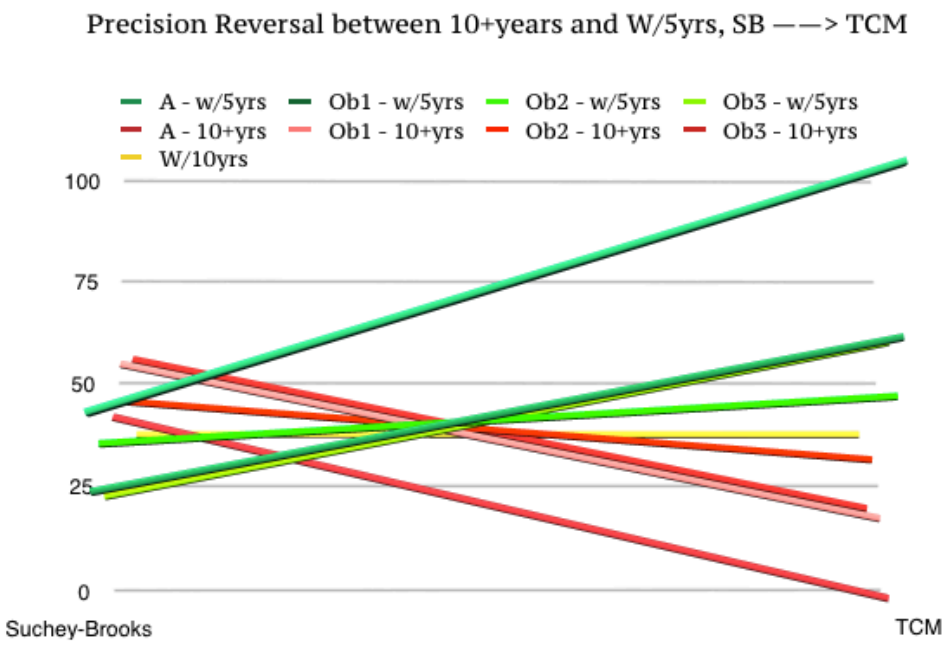


Figure 179: Precision Reversal from more than 10 years from actual age and fewer than 5 years from actual age, between the Suchey –Brooks and the TCM

While precision to within five years of actual age suplanted precision to more than 10 years, precision to within 10 years of actual age remained fairly level across techniques. Intriguingly, this reversal also appears to echo the "over" versus "under" estimation pattern detailed earlier in this chapter, where over estimation was most prevalent when using the Suchey-Brooks method while under estimation was most common when ageing by the TCM. Causes for this correlation remain unclear.

These trends may also be appreciated as percentage gains and losses, as presented below (*Table 18)*.

Table 18: Percentage increases in precision (all methods, all observers)

Increases in Precision (by %): Suchey-Brooks —–> Hartnett —–> TCM					
		SB → Hartnett	Hartnett → TCM	SB → TCM	Overall
Author					
	Precision to within 5 Years of Actual Age	40% —> 70%	70% —> 92%	40% —> 92%	52% ↑
	Precision to within 10 Years of Actual Age	20% —> 24%	24% —> 8%	20% —> 8%	12% ↓
	Precision to more than 10 Years from Actual Age	40% —> 6%	6% —> 0%	40% —> 0%	40% ↓
Observer 1					
	Precision to within 5 Years of Actual Age	24% —> 32%	32% —> 56%	24% —> 56%	32% ↑
	Precision to within 10 Years of Actual Age	24% —> 26%	26% —> 26%	24% —> 26%	2% ↑
	Precision to more than 10 Years from Actual Age	52% —> 42%	42% —> 18%	52% —> 18%	34% ↓
Observer 2					
	Precision to within 5 Years of Actual Age	34% —> 40%	40% —> 44%	34% —> 44%	10% ↑
	Precision to within 10 Years of Actual Age	22% —> 16%	16% —> 25%	22% —> 25%	2% ↑
	Precision to more than 10 Years from Actual Age	44% —> 44%	44% —> 31%	44% —> 31%	13% ↓
Observer 3					
	Precision to within 5 Years of Actual Age	23% —> 44%	44% —> 56%	23% —> 56%	33% ↑
	Precision to within 10 Years of Actual Age	23% —> 31%	31% —> 24%	23% —> 24%	2% ↑
	Precision to more than 10 Years from Actual Age	54% —> 25%	25% —> 20%	54% —> 20%	34% ↓

As can again be seen, when ageing with the Truesdell Composite Method, each of the observers experienced an (often dramatic) increase regarding the precision of their estimations when compared with both the Suchey-Brooks and Hartnett methods. Additionally, despite their somewhat mixed chi-squared

agreement, all observers, universally, estimated over 50% of the dataset to within five years of participants' actual age (whereas with the current standard - the Suchey-Brooks method - over 50% were estimated to more than 10 years from actual age). Furthermore, when the "within five years" category was nested into the "within 10 years" category, estimation of age as predicted to 10 or fewer years from the participant's actual age increased by 40% for the author, 34% for Observer One, 13% for Observer Two, and 34% for Observer Three. This means that, through the application of the TCM, age was estimated to 10 or fewer years from actual age an average of 83% of the time (versus 53% of the time using the Suchey-Brooks method – a threefold increase).

In summary, subjects were placed into appropriate Suchey-Brooks ranges an average of 89.4% of the time (86.3% with the author excluded), but only 49.4% (49.9%) of the time was the mean captured within a decade of the actual age and, within that, only 27% (26.9%) of the time was it within 5 years of the actual age. This is likely a reflection of the sample's propensity towards older individuals (approximatley 50% were 65 years or over). The Hartnett Method fared less well overall, with subjects being placed into appropriate ranges 75.5% (70.4%) of the time but, then, within the ranges themselves, fared slightly better than Suchey-Brooks with means within 10 years of actual age 65.4% (59.6%) of the time and 39.1% (33.2%) within 5 years. This is a likely due to a lack of experience with the application of the method. When using the TCM, estimations to within 10 years of actual age increased to 83.9% (79.7%) and to 67.7% (61.6%) within 5 years. When compared with Suchey-Brooks, this constitutes a 34.5% (29.8%) increase in precision to within 10 years of actual

age and a 40.7% (34.7%) precision increase to within 5 years. When compared to the Hartnett Method, precision to within 10 years was increased by 18.5% (20.1%) and 28.6% (28.4%) to within 5 years.

As can be seen by observer variation, because the Truesdell Composite Method is a novel technique a learning curve must be applied in the knowledge that, with more experience and familiarity, accuracy will improve. As can also be seen by the same observations, however, even in the absence of familiarity the TCM still presents a marked improvement over methods in current use.

Proven to be an effective predictor of age by both R - Squared values of between 83% and 86% (depending upon the model used), a successful cross-validation study, and effective observations, the author believes it may be reasonably assumed - with a high level of confidence - that conclusions based upon the results of this study may be considered statistically sound and may, therefore, be trusted.

Such conclusions will be explored in the following chapter - “Discussion.”

8

Discussion

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Abstract:

As demonstrated by the previous chapter, "Results," two biological factors (sex and menopause) and two lifestyle factors (activity level and tobacco use) were shown to exhibit significant impact on age estimation from the pubic symphyses of individuals in this sample. The following chapter will discuss the underlying mechanisms of those variables in order to hypothesize the reasoning behind those impacts as well as consider limitations of this study and outline future work.

8.0 Review of Study Results

Through face to face interviews with over 1,200 living participants coupled with skeletal analysis utilizing three independent ageing techniques – the Suchey-

Brooks method for ageing the os pubis (1990), the Hartnett method (2010), and the Truesdell Composite Method (introduced by this thesis) – this project sought to unite two interdependent yet often disconnected perspectives: an individual's "outer" world, the environment in which he or she exists and the daily practices he or she performs, and an individual's "inner" world, his or her physical flesh and bones. In doing so, this study confirmed one long held belief but disagreed with several others.

8.0.1 The Effect of Sex of Ageing from the Pubic Symphysis

As mentioned previously (see "Literature Review," section 1.4), debate continues as to whether significant morphological differences exist between the sexes regarding the estimation of age from the face of the pubic symphysis. Despite finding that "assessment of age of females by the pubic symphysis cannot be as accurate as in the case of males," Todd (as cited by Krogman 1962), in establishing his original method, concluded that females transitioned through his phases slightly later than did males (an average of two to five years delay) but that they did not diverge significantly enough to warrant their own system. When Brooks later tested this methodology on an archaeological sample she confirmed this finding, stating that "the male pubic age seems to be quite accurate, the female pubic age less so" (Brooks 1955: 11). McKern and Stewart, in devising their technique (1957), also grouped males and females together though, afterwards, published supplementary female specific criteria (Gilbert and Stewart 1973) stating "the … standards [were] not directly applicable to

females" (Suchey 1979:1). Nevertheless, even with these new sex specific standards, Suchey found that when 23 practitioners were asked to assess a series of female pubic bones "only 51% of the assessments yielded age ranges which include[d] the known age of the specimen" (Suchey 1979:1). Seven years later, when revising Todd's method, Katz and Suchey further concluded that "the male standards presented ... cannot be applied to female pubic bones [as] analysis of 500 female bone pairs has shown that greater variability is present than for the male" (1986). Additionally, that same year, Angel (also with Suchey) stated "the female pubic symphysis does not follow regular patterns in ageing as does that of the male" and that "extreme variability was found in female pubic morphology, [making] the formation of an ageing system virtually impossible" (1986). In an effort to address this, Suchey (now with Brooks) sought to remedy the issue by providing two separate sets of exemplars - one reference set specifically for males and another specifically for females (both with slightly differing age ranges) - but in the end followed Todd in providing universal phase descriptions for both (1990). In contrast, and indeed arguing the exact opposite view, Hartnett, as recently as 2010, concluded "that females undergo a *more* regular and predictable pattern of ageing in the pubic bone than males, which contradicts much of the known literature. [In fact,] when the entire sample was segregated by sex... there were few differences…" (2010: 1149).

As can be seen by this brief (and by no means exhaustive) review, after nearly a century of targeted scholarship, the literature remains divided and opinions on the subject continue to vary widely between practitioners. Why this would be after so much research remains unclear - perhaps it is the result of differential

practitioner experience (i.e. someone working predominately with men, in genocide scenarios such as Srebrenica, for example, would be more familiar with ageing males whereas someone working in Latin America, where seven of the 10 countries with the globe's highest rate of femicide may be found, might be more familiar with females), differences in sample populations, or even whether the specimens examined were "wet" (living or recently autopsied bone) or "dry" (historical or archaeological bone), as water and collagen loss could lead to bone looking and feeling older (in terms of weight) than it would when hydrated.

Based upon the results of this study, with a *p value* of <0.0001 indicating a high significance between male and female subjects (see previous "Results" chapter), that demonstrable differences between the sexes exist has again been supported. Moreover, this incongruity was exhibited across all three methods - mutually confirming the findings. Furthermore, the data also indicated a disparity of between three to five years when ageing male versus female participants (echoing Todd's original reporting of two to five years). In comparing the two female groups, however, this difference was less than one year (parous versus nulliparous). This means that the two female categories, being statistically indistinct in terms of both appearance and timing, shared more similarity with each other than *either* did with the males. As the author had, not long into the analysis, recognized the need to create discrete and separately functioning phasing guides, this came as validation and not surprise.

That the aforementioned debate continues, however, is perhaps less about whether difference has been demonstrated between the sexes (as it has many time over) but more about whether that difference is substantial enough to justify males and females requiring separate systems. These concepts seem to be often conflated, perpetuating confusion around the issue. The data produced by this study shows indisputably that dimorphism exists in at least one population. However, whether five years may be considered "significant" when estimating age, especially as ranges spanning multiple decades are given, is perhaps more opinion than fact. Based on her extensive experience with the symphyses of this sample, the author is of the opinion that, yes, men and women *should* be aged using separate, sex specific criteria – both illustrations and descriptions - and that that separation should be taken into account regarding final age ranges (i.e. they should not be combined). The author also agrees with Hartnett (2010) in her assessment that females exhibit a more regular pattern of progression than do males, representing a reverse of the majority of the literature to date. It is interesting that this agreement should come from two studies with similar samples – both comprised of fully hydrated specimens (living or recently autopsied), both utilized current or very recent populations, which were, themselves, mixed but majority "white" and of similar age distribution. Perhaps the populations upon which the "females are less regular than males" literature was based were more similar to each other (and, therefore, similar in findings) than they were to the Truesdell or Hartnett samples. The reason for this remains unclear, though secular change is one possibility, and it will be interesting to see whether this view will be repudiated or corroborated by future studies using more recent or current samples.

Whatever the reason, however – if, indeed, a reason exists at all – seeking to understand the source of these opposing conclusions would nonetheless benefit from further investigation as it may lead to better results (in that some techniques may be better suited to certain populations than others).

In light of the fact that pregnancy has been shown to have little to no impact on ageing from the pubic symphysis in this study (see below for discussion) – but that, instead, dimorphism did - perhaps the forensic community has been assessing the situation backwards and, therefore, looking for answers in the wrong place. If it is not pregnancy and childbirth that is causes males to transition before females, instead of "what are women are doing at the pubic symphysis that men are not," perhaps the question should be "what are *men* are doing at the pubic symphysis that *women* are not." As previously described, regular or frequent muscle usage in any given area creates a micro-environment of bone remodeling, triggered by a stimulation of the periosteum. The muscles and ligaments necessary for penile erection anchor directly onto the pubic symphysis and the inferior rami of the pubic bones. This sex-specific repetitive muscle motion would then trigger an oestrogen response through micro-fracturing and the subsequent activation of Wolff's law. Oestrogen regulates and accelerates epiphyseal fusion. Could this consistent, localized increase in oestrogen be the reason males transition first at the pubic symphysis? Certainly, women have higher levels of oestrogen overall, but that oestrogen is circulating and where it is localized it is in the reproductive organs, which are tucked back in the fascia. Such a theory would explain why men transition ahead of women in this area *only*, when the opposite is true for everywhere else

in the body, as well as why the "Lower Boundary" was the area most out of sync between the sexes in this study. This alternative to pregnancy as the causative agent of the differences seen between males and females at the pubic symphysis has yet to be examined and, the author believes, warrants further investigation.

8.0.2 Parity and Ageing from the Pubic Symphysis

Also shown by this study was that, in further contradiction to most of the published literature on the subject, pregnancy status – i.e. whether a woman had (parous) or had not (nulliparous) been pregnant or given birth at least once – had no significant effect on ageing from the pubic symphysis. This included both the effect of hormonal pregnancy (termination, miscarriage, or caesarean section, for example) as well as physical labour (encompassing epidural, multiple births, birth size, and length of labour).

Discrepancies between male and female age estimation have long been attributed to the probable effects of the hormone relaxin (posited first by Todd in 1920, then again by Meindl et al. in 1985) - a pregnancy specific hormone that facilitates the widening of the pelvic inlet, allowing for childbirth - and, though never experimentally verified, this explanation (and, with it, pregnancy) quickly passed into conventional wisdom as the definitive source of variation at the pubic symphysis. Originally based upon assumptions made from anatomical

specimens (Todd 1920), the relaxin theory was erroneously[24] taken up by Meindl et al. in 1985 after re-discovering Crelin's 1954 rodent experiments. On its surface, however, the theory does make sense.

As discussed in the anatomical section of this thesis (chapter one, section 1.3.1), the pelvis is comprised of three large segments, which make up the pelvic "basin"; the sacrum and the left and right innominate bones (which are themselves a composite of the ilium, ischium, and os pubis). The sacrum represents the back or "posterior" of the pelvis while the two innominates curve around and meet at the midline. The site where these two bones come together is the pubic symphysis. Unlike the shoulder or knee, this is a non-moveable joint - although, as its function is shock absorption and weight distribution between the upper and lower halves of the body, it necessarily allows some degree of "give" (generally about 2mm under normal circumstances). To accommodate movement, the pubic symphysis does not ossify (as it often does in other primates) but remains instead an intensely strong but flexible disc of fibrocartilage, similar to those between the vertebrae of the spine. In everyday life, this disc is generally between 4-5mm in width for both men and women. During a woman's pregnancy, however, this disc doubles in size to a width of 9-10mm (Stables 2005).

The mechanism for this widening is a sharp increase of relaxin. A member of the insulin family, relaxin is a peptide protein present in both males and

[24] *Erroneous as rodents A.) serve as inappropriate analogs for human pregnancy generally, and B.) because the mouse may, in fact, be unique even amongst rodents in regard to its parous response (Hall 2015).*

females. In males, it is produced (in very low levels) by the prostate and relegated to seminal fluid (where it helps with sperm motility). In females, it is produced by the reproductive tissues (luteum, ovaries, breast, placenta, decidua, etc.) during ovulation (or, the mid point of the menstrual cycle), when levels rise to encourage implantation (Sadler 2012). If a pregnancy does not occur in a given cycle, relaxin levels subside and return to stasis. If a pregnancy does occur, relaxin production increases exponentially to facilitate vasodilation (accommodating for higher maternal blood pressure) and to initiate the softening and expansion of the symphysis (Samuel *et al*. 1998). Specifically, this softening is caused by relaxin's activation of matrix metalloproteinase which begins to break down the symphysis's existing connective tissue (the Type I and Type II collagens in the fibrocartilage) while, at the same time, interrupting the manufacture of new soluble collagen (namely Type XII), facilitating a 60-90% drop in its production and synthesis at both the cellular and extracellular level (Wahl *et al.* 1977; Samuel *et al.* 1996; Zhao *et al.* 2000; Izu *et al.* 2011). Relaxin's sole objective in females is the expansion of the pubic symphysis (as periphery, non-pelvic joints remain unaffected - McDonald and Schwabe 1982; Schauberger *et al.* 1996; Marnach *et al.* 2003); however, this direct targeting also indirectly effects the surrounding bone (collateral damage, as it were) through the loss of viable extracellular matrix - the scaffold upon which precursor cells differentiate and align themselves to put down new bone (Talmage 1947). When signaled to do so, precursor osteoprogenetor cells differentiate into either osteoclasts (cells specialized to dissolve bone) or osteoblasts (cells specialized to produce bone). In a process referred to as "remodeling," the osteoclasts position themselves in a line adjacent to the site in

need of repair. They then move forward as a concerted front, dissolving the targeted bone while, behind them, similarly aligned osteoblasts follow, depositing new bone (in the form of osteoid, or unmineralized bone matrix) into the newly vacant space (Stout and Crowder 2012). Collagen, and more specifically Type XII collagen, acts as a fibroid scaffold for these osteoblasts. With the help of specific receptors (Nistri and Bani 2003), these scaffolds attract the osteoblasts and give them something to anchor to (ensuring they line up properly). This allows them to form bonds ("adhesive gap junctions") both between themselves and with the scaffold itself (Izu *et al.* 2011). By disrupting the collagen content of the extracellular matrix (by making the fibrils shorter, smaller, and more haphazard), relaxin works by effectively removing this anchor, confusing the migration and organization of these osteoblasts, throwing off their communication (as this communication is only possible through the gap junctions that could not form). This lack of communication leads to disorganization, which, in turn, inhibits their ability to produce good quality osteoid (Pinheiro *et al.* 2004). Furthermore, as that osteoid would normally be 90% collagen (Type 1), it too is compromised by relaxin, further compounding the disruption to bone formation.

Recall, however, that relaxin only *decreases* collagen production by 60-90% (Samuel *et al.* 1996; Unemori and Amento 1990); it does not stop it all together. This means that bone deposition at the face of the os pubis does not grind to a halt during pregnancy, it simply continues at a temporary 10-40% capacity. When compared, then, to males who will never experience this type of impediment and will, therefore, continue to build bone at 100%, the relaxin

theory offers a compelling argument as to why the faces of the female bones appear more erratic and difficult to age while males would remain more uniform. It does not, however, fit the evidence.

If relaxin were the underlying mechanism behind the differences between men and women, one would expect to see males transitioning through the phases first, either equal to or followed closely by the nulliparous women (as relaxin still plays a role in the menstrual cycle, but at substantially lower levels). Lastly, parous women would be furthest behind due to the delay caused by their compromised bone formation. Logically, this interruption (or interruptions in the case of multiple births) would then lead to a more haphazard, muddled, or inconsistent appearance of the symphyseal face when compared to either the nulliparous women or men, which would result in a marked inability to categorize them effectively. As this "stopping and starting" would be isolated and pregnancy specific, for the relaxin theory to be true nulliparous women would have to be shown to be statistically indistinct from the men while parous women would sharply diverge. This, as discussed above and in proceeding chapters, is the exact *opposite* of the findings demonstrated by this study – in this sample, the nulliparous women were indistinguishable from the parous women, and not the males. Further to this, according to relaxin research field leader David O. Sherwood "whereas considerable relaxin is secreted into the blood during late pregnancy in pigs and rats and the hormone plays an important role in promoting growth and extensibility of the cervix, relatively little relaxin is secreted during human pregnancy. Moreover, available evidence does not make a compelling case for any physiological role of relaxin at birth in

the human. There has been little research conducted on the role of relaxin on the pubic symphysis in women… [and] the simple truth is that, to my knowledge, no one has demonstrated a role, if any, of relaxin on the reproductive system in women" (Sherwood pers. com. 2015). It is, therefore, unlikely that the pregnancy specific hormone relaxin is the mechanism responsible for the differences seen between men and women at the pubic symphysis. This hypothesis is supported by the fact that pregnancy has, in previous chapters, been shown to exert no significant impact on the ageing reliability of this sample. As the primary function of relaxin is to widen the pelvic inlet in the event of pregnancy, that pregnancy, itself, has been eliminated as a significant factor effectively eliminates relaxin as well. Instead, a much more plausible explanation - and one that does fit the evidence - is that of simple dimorphism.

By the fifth week of embryogenesis, development of the reproductive system has begun in both males and females (due to the action of both the GPR54 and KISS1 genes). By the end of the twelfth week, or the "first trimester," both the structural and endocrine portions of the system have completed and remain active until shortly after birth. At that point, dopaminergic neurons (or nerve cells) in the hypothalamus begin to suppress the expression of Gonadotropin-Releasing Hormone (GnRH) through the introduction of somatostatin (which inhibits somatotropin, also known as human growth hormone, or "HGH"), effectively enforcing a reproductive dormancy until the age of eight to ten years old.

In females, this is when leptin becomes a major player. Leptin is a hormone (or "messenger" molecule) produced by adipose (fat cells) and is responsible for monitoring and regulating the body's energy stores. Once the body has attained an acceptable level of fat surplus (and, therefore, a sustainable energy balance), these adipose cells release leptin into the blood stream, bound for its target - the hypothalamus.

The hypothalamus is a portion of the brain containing various separate but interconnected clusters, or "populations" or "nuclei," of neuroendicrine cells (nerve cells that receive "dispatches" from the body and, in response, send out or set into motion whatever has been asked for). The cluster of cells that answers to leptin is called the Arcuate (or Infundibular) Nucleus. Once there, leptin lifts the suppressive influence of somatostatin while at the same time binds with KISS1 gene receptors to unlock a series of polypeptide proteins called "kisspeptins." These kisspeptins awaken, or "excite," the aforementioned GPR54 gene from its dormancy, allowing it to resume its secretion of Gonadotropin-Releasing Hormone (GnRH). No longer hampered by somatostatin, this flood of GnRH (along with HGH) is released by a series of increased pulses, or waves, into the neighbouring median eminence (the only area of the brain not constrained by the "blood brain barrier" and, therefore, the collection point for all hypothalamic secretions before they enter the "hypophyseal portal system" - a specialized capillary network or "blood portal" connecting the hypothalamus and anterior pituitary to facilitate rapid, unimpeded transfer).

Once through the portal to the anterior pituitary, GnRH signals for the release of two new hormones - Follicle Stimulating Hormone (FSH) and Lutenising Hormone (LH). From the pituitary, pulses of FSH and LH then make their way to the reproductive organs where they initiate the production of the androgen Testosterone which is, itself, then transformed (in the ovaries for females and the testes for males) into oestrodoil through the process of “aromatization" (or the action of the enzyme aromatase). While testosterone is converted almost entirely in females, as oestradoil is key to the commencement and regulation of the menstrual cycle, this conversion occurs to a much lesser extent in males, for whom only small amounts of oestrogen are needed for spermatogenesis and for the maintenance of bone density. The resulting developmental cascade - thelarche, pubarche, menarche, and spermarche - all triggered by the rising levels of testosterone and oestradoil (under the influence of FSH and LH) is referred to as “hypothalamic-pituitary-gonadal (gonadotropic axis) maturation,” otherwise known as puberty.

In determining why men and women differ so demonstratively at the pubic symphysis, the author believes that puberty represents the first and perhaps most important piece of a much larger puzzle. During puberty, male and female oestradoil levels begin to diverge for the first time - setting the course for adulthood. For men, having circulating amounts (that is, measurable in the bloodstream) of between 10 and 50 picograms per milliliter (pg/mL) is considered acceptable, with “normal” being between 22 and 30 pg./mL. For (pre-menopausal) women, that range balloons to a perpetually fluctuating 30 and 400 pg/mL (as a result of regular menstrual cycling), with “normal” being

between 40 and 50 pg/mL (during times of non-ovulation). Furthermore, in addition to this routine cycling, during pregnancy a woman's oestrogen level may rise to over 100 times her "normal" level, though this quickly equalizes after birth. For post-menopausal women, however, circulating oestradoil levels commonly drop to between 10 and 20 pg/mL, well below what is normal even for men (explaining why so many women rely on hormone replacement therapy to get back to the 40 to 50 pg/ mL mark, the minimum amount necessary for maintaining bone health) (New Health Guide 2015).

At any post-pubertal but pre-menopausal moment, therefore, there is far more oestradoil circulating around the female body than there is around the male body (due to menstruation). Conversely, in males, levels of testosterone "rise gradually through the teen years to as high as 1,000 ng/dL … while normal adult values range from 250 to 1,100 ng/dL" (Schubert 2015). In females, these levels peak at 45 ng/dL (Schubert 2015). It is the author's belief, therefore, that it is not pregnancy at the root of the differences seen between the sexes at the pubic symphysis, as has been long anecdotally accepted, but that, instead, it is the result of differential amounts of the sex specific hormones oestrogen and testosterone (leading to differences in robusticity) - explaining why the females in this sample grouped together indistinguishably, regardless of parity, while males diverged substantially from both.

Furthering this theory is the slight disparity seen between the parous and nulliparous groups when density is not taken into account – though this applied to the TCM only (no inconsistencies were detected using either the Suchey-

Brooks or Hartnett methods on the same sample). When data regarding Density, an integral element built into the Truesdell Composite Method, was omitted, parous women were consistently under-aged by approximately six more years than were nulliparous females. This is likely also due to the direct effects of oestrogen, which becomes elevated in parous women and continues to confer a protective effect throughout a woman's lifetime (National Institute of Health 2015). Scholarship remains mixed on this, however, with some researchers claiming that "parity, three or more births in particular, predicts a lower risk of hip fracture in the long run" (Kauppi et al. 2011:1769) while others maintain that, due to off-setting factors such breastfeeding and calcium loss ("leaching"), which keep increased oestrogen in check, as well as the fact that simply because a women has not had children, it is misleading for studies to assume it is because she is physiologically compromised (she may choose to remain nulliparous for societal reasons, for example), such results can only be described as "weak" and that parity is "neutral with respect to impact on peak bone mass" (Marcus et al. 2008:865). Others contend that a consensus has yet to be reached as to whether a link between parity and density has been established at all (Agarwal and Stout 2003), while still others concede that while fracture protection *is* acknowledged in parous women, it may be due to "means that may be independent from bone mineral density" (Hillier et al. 2003).

In this study, parous females did appear to maintain slightly better density early on, with decreases (assessed as category zero transitioning to category five) starting to affect age estimation approximately 5 to 10 years later than did the nulliparous females in this sample. This trend seemed to equalize and reverse

around the time of menopause (50 years), however, when further decreases in density (assessed as category five transitioning to category ten) began to accelerate for parous females while their nulliparous counterparts continued unchanged (*Figure 180, below*).

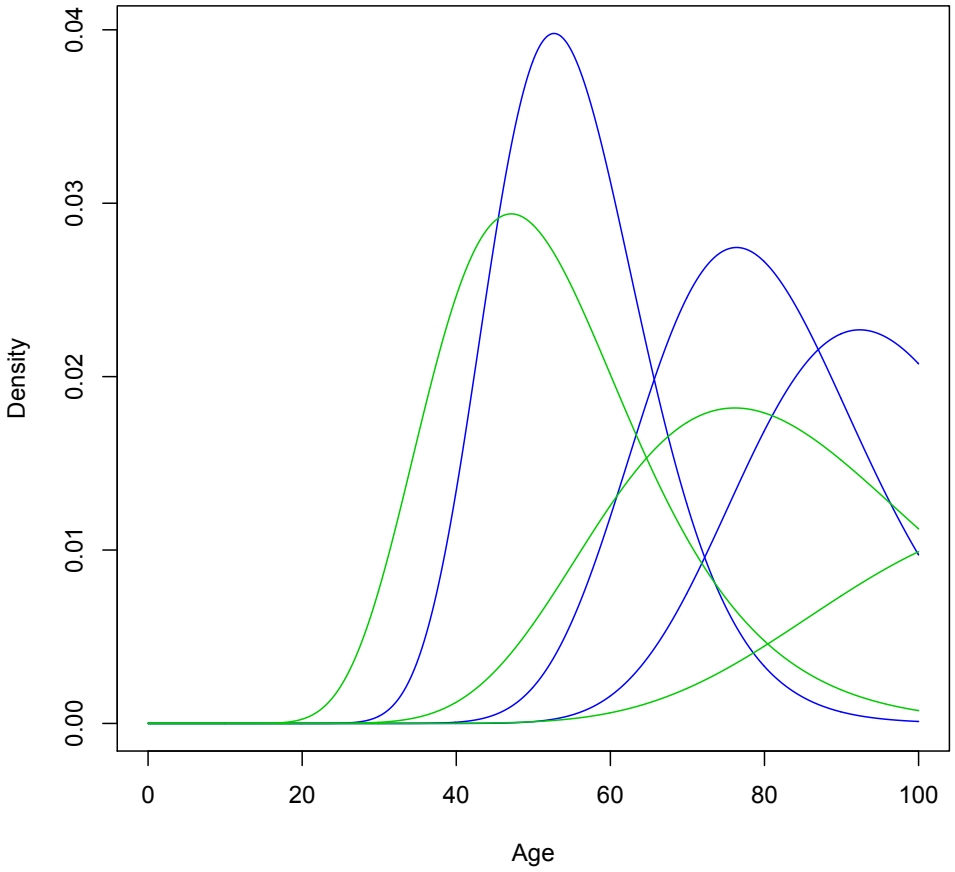


Figure 180: Transition analysis, density - parous (blue) and nulliparous (green) females

This may explain why the composition of the "average" parous face appeared slightly "older" than did the "average" nulliparous face (see chapter six, sections 6.0.4 and 6.2), while, statistically, there was no meaningful difference between

the two. Additionally, that nulliparous females fell "between" the parous female and male groups in select areas (see chapter six, section 6.2) may also be explained by this, as nulliparous females would have slightly less circulating oestrogen than would parous females (as oestrogen increases during pregnancy but returns to "normal," or nulliparous levels, soon after), but substantially more than males.

8.0.3 The Effect of Menopause on Ageing from the Pubic Symphysis

In the previous section, it was the presence of oestrogen that directly effected age estimation. In this section, oestrogen is still effecting age estimation - though this time through its absence.

With p-values of <0.0001 across all three methods (the Suchey-Brooks method, the Hartnett method, and the TCM) as well as effect sizes of 7.69, 7.89, and 7.69, respectively, menopause was by far the most influential variable of the study and was shown to exert an enormous impact on age estimation from the pubic symphysis in this sample. Based upon the results of the TCM, active flake deposition for women generally completes around the age of 40 years. After that, a noticeable outline begins to form (around 45 years), becoming fully established by the age of 50. It is with the completion of that outline, the point after which bone is no longer actively "building," that the epiphysis has finally closed. At 51 years (NHS 2015), the average age of menopause closely coincides with this completion.

Interestingly, though, the impact of menopause appeared to be binary, as, with p-values of 0.261, 0.240, and 0.251, age at menopause did not prove to be significant - either a woman had experienced menopause or she had not. Age at menopause did not matter. As can be seen in the R output for model three (chapter seven, section 7.2.3), menopause – as a variable - does not influence the model directly but rather, indirectly, through its effect on density. Through this indirect action, after menopause, women now aligned more closely with the men in this study (due to their newly mutual lack of oestrogen) than they did non-menopausal women. This represents a departure from the pregnancy status groupings where, because of *their* mutual levels of oestrogen, the female groups banded together (regardless of birth history) while the males remained separate.

Perhaps unsurprisingly, the pubic faces of pre-menopausal women appeared "youngest" in this sample, followed by males, then post-menopausal women, who appeared "oldest" (meaning most deteriorated). This order mirrors the "normal" levels of circulating oestrodoil in these groups (see above) - 30 to 400 pg/mL for pre-menopausal women, with 40 to 50 being ideal; 10 to 50 pg/mL for men, with 22 to 30 being ideal; and 10 to 20 pg/mL for post-menopausal women, with 40 to 50 being ideal (a drop placing them 10 points below the male "normal," a clear deficit and a dramatic shift).

Menopause is the cessation of the body's natural production of oestrogen. As discussed in the previous section, oestrogen acts as a safeguard for bone density in both women and men. When this buffer against bone loss is taken away,

degradation quickly follows. This includes men as well; "as men age, they often make less testosterone, and so they produce less estradiol as well … thus, changes often attributed to testosterone deficiency might be partly or entirely due to the accompanying decline in estradiol" (Wein 2013). However, as women experience dramatically higher levels of circulating oestrodoil during the entirety of their reproductive years, it would follow that the consequences of this withdrawal would be much more dramatic for women than it would be for men. It is perhaps for this reason that the pubic bones of women after menopause appear to be "older" (more weathered or coral-like) than men, which, in this sample at least, never reached the same level of deterioration - even at comparable ages.

It has been suggested that this pattern (females being more deteriorated than males) may simply be the result of differences in overall bone size and robusticity – i.e. larger bones would, naturally, be denser bones, and as males possess larger bones, they would naturally be more protected against deterioration (Simmons pers. com. 2015). However, for this to be true, variation would surely be seen within the female data set as well and not just between males and females (after all, humans come in all shapes and sizes and there is often more intra-variation within a group than inter-variation between groups). This was not seen to affect the results of this study. In the author's opinion, that the males and post-menopausal females became indistinguishable, while at the same time following the pattern of oestrogen known to be circulating in the body before and after menopause, points more towards a

withdrawal of oestrogen as the more impactful explanation, rather than size alone.

It has also been posited that the reason the female pubic symphysis is so much more difficult to age (when compared to men) is because, as a joint, it would react in a similar way as any other joint when exposed to trauma. For example, just as an elbow might be injured playing tennis and be ever after increasingly prone to arthritis, after undergoing the mechanical trauma of childbirth, it has been hypothized that the pubic symphysis becomes increasingly susceptible to deterioration (Bongiovanni pers. com 2015). This deterioration, referred to by one practitioner to "scar tissue," in turn, is what is thought to disrupt the "natural" phase progression as seen in men and thus accounts for the ageing inaccuracy seen in women. With the onset of menopause, then, and its effect on density, this "scar tissue" becomes more pronounced, which is why parous women are most difficult to age accurately (Bongiovanni pers. com 2015). This theory, however, was also disproved by the results of this study as the mechanical "trauma" of labour – as well as pregnancy more generally - has been shown to exert no significant effects on age estimation from the pubic symphysis.

8.0.4 The Effect of Activity on Ageing from the Pubic Symphysis

With p-values of 0.033 (effect size 0.69)(Suchey-Brooks), 0.047 (effect size 0.73)(Hartnett), and 0.028 (effect size 0.072)(TCM), the levels of participants' reported activity were also significant to ageing in this study.

As mentioned in the previous chapter (section 7.1.2.2), with a p-value of 0.020 in the optimum model, an active lifestyle – defined by the participant questionnaire as "dedicated cardiovascular exercise, dance, or sport, three or more times per week" – exerted the most significant effect on the model and, therefore, age estimation from the pubic symphysis. A moderately active lifestyle – defined as "walking or standing (including commuter travel) for an hour or more per day, and/or an hour or two of dedicated cardiovascular exercise, dance, or sport per week" – returned a p-value of 0.091 (not itself significant, but trending towards significance). A lightly active lifestyle – defined as "movement in and around the house and garden, with light chores and / or errands" – was not significant to the model, at 0.209. Finally, with a p-value of 0.932, immobility presented as least significant to ageing in this sample (though, with only 12 participants reporting in this category, this could also be partially due to its low power).

When the two least significant categories were collapsed and set as the reference level (or, the "control" against which all other categories will be compared), an ascending stepped pattern becomes immediately clear (*Table 19, below*).

Table 19: Activity levels and their significance

Activity Level	Description	N = 1,230	p - value	Significance
Immobile	Very minimal to no activity	12 participants (6 males, 6 female)	Reference Level	
Light	Movement in and around the house and garden, with light chores and / or errands	410 participants (202 males, 208 female)		
Moderate	Walking or standing (including commuter travel) for an hour or more per day, and/or an hour or two of dedicated cardiovascular exercise, dance, or sport per week	639 participants (332 males, 307 female)	0.091	•
Active	Dedicated cardiovascular exercise, dance, or sport, three or more times per week	169 participants (111 males, 58 female)	0.020	*

Furthermore, as evidenced by the optimum model (model 3, section 7.2.3), an active lifestyle (seen below as "ActionA") nearly doubles in significance in relation to a moderately active lifestyle ("ActionB"), when both are compared with the reference, "Light / Immobile":

```
ActionA          -1.2178     0.5336  -2.282 0.022680 *
ActionM          -0.7019     0.3721  -1.886 0.059508 .
```

This is interesting as "Active," at 17% for males and 10% for females (169 individuals in total), was far from the most prevalent response. This distinction was reserved for "Moderate," at 51% for males and 53% for females, followed by "Light," at 31% and 36%, respectively. In other words, despite the fact that less than 20% of the sample reported leading an active lifestyle, it was nevertheless that category that elicited the most significant response. This is no doubt an example of Wolff's Law in practice, which contents that bone responds

to and adapts to the stresses – in this case, weight bearing activities - placed upon it (Wolff 1892, 1986 translation). The greater the amount of movement involving the skeletal muscle, the more those muscles pull against the periosteum, creating microscopic damage. That damage, in turn, stimulates increased bone remodeling, or "turnover," at the site in need of repair. This repair not only builds up rugosity over time, making the bone physically thicker and stronger, but also increases the amount of circulating oestrogen in the body, as oestrogen is integral to fracture healing and turnover in adult bone (Vaananen and Harkonen 1996; Beil et al. 2010). This continuous stream of elevated oestrogen (which would be highest in active people, less so in moderately active people, and lowest in lightly active and / or inactive people) then safeguards the skeleton against future bone loss, explaining the stepped effect of activity on age estimation in this study.

8.0.5 The Effect of Tobacco Use on Ageing from the Pubic Symphysis

The final variable to flag up during regression testing was that of "Tobacco Use." For this, participants were asked whether or not they smoked or chewed tobacco products and, if so, how much (measured by the number of cigar / cigarettes or pinches per day). Participants were also asked to provide the age at which they started smoking or chewing tobacco. Whether the participant had quit using tobacco at any point was also noted, along with when they had quit or whether their tobacco use could better described as "off and on." With p-values of 0.010 (the Suchey-Brooks method), 0.002 (the Hartnett method), and 0.002 (TCM) and), and effect sizes of 1.85, 1.33, and 1.33, respectively, tobacco use

was also shown to exhibit a high degree of significance to the accuracy of age estimation from the pubic symphysis in this study.

The mechanism behind this may be two-fold. On one hand, nicotine - the active ingredient of the tobacco plant - has been clinically shown to interfere with bone metabolism by interfering with the regulation of hormones such as calcitonin as well as the expression and proliferation of both osteoblasts and osteoclasts (Rothem et al. 2009; Kamer et al. 2006; Tanaka et al. 2013). On the other, nicotine has also been shown to significantly reduce oestrogen circulation (Raval 2011) in women while at the same time inhibiting oestrogen production through the suppression, or "blocking," of aromatization in men (see section 5.1.3, above). Consequently, women who use tobacco are also more likely to enter into menopause earlier than those who do not (Raval 2011; American Academy of Orthopaedic Surgeons 2010; Davis 2015).

To further explore the effects of tobacco use on ageing from the skeleton and for that study to be defensible, patients would have to be carefully and specifically recruited in greater number than were presented here (as tobacco was not the focus of this project). For this reason, an investigation of this type would be better served as future work. However, while it was beyond the scope of this project to pursue tobacco use as an influencing factor beyond an initial yes or no (for reasons of time constraint and a less than ideal dataset for the purpose), it is nonetheless of interest to note the proven oestrogen link regarding smoking and age estimation given that extensive prior mention has already been made of

oestrogen and its influence on both sex and menopause in ageing from the pubic symphysis.

Indeed, while a supposition (an educated one but supposition all the same), that out of hundreds of variables with an equal chance of significance, that only three (four, if dimorphism is included) presented as significant to ageing in this study – and that each of those three exhibited strong and established associations with oestrogen in some way - the author believes it is extremely compelling as corroboration for oestrogen, more than any other factor, being the driving force behind the inconsistencies often remarked upon regarding ageing from the pubic symphysis.

8.0.6 Facial Progression and Asymmetry

In addition to the specific variables described above, this study also touched upon several additional, more general, concepts regarding the face of the pubic symphysis. The first of these was asymmetry.

During the original analysis, the pubic bones of each participant in this study were evaluated separately – first left, then right. These separate scores were then recorded individually. This was to simultaneously investigate and control for asymmetry, as perhaps one side would prove to be more reliable than the other. During regression, however, neither side was shown to be or less diagnostic regarding the estimation of age in this sample. In fact, contrary to much of the literature - including two of the three methods utilized in this study,

Suchey-Brooks (1990) and Hartnett (2010) – estimations actually improved when the two sides were averaged. Researchers have traditionally advised against averaging the pubic bones, preferring instead to trust the "older" side (Overbury et al. 2009). While controversial, based upon the results of this study it is the author's opinion that the opposite practice be adopted and that the two sides be averaged when both are present.

Another subject brought to the fore by this study was that of facial progression. Transition analyses comparing the males, parous females, and nulliparous females in this sample confirm that, for the most part, the components of the symphyseal face – the upper boundary, lower boundary, outline, surface texture, and topography – move forward together in terms of morphological timing, as opposed to some elements developing faster or slower than others. As discussed previously, the average male face (a composite of the most commonly assigned scores) appeared "youngest," the average parous face appeared "oldest," and the average nulliparous face (the most variable of the three) fell between the two (though considerably closer to the latter than the former). As traditional archetypal techniques rely on more general impressions of the face as a whole as opposed to a sum of its parts, this information may or may not be helpful in estimating age. This is because the overly broad age ranges of these methods, which provide nearly universal "coverage" by being at once expansive and overlapping, to do so by the very virtue of their *being* imprecise. These methods, in fact, operate on imprecision as these expansive and overlapping age ranges set up a "buffer" or "safety net," allowing an individual to be phased

incorrectly (for example, assigning a face as a four instead of a five) without the impact on accuracy being catastrophic.

The TCM, as presented by this thesis, adopts a similar approach – but in reverse. Instead of allowing for imprecision in categorization and relying on wide, imbricating ranges to ensure coverage, the TCM relies on more precise initial categorizations, which may themselves be "incorrect" a few places in either direction (due to systematic averaging). This, in turn, allows for narrower, more specific age ranges of no more than 22 years (as opposed to double or triple that amount), a span manageable enough for practical use.

8.1 Computed Tomography and Public Engagement

As discussed in the first chapter of this thesis (section 1.6), of the medical imaging mediums available, computed tomography, or "CT" was chosen for this study due to its ubiquity as well as its familiarity – though additional modalities such as ultrasound, which uses radio waves instead of radiation, as well as magnetic resonance imaging (MRI), which relies on magnets, were also considered. While ultrasound carries perhaps the most promise for future biological profiling research as it is non-ionizing, inexpensive, and highly portable, it as, at present, difficult to interpret for the average non-specialized practitioner (one has to really "have an eye for it" and know what he or she is looking for). As this type of inexperience and / or lack of aptitude increases rate of error, while, at the time decreases practitioner confidence (and, therefore, trust in the validity of using the medium), it is unlikely that ultrasound will be

integrated into common practice any time soon. CT images, on the other hand, depending on which rendering software is used, can be made to appear almost identical to the dry bone specimens the average practitioner is already familiar with, making the transition to "virtual" that much easier and interpretations more reliable.

Similarly, while MRI is also non-ionizing, and its images comparatively less difficult to "read" than those of ultrasound, it still requires a specialized eye. MRI is also more expensive than both ultrasound and CT due to its being a more time consuming process as, in addition to simply taking longer to produce, images hampered by movement must often be performed a second or third time. MRI also prohibits the inclusion of patients with any form of metal implant, which could include dental fillings, pacemakers, surgical implants, or hip and knee replacements – in other words, large segments of the population, most often the elderly.

For these reasons, after piloting all three, computed tomography emerged as the most practical (and most feasibly replicable) modality for the imaging of bone in this study. While the use of CT volume rendering for biological profiling has been criticized as simply seeking to "mimic" physical, real world bone instead of adopting a more engineered approach (CAD meshing, machine learning, or point cloud comparison, for example), again this would require specialized training – training the average practitioner is unlikely to possess (or, in many cases, desire). Conversely, for that average practitioner, precisely because those CT

renderings look like what he or she is already used to, the evaluation of virtual, but otherwise familiar, bone specimens is achievable now.

Also discussed in chapter one (section 1.5 and 1.7) was the author's desire for the incorporation of face to face involvement with living participants into biological profiling research as opposed to relying on anonymous data or retrospective access to medical records. While this "removed" approach provides some degree of life history information (often basic demographics and select lifestyle and disease data), it still harkens back to the paradigm of collection building – where skeletons are anonymous objects of study, with limited information and no opportunity for follow up - and, therefore, does not represent innovation or push the field forward in any meaningful way. It is not the concept of CT assisted profiling that is new (anthropologists have been scanning "mummies" since the 1970's), regardless of how much more impressive the technology has become. Anonymous and retrospective studies are simply extensions of collection building in another medium – "the head learns new things, but the heart forever practices old experiences" (Henry Ward Beecher, date unknown). What must break new ground, therefore, is methodology.

By incorporating public engagement into the study of biological profiling, not only can "what" questions (chapter one, section 1.7) be explored – such as *what* is the effect of density on age estimation from the pubic symphysis - but also "why" questions as well - such as *why* does density effect age estimation from the pubic symphysis. This is because skeletons, and the people they belong to,

do not exist in a vacuum, they live in the world and are a product of the people and places around them (just as the people and places around them may be said to be a product of them). Interaction with living participants, therefore, is imperative as it provides the missing half of the profiling puzzle.

An illustration of this might be the use of tobacco, one of the variables found to be significant to age estimation in this study. When asked at what age they began smoking and why, participants' answers often centered around the desire to "fit in," to "look cool" for their friends or potential partners, or to "spend time with people" and not be "left out." One individual recounted that he had taken up smoking cigarettes at the age of eight or nine because that was the only way he could spend time with his father, who often worked long hours. In this way, smoking was equally as socially motivated as it was biologically (in that participants stated that once they had started, it became addictive and they could not stop). In the case of smoking, then, where does culture end and biology begin? How much of the addiction, often attributed to stress relief, is endocrine and how much is the result of stepping away from the stress event? The same could be said for activity – how much of going to the gym, running a marathon, or playing team sports is socially motivated (perhaps to better attract a partner due to a societal preference in appearance, to overcome adversity and "push" oneself to victory, or to experience the sense of comradery and purpose of a group), and how much is owed to the pleasure response resulting from the rush of endorphins?

In his book "The Perception of the Environment: Essays on Livelihood, Dwelling, and Skill" (2000), social anthropologist Tim Ingold argues that organisms are not discrete entities and that "[practitioners] should be trying to find a way of talking about human life [in a way that] eliminates the need to slice it up into these different layers" (Ingold 2000:3). In his 1934 "Techniques of the Body," Mauss speaks of *physio-psycho-sociological* assemblages of actions while in his 1950 "Seasonal Variations of the Eskimo," focus turns to the effect of geography on social morphology, detailing the symbiosis between social and physical worlds. Building upon Mauss's concept of the "*habitude*," Bourdieu, with his *hexis* and *habitus* (1977), further described this interconnectivity between the body and its socio-physical environment as a "conductor-less orchestra" (1990:59).

The idea of the *habitus* and *hexis*, however, pre-date the 20th century. For the ancient Greeks, most notably Aristotle, they were defined as a person's health or "disposition" (Sachs 2016). That the physical body was engaged in a constant state of interaction with its environment, as well as the universe more broadly ("the astrological man," for example, documented the effects of the stars and planets), was widely acknowledged and formed the basis of humor theory, in which the balance or imbalance of the natural world defined an individual's health and well-being. Changes to a person's environment, therefore, including his or her social sphere, carried real, corporeal consequences. In biology and clinical medicine, this worldview has largely fallen from favour (though it can still be found as the basis of certain Chinese and Ayurvedic traditions); however, its core thesis - that the physical body is never static but is, instead, in a state of

perpetual flux and adaptation in response to its environment – deserves a reprieve. In studying the effects of socio-physical aspects such as smoking and activity level on this sample, it has become clear that, at least in part, our environment (constructed or otherwise) shapes *us* as much as we shape *it*.

Discovering this, however, would not have been possible without public engagement and the direct involvement of living participants in this study. Being able to speak to each individual personally in the format of a face to face interview, which allowed them to tell their story and provide additional information if need be, was invaluable when it came to "reading" the lives of their skeletons. Without this specificity, the results of this study would have been much less robust as many of the things controlled or accounted for could have muddied the analysis, compromising overall clarity.

The idea that incorporating living people into biological profiling research is too difficult or too time consuming to pursue, or that once the effort has been expended that people will not be interested, is simply false. For this project, every other person asked to participate, did – and not only were they interested, they were enthusiastic and happy to help. Furthermore, in speaking with the individuals and their families about the study, including what forensic anthropology is and why it is needed, many asked how they could do more. In reaching out the public and making them partners in the process, the author gathered more information than she could use while, at the same time, informing people about the importance of forensic research – something sometimes portrayed as arcane or macabre, but need not be.

With the global population set to change dramatically over the next few decades, this type of engagement will be key to staying current. Not only does interaction with living participants through medical imaging push the field forward in allowing researchers to investigate specific, targeted forensic questions but it also, as has been shown, becomes the nexus of several disciplines including public health, forensic anthropology, cultural anthropology, and more – opening avenues of interdisciplinary research that can only lead to a better, more nuanced understanding of the human body and its place in the world.

8.2 Limitations

As the participants in this study were recruited exclusively from within a hospital setting, one of the limitations of this study was the risk of a self-selecting pathological sample. Because of this, the "ordering department," or the department from which each patient's CT was ordered (cardiology, oncology, etc.), was noted for the first 100 patients and compared to their estimated ages. This initial testing returned no adverse association between ordering department and ageing accuracy. In fact, it showed no association at all. This finding would suggest that while hospital patients may indeed be self-selecting, pathology - be it chronic (e.g. cancer) or acute (e.g. urinary tract infection) - had absolutely no effect on the results of this study. Further recruitment, therefore, continued as planned.

Another potential limitation regarding this investigation was its reliance upon patient self-identification, memory, and honesty when completing the questionnaire - the risk being that inaccurate information would then undermine the data and invalidate the results and any conclusions based upon them. In order to reduce this risk, the author went through each question, one by one, with each participant, reading aloud and explaining each question as well as asking them to clarify or to be more specific where applicable. This, it was hoped, would focus the responses and dispel any potential misinterpretation. This face to face interaction also enabled the author to verify (visual) demographic information such height, weight, and body shape and to note any inconsistencies, though this measure would not make up for any purposeful inaccuracies on the part of the participants, who could lie or omit information if they so chose. Based on this personal experience with each participant during this interview process, however, the author felt thoroughly satisfied with the level of candidness and truthfulness with which the participants answered. The participants in this study were exceedingly open and honest about their life histories and experiences - some even brought in lists of their medications in case it might be helpful. The author believes, therefore, that the risk of misinformation (purposeful or otherwise) regarding this sample was small, or at least comparable to similar studies utilizing guided self-reporting (as the participants in this study are unlikely to be any more or less dishonest than they would be in any other study, equalizing the potential for adverse effect). Even so, given that lifestyle factors account for only 3% of the Truesdell Composite Method's predictive power, the overall effect exerted

by the potential of a small percentage of participants being only partially truthful is likely negligible given the large sample size in this study.

The author would have also liked to structure the observations as time series, with each observer evaluating the same dataset multiple times. This would have provided intra-observer error data as well as allowed for practice with the technique (meaning the author would expect the last observation to produce the highest number of accurate estimations). This was not possible, however, due to availability issues – both with the hospital (access is only granted for a set period) and the observers themselves (who did not have time to do multiple evaluations). Secondly, regarding the observations, the author should have also given the observers a "dummy" set of practice specimens with which to familiarize themselves with the TCM, as well as working with CT more generally. Again, due to availability, observers elected to forgo this practice.

Lastly, in a larger sense, studies of this kind - those involving medical imaging – will always be limited by the fact that they are entirely virtual and are, therefore, dependent upon the technology that collects and creates them. Because of this, vast networks of expensive, specialized equipment and data storage systems (which then require people trained to operate them) must be maintained, which may not be available to all practitioners.

8.3 Future Work

This study answered several questions; however, like any investigation it created several more. Future work generated by this project, therefore, include a more detailed exploration of the effects of tobacco and activity on age estimation, whether overall bone size as opposed to sex specific hormones (or visa versa) are more impactful on bone density, a more objective quantification of density, investigation into the timing of Upper Boundary squaring - the progression of "V" to "Y" to "T" (as assessed by axial image) – to determine whether that could be useful as a technique for ageing, as well as whether the gradual narrowing (deterioration) of the central inter-pubic cartilaginous disc might be regular and linear so as to support the creation of a technique.

The future of the TCM should also include digitization – the development of a program that would, ideally, function in much the same way as facial recognition software - to decrease practitioner subjectivity. This would mean one could laser scan (if physical) or upload (if CT or photograph) a questioned symphyseal face and receive a mean age and range automatically on his or her computer or mobile phone – both increasing speed and reducing subjectivity.

Finally, as results of this study are applicable to British samples only, future testing on additional datasets will be necessary to verify its efficacy on non-British populations. Adapting the method for dry bone is also a priority.

9

Conclusion

8.0 **Conclusion** …… 387

Abstract:

This chapter will conclude the thesis by briefly bringing summarizing the information presented by the previous chapters.

As out forth by the first chapter of this thesis ("An Introduction and Review of the Literature"), the aim of this study was to improve precision in female age estimation through the utilization of medical imaging technology and personal face-to-face interaction with living participants. As then demonstrated over the course of eight chapters, this was accomplished through the generation of a new, CT based sample of 1,238 living volunteers ("The Sample," page 184 of this document) in partnership with the department of radiology at Oxford's OUHS Churchill Hospital ("Materials and Methods," page 135 of this document). With these two elements in place, the introduction of a experimental age estimation technique designed specifically to increase precision ("Truesdell Composite Method [TCM] Analysis," page 252 of this document) was applied alongside two additional established methods (the Suchey – Brooks method for agening the Os Pubis and the Hartnett method), for comparison.

In a series of face to face interviews, study participants were guided through the completion of a questionniare, the answers to which were used to both establish the representativeness of the sample as well as ensure that any changes observed on the bones of the individuals studied (pitting, lipping, porosity, etc.) were, indeed, age related and not the results of extrinsic factors such as environment or lifestyle in disguise. Pelvic scans of each participant were then performed and age was estimated from the pubic symphysis using all three methods – ("Suchey-Brooks Analyis," page 226 of this document; "Hartnett Analysis," page 239 of this document; "Truesdell Composite Method [TCM] Analysis," page 252 of this document). The accuracy and precision of these techniques were then compared ("Results [Statistical Analysis] and "Discussion," pages 289 and 350 of this document, respectively). Results of this comparison indicate that the Truesdell Composite Method, this study's experimental technique, performed at least as effectively in establishing age from the pubic symphysis as did the two established methods. Perhaps more importantly, however, it was also successful in substantially decreasing imprecision (in relation to the other methods) within those estimations. Based on this outcome, as well as how it was brought about, the author believes it may be said that the current study has satisfied both its aim and its objectives, while also answering its research question – "can the TCM, a CT specific technique, be considered a good predictor of age?" Again, the author believes it can.

Beyond this, results of this study also indicate:

- that the more known about an individual (in this case smoking, activity level, menopause), the better the practitioner will be at estimating his or her age
- that males and females differ demonstratively at the pubic symphysis and warrant separate sex-appropriate systems, though how significant five or six years is will likely depend on intended use (archaeological versus forensic estimations)
- that pregnancy, when density is adjusted for, asserts no significant impact on reliability when ageing from the pubic symphysis (both morphology and transition timing were identical for both parous and nulliparous females, eliminating both hormonal incongruities [relaxin] and mechanical strain [labour] as relevent to age estimation)
- that differernt areas of the pubic face transition at slightly different rates in parous females, nulliparous females, and males (raising implications for more archetypical or typological methodologies) though, within each group, the face moves forward as a whole
- that density is the single most influential factor in ageing from the pubic symphysis for both males and females (regardless of parity), with differences in oestrogen as the likely cause

Many of these findings - most notably amongst them the "non-effect" of pregnancy – directly contradict the well established, if anecdotal, wisdom passed down through the literature for nearly a century. This is because, without the assistance of living people, with whom researchers may interact and ask questions about their life events and day to day activities, there has

been no meaningful way of adequately testing such theories at the level of detail required. With living volunteers, however, that need no longer be the case – especially as concerns those over the age of 60 years of age, currently the biological profile's most under represented demographic.

With the United Nations projecting a newly burgeoning, as well as rapidly ageing, world population within the next few decades, more attention needs to be paid to older individuals and not just the young because they are easier. To be rady for this future, forensic anthropologists need to leave the comfort of the lab, acknowledge, and incorporate those all around them, everyday, into their biological profiling research instead of looking past them in favour of more familiar, but more antiquated, methods – forensic anthropology is no longer physical anthropology, in purpose or purview. The world is changing and forensic anthropology needs to keep up.

In the words of Soren Blau, "Forensic anthropologists have an ethical responsibility to consider the reliability and acceptability of the techniques [they] employ" (2009:460). It is widely accepted that many of the seminal methods in use now – for example, Suchey-Brooks (1990) – are famously imprecise, as precision is sacrificed for "accuracy," especially in individuals of advanced age. In fact, historically, anyone over 60 years has been considered too difficult to even attempt and have so been, in a sense, thrown away or dismissed as not being worth spending time on. In recent years this ideology has been up-ended, however, as renewed interest in the latter half of life has lead to techniques specifically developed for age estimation in older individuals

(Watanabe and Terazawa's investigation of osteophytic activity on the vertebrae [2006], Calce's guide to ageing the acetabulum [2012], and Fayls and Prangle's methodology for assessing degradation of the clavicle [2015]). The TCM, as presented by this thesis, hopes to take its place among them by supplying a more precise and elder friendly technique for the pubic symphysis. Unlike the others, however, this methodology was the first to be developed with the help of living subjects.

With the shifting demographics of today's world, the only way forensic anthropologists will be able to keep current will be through the embracing of both medical imaging and public engagement – the act of getting out into their communities and recognizing living participants as equal partners in the biological profiling process. To do this, the field must make a conscious effort to begin supplementing its existing collections with more up to date imaging modalities such as ultrasound, MRI, and CT, and with that must come more image specific (as opposed to dry bone) techniques.

To highlight the necessity, as well as the possibilities, of this new branch of study, for this project the author focused on precision and age estimation from the pubic symphysis. However, the combination of medical imaging and public engagement also has immediate applications to each of anthropology's subdisciplines. Biological anthropologists may chose to focus on the effects of pregnancy, reproduction, and menopause on both the individual and the community, while physical anthropologists / bioarchaeologists might be interested in the skeletal effects of activity, occupation, diet, or smoking and

alcohol. Similarly, socio-cultural anthropologists might focus on family dynamics or the effects of consumerism on a community, while medical anthropologists might be interested in demographics, disease, and public health.

Lastly, while this thesis detailed females only (as the author felt that females were in greater need of attention), a male version of the Truesdell Composite Method exists as well. In addition to advocating for the integration of imaging and public engagement into biological profiling research, therefore, it is also hoped that the "TCM" may also prove helpful in the estimation of age for all older individuals – a group too long neglected.

Humans are often defined by the things around them. In archaeological contexts, a person's story is told through his or her environment and the grave goods with which he or she is buried. In cultural or material anthropology, that story is told through the items or objects with which a person lives, what he or she surrounds him or her self with on a daily basis. In medicine, studies investigating the effects of environment and lifestyle on the body are both plentiful and robust. Even so, forensic anthropologists and clinicians rarely communicate, though their study subjects – current populations - are the same.

It is therefore hoped that, with its utilization of medical imaging, interviews with living participants, and its introduction of a unique CT based technique, this thesis will encourage a more forward thinking approach to the future of modern data collection and will spark more interdisciplinary discussion as to where biology begins and lifestyle and environment ends - and how that affects

not only ageing and the biological profile, but also the role of forensic anthropology itself in an increasingly diverse and rapidly changing world.

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Images

Figure 1:

https://embryology.med.unsw.edu.au/embryology/index.php/Carnegie_stage_15

Figure 2:

https://www.pinterest.com/pin/537476536748548346/

Figure 3:

Boonrungsiman et al. 2012 (above)

Figure 4:

Wiesmann et al. 2005 (above)

Figure 5:

https://askabiologist.asu.edu/bone-anatomy

Figure 6:

https://www.youtube.com/watch?v=X6E5Rz9tOKE

Figure 7:

http://classes.midlandstech.edu/carterp/Courses/bio210/chap06/lecture1.html

Figure 8:

Barthalet 2007 (above)

Figure 9:

https://embryology.med.unsw.edu.au/embryology/index.php/Carnegie_stage_18

Figure 10:

https://embryology.med.unsw.edu.au/embryology/index.php/Carnegie_stage_22

Figure 11:

http://classes.midlandstech.edu/carterp/Courses/bio210/chap06/lecture1.html

Figure 12:

http://classes.midlandstech.edu/carterp/Courses/bio210/chap06/lecture1.html

Figure 13:

https://www.studyblue.com/notes/note/n/chapter-7-skeletal-system-physiology/deck/12262360

Figure 14:

http://classes.midlandstech.edu/carterp/Courses/bio210/chap06/lecture1.html

Figure 15:

https://www.researchgate.net/publication/276057653_Response_to_commentary/figures?lo=1

https://www.studyblue.com/notes/note/n/lab-skeletal-system-/deck/14765770

Scheuer and Black 2000 (above)

Figure 16:

Scheuer and Black 2000 (above)

Figure 17:

Gilsanz and Ratib 2005 (above)

Figure 18:

Scheuer and Black 2000 (above)

Figure 19:

http://vsrc.com.au/what-is-a-risser-sign/

Figure 20:

Scheuer and Black 2000 (above)

Figure 21:

Suchey and Webb 1985

Figure 22:

Schmidt et al. 2011 (above)

Figure 23:

Wittschieber et al. 2013 (above)

Figure 24: Scheuer and Black 2000 (above)

Figure 25: Scheuer and Black (above)

Figure 26: Ramey Burns 2008 (above)

Figure 27: Todd 1928 (above)

Figure 28:

https://www2.aofoundation.org/wps/portal/!ut/p/a0/04_Sj9CPykssy0xPLMnMz0vMAfGjzOKN_A0M3D2DDbz9_UMMDRyDXQ3dw9wMDAzMjfULsh0VAbWjLW0!/?approach=Anterior%20to%20pubic%20symphysis%20&bone=Pelvis&classification=61-B3&implantstype=&method=Operative%20treatment&redfix_url=1437997400652&segment=Ring&showPage=approach&treatment=&contentUrl=/srg/61/04-Approaches/A01-PubicSymph.jsp

Figure 29:

Image by the author (2011)

Figure 30:

https://jenjdanna.com/blog/2012/2/14/forensics-101-victim-age-determination-based-on-the-adult-pe.html

Figure 31:

Buikstra and Ubelaker 1994 (above)

Figure 32:

Parfitt et al. 1996 (above)

Figure 33:

Morgan et al. 2013 (above)

Figure 34:

Arnett 2013 (above)

Figure 35

http://boneresearchsociety.org/resources/gallery/19/#top

Figure 36: Morgan et al. 2013 (above)

Figure 37: Iscan and Loth 1985 (above)

Figure 38:

http://global.oup.com/us/companion.websites/9780195188592/student/part_one/aging/Aging1/

"Age 70, Black Male"
Figure 39:

https://www.researchgate.net/profile/Andrew_Wade

Figure 40:

Buikstra and Ubelaker 1994 (above) (cropped and enlarged)

Figure 41:

https://www.museumoflondon.org.uk/collections/other-collection-databases-and-libraries/centre-human-bioarchaeology/osteological-database/medieval-cemeteries/dominican-friary-carter-lane-photographs

"Osteophytic lipping around the rim of the left acetabulum"

Figure 42:

Kim et al. 2012 (above)

Figure 43:

Fayls and Prangle 2015 (above)

Figure 44:

http://anthropology.si.edu/writteninbone/young_old.html

Figure 45:

http://anthropology.si.edu/writteninbone/young_old.html

Figure 46:

http://www.innerbody.com

Figure 47:

https://www.quora.com/Could-a-human-ever-train-to-move-as-efficiently-as-a-primate-does-in-the-trees

Gruss and Schmitt 2016 (above).

Figure 48:

http://clinicalgate.com/pelvis-and-perineum-2/

Figure 49:

http://poonamkdc.wixsite.com/anatomy-website/bony-pelvis-crbl

Figure 50:

http://clinicalgate.com/pelvis-and-perineum-2/

Figure 51:

http://www.oregonexercisetherapy.com/blog/archives/08-2014

Figure 52:

https://www.bowchair.com/pelvic-floor/

Figure 53:

http://nonmetricpelvissexing.weebly.com/spc.html

https://www.studyblue.com/notes/note/n/anthr-360-study-guide-2014-15-mayes/deck/12288704

Figure 54:

White and Folkens 2005 (above)

Figure 55:

McKern and Stewart 1957 (above)

Figure 56:

Buikstra and Ubelaker 1994 (above)

Figure 57: Image by the author (2011)

Figure 58: Berg 2008 (above)

Figure 59:

Hartnett 2010 (above)

Figure 60:

Chen et al. 2008 (above)

Figure 61:

Chen et al. 2008 (above)

Figure 62:

Dudzik and Langley 2015 (above)

Figure 63:

http://www.un.org/apps/news/story.asp?NewsID=51526#.WHbuNhQgeRF

United Nations 2015 (above)

Figure 64:

http://www.un.org/apps/news/story.asp?NewsID=51526#.WHbuNhQgeRF

United Nations 2015 (above)

Figure 65:

https://www.thinglink.com/scene/719221188345200641

Figure 66:

https://imagine.gsfc.nasa.gov/science/toolbox/emspectrum1.html

Figure 67:

https://learn.sparkfun.com/tutorials/what-is-electricity/flowing-charges

Figure 68:

http://science.howstuffworks.com/x-ray2.htm

Figure 69:

http://www.insighttrails.com/blog/2011/05/the-hand-on-the-wall.html

Figure 70:

http://www.konicaminolta.com/healthcare/products/dr/dr30/

Figure 71:

http://www.physicscentral.com/explore/action/scans.cfm

Figure 73:

https://www.ceessentials.net/article33.html

Figure 74:

http://www.medical.siemens.com/siemens/en_INT/gg_ct_FBAs/files/brochures/ct_somatom_definition.pdf

http://www.iconarchive.com/show/imod-icons-by-babasse/DVD-R-icon.html

Figure 75:

https://www.dotmed.com/listing/computer-system/ge/aw-workstation-4.3-on-hp8200/1254785

Figure 76:

https://www.ceessentials.net/article33.html

Photo by the author

Figure 77:

http://www.diagnosticomaipu.com/images/deptomusculoesqueleticas/028.jpg

Figure 78: Images created by the author (2014)

Figure 112:

Suchey and Katz 1985 (above)

Figure 113:

White and Folkens 2005 (above)

Figure 114:

Buikstra and Ubelaker 1994 (above)

Figure 115:

Image created by the author

Figure 120:

Hartnett 2010 (above)

Figure 121:

Hartnett 2010 (above)

Figure 122:

Image created by the author

Figure 123:

Image created by the author

Figure 124:

Image created by the author

Figure 125:

Image created by the author

Figure 128:

White and Folkens 2005 (above)

Figure 129:

Image created by the author (from White and Folkens 2005)

Figure 130:

Image created by the author (from White and Folkens 2005)

Figure 131:

Image created by the author

Figure 133:

www.watchpower.eu

Figure 134:

Image created by the author

Figure 135:

Image created by the author

Figure 136:

Image created by the author

Figure 137:

Image created by the author

Figure 138:

Image created by the author

Figure 139:

Image created by the author

Figure 140:

Image created by the author

Figure 141:

Image created by the author

Figure 142:

Image created by the author

Figure 143:

Image created by the author

Figure 144:

Image created by the author

Figure 145:

Image created by the author

Figure 146:

Image created by the author

Figure 164:

Image created by the author

Appendices

(A – I)

Appendix

A

NRES Favourable Opinion

Health Research Authority
NRES Committee South Central - Hampshire A
Bristol Research Ethics Committee Centre
Level 3, Block B
Whitefriars
Lewins Mead
Bristol
BS1 2NT

Telephone: 0117 342 1381

01 April 2014

Ms. Janamarie Truesdell
Wolfson College
Linton Road
Oxford
OX2 6UD

Dear Ms. Truesdell

Study title:	**Assessing the Effects of Pregnancy on the Face of the Pubic Symphysis: Implications for Ageing.**
REC reference:	**14/SC/0061**
IRAS project ID:	**119232**

Thank you for your letter of 26 March 2014, responding to the Committee's request for further information on the above research and submitting revised documentation.

The further information has been considered on behalf of the Committee by the Vice-Chair.

We plan to publish your research summary wording for the above study on the HRA website, together with your contact details, unless you expressly withhold permission to do so. Publication will be no earlier than three months from the date of this favourable opinion letter. Should you wish to provide a substitute contact point, require further information, or wish to withhold permission to publish, please contact the REC Manager Mrs Vicky Canfield-Duthie, nrescommittee.southcentral-hampshirea@nhs.net.

Confirmation of ethical opinion

On behalf of the Committee, I am pleased to confirm a favourable ethical opinion for the above research on the basis described in the application form, protocol and supporting documentation as revised, subject to the conditions specified below.

Ethical review of research sites

NHS sites

The favourable opinion applies to all NHS sites taking part in the study, subject to management

permission being obtained from the NHS/HSC R&D office prior to the start of the study (see "Conditions of the favourable opinion" below).

Conditions of the favourable opinion

The favourable opinion is subject to the following conditions being met prior to the start of the study.

Management permission or approval must be obtained from each host organisation prior to the start of the study at the site concerned.

Management permission ("R&D approval") should be sought from all NHS organisations involved in the study in accordance with NHS research governance arrangements.

Guidance on applying for NHS permission for research is available in the Integrated Research Application System or at http://www.rdforum.nhs.uk.

Where a NHS organisation's role in the study is limited to identifying and referring potential participants to research sites ("participant identification centre"), guidance should be sought from the R&D office on the information it requires to give permission for this activity.

For non-NHS sites, site management permission should be obtained in accordance with the procedures of the relevant host organisation.

Sponsors are not required to notify the Committee of approvals from host organisations

Registration of Clinical Trials

All clinical trials (defined as the first four categories on the IRAS filter page) must be registered on a publically accessible database within 6 weeks of recruitment of the first participant (for medical device studies, within the timeline determined by the current registration and publication trees).

There is no requirement to separately notify the REC but you should do so at the earliest opportunity e.g when submitting an amendment. We will audit the registration details as part of the annual progress reporting process.

To ensure transparency in research, we strongly recommend that all research is registered but for non clinical trials this is not currently mandatory.

If a sponsor wishes to contest the need for registration they should contact Catherine Blewett (catherineblewett@nhs.net), the HRA does not, however, expect exceptions to be made. Guidance on where to register is provided within IRAS.

It is the responsibility of the sponsor to ensure that all the conditions are complied with before the start of the study or its initiation at a particular site (as applicable).

Approved documents

The final list of documents reviewed and approved by the Committee is as follows:

Document	*Version*	*Date*
Response to Request for Further Information		26 March 2014
Questionnaire: Participant Questionnaire	3	26 March 2014
Participant Information Sheet	2.0	19 March 2014
Participant Consent Form	2.0	19 March 2014
Letter of invitation to participant	1	05 March 2014
Other: CV: Lauren O'Boyle		
Other: Software Confirmation Letter		
Response to Request for Further Information		
Evidence of insurance or indemnity		01 August 2013
Other: CV: Dr Marquez-Grant		
REC application		
Protocol	1.0	22 January 2014
Investigator CV		
Letter from Sponsor		20 January 2014
Summary/Synopsis	1.0	22 January 2014
Other: CV: Prof Banks		

Statement of compliance

The Committee is constituted in accordance with the Governance Arrangements for Research Ethics Committees and complies fully with the Standard Operating Procedures for Research Ethics Committees in the UK.

After ethical review

Reporting requirements

The attached document *"After ethical review – guidance for researchers"* gives detailed guidance on reporting requirements for studies with a favourable opinion, including:

- Notifying substantial amendments
- Adding new sites and investigators
- Notification of serious breaches of the protocol
- Progress and safety reports
- Notifying the end of the study

The NRES website also provides guidance on these topics, which is updated in the light of changes in reporting requirements or procedures.

Feedback

You are invited to give your view of the service that you have received from the National Research Ethics Service and the application procedure. If you wish to make your views known please use the feedback form available on the website.

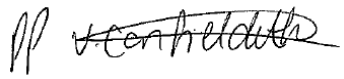
Further information is available at National Research Ethics Service website > After Review

14/SC/0061	Please quote this number on all correspondence

We are pleased to welcome researchers and R & D staff at our NRES committee members' training days – see details at http://www.hra.nhs.uk/hra-training/

With the Committee's best wishes for the success of this project.

Yours sincerely



Dr Iain MacIntosh
Chair

Email:nrescommittee.southcentral-hampshirea@nhs.net

Enclosures: "After ethical review – guidance for researchers" *[SL-AR2]*

Copy to: *Ms Heather House, Oxford University Hospitals NHS Trust*

Appendix

B

Trust Management Approval

Oxford University Hospitals NHS
NHS Trust

HH/BS/DF/8851

From the R & D Lead
OUH Research & Development
Joint Research Office
Block 60, Churchill Hospital
Old Road, Headington
Oxford OX3 7LE

Tel: (01865) (5)72240
Fax: (01865) (5)72242
Debbie.Franklin@ouh.nhs.uk

Ms Janamarie Truesdell
Wolfson College
Linton Road
Oxford
OX2 6UD

20 June 2014 (Reissued 20 June 2014)

Dear Ms Truesdell

Re: Assessing the Effects of Pregnancy on the Face of the Pubic Symphysis: Implications for Ageing
Research and Development Reference: 8851
Research Ethics Committee Reference: 14/SC/0061

Confirmation of Trust Management Approval
On behalf of the Oxford University Hospitals NHS Trust, I am pleased to confirm Trust Management Approval and Indemnity for the above research on the basis described in the application, protocol and other supporting documents.

Conditions of Approval
Your attention is drawn to the attached conditions of approval. Breach of these conditions may result in Trust Management Approval being revoked.

Recruitment

The agreed total recruitment target for your study at the OUH site is between 296 and 890 participants by 31/03/2015 as specified in the contract.

To support requirements of the OUH Trust and national recruitment targets, we will be monitoring and publishing outcomes of recruitment for your study. This will include reporting performance against the 70 calendar day period from the time of receipt of a valid research application in R&D to the time of recruitment of the first participant to your study.

Your first participant recruitment target date is 28.08.2014
In the meantime, if you recruit your first participant into the study then please send the date to researchrecruitment@ouh.nhs.uk
The R&D office will contact you in due course by email to ask about the recruitment progress against this target.

Ethics Correspondence
In order to facilitate good communications and avoid unnecessary delays please copy all correspondence with the Research Ethics Committee (REC) to R&D, providing copies of all relevant documents.

Research Sponsorship

It is noted that The University of Oxford has agreed to Sponsor this trial.

Site Specific Assessment

This Trust Management Approval letter also incorporates site specific assessment for the Oxford University Hospitals NHS Trust site.

Approved Documents

Document Type	Version	Date
Protocol	1.0	22 January 2014
Summary/Synopsis	1.0	22 January 2014
Letter of Invitation to Participant	1	05 March 2014
Participant Information Sheet	2.0	19 March 2014
Participant Consent Form	2.0	19 March 2014
Questionnaire: Participant Questionnaire	3	26 March 2014
Letter from Sponsor		20 January 2014
Evidence of insurance or indemnity		01 August 2013
Investigator's CV	Janamarie Truesdell	
REC Application		
REC Provisional Opinion		17 February 2014
REC Favourable Opinion	1	01 April 2014
REC: Response to Request for Further Information		19 March 2014
REC: Response to Request for Further Information	2	25 March 2014
NHS R&D Form		
NHS SSI Form	OUH NHS Trust	

I wish you every success with the study.

Yours sincerely,



Ms Heather House
Research and Development Lead

Copy to:	Chief Investigator:	janamariet@gmail.com
	Sponsor:	ctrg@admin.ox.ac.uk
	OUH Study Finance	study.finance@nhs.net

Oxford University Hospitals NHS
NHS Trust

Standard Conditions of Approval by Oxford University Hospitals NHS Trust for Research studies other than Clinical Trials of Investigational Medicinal Products or Medical Device Trials

Issued to Chief Investigators and Principal Investigators

1) **Commencement of the Study**

Before the study commences the Chief Investigator/Principal Investigator is responsible for the following:

a) Ensuring that all members of the research team are appropriately qualified to undertake their role(s) through education, training and experience

b) Establishing a Study Master File/Site File, which should be maintained throughout the study and be readily available to the study team.

c) Ensuring that all members of the research team who have access to patients, their organs, tissues, data or access to NHS staff, information and facilities have OUH substantive/honorary contracts or appropriate research passports/honorary research contracts/letters of access in place prior to their involvement in the study.

d) Ensuring that all appropriate approvals are in place and remain so for the duration of the study

e) Ensuring that all investigators in the study are aware of and comply with the Regulatory Framework surrounding research practice, which includes but is not limited to:

- The Department of Health Research Governance Framework for Health and Social Care 2005
- Mental Capacity Act 2005
- The Human Tissue Act 2004
- The Declaration of Helsinki 2000
- The Human Rights Act 1998
- The Data Protection Act 1998
- ICH Good Clinical Practice 1996

2) **Conduct of the Study**

a) The study will be conducted according to the all applicable regulations, principles of Good Clinical Practice and applicable OUH Trust policies.

b) The study will be conducted in accordance with the approved protocol.

c) Essential documents will be made available for audit and inspection purposes where required.

d) The Trust must be made aware of any Intellectual Property that arises from the research study.

3) **Protocol Amendments**

a) Where the OUH (NHS) Trust has taken on the role of Sponsor, investigators must submit protocol amendments to R&D Department **prior** to submission the Research Ethics Committee and MHRA, to assess any implications for the Sponsor.

b) All **substantial** amendments must be submitted to the appropriate Research Ethics Committee for approval. Documents should also be forwarded to the R&D Department for assessment as to whether the amendment affects Trust Management Approval.

c) In order for the Trust to meet its responsibilities under the Research Governance Framework **all amendments, including non-substantial amendments** must be submitted to R&D department. You should include all supporting documents.

d) Submission of substantial amendments will be acknowledged by a letter confirming on-going Trust Management Approval, non-substantial amendments will be acknowledged by email.

e) **NO** substantial amendment, except those that relate to an urgent safety measures, should be implemented until all appropriate approvals have been obtained.

4) **Change of key Site Personnel - Chief investigator/Principal Investigator**

a) Any change of nominated Chief investigator/Principal Investigator (e.g. due to relocation, maternity leave, retirement etc.) at the OUH (NHS) Trust should be notified to the R&D Department **immediately**; the host organisation needs to ensure any on-going studies have been reviewed and appropriate oversight is in place; or where needed studies have been terminated within the required timeframes.

b) All other changes in study staff should be maintained via a study delegation log.

5) **Safety reporting**

a) Appropriate safety reporting procedures will be agreed according to the perceived risks to study participants and/or the Trust. Any safety reporting requirements will be communicated in writing by the R&D Lead to the Chief/Principal Investigator.

6) **REC Annual Progress Reports and Monitoring of the Study**

a) The Chief Investigator should ensure that the REC Annual Progress Reports are completed and submitted in a timely manner on each anniversary of the REC Approval, and copied to R&D.

b) The need for on-site monitoring of the study will be assessed according to risk to study participants and/or the Trust. Any special requirements will be communicated to the Chief Investigator/Principal Investigator in writing.

c) The Trust may audit a number of hosted CTIMPs and interventional studies.

7) **NIHR and NHS Quality Accounts**

a) The Trust is obliged to submit data to the Department of Health annually. The Chief Investigator/Principal Investigator must provide to R&D department in a timely manner, such information about the study as to enable to Trust to meet its obligations.

b) In particular the Chief Investigator/Principal Investigator will forward the first participant recruited date to R&D department by emailing the information to the email address provided in the NHS permission letter.

8) **Conclusion of the Trial**

a) The Trust R&D Department should be informed within 60 days of the close of the study and a final report provided.

b) If the study is stopped early, the Trust R&D Department should be informed within 30 days outlining the reasons.

9) **Termination of Trust Management Approval**

a) The Trust reserves the right to revoke Trust Management Approval or Sponsorship for any project that is not conducted according to Trust policy or the applicable regulatory or legal framework. However, any such action will not be taken without prior discussion with the R&D Lead and/or the Medical Director together with the Chief or Principal Investigator. Furthermore, all researchers undertaking research at the Trust are subject to the Misconduct and Fraud Policy.

All Trust policies for the conduct of research within the organisation can be found at www.oxfordradcliffe.nhs.uk/research

Appendix

C

Letter of Access

Oxford University Hospitals NHS
NHS Trust

BS/LoA 379 Ref: 8851

Ms Janamarie Truesdell
Wolfson College
Linton Road
Oxford
OX2 6UD

Research Support services Manager
OUH R&D
Joint Research Office, Block 60
The Churchill Hospital
Headington
Oxford
OX3 7LE

Email: Fiona.parker@ouh.nhs.uk
Tel: 01865 572231
Fax: 01865 572242

20 Jun 2014

Dear Janamarie

Letter of access for research

Assessing the Effects of Pregnancy on the Face of the Pubic Symphysis

This letter confirms your right of access to conduct research through **Oxford University Hospital NHS Trust** for the purpose and on the terms and conditions set out below. This right of access commences on **20 Jun 2014** and ends on **01 April 2015** unless terminated earlier in accordance with the clauses below.

You have a right of access to conduct such research as confirmed in writing in the letter of permission for research from this NHS organisation. Please note that you cannot start the research until you, as the Principal Investigator for the research project, have received a letter from us giving permission to conduct the project.

The information supplied about your role in research at **Oxford University Hospital NHS Trust** has been reviewed and you do not require an honorary research contract with this NHS organisation. We are satisfied that such pre-engagement checks as we consider necessary have been carried out.

You are considered to be a legal visitor to **Oxford University Hospital NHS Trust** premises. You are not entitled to any form of payment or access to other benefits provided by this NHS organisation to employees and this letter does not give rise to any other relationship between you and this NHS organisation, in particular that of an employee.

While undertaking research through **Oxford University Hospital NHS Trust**, you will remain accountable to your employer **University of Oxford,** but you are required to follow the reasonable instructions of **Dr Susan Anthony** in this NHS organisation or those given on her/his behalf in relation to the terms of this right of access.

Where any third party claim is made, whether or not legal proceedings are issued, arising out of or in connection with your right of access, you are required to co-operate fully with any investigation by this NHS organisation in connection with any

such claim and to give all such assistance as may reasonably be required regarding the conduct of any legal proceedings.

You must act in accordance with **Oxford University Hospital NHS Trust** policies and procedures, which are available to you upon request, and the Research Governance Framework.

You are required to co-operate with **Oxford University Hospital NHS Trust** in discharging its duties under the Health and Safety at Work etc Act 1974 and other health and safety legislation and to take reasonable care for the health and safety of yourself and others while on **Oxford University Hospital NHS Trust** premises. You must observe the same standards of care and propriety in dealing with patients, staff, visitors, equipment and premises as is expected of any other contract holder and you must act appropriately, responsibly and professionally at all times.

If you have a physical or mental health condition or disability which may affect your research role and which might require special adjustments to your role, if you have not already done so, you must notify your employer and the Trust Fiona.parker@ouh.nhs.uk prior to commencing your research role at the Trust.

You are required to ensure that all information regarding patients or staff remains secure and *strictly confidential* at all times. You must ensure that you understand and comply with the requirements of the NHS Confidentiality Code of Practice (http://www.dh.gov.uk/assetRoot/04/06/92/54/04069254.pdf) and the Data Protection Act 1998. Furthermore you should be aware that under the Act, unauthorised disclosure of information is an offence and such disclosures may lead to prosecution.

You should ensure that, where you are issued with an identity or security card, a bleep number, email or library account, keys or protective clothing, these are returned upon termination of this arrangement. Please also ensure that while on the premises you wear your ID badge at all times, or are able to prove your identity if challenged. Please note that this NHS organisation accepts no responsibility for damage to or loss of personal property.

We may terminate your right to attend at any time either by giving seven days' written notice to you or immediately without any notice if you are in breach of any of the terms or conditions described in this letter or if you commit any act that we reasonably consider to amount to serious misconduct or to be disruptive and/or prejudicial to the interests and/or business of this NHS organisation or if you are convicted of any criminal offence. You must not undertake regulated activity if you are barred from such work. If you are barred from working with adults or children this letter of access is immediately terminated. Your employer will immediately withdraw you from undertaking this or any other regulated activity and you MUST stop undertaking any regulated activity immediately.

Your substantive employer is responsible for your conduct during this research project and may in the circumstances described above instigate disciplinary action against you.

Oxford University Hospital NHS Trust will not indemnify you against any liability incurred as a result of any breach of confidentiality or breach of the Data Protection Act 1998. Any breach of the Data Protection Act 1998 may result in legal action against you and/or your substantive employer.

If your current role or involvement in research changes, or any of the information provided in your Research Passport changes, you must inform your employer through their normal procedures. You must also inform your nominated manager in this NHS organisation.

Yours sincerely



Fiona Parker
Research Support Services Manager
Oxford University Hospital NHS Trust

cc:

Maxine Grout, HR Advisor - Medical Support, Block 229, Carillion Building, John Radcliffe Hospital, Headley Way, Headington, Oxford, OX3 9DU

Michelle Mhlanga, Personnel Officer, University of Oxford, School of Anthropology, 51-53 Banbury Road, Oxford OX2 6PE

Appendix

D

CUREC Approval

SCHOOL OF ANTHROPOLOGY AND MUSEUM ETHNOGRAPHY
51-53 Banbury Road, Oxford OX2 6PE
Tel: +44(0)1865 274670 Fax: +44(0)1865 274630
info@anthro.ox.ac.uk www.anthro.ox.ac.uk

From the office of the Head of School



Janamarie Truesdell
School of Anthropology and Museum Ethnography

11 April 2014

Dear Janamarie

Research Ethics Approval

Ref No.: SAME/CUREC1A/14-23

Title: Assessing the effects of pregnancy on the face of the pubic symphysis: implications for ageing

The above application has been considered on behalf of the School of Anthropology and Museum Ethnography Research Ethics Committee (SAME REC) in accordance with the procedures laid down by the University for ethical approval of all research involving human participants.

I am pleased to inform you that, on the basis of the information provided to the SAME REC, the proposed research has been judged as meeting appropriate ethical standards, and accordingly approval has been granted.

Should there be any subsequent changes to the project, which raise ethical issues not covered in the original application, you should submit details to the SAME REC for consideration.

Yours sincerely,



Marcus Banks
Professor of Visual Anthropology
Head of the School of Anthropology
University of Oxford

cc Nicholas Marquez-Grant

Appendix

E

Invitation to Participate

UNIVERSITY OF OXFORD

Oxford University Hospitals NHS
NHS Trust

Department of Radiology
John Radcliffe Hospital
Headley Way
Oxford OX3 9DU
01865 220817

Invitation to take part in Academic Research Study

Study title: Assessing the Effects of Pregnancy on the Face of the Pubic Symphysis Through Medical Imaging Technology: Implications for Aging.

Dear Patient.

We would like to invite you to take part in our research study, currently taking place in the John Radcliffe Hospital Radiology Department. Before you decide we would like you to understand why the study is being done and what it would involve for you. **One of the study team will go through the information sheet and questionnaire with you and answer any questions you have.** We'd suggest this should take about 15 minutes

We are looking for participation from adult men and women of all ages.

I have enclosed 2 documents related to this study:

1. Information Leaflet: this tells you the purpose of this study and what will happen to you if you take part.
2. Accompanying questionnaire with consent form

Please ask us, either in person or by calling the number above, if there is anything that is not clear.

It is up to you to decide whether or not you wish to participate in this the study. It will not affect your treatment in any way. If you agree to take part, we will then ask you to complete the questionnaire and to sign a consent form. You are free to withdraw at any time, without giving a reason. This would not affect the standard of care you receive.

Yours faithfully,

Dr S Anthony
Clinical Director of Radiology
Oxford University Hospitals NHS Trust

Date of issue: 5th March 2014
Version number: v 1

Appendix

F

Patient Information Sheet
(PIS)

Are there risks involved?

No. There are no anticipated risks associated with participating in this study. The scans you'll be allowing me to see will have already been ordered by your doctor for other reasons. No additional scans or tests are required. The only additional thing I'm asking you to do for this study is to fill out a questionnaire.

Who has reviewed this study?

As with any study involving the NHS, this project was reviewed by one of Oxford's three Research Ethics Committees, which are manditory juries of independent observers in place to protect your rights and interests. This study has been approved by favourable opinion by the National Research Ethics Service (NRES), specifically the South Central - Hampshire A Research Ethics Committee (Reference no. 14/SC/0061).

What will happen to the results of the research?

The results of this research will be used as the basis of a doctoral thesis and may also be published as part of future scientific journal articles and conference presentations. No individual results will be identifiable nor would your name be used in any form or fashion.

Who is organising and funding the research?

This study will form the basis of a doctoral thesis undertaken by the author and is sponsored by the University of Oxford through the School of Anthropology and Museum Ethnography. Contact information for the School of Anthropology and Museum Ethnography is provided on the back page of this pamphlet. This research is self-funded.

What if there is a problem?

It is extremely unlikely that you will be harmed by taking part in this study. However, the University of Oxford, as Sponsor, has appropriate insurance in place in the unlikely event that you suffer any harm as a direct consequence of your participation.

If you wish to complain about any aspect of the way in which you have been approached or treated during the course of this study, please contact me at:

jana.truesdell@wolfson.ox.ac.uk
or
01865 220817 / 07541 868957

You may also contact my supervisor and head of the School of Anthropology and Museum Ethnography, Marcus Banks, at marcus.banks@anthro.ox.ac.uk, or the University of Oxford Clinical Trials and Research Governance (CTRG) office on 01865 572224, or for the head of CTRG, email ctrg@admin.ox.ac.uk.

Additionally, you may wish to contact the NHS "Patient Advice and Liaison Service" (PALS), 01865 221473, or PALSJR@ouh.nhs.uk, who provide independent advice regarding participation in trials.

Thank you for your time and consideration!

Janamarie Truesdell MSc., MSc.
School of Anthropology and Museum Ethnography
51/53 Banbury Road
Oxford
OX2 6PE
+44 (0)1865 274582

UNIVERSITY OF OXFORD

Version 2.0 , REC reference no. 14/SC/0061 , 19/03/2014

Assessing The Effects Of Pregnancy On The Face Of The Pubic Symphysis: Implications For Determining Age



Patient Information Sheet

Oxford University Hospitals NHS
NHS Trust

Version 2.0 , REC reference no. 14/SC/0061 , 19/03/2014

Overview of study

Hello, I'm a researcher at the University of Oxford and I'm interested in the ways our bones change as we age, especially at a place called the "pubic symphysis." The pubic symphysis is where the two halves of your pelvis, or "hipbones," come together - if you can imagine your hips as a belt, your symphysis would be the buckle. For forensic anthropologists like me, this joint is one of the most important areas in the body as it helps us estimate age better than anywhere else.

The way in which men and women age at this joint, however, is not the same. Women tend to be less predictable and their changes take place about 2 to 5 years later than the same changes in men - odd, as the opposite applies everywhere else. So what makes the pelvis special? Is there something women are doing between the ages of 18 to 50 that men aren't? Naturally, having babies comes to mind... so that's where I'm going to start. The goal of this study, then, will be to link whether or not a woman has had a baby to the changes we see at her pubic symphysis.

The information to follow will tell you everything you need to know about this project so that you can decide whether or not you'd like to take part. Please read it carefully and if you have any further questions feel free to contact me (my contact details can be found on the back page of this pamphlet). You do not need to be pregnant to participate in the study and both men and women are invited to take part. I appreciate your time and thank you for considering participation.

What is the purpose of this study?

This study will help to determine whether pregnancy affects our ability to accurately estimate age from the pubic symphysis, a question that has been without an answer for more than a century. If we can do this, it will be a first step towards improving our understanding of how bone responds and adapts to the ways in which we live our everyday lives (environment, social structure, lifestyle, etc.).

How and why have I been asked to participate?

You have been asked to participate because you have been scheduled for an upcoming pelvic scan through the John Radcliffe radiology department. The hospital has included this leaflet with their regular pre - appointment correspondence on my behalf.

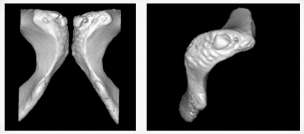
What am I being asked to do?

To participate in this study, all you have to do is fill out the enclosed questionnaire and bring it with you to your radiology appointment. Once there, you will then sign and date a standard consent form giving me permission to view that questionnaire, along with your scan, and that both may be included as part of this study.

If you forget your questionnaire, don't worry! I'll be at reception when you arrive and will be there throughout to answer any questions you may have. I'll also have spare questionnaires on hand, so you'll still have the opportunity to take part if you wish - but, of course, you are under no obligation to do so. Participation is completely up to you.

What will happen to the information I provide?

Once you have provided written consent for your scan to be used it will be anonymised by the hospital and a copy will be given to me. That information will be rendered into a 3D image and the pubic symphysis will be isolated. The result will look like this (note that it is in no way recognisable):



Four practitioners will then assign an estimated age to your scan using standard anthropological techniques. This estimated age will be compared to your actual age, and then to the information provided by your questionnaire, to find out why or why not we were right or wrong. That's it!

Do I have to take part?

No.

You are under no obligation to participate in this study.

Can I withdraw?

Yes. Participation in this study is completely voluntary and you may withdraw your consent at any time. Please see the back page of this pamphlet for more information.

What are the benefits? How do my scan and questionnaire help you?

As stated earlier, this study will further our understanding of how everyday experiences and lifestyle choices affect the ageing of our bones, or, more specifically, the determination of age from our bones. This study will not only produce much needed information about the effects of pregnancy on the pubic symphysis but it will also establish a novel new methodology to be used going forward - allowing us to be more specific in our work through an increase in the accuracy of our techniques.

Will my information be kept confidential?

Yes. This study will ensure participants' anonymity is maintained in full compliance with the Data Protection Act (which requires data to be anonymised as soon as it is practical to do so). While the outcomes will be used as part of a doctoral thesis that will exist both in print and online in the University archives, your data will be anonymised and your name will never be used. You will be identified only by a hospital assigned ID number, the same for both your questionnaire and scan, and all documents will be stored securely by the School of Anthropology and Museum Ethnography and seen only by me (though responsible members of the University of Oxford or the Oxford University Hospitals NHS Trust must be given access to data for monitoring and/or auditing purposes to ensure we are complying with regulations).

Appendix

G

Participant Questionnaire

Participant Questionnaire

Please refer to the accompanying Patient Information Sheet leaflet for more information about this questionnaire.

Instructions

Please answer as many questions as you can to the best of your recollection.

For each question, please put a tick in the box next to the answer that best describes you and/or your experience. **Men, please complete sections 1 and 2. Women, please complete sections 1, 2, and 3.**

Don't worry if you make a mistake. Simply cross it out and tick the correct answer.

Section 1: Please tell us about yourself (both male and female participants)

Q 1 Are you male or female?

☐ Male ☐ Female

Q 2 What is your current age?

_____ years

Q 3 How tall are you? (in metres)

☐ 1.0 - 1.5 ☐ 1.5 - 1.6

☐ 1.6 - 1.7 ☐ 1.7 - 1.8

☐ 1.8 - 1.9 ☐ 1.9 - 2.0

☐ 2.0 - 2.1 ☐ 2.1 - 2.2

Q 4 What is your ethnic group?

☐ White

☐ Asian

☐ South Asian

☐ East Asian

☐ Black, African or Caribbean

☐ Arab

☐ Other ethnic group

☐ Mixed/Multiple ethnic groups

If you answered “other” or “mixed/multiple ethnic groups,” please describe below:

Q 5 Where were you born? (city/country)

Q 6 How long have you lived in the UK?

- ☐ Less than 1 year
- ☐ 1 - 4 years
- ☐ 5 - 9 years
- ☐ 10 - 14 years
- ☐ More than 15 years

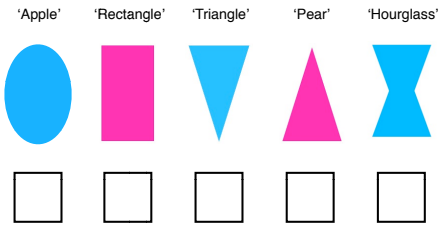
Q 7 If less than 5 years, where did you live before? For how long?

Q 8 How much do you currently weigh?

_____ *st* _____ *lbs*

(or) _____ *kgs*

Q 9 Which image best illustrates the shape of your body?



☐ ☐ ☐ ☐ ☐

Q 10 Has your weight (as described in Q8) fluctuated by more than 3 stone (25 kgs) within the last:

- ☐ Year?
- ☐ 3 years?
- ☐ 5 years?
- ☐ My weight has not fluctuated to that degree over any of these periods

If yes, please describe:

Section 2: Please tell us about your lifestyle (both male and female participants)

Q 11 How would you describe your level of activity?

- ☐ I am immobile
- ☐ Light

  Movement in and around the house and garden, light chores and errands.
- ☐ Moderate

  Walking or standing (including travel) for an hour or more per day, and/or an hour or two of dedicated cardiovascular exercise, dance, or sport per week.
- ☐ Active

  Dedicated cardiovascular exercise, dance, or sport three or more times per week.

Q 12 Do you currently engage in activities that involve twisting or kicking movements such as dance, gymnastics, rugby, or football?

☐ Yes ☐ No

If yes, please describe:

_____

_____

How long have you been doing this?

☐ years

Q 13 Do you currently engage in activities that involve upright stabilisation such as horse riding or skating?

☐ Yes ☐ No

If yes, please describe:

_____

_____

How long have you been doing this?

☐ years

Q 14 Have you ever been treated for a condition known as “osteitis pubis” (a joint infection)?

☐ Yes ☐ No

If yes, when was this diagnosed?

_____ /_____ /_____

Was treatment successful?

☐ Yes ☐ No

Q 15 Do you suffer from joint pain or stiffness, or have you been diagnosed with any form of arthritis?

☐ Yes ☐ No

When did this start?

☐ years ago

Q 16 How would you describe your diet?

☐ Bad / Poor

☐ Average

☐ Good / Healthy

Q 17 Do you smoke or chew tobacco?

☐ Yes ☐ No

If yes, approximately how many cigarettes (if smoking) or pinches (if chewing) per day?

☐	1 - 2	☐	3 - 4
☐	5 - 6	☐	7 - 8
☐	9 - 10	☐	11 - 12
☐	13 - 14	☐	15 - 16
☐	17 - 18	☐	19 - 20
☐	21 - 22	☐	23 - 25 +

Q 18 At what age did you begin smoking or chewing tobacco?

☐ years

Q 19 Do you drink alcohol?

☐ Yes ☐ No

If yes, how many units per week?



http://theariasadvantage.com/cellulitescore_files/img/11.jpg

☐	< 4	☐	5 - 9
☐	10 - 14	☐	15 - 19
☐	20 - 24	☐	25 - 29
☐	30 - 34	☐	35 - 40 +

Q 20 At what age did you begin drinking alcohol?

☐ years

Men STOP

Section 3: Please tell us about your pregnancy history (female participants only)

Q 21 How many times have you been pregnant?

☐ 0 ☐ 2
☐ 1 ☐ 3 +

If "0," please skip to Q 30

Q 22 How many times have you given birth?

☐ 0 ☐ 2
☐ 1 ☐ 3 +

Q 23 How old were you at the time of your:

1st baby: ☐ years old

2nd baby ☐ years old

3rd baby: ☐ years old

Q 24 Did you experience any pain or discomfort (i.e "grinding" or "dislocated" sensations) at the pubic symphysis during your pregnancy?

	Y	N
1st baby:	☐	☐
2nd baby:	☐	☐
3rd baby:	☐	☐

Q 25 Did any of these births require an epidural?

	Y	N
1st baby:	☐	☐
2nd baby:	☐	☐
3rd baby:	☐	☐

Q 26 Were any of these births by caesarean?

	Y	N
1st baby:	☐	☐
2nd baby:	☐	☐
3rd baby:	☐	☐

Q 27 Were any of these births multiple births (i.e. twins or triplets)?

	Y	N
1st birth:	☐	☐
2nd birth:	☐	☐
3rd birth:	☐	☐

If "yes," please specify:

	Twins	Triplets
1st birth:	☐	☐
2nd birth:	☐	☐
3rd birth:	☐	☐

Q 28 What was the weight of your:

	< 1 kg	1 - 2 kgs	2 - 3 kgs	3 - 4 kgs	4 - 5 kgs	5 - 6 kgs
1st baby:						
2nd baby:						
3rd baby:						

How long was the labour of your:

	< 5 hrs	6 - 10 hrs	11 - 15 hrs	16 - 20 hrs	21 - 24 hrs	25 + hrs
1st baby:						
2nd baby:						
3rd baby:						

Q 29 For which of these births did you breastfeed?

☐ 0 ☐ 2

☐ 1 ☐ 3 +

For how long?

1st baby: ☐ mths ☐ yrs

2nd baby: ☐ mths ☐ yrs

3rd baby: ☐ mths ☐ yrs

Q 30 Have you ever taken, or are you currently taking, hormone or collagen supplements?

☐ Yes ☐ No

Q 31 Have you ever taken, or are you currently taking, birth control or contraception?

☐ Yes ☐ No

Q 32 Have you reached Menopause?

☐ Yes ☐ No

Around what age did this begin? _____ years

Appendix

H

Consent Form

Oxford University Hospitals NHS
NHS Trust

CONSENT FORM

Study Title: Assessing the Effects of Pregnancy on the Face of the Pubic Symphysis Through Medical ImagingTechnology: Implications for Ageing

Version 2.0, NRES reference no.14/SC/0061, 19/03/2014

Author / Researcher: Janamarie Truesdell, MSc., MSc. (Candidate, DPhil)

Subject Number: _____ (Initial)

I confirm that I have read and understand the information provided regarding the above study (including what my data entails, how it will be used, and for what purpose). I have had sufficient opportunity to review and consider that information, have had time to ask questions, and have had those questions answered to my satisfaction.	☐
I understand that my participation in this study is voluntary and that I will not be remunerated.	☐
I understand that I may complain and/or withdraw my consent by contacting the researchers at any time and for any reason.	☐
I agree to take part in the above study and hereby give permission for the author to access my scan(s).	☐

_____	_____	_____
Patient Name (Print)	Patient Signature	Date
_____	_____	_____
Researcher	Signature	Date

Appendix

I

The TCM (female)

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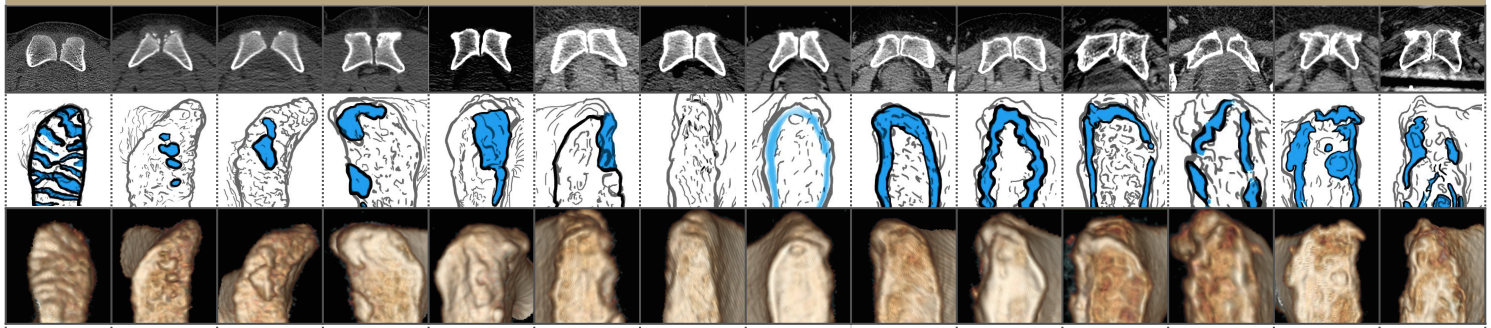
DENSITY



HIGH	MEDIUM	LOW
THICK, BRIGHT, UNBROKEN OUTLINE UNIFORM INTERIOR (BLACK AREAS CONSTITUTE >25% OF THE WHOLE)	VENTRAL (TOP) ASPECT HAS NOTICEABLY THINNED AND MAY EXHIBIT BROKEN BORDER AND/OR "PEARLS" OF ACTIVITY "MOTTLED" OR "STRIPED" INTERIOR (GREY AND BLACK AREAS IN EQUAL PROPORTION, "50 / 50")	VENTRAL (TOP) ASPECT HAS THINNED TO THE POINT OF TRANSPARENCY "HOLLOW" BLACKENED INTERIOR (BLACK AREAS CONSTITUTE >75% OF THE WHOLE)
0	5	10

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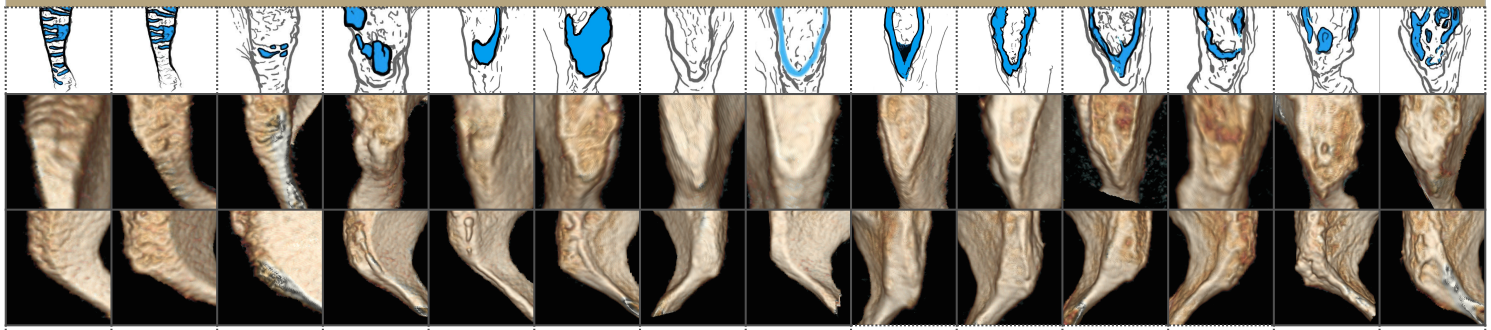
UPPER BOUNDARY (UB)



Open Epiphysis	**Soft Tissue Nodule Formation**	**Nodule Attachment**	**Attachment with "Squaring Off"**	**Distinction withActivity (Relief)**	**Distinction with Breach (Recess)**	**Emergence of Outline**	**Established Outline**	**Raised or Swelled Outline**	**Initial Degradation**	**Continued Degradation**	**Degradation with Ventral Breakdown**	**Partial Obliteration**	**Obliteration**
Open epiphysis reaches upwards towards the tubercle without interruption Epiphysis may appear triangular or boomerang shaped	Open epiphysis continues unchecked, though ossific nodules of varying size have begun to appear in the soft tissue	Ossific nodules have attached to the surface, interrupting the "flow" of the still open epiphysis (similar in appearance to that of rocks in a stream).	Additional nodules have crept up from the midface to create a more distinct, "filled in" UB and "squared off" profile	While nodule activity continues, the UB has flattened and become visually distinct from the tubercle behind	Remodeling at the ventral hiatus takes the form of roughened irregularity, with large variations in surface topography "Mitten" shaped appearance	The face has flattened and become its own entity through the formation of a faint shadow "rim" or "outline" visible anteriorly but not ventrally	"Rim" or "outline" has thickened to become a distinct, more permanently established border around the (flat) UB that, although faint, does not disappear ventrally	"Rim" or "outline" has swelled and raised to create a cupped or "hooded" depression at the centre of the UB *Outline is Thick, Regular*	"Rim" remains raised and thickned but, while still intact and unbroken, it has begun to scallop, becoming more irregular *Outline is Thick, Irregular*	Thinned "rim" has begun to deteriorate and fade, becoming less prominent "Rim" may recede up and back towards the tubercle *Outline is Thin, Regular*	Tubercle outgrowths have become increasingly prominent Outline has assumed a patchy, scalloped appearance *Outline is Thin, Irregular*	"Rim" has been nearly obliterated at the UB by deterioration coupled with irregular outgrowth Large, deep macro-pores erode the surface	Outline has been completely obliterated at the UB by degradation, irregular outgrowth, and macro-pores. Rough "coral- like" texture
Ridges and Furrows	***Nodule Formation***	***Nodule Attachment***	***Containment***	***Squaring Off***	***Ventral Hiatus***	***"Vanishing" Rim***	***"Shadow" Rim***	***Thick - Reguar***	***Thick - Irregular***	***Thin - Regular***	***Thin - Irregular***	***Erosion***	***Obliteration***
3	4	5	6	7	8	9	10	11	12	13	14	15	16

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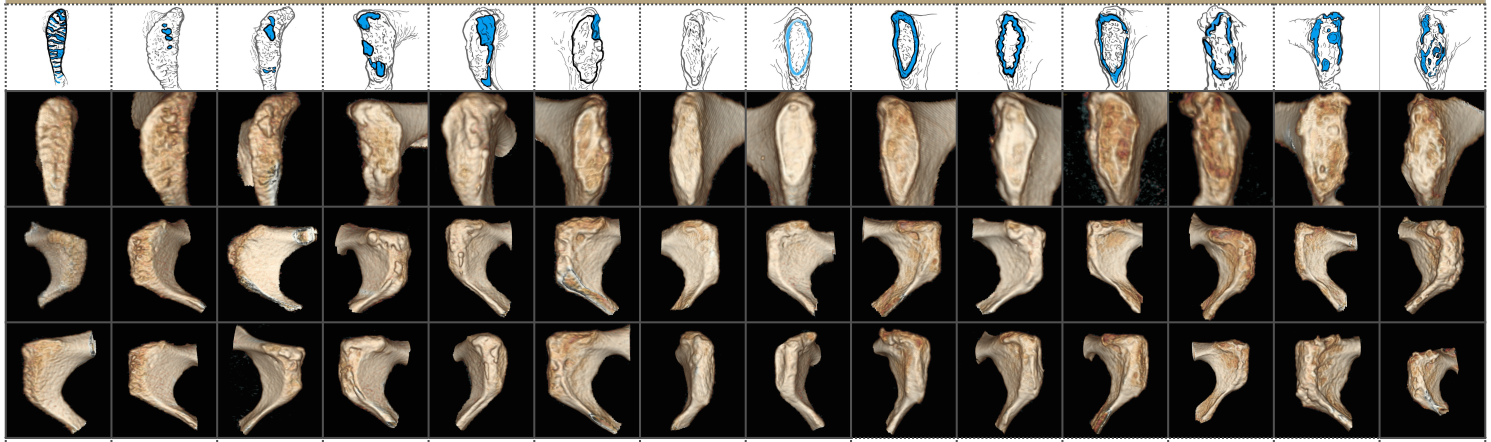
LOWER BOUNDARY (LB)



Open Epiphysis Open epiphysis "flows" down the ramus without interruption Sharp, Jagged Surface	**Ramus Distinction** The LB is still open and without nodule formation, but epiphyseal closure moving up the ramus has begun to thicken and contain the "ridges and furrows" to the face	**Nodule Formation** Small ossific nodules have formed and attached, either remaining discrete or creating a raised, overall thickening of the LB	**Attachment with "Squaring Off"** Ossific Nodules have combined to create a thickened separation between the face and ramus Profile "squaring off"	**Initial Activity** Combined nodules begin to move up along the ventral border Widened "V" or "✓" shape	**Continued Activity** Nodule activity and swelling continues and proceeds upwards along the ventral border Widened "✓" shape	**Emergence of Outline** The face has gained distinction through the formation of a faint shadow "rim" or "outline" that now contains it "V" shape *"Vanishing" Rim*	**Established Outline** The thinly edged "rim" or "outline" begun in the previous stage has now thickened to establish a clear and definite border around the LB "Shadow" Rim	**Raised or Swelled Outline** "Rim" becomes raised to create a cupped central depression at the LB Cupped "V" shape	**Outline Degradation** "Rim" begins to degrade through raised, roughened overgrowth Swollen, convex "V" shape	**Continued Degradation** Thinning "rim" has begun to deteriorate and fade while macro-pores become visible Flat "V" shape	**Degradation with Breakdown** "Rim" is still visible but exists within a mix of macro-pores and overgrowth Irregular "V" shape	**Partial Obliteration** "Rim" is nearly obliterated at the LB by deterioration and irregular outgrowth while macro-pores erode and undermine the surface	**Obliteration** "Rim" has been completely obliterated by degradation, irregular overgrowth, macro-pores, and a rough "coral like" texture
No Interruption	***Facial Containment***	***Nodule Formation***	***Nodule Attachment***	***Consolidation***	***Squaring off***	***"Vanishing" Rim***	***"Shadow" Rim***	***Cupped Concavity***	***Swelled Convexity***	***Flat, Level Face***	***Erosion***	***Outgrowth***	***Obliteration***
3	4	5	6	7	8	9	10	11	12	13	14	15	16

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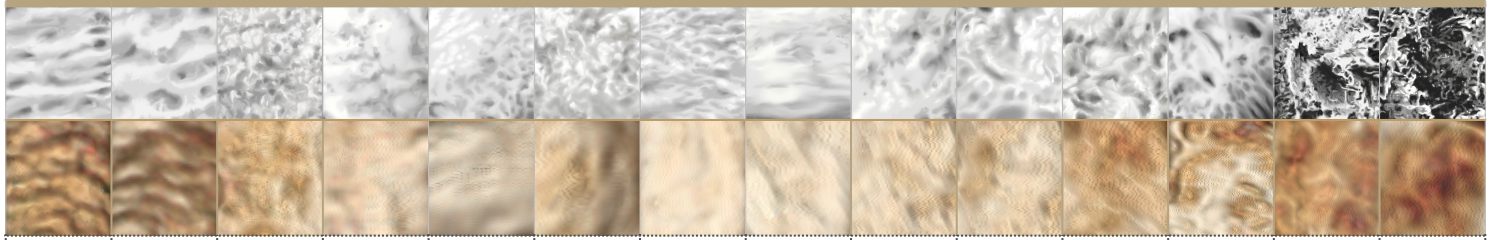
OUTLINE



Open Open epiphysis reaches upwards towards the tubercle Epiphysis may appear boomerang shaped Edges appear "jagged" on both sides Upper and Lower boundaries rounded in profile	**Open with UB Nodule Formation** Epiphysis remains open though ossific nodules have begun to appear in the soft tissue Edges "jagged" on both sides	**Open with UB and LB Nodule Formation** Ossific nodules have fully attached at the UB and have begun forming at the LB Edges remain open but "jagged" appearance has lessened Profile interrupted by nodules at both UB and LB	**Partial with Central Nodule Formation** Nodules from the UB and the LB merge along the ventral border ("rampart") Edges are sharp but no longer "jagged" Profile beginning to "square off" as nodules condense	**Partial with Ventral Nodule Formation** Nodule activity (building up) is contained to the mid and upper ventral border Dorsal edge remains sharp, ventral edge remains open Profile now square in appearance	**Partial with Ventral Hiatus** Nodule activity (breaking down) is contained to the mid and upper ventral border Dorsal edge remains sharp, the ventral edge remains open, Profile is squared	**Emerging** Both dorsal ("plateau") and ventral ("rampart") borders are now level creating a broad flattened face contained within a faint shadow "rim" Outline may present as an elongated oval shape *"Vanishing" Rim*	**Established** Shadow "rim" emergent in the previous stage continues to gain definition and, while faint, does not disappear ventrally Outline may present as an "inverted teardrop" shape *"Shadow" Rim*	**Pronounced** "Rim" swells and rounds to create cupped depressions at both the UB and LB "Pointed oval" shape *Outline is Thick, Regular*	**Initial Degradation** Swelled "rim" begins to lose definition taking on a scalloped appearance "Pointed oval" shape *Outline is Thick, Irregular*	**Continued Degradation** Outline continues to degrade as "rim" edges thin "S" or pinched "oval" shape *Outline is Thin, Regular*	**Complete Degradation** "Rim," while still visible, may become confused amid deterioration, irregular outgrowths, and erosion *Outline is Thin, Irregular*	**Partial Obliteration** "Rim" is nearly obliterated by deterioration and irregular outgrowth, macro-pores erode and undermine the face Erosion	**Obliteration** Outline has been obliterated by degradation, irregular outgrowth, macro-pores, and a rough "coral like" texture Erosion
Ridges and Furrows	***Nodule Formation***	***Nodule Attachment***	***Central Nodules***	***Ventral Activity***	***Ventral Hiatus***	***"Vanishing" Rim***	***"Shadow" Rim***	***Thick - Regular***	***Thick - Irregular***	***Thin - Regular***	***Thin - Irregular***	***Erosive Outgrowth***	***Uniform Destruction***
3	4	5	6	7	8	9	10	11	12	13	14	15	16

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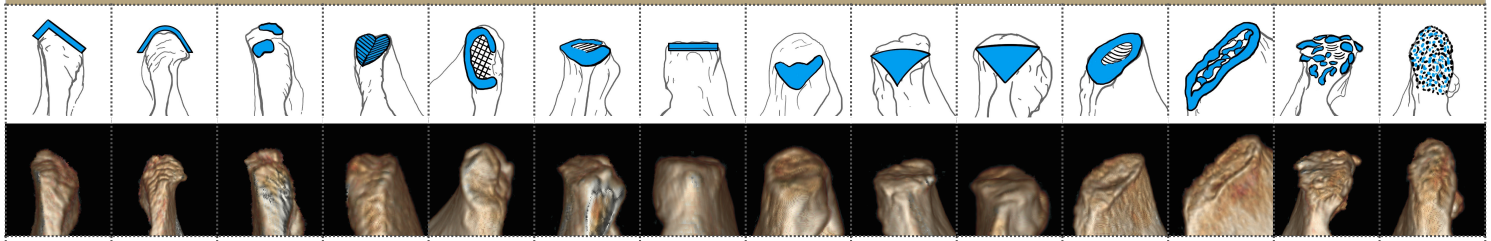
SURFACE TEXTURE



Sharp Ridge and Furrow System Sharp, thinly peaked and densely packed ridges and furrows present across the entirety of the open epiphysis	**Ridge and Furrow System with UB Nodule Formation** Swelled, thickening ridges and furrows present across the entirety of the open epiphysis - ossific nodule formation at the UB	**Shallowing Ridge and Furrow System with LB Nodule Formation** Ridges and furrows, while still visible, have begun to "fill in" creating peaks and valleys - like merangue or choppy water (easily confused w/ porosity) LB nodules	**Shallowed Ridge and Furrow System with Central Activity** Ridges and furrows continue to shallow and may now be sporadic or hardly visible Central nodules	**Mixed Surface with Ventral Activity** Surface is now a mix of smoothness and areas of shallow ridges and furrows Nodule activity (build-up) along the sup. ventral border	**Mixed Surface with Ventral Hiatus** Surface is a mix of smoothness and areas of shallow ridges and furrows Nodule activity (breakdown) along the sup. ventral border	**Smooth - Flat** Ridges and Furrows have now disappeared (remnants may persist) and have been replaced by a smooth, level surface Nodule activity has ceased	**Smooth - Mixed Topography** Surface is smooth (though remnants of ridges and furrows may persist) Face is a mix of raised areas (typically the LB) and depressions (UB)	**Appearance of micro pores** Surface remains smooth but with the addition of micro pores "Sandpaper" appearance	**Appearance of macro pores** Surface remains smooth but macro pores begin to appear below and amongst the micro pores	**Initial Degradation** Surface remains smooth but both micro and macro pores deepen and begin to undermine surface integrity	**Mixed Degradation** Surface is a mixture of smoothness and degradation (50%) as structural integrity is eroded from below "Crumbling" appearance	**Severe Degradation** Surface is now more eroded than it is smooth and intact (75%) "Wasted" or "wizened" appearance Low Density	**Complete Degradation** Surface is now completely eroded "Hollow," or "coral - like" appearance Very low Density
Sharp, Narrow Ridges and (Deep) Furrows	***Thick, Wide Ridges and (Deep) Furrows***	***Irregular Peaks and (Deep) Valleys***	***Rounded Peaks and (Shallow) Valleys***	***Gently Rolling "Surface Waves"***	***Soft "Billowy" Surface***	***Smooth, Flat Surface***	***Smooth, Mixed Surface***	***Micro-Pores***	***Macro-Pores***	***Coalescence Deepening of Macro-Pores - "Sinkholes"***	***50% Degradation***	***75% Degradation***	***≥ 90% Degradation***
3	4	5	6	7	8	9	10	11	12	13	14	15	16

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TOPOGRAPHY



Triangular - Pointed Apex Level but jagged profile raked dorso-ventrally Inferior/ superior view is triangular with sharply pointed apex	**Triangular - Softened Apex** Level but jagged profile raked dorso-ventrally Inferior/ superior view is triangular with softening apex UB nodule visible in the distance	**Convex with Nodules** Mixed profile - raised extremities, flattened centre (lateral edges sharp) Inferior/ superior view is convex as seen behind LB nodule formation	**Valley** Level but slightly scalloped profile Inf/Sup view shows both dorsal and and ventral borders raised forming a long, deep "valley" down the centre of the face	**C-Shape** Level profile raked ventro-dorsally Inferior/ superior view is flat with the exception of a deep central depression on the ventral side (Niagara's) "Horseshoe Falls"	**Filling in or flattened C-Shape** Level profile Inferior/ superior view is vallied but with nodule activity on the (ventral) side	**Plateau** Level profile Inferior/ superior view is flat Tubercle activity may or may not be seen in the distance	**Tulip, or Heart Shaped with depressed background** Profile is level but may contain a dorsal spur at the midface Inferior/ Superior view is tulip or heart shaped with a cupped distal depression	**S-Shape with depressed background** Profile is curved, with an S-Shape Inferior/ Superior view is like a "roller-coaster" or as if looking at an "s" on its side (convex foreground with concave background)	**Shallowed S-Shape with depressed background** Profile is still curved, though less pronounced Inferior/ Superior view is similar to the previous but but rounding has flattened (somewhat like a cake that has fallen after being taken out of the oven)	**Crater** Profile may be flat or slightly curved with a dorsal spur at the midface Rim outline is elevated around the face giving the appearance of a depressed centre Smooth cup or basin	**Filled in Crater** Profile and Inferior/ Superior view remains similar to the previous Central depression becomes obscured by rough erratic outgrowths, or a mix of both Irregular cup or basin, as if filled in with rocks	**Mixed Topography** Profile is a mix of level and concave due to UB and LB degradation Inferior/ Superior view is a mix of textures while the face loses shape and integrity Flat and Irregular	**Coral-Like** Profile is either level or convex due to UB and LB destruction Inferior/ Superior view is convex, porous, and coral like in texture
Sharp Triangle	***Softened Triangle***	***Nodule "Bookends"***	***"V " Shaped Valley***	***"C" Shape, Sloped Interior***	***"C" Shape, Flattened Interior***	***Flat Surface, or "Plateau"***	***Heart (Sometimes Tulip) Shape***	***"S" Shape, High Rounded Curve***	***"S" Shape, Low Flattened Curve***	***Empty "Crater" or "Basin" Shape***	***Filled in "Crater" or "Basin" Shape***	***"Field of Rocks and Boulders," Flat***	***Coral Like Texture, Rounded***
3	4	5	6	7	8	9	10	11	12	13	14	15	16