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Manikin-based simulation within the University of Zurich Chiropractic Medicine Study Program: a mixed-methods case study

A thesis presented in partial fulfilment of the degree of Master of Science, Medical Education

by

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Abstract

Purpose:

Chiropractic students often report that they do not feel adequately equipped to deliver spinal manipulation to different patient populations in their early clinical careers (i.e. final year of studies). This topic has not been previously investigated in the chiropractic education literature. Therefore, the study reported in this thesis was conducted to answer the research question 'Despite reporting low confidence in their ability, are fourth, fifth, and sixth year students in the University of Zurich Chiropractic Medicine Study Program (2024–2025) able to modulate thoracic spine manipulation?'. A secondary aim was to investigate if manikin-based simulation would be a feasible addition to the current chiropractic technique skills curriculum as a means to scaffold these students from the classroom into their early clinical practice.

Methods:

A mixed-methods case study was conducted using a sample of students in the fourth, fifth and sixth years of the University of Zurich Chiropractic Medicine Study Program. Participants attended a single quantitative data collection session (~30 minutes) and delivered thoracic spine manipulation to both a manikin and a human in response to two different vignettes of patient presentations commonly encountered in their early clinical careers. The order of delivery (manikin vs. human and vignette number) was randomized. Following this, participants were asked to volunteer to participate in a single focus-group interview (~60 minutes) discussing their opinions on manikin-based simulation and its integration within the Study Program curriculum.

Results:

Students (n=30) were able to consistently modulate peak forces applied to both a manikin ($p<0.001$) and human ($p<0.001$) for two commonly encountered cases (20-25-year old female and 50-55-year-old male:). Despite this, students were unable to modulate their preload forces (manikin: $p=0.147$, human: $p=0.629$). All focus-group interview participants (n=4) viewed manikin-based simulation positively and advocated for its' systematic integration in the chiropractic technique skills curriculum. Thematic analysis of the focus-group interviews revealed two main themes: i) students' high intolerance of uncertainty, and ii) the educational benefits of manikin-based simulation.

Discussion:

The use of manikin-based simulation as an instrument to decrease intolerance of uncertainty was a latent theme within the data while the educational benefit was discussed explicitly. Intolerance of uncertainty was discussed with reference to four interconnected sub-themes: i) the need for psychological safety, ii) a dependence on objective feedback, iii) a lack of confidence, and iv) challenges with manikin tactile fidelity. Similarly, four aspects that were discussed as important for the educational benefit of manikin-based simulation within chiropractic education were: i) the importance of familiarization, ii) the facilitation of intentional, participatory learning, iii) the facilitation of motor learning processes, and iv) the timing of manikin-based simulation. The literature discussing manikin-based simulation within chiropractic education is limited and therefore, this thesis contributes in a meaningful way to the further understanding of this topic within the chiropractic profession.

Candidate Statement

I certify that the work incorporated in this thesis has not been submitted for a higher degree to any other university or institution. I certify that the work presented in this thesis is my own except as acknowledged in the text.

The study was approved by the University of Oxford Education (Educ) DREC of the on 14th February 2025 (Approval number: 892142) and was deemed to be outside the scope of the Zurich Cantonal Ethics Commission on 25th February 2025 (BASEC ID: Req-2025-00239) (Appendix A & Appendix B).

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One last consideration – my thoughts from eleven years ago, ‘Grasshopper still has much to learn’ and from five years ago ‘When the going gets tough, get up and get going’ – have kept me on my toes and are still very relevant today!

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List of Abbreviations

BMI – body mass index

cm – centimeter

DIP – downward incisural point

DREC – Departmental Research Ethics Committees

Hz – Hertz

IQR – interquartile range

kg – kilogram

ms - millisecond

n – number of participants

N – Newtons

PAT – Palpation and Adjusting Trainer manikin (Hands on Tools, USA)

SAMR – Substitution, Augmentation, Modification, and Redefinition (SAMR) model

SD – standard deviation

sec – seconds

3D – three-dimensional

Chapter 1: Introduction

This chapter introduces the reader to the areas of manikin-based simulation, force-sensing technology and intolerance of uncertainty. Specifically, relevant definitions for and a brief description of, these topics will be provided and the context in which the mixed-methods case study reported in this thesis is situated is explained. Finally, the rationale for the study and the research aims and question will be specified.

1.1 Manikin-based simulation and force-sensing technology

Simulation can be defined as '… a technique …. to replace or amplify real experiences with guided experiences that evoke or replicate substantial aspects of the real world in a fully interactive manner' (Gaba, 2004, pi2).

Manikin-based simulation in chiropractic education typically utilizes low-fidelity models integrated with force-sensing equipment, to measure forces applied during spinal manipulation procedures (Figure 1). In this thesis, a manikin is defined as a physical model replicating human anatomical structures (de Kock et al., 2023). Spinal manipulation is defined as the application of an high-velocity, low-amplitude thrust to a joint with the intention of moving the articulation past its physiological range of motion but without exceeding its anatomic limit (Herzog, 2010). Spinal manipulation is one of several evidence-based therapeutic approaches that can be applied when treating patients (Côté et al., 2016; Bussieres et al., 2018). Considering the CanMEDS Physician Competency Framework (Frank JR, Snell L, Sherbino J, 2015), spinal manipulation is one of many other competencies (e.g. effective triaging and diagnosis of musculoskeletal dysfunctions, excellent communication skills etc), that must be

achieved by chiropractic experts in their daily practice. As such, I would like to acknowledge that although there are many other competencies that are taught to our students in the classroom, for the purposes of this thesis, I will focus on the delivery of spinal manipulation.



Figure 1: Manikin-based simulation, including the use of force-sensing technology.

Spinal manipulation can be quantified biomechanically, using force-sensing technology, allowing for an objective description of the applied technique. As shown in Figure 2, five main biomechanical parameters are measured: i) preload force: the clinician establishes contact with the targeted vertebral level and applies pressure to achieve the pre-thrust positioning, ii) downward incisural point (DIP): a transient force reduction occurring immediately prior to the manipulation, iii) peak force: the highest force generated during the manipulation, iv) rate of force application: determined by dividing the force differential between maximum and DIP forces by manipulation duration, and v) manipulation duration: the timeframe from DIP to maximum force (Bergmann, 2011).

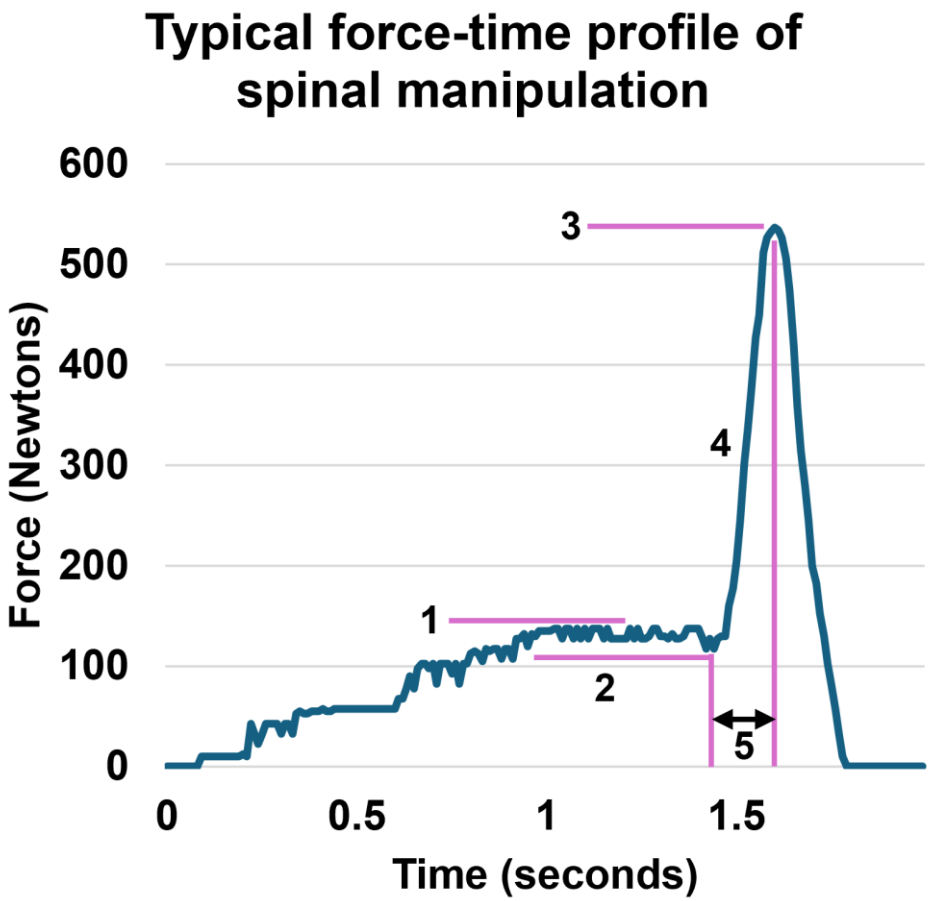


Figure 2: Typical force-time profile of spinal manipulation.
1: Preload force, 2. Downward incisural point, 3. Peak force, 4. Rate of force application, 5. Thrust duration.

In the classroom, spinal manipulation is traditionally taught by an 'expert', usually a chiropractor with many years of clinical experience, who demonstrates the technique of interest to a group of students who are then asked to remember and replicate the technique while practicing on their colleagues (Wulf et al., 2010). Experienced chiropractors then walk through the classroom, providing subjective feedback to students on their performance. Student mastery of the technique is then subjectively assessed during an end-of-semester examination. As different chiropractors place emphasis on various (often divergent) aspects of spinal manipulation delivery, feedback, and/or examination marks delivered to students may result in confusion and a lack of confidence. Specifically, what 'looked good' to one examiner the day before the exam might 'look terrible' to another examiner

during the examination. Furthermore, as both practice and examinations are usually conducted on colleagues, who are mostly young and healthy, the ability to modulate spinal manipulation delivery to specific patient populations (e.g. an older, osteoporotic patient) is not practiced. As such, students often report a lack of confidence in their spinal manipulation skills during their early clinical practice, despite achieving high scores in their examinations.

1.2 Intolerance of uncertainty within chiropractic education

In contemporary healthcare, professional accountability includes a commitment to delivering high-quality, evidence-based care (Innes et al., 2017). Psychological attributes, particularly intolerance of uncertainty, have emerged as influential factors in healthcare decision-making, warranting further investigation within medical education (Hong and Lee, 2015; Shihata et al., 2016). Intolerance of uncertainty is defined as a dispositional tendency to react negatively to uncertain situations due to inflexible beliefs about unpredictability and its perceived threat (Carleton, 2012). This cognitive rigidity can impair behavioral performance and clinical decision-making and is often the result of low confidence in one's ability to perform in novel situations (Thibodeau et al., 2013). Evidence from primary care settings highlights that elevated intolerance of uncertainty correlates with reduced adherence to evidence-based guidelines, excessive diagnostic testing, greater variation in treatment approaches, and increased resource utilization (Ghosh, 2004). For example, one study estimated that medical management costs rose by 17% for each standard deviation increase in uncertainty scores (Allison et al., 1998). Within chiropractic practice, analogous behaviors such as extended maintenance care in non-responsive low back pain cases, have been reported across several surveys, suggesting

intolerance of uncertainty may influence treatment persistence independent of clinical efficacy (Debarle et al., 2014).

High intolerance of uncertainty also undermines practitioner confidence, causing reluctance to revise decisions despite new information and a tendency to engage in cautious behaviors even when the perceived threat is minimal (Innes et al., 2017). These traits conflict with the adaptive decision-making processes that clinical practice demands. The relationship between intolerance of uncertainty and anxiety further complicates professional development, as individuals with elevated anxiety are more prone to develop negative self-perceptions and doubt their capacity to handle complex, ambiguous situations (Gentes and Ruscio, 2011; Carleton, 2012). Such internal models may drive reliance on external validation rather than fostering independent, critical thinking – a key educational aim in competency-based medical education (Behar et al., 2009).

Conversely, students and practitioners with low intolerance of uncertainty demonstrate psychological flexibility, resilience and confidence (Wild et al., 2014; Shihata et al., 2016). They are less distressed by ambiguity, more confident in navigating complex cases, and better equipped to make timely decisions (Einstein, 2014). These attributes align with the goals of medical and chiropractic education, which increasingly emphasizes reflective practice, clinical reasoning, and the development of adaptive expertise. Fostering confidence within chiropractic students in certain aspects of their training, specifically the development of the complex psychomotor skills required to successfully deliver spinal manipulation, may be one way in which to decrease intolerance of uncertainty within early-career chiropractic practitioners. Specifically, embedding structured strategies (e.g. manikin-based simulation) with objective feedback and

providing the opportunity for students to reflect on their performance could support learners in developing the emotional and cognitive tools necessary for effective practice (Innes et al., 2017).

In sum, intolerance of uncertainty represents a critical, yet often underappreciated, factor in clinical education and decision-making. Addressing it within the scope of chiropractic technique skills education could lead to improved clinical outcomes, greater cost efficiency, and enhanced practitioner well-being. One way to increase confidence within students as they transition from the classroom into their early clinical practice is through the use of manikin-based simulation and force-sensing technology, to objectively demonstrate their ability to modulate force during the delivery of spinal manipulation to diverse patient populations.

1.3 Study rationale

Students often report that they do not feel adequately equipped to deliver spinal manipulation to different patient populations in their early clinical careers (i.e. final year of studies). However, this topic has not previously been investigated in the chiropractic education literature. Therefore, I chose to use a mixed-methods case study research design to investigate if students in the fourth, fifth and sixth years of the University of Zurich Chiropractic Medicine Study Program (academic year 2024-2025) were able to modulate their delivery of thoracic spine manipulation in response to two short clinical cases (vignettes) of commonly encountered patients in chiropractic practice. A secondary objective was to investigate if manikin-based simulation would be a feasible addition to the current chiropractic technique skills curriculum as a means to scaffold these students from the classroom into their early clinical practice.

The research question addressed by the study was: ‘Despite reporting low confidence in their ability, are fourth, fifth, and sixth year students in the University of Zurich Chiropractic Medicine Study Program (2024–2025) able to modulate thoracic spine manipulation?’

1.4 Summary

This chapter briefly introduced the reader to the topic of manikin-based simulation within chiropractic education and the concept of student’s intolerance of uncertainty within the same context. Building on this, the rational for why it is important to conduct research in this field was introduced. Further strengthening this line of reasoning, the following chapter provides a comprehensive review of manikin-based simulation in the chiropractic education literature.

Chapter 2: Literature review

This chapter will critically evaluate the current state of manikin-based simulation in the chiropractic education literature. Educational theories and models will first be discussed, followed by a detailed discussion of the literature. Specifically, manikin-based simulation will be described in the context of its' use for spinal manipulation skills acquisition and development, manikin fidelity, decreased risk to recipients and transfer to practice.

2.1 Manikin-based simulation in the chiropractic education literature

Simulation-based training has extensive historical roots in aviation (including flight simulator programs) and military contexts (such as tactical exercises) (Ayaz and Ismail, 2022). Relating directly to the current discussion, the earliest documented application of manikin-based simulation in medical training dates to the 17th century, when French physicians employed obstetric models for educational instruction (Buck, 1991). Contrasting with this established history in medical training, the first reported use of manikins within chiropractic education occurred in 1998 (Young et al., 1998). Since then, manikin-based simulation in chiropractic education has primarily been used for the teaching and learning of spinal manipulation skills (Stainsby et al., 2016; de Kock et al., 2023). Although the studies reported in these reviews show promise for the use of manikin-based simulation within chiropractic education, they do not reveal any studies reporting on the modulation of spinal manipulation delivered by students in response to different short clinical cases. Furthermore, all discussion of manikin-based simulation in the literature describes individual accounts of simulation-based training and fails to show systematic integration into the curriculum.

This lack of systematic integration within the curriculum is one of several factors that highlights clearly the infancy of simulation-based learning in the chiropractic education literature. In contrast to this, over the past 15 years, medical education experts have implemented 12 essential elements and optimal practices for simulation-based training, as first introduced in McGaghie and colleagues' in their 2010 seminal review: 'i) feedback provision, ii) intentional practice, iii) curricular integration, iv) outcome assessment, v) simulation authenticity, vi) skill development and retention, vii) competency-based learning, viii) clinical transfer, ix) collaborative training, x) high-stakes evaluation, xi) faculty development, and xii) educational and professional settings' (McGaghie et al., 2010, p50). While there appears to be a benefit of using simulation-based training for spinal manipulation skill development and retention (de Kock et al., 2023), there is a considerable overrepresentation of this element within the chiropractic education literature. Furthermore, other elements, such as clinical transfer and curricular integration, are entirely neglected. In this chapter, the use of manikin-based simulation within the chiropractic education literature will be discussed using the McGaghie and colleagues (2010) framework. Specifically, i) the use of manikin-based simulation for acquiring and developing spinal manipulation skills, ii) simulation authenticity, including manikin fidelity, iii) decreased risk to the recipient, and iv) the transfer of skills learned to clinical practice. The topic of curricular integration will be discussed further in the Discussion section (5.2.4 Curriculum integration). However, before these areas are explored, an introduction to the educational theories and models underpinning manikin-based simulation will be provided.

2.2 Educational theories and models

Manikin-based simulation aligns strongly with pedagogical approaches such as constructivism, situated learning, and experiential learning theories, all of which emphasize active student participation and meaningful engagement in educational activities (Battista and Nestel, 2019). These theoretical foundations encourage dynamic learning experiences, positioning simulation-based training as an opportunity to expand educational opportunities beyond traditional sequential methods, thus achieving outcomes that exceed initially established learning objectives (Jensen, 2024). Supporting evidence that simulation-based education can accomplish this outcome was demonstrated by Paskins and Peile (2010), who reported that 28 graduating medical students described their experiences of simulation-based instruction in emergency scenarios using SimMan® (a moderate-fidelity full-body manikin) to be '…. a different way of learning that was more practical, hands-on and allowed students to problem solve and apply theory, and that material taught in this way was easier to remember and retain…. ' (Paskins and Peile, 2010, p4).

Although students demonstrate positive attitudes toward manikin-based simulation, studies reporting on such training in medical and chiropractic programs frequently fail to articulate explicit objectives, underlying educational frameworks, or pedagogical justification (Gormley and Murphy, 2023). Consequently, this leaves readers uncertain about the educational reasoning for substituting human recipients with manikins, and unclear about why manikins were chosen instead of other available options such as treatment tables or force plates (both have been described, see (Stainsby et al., 2016; de Kock et al., 2023)). This often makes it difficult for the reader to assess the influence of the

technology on the educational task and to fully evaluate the pedagogical benefit of the simulation to the students.

The ‘Substitution, Augmentation, Modification, and Redefinition’ (SAMR) model (Puentedura, 2006) is a useful tool that is widely used within medical education to facilitate this assessment. Specifically, the four levels of the model prompts users to reflect on how the use of technology influences different ‘levels’ of teaching and learning (Hamilton et al., 2016):

1. Substitution:

The technology acts as a direct substitute for an existing instrument without any functional change. For example, replacing a human with a manikin for the practice of spinal manipulation delivery.

2. Augmentation:

The technology acts as a direct substitute, but with functional improvements. For example, using a manikin with force-sensing technology to objectively quantify the delivery of spinal manipulation.

3. Modification:

The technology facilitates a significant redesign of a task. For example, students are asked not only to use the manikin to acquire and develop spinal manipulation skills but also to modulate their delivery of the procedure, based on a short clinical history (vignette) and using force-sensing technology.

4. Redefinition:

The technology enables the creation of entirely new tasks that were previously impossible. For example, students could deliver spinal manipulation to their colleagues but in an augmented reality environment. Such an environment could include the use of a virtual reality headset, with the subsequent projection of the

relevant anatomical landmarks on the recipient, including modification of the patient demographics seen by the student (e.g. older female). At the same time, the student could be visually immersed in their future clinical environment (e.g. room furnishings etc).

In the context of manikin-based simulation in chiropractic education, most studies describe replacing a human with a manikin to teach spinal manipulation skills, reflecting the lowest level of the SAMR model – substitution. Despite this, advantages exist for the use of manikin-based simulation for the acquisition and development of spinal manipulation skills.

2.3 Spinal manipulation skill acquisition and development

Manual spinal manipulation represents the fundamental treatment approach in chiropractic practice globally and demands the development of complex psychomotor skills for successful implementation (Marchand et al., 2017). As noted earlier, instruction typically follows a traditional pattern where experienced clinicians demonstrate procedures to learners, who subsequently practice replicating these techniques, commonly referred to as the ‘see one, do one' methodology (Cameron, 1997). The Dreyfus framework, a widely accepted educational model for competency development, can be used to describe the acquisition process for spinal manipulation abilities (Dreyfus and Dreyfus, 1986). This framework identifies five developmental stages, beginning with novice, characterized by minimal contextual awareness and rigid adherence to prescribed protocols (demonstrating high intolerance of uncertainty), progressing to expert practitioner, who executes spinal manipulation smoothly while comprehending diverse clinical situations (i.e. low intolerance of uncertainty). Progression from novice to expert practitioner requires both repetitive training

and clinical exposure (Owens et al., 2016), which are crucial for establishing appropriate biomechanical coordination, force modulation, and professional assurance (Descarreaux et al., 2005). Contemporary research shows manikins are becoming more prevalent for the instruction and practice of spinal manipulation (Stainsby et al., 2016; de Kock et al., 2023). The initial comprehensive review addressing this subject, published in 2016, offered a best-evidence analysis of instructional approaches to evaluate the efficacy of manikins in spinal manipulation training (Stainsby et al., 2016). The researchers systematically evaluated 20 publications, comprising nine randomized controlled studies, nine longitudinal investigations, and two systematic reviews with meta-analyses. However, only 11 investigations satisfied methodological quality criteria and were incorporated into the analysis. Multiple devices were documented for spinal manipulation instruction: a 'Thrust in Motion' cervical simulator (Young et al., 1998), an instrumented cardiopulmonary resuscitation model (Descarreaux et al., 2005), a cushioned contact surface with load measurement cell (Enebo and Sherwood, 2005), an instrumented therapy table incorporating force detection systems (Triano and Schultz, 1997) and a ‘Dynadjust’ instrument (Triano et al., 2003).

Several of these devices (including the cushioned contact system with load cells and instrumented therapy tables equipped with force detection or measurement systems) captured the force-time characteristics of spinal manipulation delivery. This capability is significant because multiple investigations have reported positive outcomes when students are directed to achieve specific peak force targets during spinal manipulation delivered to manikins (Descarreaux et al., 2005; Pasquier et al., 2017; Shannon et al., 2020). Nevertheless, the definition

of a 'clinically effective spinal manipulation', in terms of biomechanical characteristics, remains unknown (Descarreaux and Dugas, 2010). Without establishing whether peak forces applied during spinal manipulation are biomechanically meaningful, the clinical relevance of these investigations therefore remains questionable. The researchers observed that various devices are utilized in chiropractic training for spinal manipulation instruction but determined that these tools' influence on student advancement to clinical application, knowledge and skill transfer capabilities, and resulting patient care outcomes remains undetermined. Thus, manikin-based simulation can be used by students for spinal manipulation skill acquisition and development but how this then transfers to clinical practice is unknown (Ringsted, 2010).

More recently, de Kock and colleagues (2023) conducted a revised systematic analysis of instructional approaches for developing psychomotor proficiency in spinal manipulation. Compared with the Stainsby and colleagues (2016) review, an additional 14 articles, including 10 longitudinal studies and four randomized controlled investigations underwent systematic evaluation. This analysis identified additional teaching instruments, including 'a computer-interfaced apparatus, a human-like simulator, and a 3-dimensional electro-goniometer incorporating instrumented spatial connections' (de Kock et al., 2023, p116). Regrettably, consistent with the previous Stainsby analysis, the researchers concluded that whether utilizing these instruments enhances competency development in beginning chiropractors remains uncertain, and consequently, this review failed to substantially progress existing knowledge. Furthermore, there was no discussion in either review regarding the importance of simulation authenticity during the educational encounter.

2.4 Manikin fidelity

Simulation authenticity in the context of manikin-based simulation is described here primarily in the context of manikin fidelity. Fidelity is highly relevant to manikin-based simulation because it describes how closely the manikin resembles real-world practice. Fidelity should be sufficient to enable learners to disregard the fact that the manikin is not real and to engage with it as if it were an actual clinical situation (Ker and Shippey, 2017). Frequently misunderstood as simply 'reality,' fidelity includes physical characteristics (e.g. appearance, tactile sensation, auditory and olfactory elements), semantic authenticity (i.e. the logical consistency of the clinical scenario), and phenomenological authenticity (i.e. how the simulation affects learner cognition and emotions) (Dieckmann et al., 2007). Within chiropractic training, fidelity holds particular significance since the delivery of spinal manipulation depends extensively on haptic feedback, including tactile perception of tissue resistance before and during the thrust. However, achieving adequate manikin fidelity for manikin-based simulation chiropractic education presents ongoing difficulties and, excluding one investigation discussed below, has received minimal attention in the literature. Therefore, the relationship between fidelity and effective instruction of spinal manipulation techniques remains unclear.

Furthermore, most published literature regarding manikin applications in chiropractic training emphasizes thoracic spinal techniques exclusively (de Kock et al., 2023), despite clinical practice primarily involving lumbar region treatment, followed by cervical spine procedures (Beliveau et al., 2017). This is predominantly due to design limitations of the most commonly used manikin, which consists of a hard torso, with or without, a head attachment (Canadian

Memorial Chiropractic College, 2024). The exception to this is a human head and torso manikin, featuring articulating vertebrae, pelvic structures, and femoral components. This Palpation and Adjustment Trainer (PAT) manikin can receive spinal manipulation to the neck, thoracic and lumbar spines and pelvis in a supine, prone or side-lying position (Owens et al., 2022). Furthermore, mechanical properties of the manikin have been quantified and its mechanical response was reported to resemble human tissue behavior across various stiffness measurements (Owens et al., 2021). These biomechanical assessments suggest that the manikin has mid- to high-tactile fidelity, especially in comparison with other commercially available options. Additionally, the PAT manikin was created to enhance not only spinal manipulation competencies, but also palpation, and includes 64 pressure sensors positioned on critical vertebral and anatomical reference points to deliver force application feedback (Owens et al., 2021). Despite this positive attribute of the PAT manikin, certain limitations persist; specifically, the researchers acknowledge that the extensive sensor array creates insufficient data collection frequency, complicating the accurate recording of spinal manipulation (data are typically collected at a minimum of 100Hz due to the ballistic nature of the procedure (Gudavalli et al., 2013)). Thus, if the biomechanical quantification of spinal manipulation is necessary, it is recommended that extra force-sensing equipment, including pressure sensors or force plates, is used. The use of such additional equipment has the potential to reduce tactile sensation, especially for users who are not familiar with the equipment, possibly compromising the authenticity of the simulation. Additionally, the authors did not report manufacturing expenses, creating ambiguity regarding whether the manikin's cost aligns with the reader’s

institutional educational funding constraints.

Ultimately, with the exception of the PAT manikin, anecdotal observations from experienced chiropractors and physiotherapists, along with my personal observations, indicate that commonly utilized manikins demonstrate poor fidelity, exhibiting excessive rigidity and absent tactile responses such as variable resistance under applied force, which characterize actual human spinal structures. Without this tactile information, it is possible that novice practitioners (i.e. students) may apply spinal manipulation differently to the manikin (e.g. with more force than necessary). The reinforcement of such psychomotor patterns may present a risk to both the student and the recipient.

2.5 Decreased risk to recipients

In the absence of skilled mentors and clear biomechanical understanding of proper technique, learners struggle to evaluate their own performance during independent practice sessions (Enebo and Sherwood, 2005). This may result in the formation of faulty movement patterns and/or the delivery of excessive force during spinal manipulation delivery. If such events occur during unsupervised practice sessions, there is an increased injury risk for both the recipient (Owens et al., 2016) and the learner (Ndetan et al., 2009) performing the procedure. However, if a manikin is used during unsupervised practice, this removes the risk to the recipient. Furthermore, if the novice practitioner was using force-sensing equipment to measure the applied forces during the practice session, this could help to limit the application of excessive force as the student could quantify and practice modulating their applied forces. Similarly, if the student was hesitant to apply higher forces to a human recipient, for fear of harming their (e.g. smaller) colleague, manikin-based simulation could be used to provide a psychologically-

safe environment in which the student was able to practice the repeated application of higher force spinal manipulation. As mentioned above, the use of force-sensing equipment may facilitate the learning of force modulation. Specifically, students can repeatedly attempt to reach force targets when delivering spinal manipulation to all regions of the spine, thus developing modulation strategies necessary for their early clinical practice, when they are tasked with delivering spinal manipulation to patients, rather than their colleagues (Descarreaux et al., 2005; Pasquier et al., 2017). This is a salient point as patients often display altered movement biomechanics and guarding behaviors, due to pain and/or apprehension, during investigation and treatment of spinal biomechanical dysfunction. This topic is especially important in the cervical spine. Although complications from spinal manipulation are typically temporary and mild, including muscular discomfort or tiredness (Nielsen et al., 2017), severe adverse outcomes, such as vertebral artery injury and cerebrovascular accidents, have been associated with cervical spine manipulation (Cassidy et al., 2008). As such, it is imperative that novice practitioners are able to safely modulate force delivery during spinal manipulation. To learn force modulation, students must repeatedly deliver spinal manipulation, in order to develop the necessary psychomotor skills (Stainsby et al., 2016).

In summary, it is worth emphasizing that the opportunity for novice practitioners, specifically students, to repeatedly practice spinal manipulation through manikin-based simulation provides substantial advantages. Specifically, it creates a 'safe-to-fail' setting that reduces the likelihood of recipient harm while allowing students to build competence and confidence (Enebo and Sherwood, 2005). Learners can

train as frequently as necessary without endangering others, promoting mastery of complex psychomotor skills according to their individual learning timeline. Despite this clear advantage, exactly how the delivery of spinal manipulation to a manikin translates to that delivered in clinical practice is unknown (Ringsted, 2010).

2.6 Transfer to practice

In contrast to this uncertainty within the chiropractic education literature regarding the transfer of spinal manipulation skills learned during simulation to clinical practice, medical education utilizing simulation has demonstrated enhanced patient care results, based on a systematic analysis of 50 publications examining medical procedural competencies including catheter placement and digestive endoscopy (Zendejas et al., 2013). As mentioned previously, manikins are predominantly employed as human replacements in spinal manipulation instruction and practice. Additionally, it remains unknown whether, or how, competencies developed using manikins translate into clinical application (Stainsby et al., 2016; de Kock et al., 2023). However, recent research indicates that seasoned clinicians can adjust biomechanical parameters, including peak force, according to varying clinical scenarios (Passmore et al., 2022; Nyirö et al., 2024), haptic feedback regarding pressure and force (Passmore et al., 2019), and recognized contextual elements such as patient age (Maiers et al., 2025). One of these investigations explored how brief clinical case descriptions (vignettes) influence thoracic spinal manipulation using manikins, reporting that experienced clinicians modified their peak force according to the vignette, reflecting actual practice patterns (Nyirö et al., 2024).

Despite this, the use of manikins as substitutes for human recipients during spinal

manipulation represents a missed opportunity to leverage manikin-based simulation technology to rethink and transform the teaching and future learning experiences of chiropractic students (Grainger et al., 2024). Encouragingly, at one educational institution in Canada, manikin-based simulation in chiropractic education is extending beyond the teaching and learning of spinal manipulation to encompass other vital healthcare professional competencies. One research group showed that learners could accurately recognize abnormal respiratory sounds through stethoscope examination (da Silva-Oolup et al., 2022), retain knowledge and act appropriately in cardiac emergency simulations (Giuliano and McGregor, 2016), and enhance the speed of implementing crucial emergency procedures across various situations (Starmer et al., 2014). Notably, despite successfully identifying abnormal respiratory sounds, learners reported limited confidence in their assessments (da Silva-Oolup et al., 2022). However, no variations were found in learner stress levels between virtual and face-to-face simulation introductions during cardiac emergency training (Giuliano and McGregor, 2016). Although these results show promise, they represent primarily individual accounts of simulation-based training and fail to show incorporation into comprehensive educational programs.

2.7 Summary

This chapter outlined the existing literature related to the use of manikin-based simulation within chiropractic education. Specifically, manikin-based simulation was described in the context of its use for spinal manipulation skills acquisition and development, manikin fidelity, decreased risk to recipients and transfer to practice. While it is unknown whether, or how, spinal manipulation competencies developed using manikin-based simulation are relevant clinically, one way to

address this gap in the literature is to investigate similarities and differences between spinal manipulation delivered to a manikin and human recipients, in response to a short clinical scenario (vignette). Therefore, the following chapter is a description of the methodology that was used during the current research study to address this gap in the literature.

Chapter 3: Methodology

This chapter will outline the methodology used in the mixed-methods case study, reporting on both the ability of students in the fourth, fifth and sixth years of the University of Zurich Chiropractic Medicine Study Program (academic year 2024-2025) to modulate their delivery of thoracic spine manipulation in response to being presented with different vignettes of patient presentations commonly encountered in their early clinical careers and on their opinions regarding the systematic implementation of manikin-based simulation within the curriculum.

3.1 Justification for using case study methodology

A case study can be defined as:

> *"...an entity that is studied as a single unit and has clear boundaries in both time and space (location). Case study research might focus on a particular event, specific programme or organisation… multiple data sources are used…" (Finn et al., 2023, p5).*

As discussed above (2.1 Manikin-based simulation in the chiropractic education literature) and considering the comparatively limited scale and developmental phase of the chiropractic profession (relative to medicine), case study approaches provide an optimal methodology for examining the complexities and distinctive characteristics of spinal manipulation procedures delivered by chiropractic students within an individual country, such as Switzerland. There are many different types of case study research (Merriam, 1985; Cleland et al., 2021); however, this thesis will focus on an atheoretical (descriptive) single-case approach (Cheek et al., 2018), examining students enrolled in a single Chiropractic Medicine Study Program. An atheoretical approach is most

appropriate in the current context as it examines a single cohort, gathering rich, descriptive data about experiences and behaviors without being constrained by pre-existing theoretical frameworks. This approach aims to uncover unique patterns and insights within specific contexts, often leading to the development of new theoretical concepts rather than testing established theories (Cleland et al., 2021). Therefore, all Swiss chiropractic students in their fourth, fifth or sixth year of study were invited to participate in this study. Multiple data collection methods were employed, including biomechanical measurements of applied forces, questionnaires, and focus group interviews. Using several data collection methods, and the subsequent analysis of the results that were obtained, provided an in-depth understanding of how Swiss chiropractic students in their final years of study delivered spinal manipulation during manikin-based simulation and their opinions on the proposed systematic integration of simulation within the technique skills curriculum. The quantitative results often supported the arguments that were made by students in the focus-group interviews. Having established the appropriateness of case study research for addressing the research questions, I will now explain why this study is personally meaningful to me and discuss the research paradigms underpinning this work.

3.2 Paradigm in which this research is situated

Regarding axiology, I believe it is important to first investigate if the current cohort of chiropractic students are able to modify their spinal manipulation to different patient vignettes to ensure that the ultimate goal of their education (to produce safe and effective graduates) is currently being achieved. This should be done objectively (i.e. using force-sensing technology) and if appropriate, the results of this case-study should be used to inform revision of the technique skills

curriculum to ensure that students moving from the classroom to early clinical practice are confident (thus achieving a low intolerance of uncertainty) in their ability to modify the delivery of spinal manipulation to different clinical populations. To achieve this objective, I situated this study within a post-positivist framework, asserting that a singular fundamental reality exists, although it cannot be completely captured. From an ontological perspective, I followed critical realism principles, which maintain that research findings are necessarily flawed due to the intricacy of research questions and constraints of methodological techniques. From an epistemological standpoint, I adopted relative objectivism, considering that understanding is tentative and grounded in theories that remain unrefuted. Although objective comprehension of reality represents the goal, it is practically unachievable. Therefore, I utilized a falsification-oriented research approach, stressing that scientific progress occurs by examining whether theories can be refuted, employing a deductive methodology. I acknowledge that attaining entirely objective results is improbable (Bergman et al., 2012). While it may seem counterintuitive to the reader that an atheoretical case study is situated within a post-positivist paradigm, one of most highly cited case study methodologists, Yin, also operates within this paradigm (Yin, 2009). Specifically, the purpose of an atheoretical cases study has been framed by Yin as “To describe an intervention or phenomenon and the real-life context in which it occurred’’ (Yin, 2003, p109). Cleland and colleagues take this concept further, stating that in the post-positivist (Yin) paradigm, atheoretical cases studies should “…explain a particular situation, phenomenon or event, describe the problem. Put simply, what happened, involving whom and where?’’ (Cleland et al., 2021, p1137). As such, I believe that situating the current study within this

paradigm is not only appropriate, but also necessary.

3.3 Methods

3.3.1 Setting

Kinematic data collection was conducted at a single publicly-funded orthopedic hospital in Switzerland. Focus group interviews were conducted online via Microsoft Teams (Microsoft365).

3.3.2 Screening and consent processes

Volunteers responded in the first instance to written advertisements (Appendix C) placed around the University of Zurich Chiropractic Medicine Study Program campus, Balgrist Hospital which directed them to contact the research student to arrange a screening appointment. Recruitment occurred from 10th March to 14th April 2025. Once a volunteer had satisfied the inclusion and exclusion criteria (Table 1), read the patient information sheet (Appendix D) and provided written consent, they were enrolled as a participant in the trial and were given a study specific identification number (Appendix E).

Table 1: Inclusion and exclusion criteria for study participants.

Inclusion Criteria	Exclusion Criteria
• Fourth, fifth or sixth year student in the University of Zurich Chiropractic Medicine Study Program	• Contraindication to the delivery or receipt of thoracic spinal manipulation (e.g. injury, illness) • Unable to attend a single ~30-minute kinetic data collection session

3.3.3 Kinetic data collection equipment

The manikin used during data collection was a mid-fidelity ‘Palpation and Adjustment Trainer’ (PAT) (Hands on Tools, USA) manikin (Figure 3). PAT is

constructed using a 3D printed, movable plastic spine embedded in flexible silicon. The physical dimensions of PAT are based on anatomic measurements of the average size of an American Caucasian adult male human spine. Furthermore, the mechanical properties of PAT's spine are reportedly similar to that of a human spine (Owens et al., 2021, 2022). As seen in Figure 3, kinetic data were collected using a customized, thin, flexible pressure pad, placed between the participant's hands and the recipient (manikin or human). As the main forces during thoracic spinal manipulation are directed perpendicularly to the spine (Gudavalli, 2005), and a thoracic spine manipulation occurs at a rate of 416-8700 N/sec and lasts 82-541 ms (Gorrell et al., 2023), the use of the Pliance system (Novel Pliance, Germany, ~20 cm x 10 cm x 0.02 cm, 100 Hz) was adequate for data collection (Gudavalli et al., 2013).



Figure 3: Kinetic data collection experimental setup.
PAT manikin and force-sensing technology.

3.3.4 Flow through the study

An overview of participant flow through the study is presented below (Figure 4). Following enrollment into the study, each participant was then asked to complete

a brief pre-data collection questionnaire, during which demographic data (e.g. year of birth, sex, year of study in the Study Program) were collected in Microsoft Forms (Microsoft365) (Appendix F). On completion of this questionnaire, participants were paired with another student and were randomly allocated to deliver spinal manipulation to either the PAT manikin or their student partner, beginning with one of two clinical cases (vignettes, Figure 5 & Figure 6), the order of which was also randomized. The randomization sequences were created using a computer-generated random number sequence created by a research assistant in the Chiropractic Medicine Department who had no further involvement in the study. The randomization allocation was delivered to the research student in an individual opaque envelope by a second research assistant who assisted with kinetic data collection.

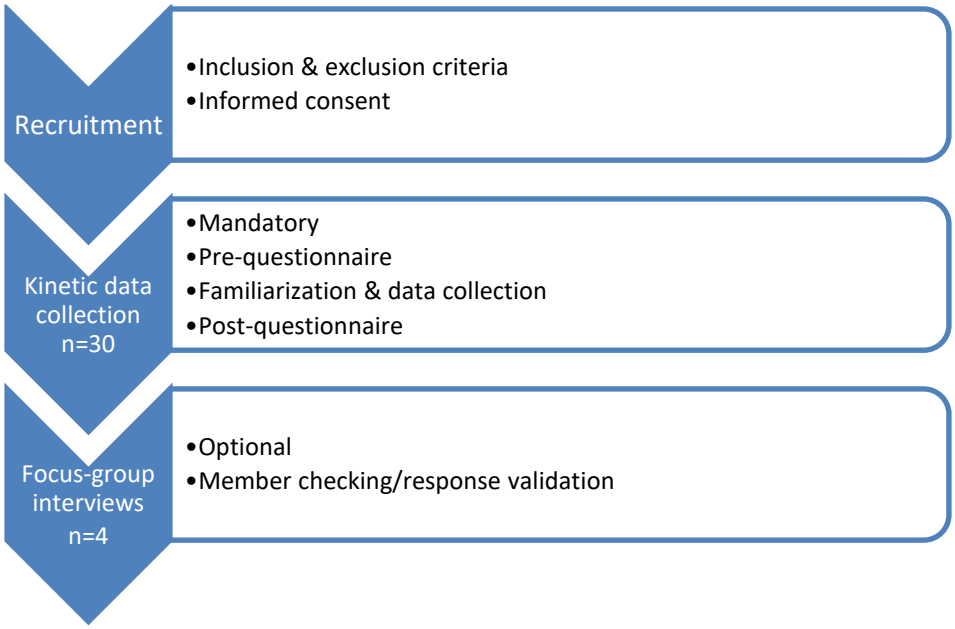


Figure 4: Flow through the study.

During familiarization, all participants were instructed to deliver three prone, posterior-to-anterior spinal manipulations to the manikin, using their preferred hand contact. Kinetic data were not recorded during familiarization, however,

participants used the pressure pad, placed between the participant's hands and the recipient's thoracic spine, allowing them to become comfortable with the use of the force-sensing technology. All students had previously experienced approximately the same level of limited access to manikin-based simulation within their normal chiropractic technique skills classes.

Imagine the following scenario:



- Healthy male patient
- Age: 50-55 years old
- Height: 180cm
- Normal body weight for height (80-85kg)
- Responded well to previous manual therapy on mid-thoracic spine
- No radiation, no signs or symptoms of inflammatory or degenerative pathologies

Figure 5: Vignette for 50-55-year-old male.

Imagine the following scenario:



- Healthy female patient
- Age: 20-25 years old
- Height: 165cm
- Normal body weight for height (60-65kg)
- Responded well to previous manual therapy on mid-thoracic spine
- No radiation, no signs or symptoms of inflammatory or degenerative pathologies

Figure 6: Vignette for 20-25-year-old female.

Prior to the beginning of data collection, the research student marked the T6 vertebrae of the manikin and each participant was then asked to count and mark the T6 vertebrae of their prone student partner. Once this was done, participants were instructed to read the first vignette carefully and to deliver two spinal manipulations to the recipient (manikin or human). Beyond the limitation of delivering a posterior-anterior thoracic spine manipulation to the marked level of

T6 on both the manikin and the human, participants were free to choose the most appropriate hand-contact (e.g. Appendix G) based on their personal preference, clinical experience and the information provided in the vignette. These particular vignettes were developed to be representative of two commonly encountered patient scenarios in the students' early clinical careers. Furthermore, I felt that the vignettes were sufficiently different (i.e. ages, body morphology) for the students to be able identify that they should modulate their delivery of spinal manipulation, without having to be told to do so.

Participants could choose an alternate hand contact for the two vignettes but could not change hand contacts between the manikin and the human for the same vignette. Kinetic data were collected during this phase of the study, as described above. Following the delivery of two manipulations to either the manikin or human, participants then used the same vignette to deliver two thoracic spine manipulations to the alternate recipient. The second vignette was then presented to the participant and the same process was followed (two manipulations to the manikin or human and then two manipulations to the other recipient). Once kinematic data were collected for the first of the two students in the pair, the process was repeated for the second participant. Following the completion of data collection for the second participant, both participants completed a brief post-data collection questionnaire, during which opinions regarding the use of manikin-based simulation within the Study Program and their willingness to participate in the focus-group interviews were collected in Microsoft Forms (Microsoft365) (Appendix H).

If the participant did not indicate that they wished to be contacted regarding the focus-group interviews, their involvement in the study was complete following

kinetic data collection. However, if the participant indicated that they were willing to be contacted regarding the focus-group interviews, they were sent a link via Microsoft Forms (Microsoft365) to indicate their preferred time for the focus-group interviews. Focus-group participants attended a single session, lasting approximately 60 minutes, during which a pre-prepared study guide was used to elicit opinions regarding the use of manikin-based simulation within the Chiropractic Study Program (Appendix I). More specifically, the research student asked participants to describe their experiences with the PAT manikin and manikin-based simulation and any changes in opinion that may have occurred over time as the participants became more familiar with the manikin. Following that, participants were asked to reflect on advantages and challenges to the use of manikin-based simulation within the Study Program.

Finally, the feasibility of the systematic and longitudinal integration of manikin-based simulation into the Study Program was discussed. All focus-group participants were provided with the opportunity to provide any further information/opinions regarding the study and/or manikin-based simulation before the interview was concluded. Due to differing availability of the students (class scheduling across different year groups), two ~60 minute focus-group interviews (2 x n=2) were held. Students attended only one of these sessions and both focus-group interviews were audio and video recorded.

3.3.5 Data

Fetters and colleagues (2013) suggest that a true mixed-methods study must contain integration between different data ‘types’ at multiple levels (Fetters et al., 2013). Fulfilling this requirement, integration of the data at the methodological level of ‘connection’ was achieved as the students participating in the focus-

group interviews also participated in the kinetic data collection. Furthermore, once initial thematic analysis had been initiated, insights into the quantitative data were used to further support/challenge the opinions of students who participated in the focus-group interviews. Additionally, at the interpretation and reporting level, ‘merging’ and ‘embedding’ were both used, with links between the different data at several points being highlighted in the Discussion and Conclusion chapters of this thesis.

3.3.5.1 Quantitative data

Primary outcome measures for the kinetic data were preload and peak force as these biomechanical parameters have been shown to be important for the elicitation of neurophysiological responses to spinal manipulation (Herzog, 2010; Gorrell et al., 2020).

3.3.5.2 Qualitative data

Thematic analysis was used to identify themes emerging from the focus-group interviews. These themes were summarized to describe participants opinions and beliefs regarding the use of manikin-based simulation within the Study Program technique skills curriculum. See Analysis 3.3.7 below for further details.

3.3.6 Sample size calculation

As this study used an atheoretical, single-case study design, no sample size calculation was performed for either quantitative or qualitative data collection. Instead, recruitment strategies (i.e. advertising, word of mouth via participants following their completion of the study) were focused on collecting data from as many of the students as possible (the total number of years 4-6 students in the academic year 2024-2025 was 37.

3.3.7 Analysis

3.3.7.1 Kinetic data

Statistical analysis was performed using IBM SPSS® software (V: 30.0.0.0 (171)). A significance level of 0.05 was used. Data were assessed for normality of distribution using probability plots. Normally distributed data were analysed using Paired T-Tests to assess statistically significant differences between thoracic spine manipulation delivered to humans vs. the manikin and the two vignettes. Analysis of data which did not have a normal distribution was performed using the Friedman Test (comparison between year groups) and the Wilcoxson Test (differences between humans vs. the manikin and the two vignettes among different year groups).

3.3.7.2 Focus-group interviews

Focus-group interviews were conducted by myself and I hold a clinical qualification in Chiropractic (MChiroprac) and a PhD in biomechanics, but I have no previous experience conducting, transcribing or analyzing focus-group interview data. I am currently employed as the Head of Teaching in the Chiropractic Medicine Study Program at a publicly-funded university in Switzerland and this project was completed as part of my Master of Science, Medical Education studies. As mentioned previously, all participants were known to the research student and recruitment was via convenience sampling. Focus-group interviews were audio and visual recorded online in Microsoft Teams (Microsoft365). Following the conclusion of the interview, I transcribed the interviews using the downloaded session transcript as a starting point and relistening to the recordings several times and checking the interview diaries to ensure accuracy. Transcripts were then returned to all participants within one

week for member checking. Participants were specifically instructed to check the documents for accuracy and were asked to add any further thoughts they may have had since the interview. Following member checking, all participant involvement in the study was complete. Once the transcripts were received from the participants, a mixture of deductive and inductive thematic analysis was performed (Nvivo 15.2.0 (21)). Specifically, a six-step process was followed: i) familiarization with the data, ii) coding, iii) generating themes, iv) reviewing themes, v) defining and naming themes, and vi) writing the results (Saldana, 2011). A deductive approach (that students lacked confidence when delivering spinal manipulation) was used to guide the initial analysis, followed by the use of an inductive approach to identify additional themes within the data. The data were analyzed for both semantic and latent themes (Vaismoradi et al., 2013).

3.3.8 Methodological rigor

In this research study, triangulation and reflection were key strategies to ensure credibility and depth of understanding across both the quantitative and qualitative data sources.

3.3.8.1 Triangulation

Methodological triangulation was achieved through the integration of both quantitative (kinetic) and qualitative (focus-group interviews) data, in addition to the questionnaire data. This offered both objective and subjective insights into participants' delivery of thoracic spinal manipulation and the use of manikin-based simulation. To enrich the quantitative findings and enhance interpretive validity, thematic analysis of focus-group interviews was employed, using both deductive and inductive approaches. The deductive analysis was guided by existing theoretical frameworks, allowing for the identification of patterns aligned

with known constructs, while the inductive analysis permitted emergent themes to surface organically from participant narratives. Triangulation was achieved by comparing and contrasting these different types of data: the kinetic metrics against the thematic findings. This multidimensional approach reduced researcher bias and illuminated nuanced relationships between physical data and participants' expressed experiences and opinions. The recursive interplay between quantitative measures and qualitative interpretation enabled a comprehensive understanding of the research phenomenon, underscoring the study's credibility and trustworthiness. By embedding triangulation and rigorous analytical procedures throughout, the research demonstrated methodological coherence and transparency, essential for producing reliable and replicable findings.

3.3.8.2 Reflection

Throughout the data collection and analysis phases of this case study research, I engaged in ongoing reflexivity to critically examine my influence on the research process and outcomes. Firstly, my role as Head of Curriculum and chiropractic technique skills lecturer within the Study Program, and the possibility that students volunteered to participate in the study as they felt compelled to do so due to the presence of an unequal power relationship. However, it was made explicit to all students several times, verbally and in writing, that their participation/non-participation in the research study would in no way influence their progression through their studies. Furthermore, prior to the onset of recruitment, all advertising materials were approved by the University of Oxford Education (Educ) DREC as being acceptable. Secondly, my enthusiasm and belief that the use of manikin-based simulation and force-sensing technology

within the Study Program are known to the students and it is possible that this knowledge may have influenced their performance during kinetic data collection, depending on their individual beliefs regarding the subject. Furthermore, it is possible that only the students who view manikin-based simulation positively volunteered for the focus-group interviews, thus skewing the data. I was sensitive to this possibility and attempted to maintain a conscious awareness of my personal biases that could influence the quantitative and qualitative data collected. This was particularly crucial during thematic analysis of the focus-group interviews, which combined deductive coding based on existing frameworks and inductive exploration of emergent themes. Recognizing that my academic background and experiential lens might privilege certain narratives or constructs, I used reflective journaling and peer debriefing to confront and mitigate such biases. During focus group facilitation, open-ended questioning and neutral probing were used to minimize leading responses, preserving the integrity of participants' voices. By acknowledging subjectivity as an inherent component of qualitative inquiry, I saw reflection not as a barrier but as a tool for enhancing transparency and trustworthiness. This self-awareness contributed to more balanced data representation and nuanced understanding, reinforcing the credibility of my findings.

3.4 Summary

This study was designed to investigate if students in the fourth, fifth and sixth years of the University of Zurich Chiropractic Medicine Study Program (academic year 2024-2025) were able to modulate their delivery of thoracic spine manipulation in response to being presented with different vignettes of patient presentations commonly encountered in their early clinical careers. A secondary

objective was to investigate if manikin-based simulation would be feasible as a means to scaffold these students from the classroom into their early clinical practice. The results of this study will be outlined in chapter four.

Chapter 4: Results

This chapter will report on quantitative data collected from students in the fourth, fifth and sixth years of the University of Zurich Chiropractic Medicine Study Program (academic year 2024-2025) during the delivery of thoracic spine manipulation and qualitative data collected from a small sample of these students during focus-group interviews regarding their opinions on the implementation of manikin-based simulation within the curriculum.

4.1 Characteristics of study participants

Baseline characteristics of the thirty participants revealed 21 women (70%), with an average age of 26 ± 2.1 years and BMI 22 ± 2.3 kg/cm^2. The majority of the cohort were right-handed (83%) and in their fourth year of study (43%). Thoracic spine manipulation was most commonly delivered 5-10 times per week (40%) and with the exception of one individual (3%), all participants had previously experienced manikin-based simulation, usually less than five times (57%). These characteristics are presented in Table 2.

Participant flow through the trial is outlined in Figure 7. Thirty-two respondents were screened for inclusion in the study with two excluded as they did not have time to participate in data collection. Kinetic data were collected from all thirty participants, with four of these individuals also attending a focus-group interview (13%). A wide variety of hand contacts were used during kinetic data collection (Appendix G).

Table 2: Participant baseline characteristics.

Demographic information	
Sex (female), n (%)	21 (70)
Age, years, n (%): <25 25-30 >30	 11 (37) 18 (60) 1 (3)
Height, cm (mean ± SD)	172 ± 9.4
Weight, kg (mean ± SD)	67 ± 11.6
Handedness, n (%): Right Left Ambidextrous	 25 (83) 4 (13) 1 (3)
Year of study, n (%): Fourth Fifth Sixth	 13 (43) 8 (27) 9 (30)
Frequency of thoracic spine manipulation delivery, per week, n (%): < 5 5-10 10-15 15-20 >20	 4 (13) 12 (40) 7 (23) 6 (20) 1 (3)
Previous experience with manikin-based simulation, n (%): Yes No	 29 (97) 1 (3)
Number of thoracic spine manipulations delivered to a manikin, n (%): < 5 5-10 10-15 15-20 >20	 17 (57) 9 (30) 3 (10) 0 1 (3)

Abbreviations: n: number of participants, %: percentage, cm: centimeters, kg: kilograms, <: less than, > greater than, SD: standard deviation.

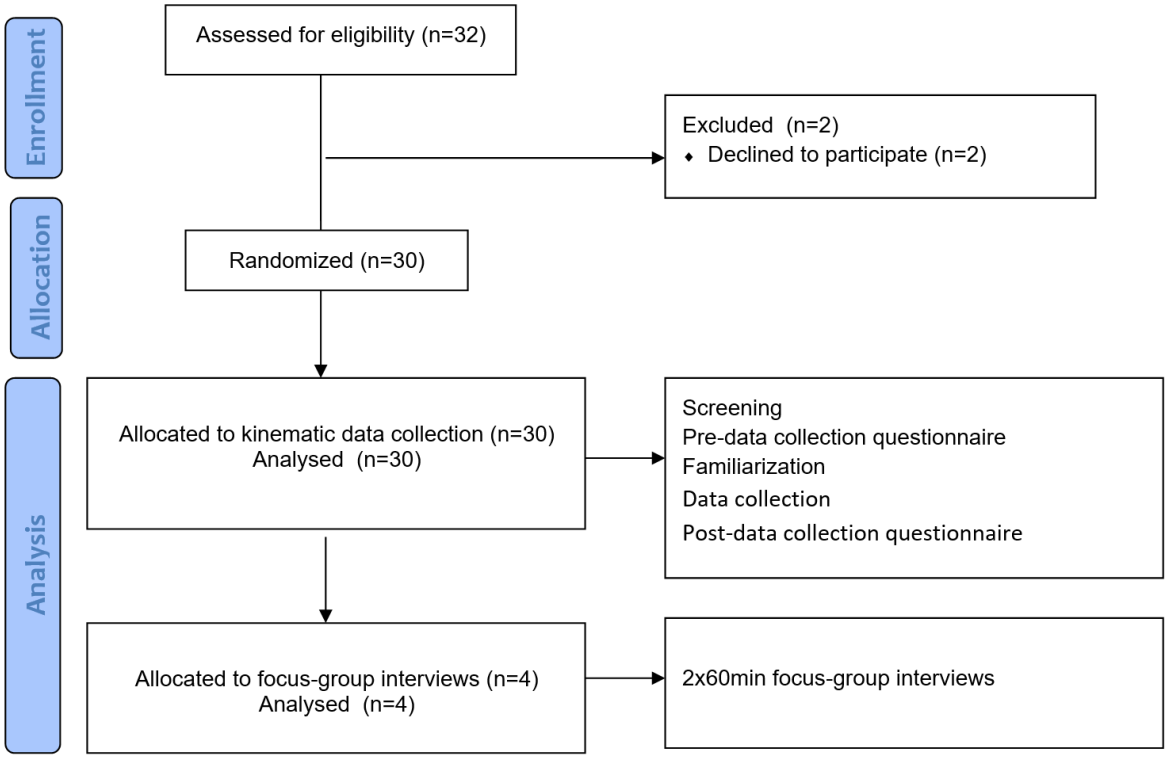


Figure 7: Participant flow diagram.
n: number of participants.

4.2 Kinetic data

Kinetic data were collected from 30 participants, as described above in ''Characteristics of study participants''. These participants represented 81% of the 37 students enrolled in the Study Program during the academic year 2024-2025. In total, kinetic data on 240 thoracic spinal manipulations were collected.

4.2.1 Preload force

4.2.1.1 Overall

As seen in Table 1Table 3 and Figure 8, larger median preload forces were applied to the manikin, compared to the human for both vignettes (p's<0.001). However, there was no difference in the median preload force applied to either the manikin (p=0.147) or human (p=0.629) between the two vignettes.Table 1

Table 3: Entire cohort median preload forces.

	Manikin median (IQR)	Human median (IQR)	
20-25-year-old female vignette	51 (11.9, 89.9)	30 (10.0, 56.2)	**p<0.001**
50-55-year-old male vignette	49 (22.5, 93.6)	34 (12.5, 58.0)	**p<0.001**
	p=0.147	p=0.629	

4.2.1.2 Comparison of year groups

As seen in Table 4, Table 1Figure 9 and

Figure 10, there were no differences in the median preload force applied by participants in the three year groups for either vignette, for either the manikin or the human.

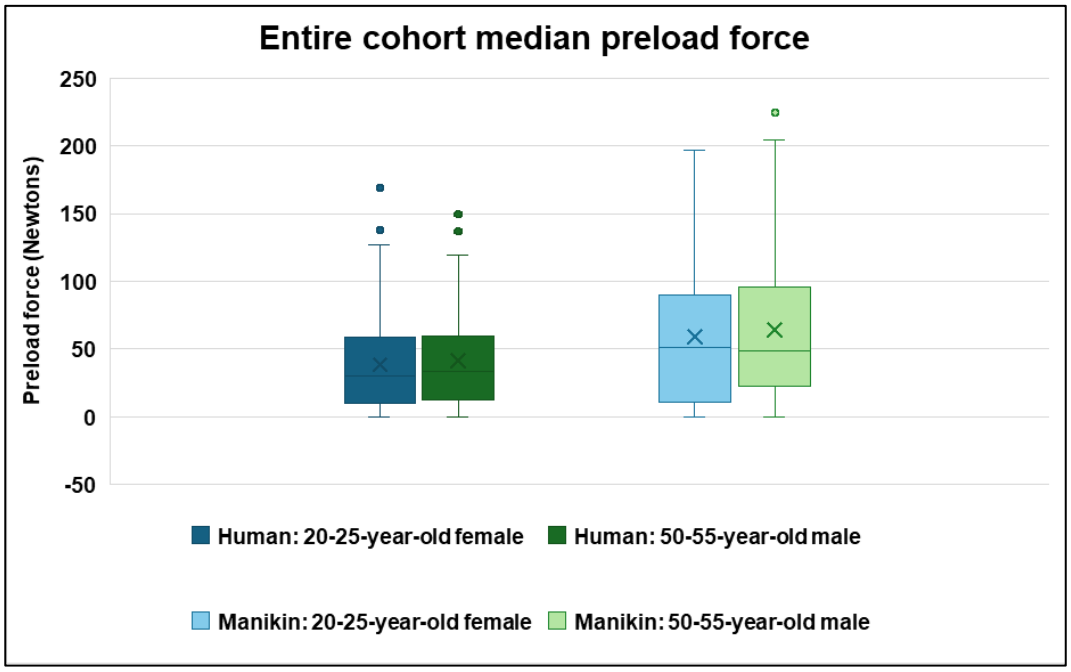


Figure 8: Entire cohort median preload force.
X: mean.

However, when presented with the 20-25-year-old female vignette, more preload force was applied to the manikin, compared to the human, in both the fourth (p<0.001) and sixth years (p=0.049). Additionally, when presented with the 50-55-year-old male vignette, more preload force was applied to the manikin, compared to the human, in the fourth year (p<0.001).

Table 4: Comparison of year group's median preload force.

	Manikin median (IQR)	Human median (IQR)	
20-25-year-old female vignette			
Year 4	61 (22.5, 89.2)	31 (2.5, 52.4)	**p<0.001**
Year 5	41 (0.0, 68.7)	26 (11.2, 55.5)	p=0.255
Year 6	55 (13.1, 89.9)	41 (15.0, 61.2)	**p=0.049**
	p=0.892	p=0.148	
50-55-year-old male vignette			
Year 4	64 (34.3, 99.9)	34 (12.4, 57.4)	**p<0.001**
Year 5	45 (10.0, 83.0)	32 (21.8, 58.0)	p=0.065
Year 6	32 (23.7, 66.8)	35 (12.5, 57.4)	p=0.306
	p=0.602	p=0.551	

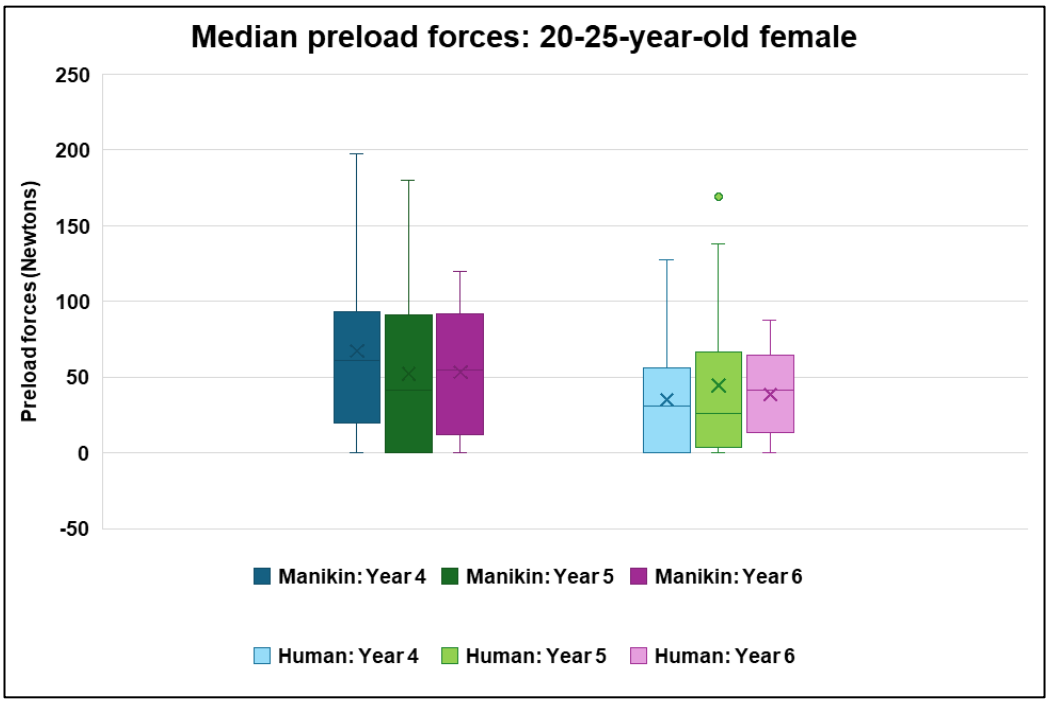


Figure 9: Median preload forces: 20-25-year-old female vignette.
X: mean.

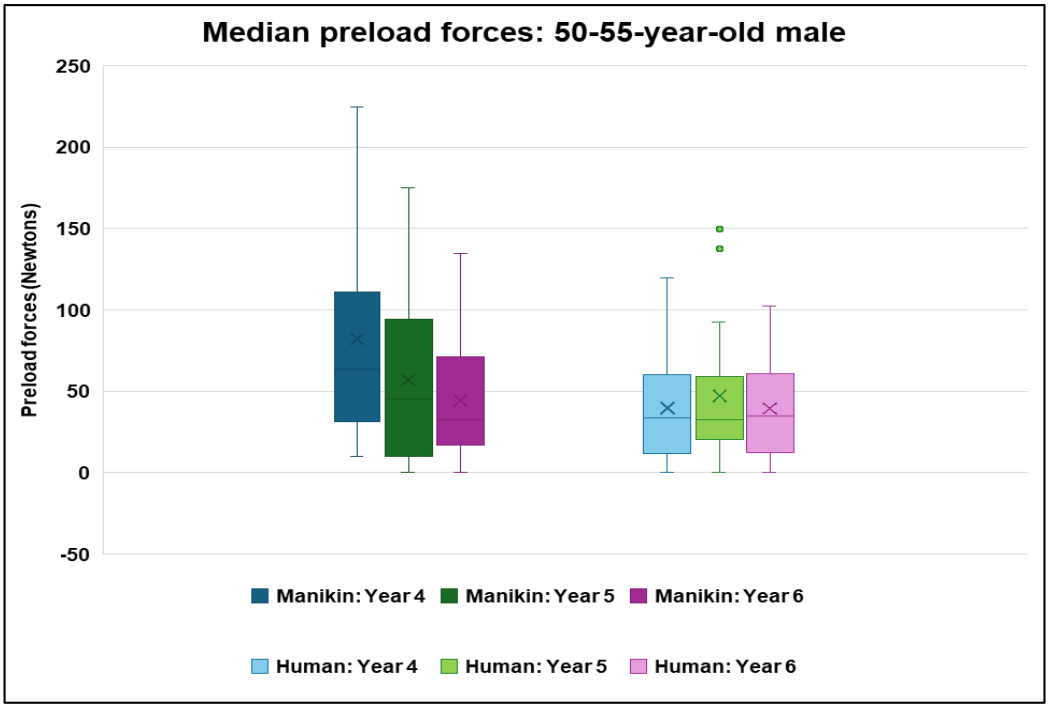


Figure 10: Median preload forces: 50-55-year-old male vignette.
X: mean.

4.2.2 Peak force

4.2.2.1 Overall

As seen in Table 1Table 5 and Figure 11, participants applied thoracic spine manipulation with greater mean peak forces to the 50-55-year-old male vignette, compared to the 20-25-year-old female vignette, on both the manikin and human (p's<0.001). Furthermore, manipulation was delivered with greater mean peak force to the manikin, compared to the human, for both vignettes (p's<0.001).

Table 5: Entire cohort mean peak force.

	Manikin mean ± SD	Human mean ± SD	
20-25-year-old female vignette	280 ± 111.4	205 ± 91.5	**p<0.001**
50-55-year-old male vignette	338 ± 114.0	239 ± 91.5	**p<0.001**
	p<0.001	**p<0.001**	

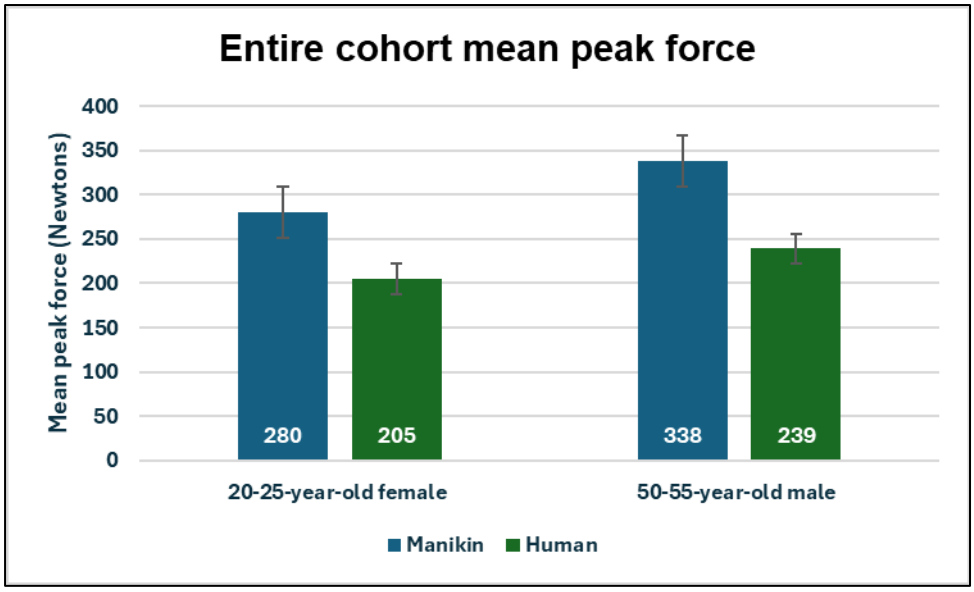


Figure 11: Entire cohort mean peak force.

4.2.2.2 Comparison of year groups

As seen in Table 1Table 6, Figure 12 and Figure 13, participants in all year groups applied thoracic spine manipulation to both vignettes with larger median peak force to the manikin, compared to the human (p's<0.05). Furthermore, when thoracic spine manipulation was applied to the 20-25-year-old female vignette, there were differences in the median peak forces between year groups for both the manikin (p=0.007) and the human (p<0.001). Similarly, when thoracic spine manipulation was applied to the 50-55-year-old male vignette, there were differences in the median peak forces between year groups for the human (p=0.047).

Table 6: Comparison of year group's median peak force.

	Manikin median (IQR)	Human median (IQR)	
20-25-year-old female vignette			
Year 4	220 (171.0, 295.8)	155 (102.4, 214.1)	**p<0.001**
Year 5	266 (179.1, 363.9)	223 (159.8, 270.9)	**p=0.015**
Year 6	321 (255.9, 367.0)	228 (186.0, 286.5)	**p<0.001**
	p=0.007	**p<0.001**	
50-55-year-old male vignette			
Year 4	302 (244.0, 386.9)	216 (116.7, 276.5)	**p<0.001**
Year 5	322 (226.5, 400.7)	245 (191.6, 305.8)	**p<0.001**
Year 6	367 (312.7, 421.3)	263 (230.9, 292.7)	**p<0.001**
	p=0.174	**p=0.047**	

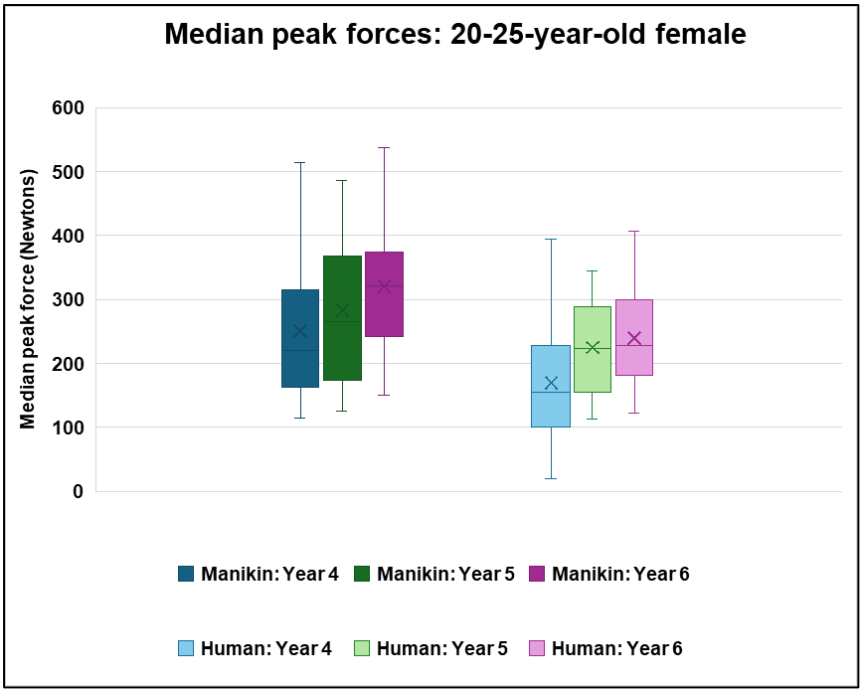


Figure 12: Median peak forces: 20-25-year-old female vignette.
X: mean.

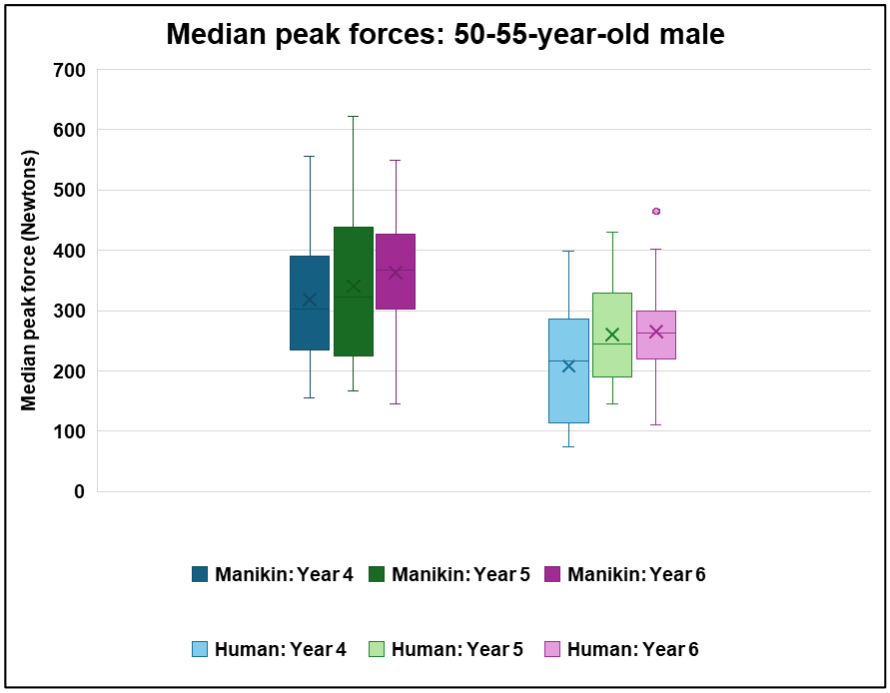


Figure 13: Median peak forces: 50-55-year-old male vignette.
X: mean.

4.3 Focus-group interviews

Two focus-group interviews, with a total of four participants, were conducted. These participants represented 11% of the 37 students enrolled in the Study Program during the academic year 2024-2025.

Demographic data were not captured, with the exception that one of the participants was in each of the fourth and fifth years of study and the remaining two were in their sixth year of study. Two themes, each with four sub-themes, were identified from participant opinions regarding the use of manikin-based simulation within the Study Program technique skills curriculum (Figure 14).

4.3.1 Intolerance of uncertainty

Intolerance of uncertainty was identified as a latent theme within the data, with the subsequent identification of four sub-themes (Figure 15). These sub-themes: i) the need for psychological safety, ii) the need for objective feedback, iii) student confidence, and iv) manikin tactile fidelity, will be reported in the following section.

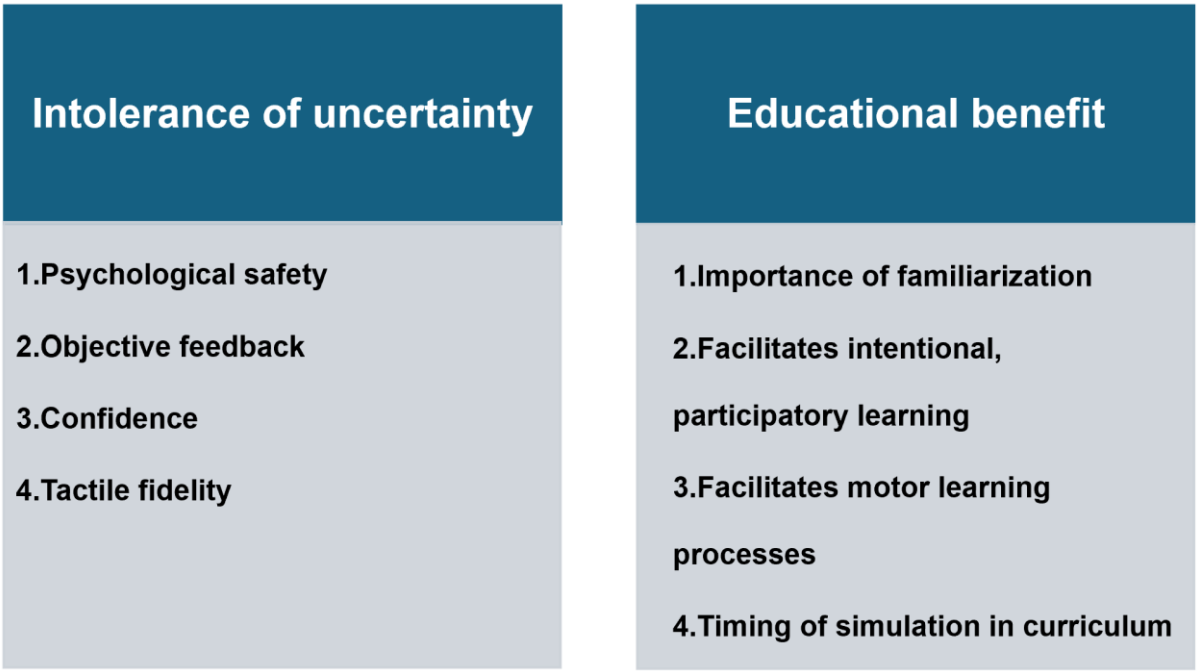


Figure 14: Themes identified from focus-group interviews.

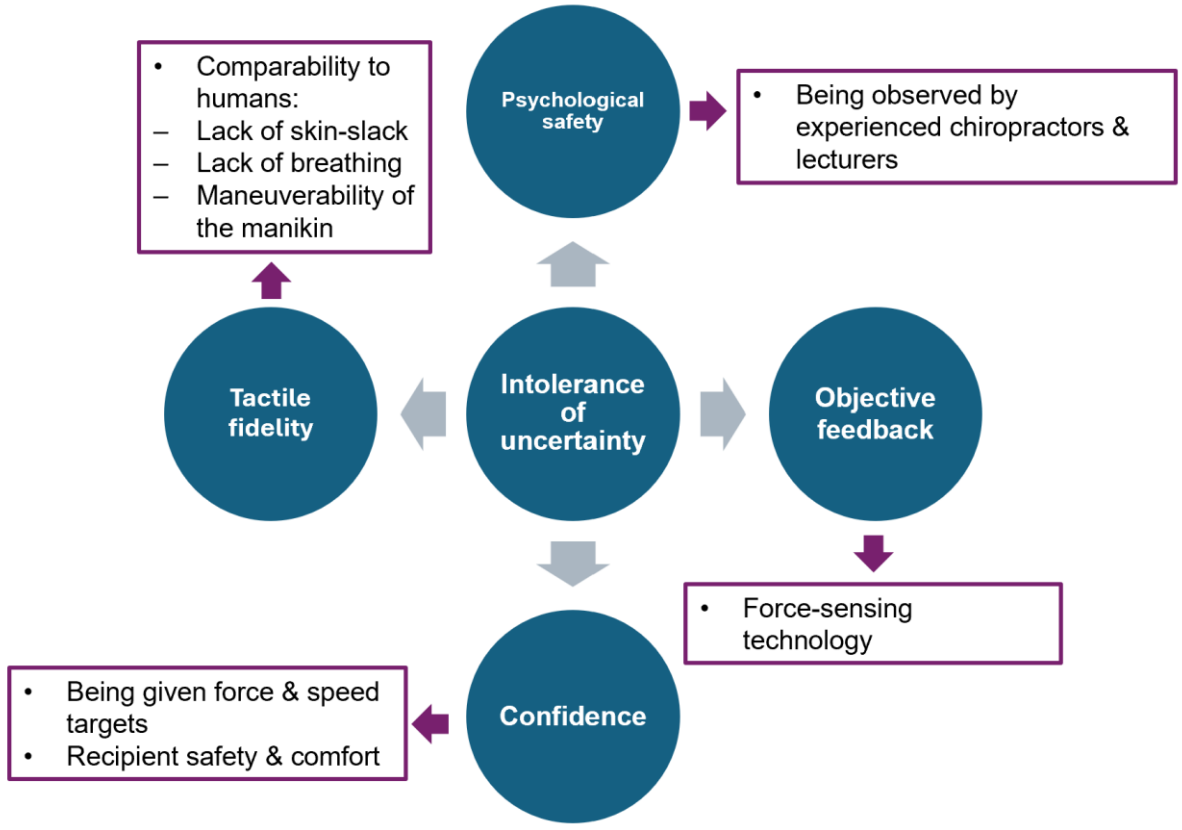


Figure 15: Intolerance of uncertainty sub-themes.

4.3.1.1 Students do not feel psychologically-safe

The need for psychological safety during manikin-based simulation was expressed by two participants and was linked in both instances to observation by more experienced practitioners. One participant stated that they had previously felt intimidated while participating in manikin-based simulation in the presence of experienced chiropractors:

> *'… it was weird, when there were others, chiropractors, in there and we were like, OK, I have no idea what I'm doing, let's go.' Participant A*

The participant was clearly uncomfortable at this point in the interview, avoiding eye contact with the camera. Similarly, another participant stated that they preferred to participate in manikin-based simulation without observation from their teacher, as this reduced their anxiety at performing spinal manipulation:

> *'…I mean, let's say you're standing there as our teacher, right? And then there is PAT and I'm more nervous because someone is standing there and watching with me…. if I'm just by myself, just me and PAT and the screen, then I don't have that…' Participant C*

In contrast to the other participant, there was no avoidance of eye contact with the camera, despite the interviewer being the 'teacher' that was referred to. Furthermore, when asked to clarify whether the participant also felt the same way about being observed by their colleagues, they responded that they were happy to be observed by their colleagues as they felt that they were able to benefit from 'peer-peer' learning, without feeling nervous.

4.3.1.2 Students need objective feedback

Similarly, participants expressed a preference for being provided with objective and quantifiable feedback (achieved through the use of force-sensing technology) during manikin-based simulation, rather than subjective feedback, provided by an experienced practitioner. This desire for external validation that they are 'within normal (biomechanical) limits', provided without being observed by a more experienced practitioner, provided by the visual feedback would allow them to firstly identify where their performance could be improved and following this, to immediately address any deficit:

> *'So I think the pressure mat is great, right. That's what I actually like most about PAT because I can see where I lose the preload, I can see where I was fast, so I think it's definitely the greatest benefit because I again get the visual feedback. I can do it right away, right again. If I see that something wasn't good and I can try to adjust my preload or something until I see it on the screen.' Participant D*

This concept of improvement by using objective feedback and seeing '…that something wasn't good…' was raised by participants in both interviews. Interestingly, participants reported several times that they should be given specific force targets from the literature (e.g. (Gorrell et al., 2023)) during manikin-based simulation:

> *'OK, just try to focus on your thrust, you should be in that range' Participant A*

> *'But with the pressure mat one advantage is there are known values. How fast should a cervical spine manipulation should be? How fast should a*

lumbar spine manipulation be? And for me, I think it's great thing if you see (in) black and white, what's your speed? Then you can say, OK, is that generally too slow too?' Participant C

This need for '…black and white…' objective feedback suggests a lack of confidence in their delivery of spinal manipulation.

4.3.1.3 Students lack confidence

This lack of confidence was also mentioned frequently in another context – recipient comfort and safety. Specifically, that multiple thrusts could be applied to the manikin, in rapid succession, without concerns for recipient comfort or safety. This was seen as an advantage of manikin-based simulation by one participant who mentioned that the delivery of spinal manipulation to the PAT manikin does not pose risks of injury or discomfort to the recipient:

'Well, what I really like about PAT is that as participant C said, he doesn't get a backache or something. So we can use him as much as long as we want. As much as we want and except for manipulations that I think are harder and are not very nice to be exercised on for our students, then PAT is quite a good substitute. And also I think for manipulations that might need a little bit more force or body weight where I wouldn't dare to use my whole body weight on say X, who is rather small and I wouldn't hesitate with PAT because he's quite robust I think. So, that's definitely an advantage.' Participant D

Despite this, some participants struggled to offset this benefit with a loss of tactile fidelity.

4.3.1.4 Students struggle with manikin tactile fidelity

Specifically, some participants described that the tactile fidelity of the manikin made it challenging for them to deliver spinal manipulation:

> *'I think the pre-tension was completely different for me.' Participant A*

> *'I think it's a bit too hard' Participant B*

Additionally, the absence of skin-slack was explicitly mentioned as a disadvantage:

> *'I mean, there's no tissue slack' Participant A*

> *'So if you I feel like when you do it for the first time, you put your hands on it and let's say you do thoracic manipulation where you want to typically like take the skin slack and go really into the skin with your hand. And obviously that's super hard when you have a mat between you and PAT or between you and the real patient.' Participant C*

One participant also mentioned that delivering thoracic spine manipulation to the manikin was not realistic due to the inability of the manikin to breathe upon their command.

> *'But …. what irritated me the most was the breathing in breathing out. That just doesn't come with a manikin, right? So that's I think what makes it really difficult' Participant B*

However, as expressed by one participant, the use of a low- to mid-fidelity manikin during simulation should not influence the usefulness and utility of the experience:

> *'… students need to stay aware that PAT is PAT, and not a human. So a*

good adjustment on him is still just theoretically a good adjustment, and people need to be aware that they still will need to be able to adjust the manipulation to the patient lying on table in front of them.' Participant D

4.3.2 Educational benefit

Educational benefit was identified as a sematic theme, with participants explicitly discussing each of the four identified sub-themes (Figure 16). These sub-themes: i) the importance of familiarization, ii) the facilitation of intentional, participatory learning, iii) the facilitation of motor learning processes, and iv) the timing of manikin-based simulation, will be reported in detail in the following sections.

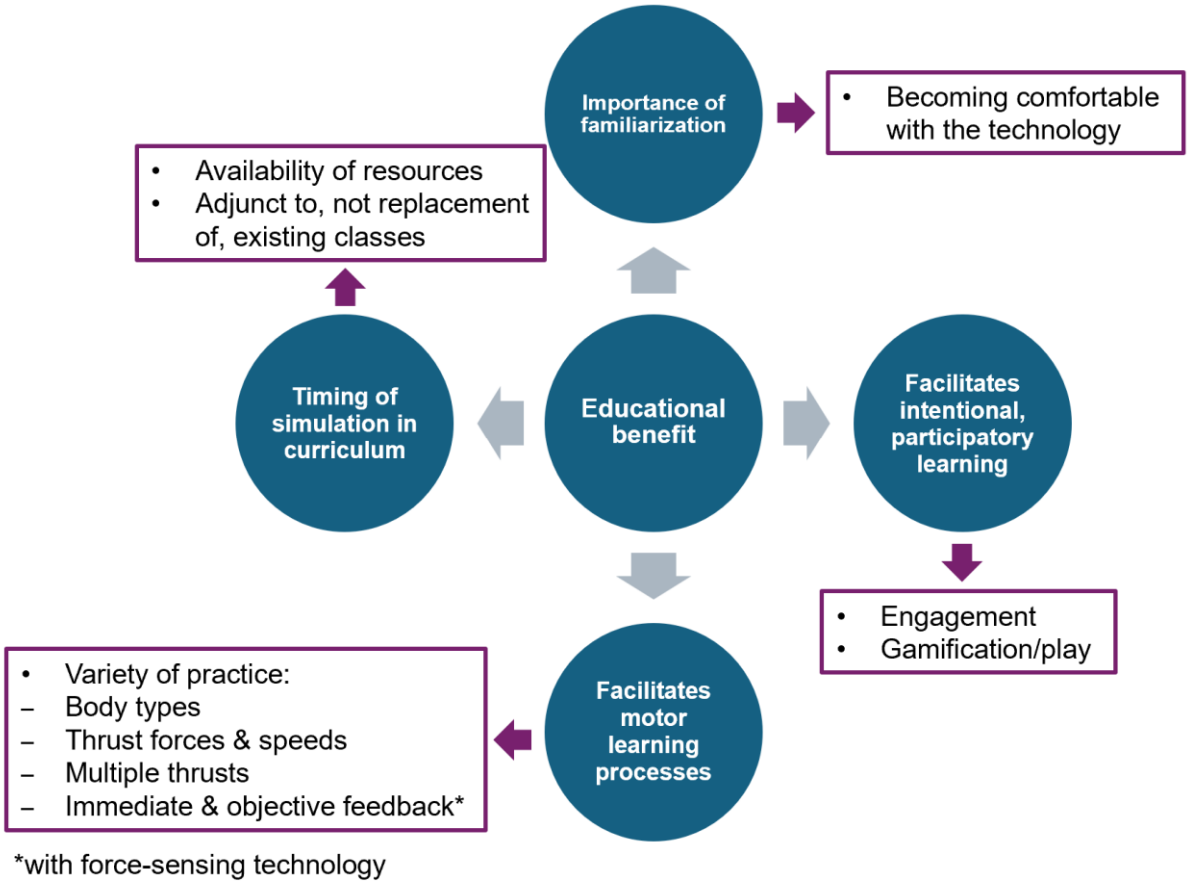


Figure 16: Educational benefit sub-themes.

4.3.2.1 Familiarization is important

The importance of allowing adequate time for familiarization with the force-sensing technology and the manikin during simulation were explicitly discussed by the participants. Two participants felt that they had been given adequate time to become familiar with the equipment:

> *'I remember the first time I was just irritated by the feeling and my thrust was, I think, less than a mobilization. And the second time you use it, you get a little bit into the tissue characteristic. You can even play with the taking slack out. I mean taking slack out of silicon is a little bit funny, but actually it was right. So you get used to it, definitely.' Participant B*

> *'… I feel like when you do it for the first time, you put your hands on it and let's say you do thoracic manipulation where you want to typically take the skin slack and go really into the skin with your hand. And obviously that's super hard when you have a mat between you and PAT or between you and the real patient. But I feel if you do it, you have to adjust a little bit and let's say sacrifice skin slack, or just do skin slack as good as possible, but I feel like if you do it like 3-4-5-6 times it gets better and better and I don't believe that it's way different when I do it without or with the mat' Participant C*

This is in direct contrast to another participant who felt that they had not become familiar with the equipment, and that this influenced their delivery of spinal manipulation in a detrimental way:

> *'And I think I also didn't like take time to get used to it on side… for me it was just a weird setting doing some kind of manipulation…. Yeah, I should*

have at least touched the manikin a bit more.' Participant A

This participant had previously mentioned not being comfortable with being observed by experienced practitioners during manikin-based simulation. Nevertheless, adequate familiarization and feeling comfortable with the equipment allows participants to most fully participate in the simulation.

4.3.2.2 Facilitates intentional, participatory learning

Manikin-based simulation encourages intentional, participatory learning for students by requiring active engagement rather than passive observation. Participants reported becoming intentionally and actively engaged in the learning experience:

'Oh, right, so I have to pay attention not only on the thrust, but also on the preload. It's going to be recorded, so yeah.' Participant D

Furthermore, the simulation environment naturally incorporates gamification elements, allowing students to experiment playfully with different approaches in a 'safe to fail' environment, promoting deeper learning through trial-and-error discovery:

'It's just playing around with different games, different exercises, different styles.' Participant B

'But OK, then you can play with it and you can also see whether when you increase your thrust threshold, whether the low amplitude goes up and time and so on, and I think those are things you probably don't really want to play a lot around with your colleagues, especially when doing higher thrusts.' Participant A

4.3.2.3 Facilitates motor learning processes

The opportunity to perform multiple thrusts without considering recipient comfort, enables repetitive practice of the necessary psychomotor skills, which are crucial for muscle memory formation. The controlled environment enables experimentation with different approaches while building procedural knowledge through consistent, unrestricted practice sessions that would be impossible with human subjects. The value of such practice during manikin-based simulation was recognized by the participants:

> *'The one advantage I see is that you can give as many impulses as you want or as you have time of course, because when you practice on each other, especially in year four and five, where you practice like two to three times a week, you can maybe even more in the fifth year, you can't just go and let's say do a thoracic manipulation ten times on the same person because you can do the setup but not like the impulse itself.' Participant C*

Furthermore, the ability to practice on different imagined body types, varying thrust forces and speeds to develop adaptability, combined with immediate and objective feedback, allows students to refine techniques systematically:

> *'Yeah, at the end, it's all about getting used to different types of tissues, different types of people, and different types of mannequins.' Participant B*

4.3.2.4 Timing of manikin-based simulation in the curriculum

Appropriate timing of such experiences within the curriculum is crucial for the effectiveness of manikin-based simulation in chiropractic education. Different participants viewed this differently, with participants from the sixth study year advocating for the inclusion of manikin-based simulation in the curriculum from

the fourth year:

> *'I think you can start in the fourth, especially if the manikin is for thoracic spine, why not?' Participant A*

> *'… vignettes would be great, starting at the fourth maybe.' Participant B*

In contrast to this, another participant, from the fifth study year, advocated for inclusion from the fifth year:

> *'I think in the 5th year, I would say, depending on the week because you have fuller and less full weeks.' Participant C*

Despite these differing opinions, participants were united that manikin-based simulation should serve as an adjunct to, not substitute for, traditional chiropractic technique skills classes:

> *'… the more you practice with PAT, the less you practice with humans. Let's say like that, I mean the one is not better than the other, I think both are important, but I would call that, I mean it's time you have to invest.' Participant C*

> *'PAT is a good additional feature or something like for classes, but he's not a substitute for learning on other students' Participant D*

Another participant echoed this sentiment and suggested that another important aspect is ready access to the technology, to allow students to self-select when best to utilize the resources:

> *'But I wouldn't give it too much time. I think best thing is still do practice on human beings and I think technical courses are still rather little and there aren't that many. But I think it would be perfect if that's possible, that the*

manikin is always there.' Participant A

4.4 Summary

The results from this study show that despite a lack of confidence in their ability to do so, chiropractic students were able to modify the delivery of thoracic spine manipulation, delivered to both a human and manikin, based on two common clinical presentations. Furthermore, all four participants who attended the focus-group interviews view manikin-based simulation positively and would like to see it systematically embedded in the Study Program technique skills curriculum. The use of manikin-based simulation as a tool to decrease intolerance of uncertainty was a latent theme within the data while the educational benefit was discussed explicitly. A detailed discussion of these results follows in Chapter 5.

Chapter 5: Discussion

This chapter will discuss the results reported in chapter four in relation to the existing chiropractic education literature, specifically with respect to intolerance of uncertainty and educational benefit, including future possibilities for curriculum integration of manikin-based simulation. Additionally, limitations of the study will be outlined.

5.1 Intolerance of uncertainty

This study of 30 participants shows that despite a lack of confidence in their ability to do so, chiropractic students were able to somewhat modulate the forces they applied during thoracic spine manipulation, delivered to both a human and manikin, based on two common clinical presentations. However, despite objective quantification demonstrating this, high intolerance of uncertainty was experienced by the participants and was identified as a significant theme in the focus-group interviews. This high intolerance of uncertainty may influence chiropractic students' learning experiences during manikin-based simulation of spinal manipulation by eroding confidence and increasing anxiety (Hancock et al., 2025). Chiropractic students exhibiting high intolerance of uncertainty demonstrated specific behavioral patterns during manikin-based simulation. Their aversion to observation by experienced practitioners likely stems from discomfort with performance ambiguity and fear of negative evaluation in uncertain situations. These students prefer to rely on external (objective) feedback, including force and speed targets, because they cannot tolerate the ambiguity of subjective assessment that occurs when they are observed by more experienced practitioners. Low manikin fidelity particularly challenges them, as

limited tactile feedback created additional uncertainty about whether they were applying the technique correctly for the given simulated clinical presentation. This intolerance manifested as anxiety leading to dependency on concrete, measurable parameters rather than developing internal confidence and adaptability. Such students may struggle with the inherent uncertainty of early clinical practice, where patient responses and optimal techniques are often ambiguous. These patterns manifest through four interconnected sub-themes: i) the need for psychological safety, ii) dependence on objective feedback, iii) lack of confidence, and iv) challenges with manikin tactile fidelity.

5.1.1 Providing psychological safety

Psychological safety is crucial for effective chiropractic education during manikin-based simulation. Indeed, imposter syndrome when learning complex psychomotor skills (e.g. spinal manipulation) has been reported in both chiropractic students (Kimball et al., 2021) and experienced physical therapists (Carroll and Griech, 2023). When students feel secure from judgment or punitive consequences, they may be able to engage more authentically with the learning of spinal manipulation. A psychologically-safe environment encourages admissions of uncertainty and repeated practice without fear of repercussions. In learning spinal manipulation, where precise hand placement and force application are critical, students must feel comfortable making errors as part of their learning. Psychological safety enables experimentation, constructive feedback reception, and confidence building for future patient interactions. Without this safety, students may become overly cautious or rush through techniques in which they are not yet comfortable delivering or, worse than this, avoid entirely delivering such techniques in the presence of more experienced

practitioners. This behavior was described by one participant in the focus-group interviews who admitted that they did not spend adequate time familiarizing themself with the manikin during data collection, despite the opportunity to do so:

> *'And I think I also didn't like take time to get used to it on side… for me it was just a weird setting doing some kind of manipulation…. Yeah, I should have at least touched the manikin a bit more.' Participant A*

However, the controlled environment during manikin-based simulation typically provides ideal conditions for establishing psychological safety, allowing students to build competence and confidence, creating poised practitioners for clinical practice. Despite the desire not to be observed by more experienced practitioners during manikin-based simulation communicated by the focus-group participants, chiropractic students need to accept and adapt to the reality that they will always be 'observed' (at the minimum by their patient) during the delivery of spinal manipulation. One way to address this situation, could be to use 'near-peer' or 'peer-peer' observation and feedback during simulation sessions (Granger et al., 2024). Based on participant responses in the focus-group interviews, the use of 'peer-peer' observation and feedback could be welcomed by students in the Study Program, specifically, one participant who indicated that they felt nervous when being observed by an experienced practitioner:

> *'…I mean, let's say you're standing there as our teacher, right? And then there is PAT and I'm more nervous because someone is standing there and watching with me…. if I'm just by myself, just me and PAT and the screen, then I don't have that…' Participant C*

However, this does not fully address the topic of anxiety induced by observation during manikin-based simulation. Evaluation apprehension is a well-defined topic in the literature that can result in anxiety and resulting performance decreases (Cottrell et al., 1968; Eysenck and Calvo, 1992) and physiological stress (Hills et al., 2019). Despite this, there are other possible ways in which psychological safety could be increased during manikin-based simulation.

5.1.2 Objective feedback as an instrument

One way in which this could be done is to use objective feedback. As stated by participants in the focus-group interviews, when objective feedback is used, students are provided with measurable, objective information that eliminates subjective interpretation. Unlike general comments, objective feedback focuses on quantification of the biomechanical characteristics of spinal manipulation (e.g. peak force) and enables students to identify individual aspects of spinal manipulation delivery that should be improved:

> *'So I think the pressure mat is great, right. That's what I actually like most about PAT because I can see where I lose the preload, I can see where I was fast, so I think it's definitely the greatest benefit because I again get the visual feedback. I can do it right away, right again. If I see that something wasn't good and I can try to adjust my preload or something until I see it on the screen.' Participant D*

Students are able to track their development systematically, building confidence through objective evidence of performance. However, it is important to note that there currently exist no specific force targets from the literature to indicate optimal dosages, for either effectiveness or safety, of manipulation in any anatomic region (Snodgrass et al., 2014; Page and Descarreaux, 2019). As such, this may

result in a false ‘sense of security’ for students who wish to decrease their intolerance of uncertainty by using objective feedback on force application. Despite this, there have been recent efforts by one educational institution to develop target forces for lumbar spine (side-posture) manipulation (Owens et al., 2016; Russell et al., 2023). As these targets were obtained from a very small sample of experienced chiropractors (n=11 and n=7, respectively), care should be taken not to overinterpret the findings. Furthermore, literature reporting on the applied forces during spinal manipulation reveals that there is considerable heterogeneity among practitioners (Downie et al., 2010; Gorrell et al., 2023). As such, any force ranges provided to students would be substantial and as a result, it could be argued, is of limited use.

Interestingly, in the current study, despite displaying similar heterogeneity in force application to their more experienced counterparts, students were better able to modulate peak, compared to preload, forces during thoracic spine manipulations delivered to the two vignettes (Table 3 & Table 5). To my best knowledge, this result has not been previously reported. A reason for this heterogeneity could be that the tissue ‘end-feel’ indicating the pre-thrust positioning and the rapid transition into the thrust phase of spinal manipulation is variable between anatomic regions both intra- and inter-individual. As students are considered ‘novice’ practitioners according to the Dreyfus and Dreyfus model (Dreyfus and Dreyfus, 1986), and by definition, are not yet able to perform well in uncertain conditions (i.e. different pre-thrust positioning), it follows that their preload forces would be more variable/unpredictable in comparison to their peak forces. This hypothesis is supported by my anecdotal experiences that students typically focus more on practicing the spinal manipulation thrust, compared to

finding the optimal pre-thrust positioning. This argument supports the wider discussion that the current cohort of students display a high intolerance of uncertainty regarding the delivery of spinal manipulation. Fundamentally, they prefer to practice spinal manipulation thrust delivery, compared to developing the complex palpation skills necessary to find the optimal pre-thrust positioning.

This finding does however raise the question of the relevance of providing novice practitioners with target forces (preload or peak) for spinal manipulation. The current data suggest that the students in this study struggled to apply consistent and reproducible forces during thoracic spine manipulation, and it could be argued that then adding another variable/expectation of performance to the situation (i.e. force targets) could be counter-productive. Perhaps, as a first step, consistent force application should first be mastered by the students, giving them confidence and a sense of achievement. The topic of timing of manikin-based simulation within the curriculum will be discussed later in this chapter (5.2 Educational benefit).

5.1.3 Building student confidence

Despite the concern that providing students with another variable/expectation of performance might overwhelm them, forces applied by experienced practitioners during the delivery of spinal manipulation have been published in the literature (Downie et al., 2010; Gorrell et al., 2023) and may provide students with a rough target to work towards during manikin-based simulation. Specifically, the ability to successfully stay within the range of forces delivered by experienced practitioners may help to build student confidence, in terms of both the effective, and safe, delivery of spinal manipulation. Indeed, this desire for the provision of target force ranges during manikin-based simulation was discussed in both

focus-groups by participants in all three year groups:

> *'OK, just try to focus on your thrust, you should be in that range' Participant A*

> *'But with the pressure mat one advantage is there are known values. How fast should a cervical spine manipulation should be? How fast should a lumbar spine manipulation be? And for me, I think it's great thing if you see (in) black and white, what's your speed? Then you can say, OK, is that generally too slow too?' Participant C*

This suggests that students are currently lacking confidence in their application of spinal manipulation and require external validation that they are 'on the right track'. Indeed, confidence plays a crucial role in reducing intolerance of uncertainty for students delivering spinal manipulation. As previously discussed, when students lack confidence, they are often uncomfortable with the inherent unpredictability of recipient responses, leading to avoidance tactics, such as the choice of other interventions (e.g. spinal mobilization), even when spinal manipulation delivery would be indicated. Building confidence through repeated practice and successful experiences helps students develop tolerance for uncertain situations, enabling them to proceed with manipulation delivery despite uncertainty regarding recipient responses. Confident students can adapt to the variable clinical encounter (e.g. recipient preferences, different body morphologies). This adaptability is a hallmark of expert practitioners and is essential for effective manipulation delivery. In contrast to this, high intolerance of uncertainty can result in tentative, ineffective treatments that compromise recipient outcomes and professional development. By removing uncertainty regarding recipient responses (including the question of 'Will I hurt the recipient

if I thrust again?'), manikin-based simulation facilitates increased student confidence to practice the application of multiple thrusts, in quick succession, without concerns for the recipient's comfort or safety. This means that students are more confident (lower intolerance of uncertainty) to practice spinal manipulation and thus have the opportunity to improve their spinal manipulation in a safe environment.

5.1.4 Moving beyond manikin tactile fidelity

Despite this advantage of being able to repeatedly apply spinal manipulation to the manikin without concerns for the comfort or safety of the recipient, an important consideration for any manual therapist during manikin-based simulation is tactile fidelity of the recipient. Despite the fact that the importance of tactile fidelity decreases as chiropractic students' progress from novice to experienced practitioners, the topic is still relevant for manikin-based simulation involving students, as highlighted during the focus-group interviews:

> *'I think the pre-tension was completely different for me.' Participant A*
>
> *'I think it's a bit too hard' Participant B*

In contrast to the student's experiences, expert practitioners have developed internal mental models and procedural knowledge that reduce their dependence on immediate tactile feedback (Dreyfus and Dreyfus, 1986). Indeed, as students became more familiar with the equipment in this study, the issue of the use of low- to mid-fidelity manikins during simulation decreased in importance. This 'learning' was articulated by one participant:

> *'… I feel like when you do it for the first time, you put your hands on it and let's say you do thoracic manipulation where you want to typically take the*

> *skin slack and go really into the skin with your hand. And obviously that's super hard when you have a mat between you and PAT or between you and the real patient. But I feel if you do it, you have to adjust a little bit and let's say sacrifice skin slack, or just do skin slack as good as possible, but I feel like if you do it like 3-4-5-6 times it gets better and better and I don't believe that it's way different when I do it without or with the mat' Participant C*

Supporting this 'learning effect', the literature reveals that experienced practitioners are able to modulate the biomechanical characteristics (e.g. peak force) of spinal manipulation delivered to a low-fidelity manikin (Canadian Memorial Chiropractic College, 2024) based on different vignettes (Nyirö et al., 2024). However, it is unclear if these results are directly comparable to a student cohort and/or manipulation that is delivered clinically. Interestingly, the lack of tactile fidelity of the manikin in the current study could have been one factor for the differences in peak and preload force application between the manikin and human (for both vignettes). Specifically, peak forces were higher on the manikin consistently across the entire cohort and also within individual year groups, for both vignettes. This finding was replicated for the preload forces for the overall cohort (greater median preload forces delivered to the manikin vs. human for both vignettes) but not all of the year groups. Furthermore, when considering the year level of the students who reported that tactile fidelity was a major barrier to their delivery of thoracic spine manipulation in the focus-groups, these year groups (year four and six) seemed to struggle more with modulation of preload forces than the fifth year. This result highlights the importance of allowing students adequate time for familiarization with the equipment and advocates for

the systematic integration of manikin-based simulation within the literature, ensuring that the influence of manikin tactile fidelity is decreased with time. This topic will be discussed further in 5.2 Educational benefit.

5.1.5 Future directions

Considering intolerance of uncertainty and based on the results obtained in the current study and the available literature, I recommend two areas in which I believe manikin-based simulation within chiropractic education should proceed.

5.1.5.1 Ensuring psychological safety despite observation

There should be a concerted effort to focus on creating simulation environments that better address students' anxiety related to observation and performance ambiguity. This could include implementing peer- or near-peer observation models, fostering an overarching culture of error tolerance, and designing vignettes that promote psychological safety, thereby enabling students to build confidence and decrease their intolerance of uncertainty in the technique skills classroom, before they enter their early clinical practice. While I advocate for the continued use of force-sensing technology, I do not believe there should be a focus on the provision of target force ranges to students. Instead, time should also be set aside in the curriculum for developing palpation skills that allow students to find the optimum tissue ‘end-feel’ from where to begin thrust delivery. Specifically, future directions may involve refining feedback systems to better support novice learners, and integrating these tools into simulation to promote confidence and skill mastery without over-reliance on tactile fidelity.

5.1.5.2 Moving to redefinition of manikin-based simulation

As simulation technology advances, future strategies could involve transitioning from low- to mid-fidelity manikins toward higher-fidelity, realistic models such as

augmented and/or virtual reality. This progression could help students develop internal mental models for tactile feedback, enabling better modulation of applied forces during spinal manipulation. Furthermore, being able to practice virtually in their future clinical environment may alleviate some anxiety regarding the transition from the classroom to early clinical practice (Nevalainen et al., 2010). Additionally, the benefit of optimizing fidelity levels appropriate for different stages of learning to maximize educational benefit while considering resource constraints could be explored.

5.2 Educational benefit

Despite some uncertainty regarding the optimal delivery of manikin-based simulation, it can be argued that there is educational benefit to the use of manikin-based simulation within chiropractic education (Stainsby et al., 2016; de Kock et al., 2023). However, as discussed previously, adequate familiarization is crucial for the success of manikin-based simulation as it facilitates psychological safety while also reducing cognitive load from equipment unfamiliarity, allowing students to focus on technique development rather than navigation of the technology (Lapierre et al., 2022). Simulation inherently facilitates intentional and participatory learning, as students actively engage with the simulation rather than passively observing, promoting deeper understanding and retention. This active participation facilitates motor learning processes by providing students with a reliable and safe practice environment where they can develop muscle memory and refine their spinal manipulation skills through repetition (Elendu et al., 2024). Curriculum timing is essential as simulation must not detract from time spent working with human recipients and should occur at times where the students will not be overwhelmed with the additional workload (Watson et al., 2012). Four

aspects that are important to the educational benefit of manikin-based simulation within chiropractic education will be discussed in the following sections: i) the importance of familiarization, ii) the facilitation of intentional, participatory learning, iii) the facilitation of motor learning processes, and iv) the timing of manikin-based simulation within the curriculum.

5.2.1 Familiarization is important

As discussed previously (5.1.1 Providing psychological safety), adequate familiarization is essential for chiropractic students during manikin-based simulation. Not only does familiarization reduce cognitive burden from equipment unfamiliarity, allowing students to focus on technique mastery (Lapierre et al., 2022), it also facilitates increased confidence and thus decreased intolerance of uncertainty regarding participation in the simulation session. Specifically, familiarization with the manikin and force-sensing technology are important in terms of student understanding of tactile fidelity. Supporting this, as indicated in the focus-group interviews, once students feel comfortable with the equipment, they do not feel that a lack of tactile fidelity impacts their performance:

> *'…But I feel if you do it, you have to adjust a little bit and let's say sacrifice skin slack, or just do skin slack as good as possible, but I feel like if you do it like 3-4-5-6 times it gets better and better and I don't believe that it's way different when I do it without or with the mat' Participant C*

Once again considering the quantitative data reported in this thesis, both participants in the year group that have had the least exposure to manikin-based simulation (year six), reported struggling with the tactile fidelity of the manikin:

> *'I think the pre-tension was completely different for me.' Participant A*

‘I think it's a bit too hard’ Participant B

Furthermore, one of these students also reported that they did not take adequate time familiarizing themself with the manikin during data collection, despite the opportunity to do so:

‘And I think I also didn't like take time to get used to it on side… for me it was just a weird setting doing some kind of manipulation…. Yeah, I should have at least touched the manikin a bit more.’ Participant A

In contrast to this, the other two participants (years four and five), reported that they were comfortable with the equipment and did not feel that it adversely influenced their performance (e.g. quote from Participant C above). Further supporting the hypothesis that adequate familiarization decreases the effect of limited manikin tactile fidelity, the forces applied by sixth year students were greater on the manikin, compared to the human, for both preload (20-25-year-old female vignette) and peak (both vignettes) force, suggesting that in the absence of ‘normal’ tactile fidelity, students with a higher intolerance of uncertainty compensated by applying more force. While the participants from the sixth year of study that attended the focus group interviews should not be considered representative of the entire study cohort (n=2, 22%), this finding highlights the importance of adequate familiarization during manikin-based simulation to encourage full participation in the session.

5.2.2 Intentional, participatory learning

Manikin-based simulation encourages intentional, participatory learning for chiropractic students by requiring active engagement rather than passive observation and for some students, this makes the experience of learning spinal

manipulation fun. The simulation environment naturally incorporates elements of gamification, allowing students to experiment playfully with different procedures without real-world consequences for the recipient. This playful exploration promotes deeper learning through trial-and-error discovery:

> *'But OK, then you can play with it and you can also see whether when you increase your thrust threshold, whether the low amplitude goes up and time and so on, and I think those are things you probably don't really want to play a lot around with your colleagues, especially when doing higher thrusts.' Participant A*

Being able to experiment in a 'safe-to-fail' environment has the potential to increase participation from students with high intolerance of uncertainty. Such students may typically avoid practicing spinal manipulation on their colleagues for a number of reasons. Specifically, there may be a fear of hurting the recipient due to repeated thrusts and/or due to the delivery of higher forces (as indicated in the quote above). Manikin-based simulation may thus be a way for such students to become intentionally engaged with learning spinal manipulation. Instead of avoiding practicing spinal manipulation, students are able to challenge themselves in a psychologically-safe environment to improve performance, transforming their technical skill acquisition and development into an interactive, purposeful learning experience, as described by one participant:

> *'Oh, right, so I have to pay attention not only on the thrust, but also on the preload. It's going to be recorded, so yeah.' Participant D*

Considering gamification in greater detail, encouraging students to work in small groups (i.e. 'peer-peer' as discussed previously in 5.1.1 Providing psychological

safety) could facilitate increased participation in spinal manipulation practice as they organically challenge each other to improve their performance of spinal manipulation. Supporting this hypothesis, gamification has been reported as a beneficial strategy within medical education for increasing participation, especially in the context of digital native students (Krishnamurthy et al., 2022; Wang et al., 2024).

5.2.3 Facilitates motor learning processes

Irrespective of the reason for increased practice, manikin-based simulation facilitates motor learning for chiropractic students by providing varied practice opportunities essential for spinal manipulation skill development:

> *'It's just playing around with different games, different exercises, different styles.' Participant B*

As described in the previous section (5.2.2 Intentional, participatory learning), students can perform multiple thrusts without consideration of recipient comfort, enabling repetitive practice, which is crucial for muscle memory formation. Similarly, students can practice on different imagined body types, varying thrust forces and speeds to develop adaptability. This variety, combined with immediate and objective feedback, allows students to refine their delivery of spinal manipulation systematically (Sattelmayer et al., 2016). The ability to deliver spinal manipulation in an effective and safe way is a fundamental component of chiropractic education. Motor competency acquisition progresses through three interconnected phases: cognitive, associative, and autonomous, providing a structured approach for organizing educational content (Triano et al., 2012). This learning progression corresponds to neurological adaptations through mechanisms including neural adaptation, plasticity, and behavioural conditioning

(Dayan and Cohen, 2011). Effective spinal manipulation competency development demands adequate repetition combined with strategic feedback approaches, specifically performance-based and outcome-based knowledge (Triano et al., 2003). Spinal manipulation training should strategically combine manikin-based simulation experiences with spinal manipulation delivered to human recipients to create comprehensive, risk-free learning environments before students transition to providing direct patient care.

5.2.4 Curriculum integration

The simulation experience must be strategically positioned to complement theoretical knowledge, the delivery of spinal manipulation to human recipients and to adequately prepare students for early clinical practice. Simulation should serve as an adjunct to, not replacement of, existing classes and human recipient practice:

> *'PAT is a good additional feature or something like for classes, but he's not a substitute for learning on other students' Participant D*

Furthermore, ready availability of simulation resources ensures students can access practice opportunities when needed, reinforcing learning at optimal moments (e.g. 'just in time' learning):

> *'And I think I would not use him where structured, but maybe say when I've got a time gap or something, I think I would use him until I am tired to do some manipulations or whatever. Especially if it's…. plugged in but still there lying around, I think sometimes we in fourth year would use him to talk about our position to the patient and how to hold our hands, because for that we have somebody lying down and everybody can see and we can*

talk about do you stand in fencer stance or whatever. So you I think it would be used not in a very structured way, but I think he would be used. Yeah. At least by me.' Participant D

Poor timing diminishes the educational value and integration with the overarching curricular objectives. Furthermore, manikin-based simulation should be used as an adjunct to, not substitute for, traditional chiropractic technique skills classes (Triano et al., 2012). If it is shown that interventions delivered to manikins are relevant to those delivered clinically (i.e. the use of manikins is validated), this would provide the opportunity for manikins to be increasingly used in higher fidelity simulations involving progressively more complex vignettes (i.e. scaffolding within the curriculum). This approach would allow manikins to be used beyond simply developing spinal manipulation skills, extending into areas such as adverse event crisis management (Ker and Shippey, 2017). For instance, in the early years, manikins could be employed to teach and quantify the force-time profile of spinal manipulation, promoting consistency and repeatability of the intervention – although it is important to acknowledge that the active components of 'clinically effective spinal manipulation' are not yet fully understood. Towards the end of their studies, manikin-based simulation could function to not only enable the adaptation of spinal manipulation approaches across diverse clinical situations, enhancing student preparation for clinical practice, but also to recreate uncommon and critical incidents, including cardiac emergencies during standard consultations, as explored by McGregor and Giuliano (2012). Using the SAMR framework, this development would transition from the present predominant application, simple replacement of a manikin as the treatment recipient (substitution), to a more sophisticated function

incorporating enhancement or complete restructuring of the simulation encounter (modification and/or redefinition). Learners would subsequently perceive the manikin as an actual patient, synthesizing multiple data sources from case histories and clinical assessments (vignettes) prior to implementing therapeutically appropriate procedures. Reinforcing this concept for utilizing significantly expanded manikin-based training within chiropractic curricula, initial evidence from the physiotherapy education literature indicates that clinical instruction in simulated educational settings can substitute 25% of hands-on patient contact time without undermining student professional development (Watson et al., 2012).

5.2.5 Future directions

Considering the topic of educational benefit and based on the results obtained in the current study and the available literature, I recommend three areas in which I believe manikin-based simulation within chiropractic education should proceed.

5.2.5.1 Building confidence through familiarization

Adequate, and possibly individualized, familiarization of students to the simulation equipment, in a psychologically-safe environment, should be performed. This will help reduce cognitive load, increase confidence, and mitigate anxiety, ensuring students can focus on mastering psychomotor skills during simulation sessions.

5.2.5.2 Making gamification part of the curriculum

Further incorporation of gamification elements and active engagement strategies can promote deeper, intentional learning. Designing simulation scenarios that encourage trial-and-error exploration and peer challenge, supported by objective feedback, can enhance motor skill development and motivation among students.

Using objective feedback to add a gamification element to manikin-based simulation sessions should be investigated, especially in digital-native student cohorts.

5.2.5.3 Systematic and longitudinal implementation into the curriculum

Simulation experiences should be strategically aligned with curriculum progression, starting with basic skill acquisition and advancing toward more complex scenarios that mimic real clinical encounters (e.g. vignettes with increasing complexity). This includes using simulation not only for technique acquisition and development, but also for crisis management and decision-making, ultimately preparing students for diverse and unpredictable clinical situations.

5.3 Limitations

This mixed-methods case study has several limitations that must be acknowledged when interpreting the findings. Most significantly, my position as Head of Curriculum within the Study Program presents a conflict of interest in the recruitment and data collection processes. This dual role may have inadvertently influenced student participation decisions, as participants might have felt obligated to participate or provide socially desirable responses due to the perceived power dynamics inherent in the student-teacher relationship. Students may have been reluctant to express critical views or negative experiences, potentially limiting the authenticity and completeness of the data collected. Despite efforts to emphasize voluntary participation and confidentiality and all recruitment materials and methods being approved by the University of Oxford Education (Educ) DREC as being acceptable, the hierarchical relationship could

not be entirely eliminated from the research context.

Regarding the quantitative component of this study, the relatively small sample size (n=30) significantly limits the generalizability of the statistical findings to other chiropractic student populations. This modest sample size reduces the statistical power to detect meaningful differences and relationships within the data, potentially leading to Type II errors where true effects remain undetected. Specifically, the small number of participants in each year of study (year four: 13, year five: 8, year six: 9) means that any comparison within year groups is limited, despite non-parametric statistical testing being used. However, as this cohort represents 81% of the student population of interest, I advocate that the results are likely representative of the entire population. Furthermore, the findings may not be representative of broader medical education contexts, different institutional settings, or diverse student populations, thereby constraining the external validity of the quantitative results. However, as the research question investigated in this study concerned specifically with the ability of the fourth, fifth and sixth years of the University of Zurich Chiropractic Medicine Study Program (academic year 2024-2025) to modulate thoracic spine manipulation and their opinions regarding manikin-based simulation within the chiropractic technique skills curriculum, the appropriate study design was employed to answer the current research question.

The qualitative data collection faced substantial limitations that compromise the depth and reliability of the findings. The very small sample size for focus-group interviews (n=4) means that data saturation was likely not achieved, suggesting that important themes, perspectives, or experiences may have been missed. As a result, it was not possible to employ theoretical triangulation (i.e. more than one

theoretical position/theory is used by multiple coders). This has likely resulted in an incomplete exploration of student opinions regarding if it would be feasible to use manikin-based simulation within the curriculum to scaffold students from the classroom into their early clinical practice. Additionally, the reliance on volunteer participants introduces selection bias, as those who chose to participate in focus groups may have had particularly strong opinions, specific motivations, or characteristics that differ systematically from non-participants, potentially skewing the qualitative data toward certain viewpoints. The qualitative data analysis was further limited by having only one coder, which eliminates the possibility of intercoder reliability assessment and reduces confidence in the analytical rigor. Without multiple coders to verify theme identification and interpretation, there is increased risk of researcher bias influencing the analytical process and findings and investigator triangulation was not performed. This single-coder limitation is particularly concerning given my potential conflict of interest, as personal investment in the curriculum being evaluated might unconsciously influence data interpretation and theme development, potentially compromising the objectivity of the qualitative analysis. In response to this, I reflected on my biases before, during and after, data collection and reflected on how these biases might have influenced the study, not only during data collection, but also during analysis.

5.4 Summary

This chapter discussed the results of this study with reference to the existing literature related to the use of manikin-based simulation within chiropractic education. Specifically, the role of intolerance of uncertainty, the educational benefit of and possible future directions for manikin-based simulation within

chiropractic education were discussed. The following chapter provides the concluding remarks in this thesis.

Chapter 6: Conclusion

This thesis reported on a mixed-methods case study investigating if students in the fourth, fifth and sixth years of the University of Zurich Chiropractic Medicine Study Program (academic year 2024-2025) were able to modulate their delivery of thoracic spine manipulation in response to being presented with different vignettes of patient presentations commonly encountered in their early clinical careers. Furthermore, a small selection of these students provided their opinions on manikin-based simulation and its integration within the Study Program curriculum. The literature discussing manikin-based simulation within chiropractic education is limited and therefore, this thesis contributes in a meaningful way to the further understanding of this topic within the chiropractic profession.

The research question addressed by the study ‘Despite reporting low confidence in their ability, are fourth-, fifth-, and sixth-year students in the University of Zurich Chiropractic Medicine Study Program (2024–2025) able to modulate thoracic spine manipulation?’ was partly answered in the affirmative. While students were able to consistently modulate peak forces applied to both a manikin and human, in response to two cases commonly encountered during their early clinical career, the modulation of preload forces was more variable. All four focus-group interview participants viewed manikin-based simulation positively and advocate for its systematic inclusion in the chiropractic technique skills curriculum. The use of manikin-based simulation as a tool to decrease intolerance of uncertainty was a latent theme within the data while the educational benefit was discussed explicitly. Intolerance of uncertainty was discussed with reference to four interconnected sub-themes: i) the need for psychological safety, ii) dependence

on objective feedback, iii) lack of confidence, and iv) challenges with manikin tactile fidelity. Similarly, four aspects that are important to the educational benefit of manikin-based simulation within chiropractic education, were discussed: i) the importance of familiarization, ii) the facilitation of intentional, participatory learning, iii) the facilitation of motor learning processes, and iv) the timing of manikin-based simulation.

While this thesis addressed the broad issue of intolerance of uncertainty and educational benefit of manikin-based simulation, it raised a number of other questions which could form the basis for future research. These include: Is spinal manipulation applied to manikins and humans by students comparable to those delivered by experienced practitioners? Are there differences in the performance of spinal manipulation by students when exposed to manikins of varying tactile fidelity (e.g. low- vs. medium- vs. high-fidelity)? Is there an optimum time for the implementation of manikin-based simulation in the chiropractic skills technique curriculum?

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Appendices

Appendix A: Oxford ethics approval.

Education (Educ) DREC
15 Norham Gardens, Oxford, OX2 6PY

Applicant: Lindsay Gorrell
Principal Investigator: Helen Higham
Department: Education

Study title: The effect of manikin-based simulation on the development of thoracic spine manipulation skills – scaffolding students from the classroom to clinical practice.
(Version: 1.0)

Ethics reference: Education (Educ) DREC - 892142

Dear Helen Higham,

On behalf of the Committee, I confirm that the above research study described in the application and other supporting documentation submitted to the committee has been carefully considered on behalf of the Education (Educ) DREC in accordance with the University's regulations and policy for ethics approval of research involving human participants, human tissue and/or personal data. The opinion is as follows:

Opinion of Research Ethics Committee: Favourable Opinion

Subject to the following conditions:

Decision Date: 14 Feb 2025, 13:57

Opinion End Date: 14 Aug 2026

If favourable, insurance-provided indemnity arrangements will be in place between the decision date and opinion end date and you may now commence your study activities. Should you plan to continue the research beyond the end date above, it is your responsibility to ensure that you request, and receive, an extension (via amendment) from the committee for indemnity to remain in place. You may be required to provide a justification.

Please note the following:

Amendments: Should there be any subsequent changes to the reviewed study, applications for amendments can be made via the Oxford Ethics Application System (Worktribe Ethics).

Reports: Studies considered by OxTREC are expected to submit an *annual progress report* on each anniversary of study approval, until the study is completed. An end of study report is also required.

Audit: This study may be selected for audit at the discretion of the Research Governance, Ethics and Assurance Team.

Data safety: It is the responsibility of the PI to ensure that all data collected during the course of the study is stored and transferred safely and securely in accordance with University requirements. Further guidance and advice are available from the Research Data Team. Additional information is

available at https://researchsupport.web.ox.ac.uk/governance/ethics

Yours Sincerely

Education Ethics Officer

Appendix B: Zurich ethics approval.

Kanton Zürich
Kantonale Ethikkommission
Prof. em. Dr. med. David Nadal
Präsident Abteilung A
Prof. em. Dr. med. Konrad E. Bloch
Präsident Abteilung B

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Department of Chiropractic Medicine
Dr. Lindsay Gorrell
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8008 Zürich

25.02.2025 / ktr

Anfrage BASEC-ID	Req-2025-00239
Projekttitel	The effect of manikin-based simulation on the development of thoracic spine manipulation skills – scaffolding students from the classroom to clinical practice.
Antragsteller/in	Dr. Lindsay Gorrell
Datum der Anfrage	14.02.2025

Nicht-Zuständigkeitserklärung

Sehr geehrte Frau Dr. Gorrell

die Kantonale Ethikkommission Zürich fest, dass das in den eingereichten Unterlagen beschriebene Projekt nicht in den Geltungsbereich des Humanforschungsgesetzes fällt. Die Ethikkommission ist daher für die Beurteilung des Projekts nicht zuständig.

Eine Bewilligung für die Durchführung des beschriebenen Projekts durch eine Schweizer Ethikkommission ist nicht notwendig.

Hauptgrund: Es werden keine individuellen gesundheitsbezogenen Daten erfasst oder analysiert, sondern der Lern-Effekt eines Trainings.

English is not an official language of the Swiss Confederation. This translation is provided for information purposes. Only the clarification of responsibility in the official language of a Swiss Ethics Committees is the valid one. The project cited above does not fall within the scope of the Swiss Human Research Act. An approval of the project by a Swiss Ethics Committee is not required and the Ethics Committee Zürich is therefore not responsible for its evaluation.

Für die Bearbeitung dieser Zuständigkeitsabklärung wird Ihnen gemäss Ihren Angaben und der aktuellen swissethics-Gebührenordnung der Betrag von CHF 200.00 in Rechnung gestellt.

Freundliche Grüsse

i.A.

Prof. em. Dr. med. David Nadal
Präsident Abteilung A

i.A.

Prof. em. Dr. med. Konrad E. Bloch
Präsident Abteilung B

Rechtliche und administrative Hinweise

Mit dieser Stellungnahme wird nichts über die Qualität des Projekts ausgesagt.

Alle anwendbaren gesetzlichen Bestimmungen sind einzuhalten. Insbesondere ist eine korrekte Information von Teilnehmenden sicherzustellen und der Datenschutz zu gewährleisten.

Es liegt in Ihrer Verantwortung, zu prüfen, ob die Institution, in der das Projekt allenfalls stattfinden wird, vor Beginn informiert werden muss und ob eine Überprüfung des Projekts durch eine Prüfstelle erfolgen muss.

Die Nicht-Zuständigkeitserklärung gilt ausschliesslich für das in der Anfrage beschriebene Projekt und für die darin erwähnten Forschenden oder Forschungsgruppe.
Die Nicht-Zuständigkeitserklärung ist nicht übertragbar auf eine weitere Verwendung von Daten und/oder von biologischem Material für andere Projekte oder wenn Daten und/oder biologisches Material an andere Forschende weitergegeben werden. In solchen Fällen muss die Zuständigkeit erneut abgeklärt werden.

Appendix C: Recruitment advertisements.

Online Participants Recruitment (E-Mail)/Newspaper advert:

To Whom It May Concern:

I am conducting a research project as part of my MSc in Medical Education at Oxford. The study will quantify the delivery of spinal manipulation. I am looking for chiropractic students to deliver spinal manipulation to a human and a manikin.

More information can be provided upon request. Please email Lindsay Gorrell (lindsay.gorrell@st-hildas.ox.ac.uk) if you are interested and we can arrange a time to talk.

Best,

Social Media Participant Recruitment Post

CALLING YEARS 4-6 CHIROPRACTIC STUDENTS– I NEED YOU! I am conducting a research project as part of my MSc in Medical Education at Oxford and recruiting participants for an innovative study quantifying the delivery of spinal manipulation. Please contact (lindsay.gorrell@st-hildas.ox.ac.uk) for more information.

Appendix D: Participant information sheet.

Assoc. Prof. Helen Higham
Nuffield Department of Clinical Neurosciences
Level 6, West Wing, John Radcliffe Hospital, Oxford OX3 9DU
+44 7966360556
helen.higham@ndcn.ox.ac.uk

Dr. Lindsay Gorrell
Department of Education, University of Oxford
15 Norham Gardens, Oxford OX2 6PY, UK

The effect of manikin-based simulation on the development of thoracic spine manipulation skills – scaffolding students from the classroom to clinical practice

PARTICIPANT INFORMATION SHEET

Central University Research Ethics Committee Approval Reference: [(Educ) DREC - 892142]

1. Introductory paragraph

You are being invited to take part in a research project. Before you decide it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and discuss it with others if you wish. Ask us if there is anything that is not clear or if you would like more information. Take time to decide whether you wish to take part.

2. Why is this research being conducted?

This project closes the gap between your university classes and entry into clinical practice by using force-sensing technology and manikins to teach spinal manipulation skills for frequently treated patient presentations in clinical practice. Students report that they lack confidence when applying spinal manipulation to patients during their first months in clinical practice as they have not had the possibility to practice adapting their spinal manipulation skills to specific patient populations during their university classes. One way to address this could be to use manikin-based simulation and simulated clinical patient presentations in the chiropractic technique skills classroom.

The purpose of the study is to investigate the effect of using manikin-based simulation and clinically relevant simulated clinical patient presentations on the delivery of thoracic spine manipulation delivered by chiropractic students to live humans.

3. Why have I been invited to take part?

You are contacted to participate as a 4th, 5th or 6th year student in the University of Zurich Chiropractic Medicine Program.

4. Do I have to take part?

No. It is up to you to decide whether to take part. You can withdraw yourself from the research, without giving a reason, and without negative consequences, by advising me of this decision. The deadline by which you can withdraw any information you have contributed to the research is 31.05.2025. Any questionnaire and biomechanical data that has been collected up to that point will still be used (as the data are collected anonymously) but any data collected during the focus-group will be deleted and will not be used in the analysis.

5. What will happen to me if I take part in the research?

All data will be collected at Balgrist University Hospital, Zurich. You will be asked to attend a single data collection session, lasting approximately 30 minutes, in which we will measure the forces (using a pressure mat) that you apply to both a manikin and live human, according to two different clinical scenarios. Prior to and following data collection, you will complete a short questionnaire administered using Microsoft Forms. The order of manikin vs human and which clinical scenario you will use first will be randomized, meaning that each of the options is equally likely (such as when you flip a coin). At the end of this session, you will be asked to attend a focus-group interview with some of your colleagues, lasting approximately 60 minutes and held 1 week after the completion of data collection, in which we will ask for your opinions and beliefs regarding the use of manikins in the teaching and learning of chiropractic technique skills. Details regarding the focus-group interviews will be posted in the student area of the skills rooms at Balgrist and will be entirely optional. Focus-group interviews will be conducted using Microsoft Teams. Verbal consent from all participants will be obtained at the beginning of the interview and audio and video-recording will be used.

Data collection schedule:

Study period	**Recruitment**	**Intervention**	**Focus-group interview**
Time (days)	**> 1 day**		**Optional**
Duration (minutes)	NA	~30	~60
Oral and written information	+		
Consent		+ (written)	+ (verbal)
Check inclusion/ exclusion criteria		+	
Demographics		+	
Randomization		+	
Questionnaires		+	
Data collection		+	+
Safety		+	

6. What are the possible disadvantages and risks in taking part?

Spinal manipulation has been a component of manual therapy and physical rehabilitation programs for many years. Manual treatments, such as spinal manipulation, are infrequently associated with transient minor musculoskeletal side effects such as muscle soreness and local discomfort. However, as the study involves only procedures that you routinely apply in your chiropractic technique skills classes, this is unlikely. There is no evidence for serious adverse events.

7. Are there any benefits in taking part?

You will not have any personal benefit from participating in this study. We expect that the results of this study will help us to better understand the forces delivered during spinal manipulation. The results of this study will be considered in future revisions of the chiropractic technique skills curriculum of the University of Zurich Chiropractic Medicine Program.

8. Expenses and payments

There will be no renumeration for your participation in this study.

9. What information will be collected and why is the collection of this information relevant for achieving the research objectives?

The biomechanical characteristics of thoracic spinal manipulation will be quantified using a thin, flexible pressure pad. Biomechanical characteristics include preload and peak force, thrust duration and rate of force application. You will complete a brief pre- and post-data collection questionnaire using Microsoft Forms. Data to be collected will include: year of study, age, sex, previous experience with the use of the manikin and force-sensing technology and which technique was used during data collection.

Interested participants will then attend an optional focus-group interview, lasting approximately 60 minutes and video- and audio-recorded on Microsoft Teams in which their opinion of the implementation of manikin-based simulation into the chiropractic skills technique curriculum will be discussed. Transcription using Microsoft Word will be performed by the research student (Dr. Lindsay Gorrell).

Collecting these data necessary to address the purpose of the study, i.e. to investigate the effect of using manikin-based simulation and clinically relevant simulated clinical patient presentations on the delivery of thoracic spine manipulation delivered by chiropractic students to live humans.

Biomechanical characteristic data and data collected during the questionnaires will be anonymised at the time of data collection, thus we will not collect any data that could directly identify you. Recordings of the focus-group interviews will be deleted immediately following transcription by Dr. Lindsay Gorrell. The study will be completed by December 2025.

The data you provide may be shared with Dr. James Thomas and Dr. Helen Higham (co-supervisors of the research student, Dr. Lindsay Gorrell) and the results will be written up for a Master of Science, Medical Education degree.

Identifiable data (including consent forms) will be stored at the University of Oxford for three years. Other research data will be stored for three years after publication or public release of the work of the research.

10. Will the research be published? Could I be identified from any publications or other research outputs?

The findings from the research will be written up as part of my Master of Science, Medical Education degree requirements and for publication in a peer-reviewed journal. It will not be possible for participants to be identifiable from the outputs and if you do not wish for your focus-group data to be included, please advise us by 31.05.2025. After this date, all data will be included in the data analysis.

I would like your permission to use direct quotations but without identifying you in any research outputs. A copy of my thesis will be deposited online in the Oxford University Research Archive where it will be publicly available to facilitate its use in future research.

11. Data Protection

The University of Oxford is the data controller with respect to your personal data, and as such will determine how your personal data is used in the research. The University will process your personal data for the purpose of the research outlined above. Research is a task that is performed in the public interest. Further information about your rights with respect to your personal data is available from the University's Information Compliance website at https://compliance.admin.ox.ac.uk/individual-rights.

12. Who has reviewed this research?

This research has received ethics approval from a subcommittee of the University of Oxford Central University Research Ethics Committee. (Ethics reference: **(Educ) DREC - 892142)**. Furthermore, this research has been reviewed by the Zurich Kantonal Ethics Kommittee (Ethics reference: **Req-2025-00239)**.

13. Who do I contact if I have a concern about the research or I wish to complain?

If you have a concern about any aspect of this research, please contact myself, Dr. Lindsay Gorrell (lindsay.gorrell@st-hildas.ox.ac.uk), Assoc. Prof. Helen Higham (helen.higham@ndcn.ox.ac.uk) or on +44 7966360556, Dr. James Thomas (james.thomas@ndcn.ox.ac.uk) or on +44 (01865) 231510, or the University of Oxford Research Governance, Ethics & Assurance (RGEA) team (rgea.complaints@admin.ox.ac.uk) or on +44 (0)1865 616480, and we will do our best to answer your query. We will acknowledge your concern within 10 working days and give you an indication of how it will be dealt with.

14. Further Information and Contact Details

If you would like to discuss the research with someone beforehand (or if you have questions afterwards), please contact:

Dr. Lindsay Gorrell
Department of Education, University of Oxford
15 Norham Gardens, Oxford OX2 6PY, UK
lindsay.gorrell@st-hildas.ox.ac.uk

Dr. James Thomas
Nuffield Department of Clinical Neurosciences
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Assoc. Prof. Helen Higham
Nuffield Department of Clinical Neurosciences
Level 6, West Wing, John Radcliffe Hospital, Oxford OX3 9DU
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Appendix E: Informed consent form.

Assoc. Prof. Helen Higham
Nuffield Department of Clinical Neurosciences
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+44 7966360556
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Dr. Lindsay Gorrell
Department of Education, University of Oxford
15 Norham Gardens, Oxford OX2 6PY, UK

Consent to take part in the study: The effect of manikin-based simulation on the development of thoracic spine manipulation skills – scaffolding students from the classroom to clinical practice.

Central University Research Ethics Committee (CUREC) approval reference: **(Educ) DREC - 892142**

Purpose of Study: To investigate the effect of using manikin-based simulation and clinically relevant vignettes on the delivery of thoracic spine manipulation delivered by chiropractic students to live humans.

	Please initial each box if you agree with the statement
I confirm that I have read and understand the information sheet version 1.0, dated 03.02.2025 for the above research. I have had the opportunity to consider the information, ask questions and have had these answered satisfactorily.	☐
I understand that my participation is voluntary and that I am free to withdraw at any point until **31.05.2025**, without giving any reason.	☐
I understand who will have access to personal data provided, how the data will be stored and what will happen to the data at the end of the project.	☐
I understand that I will not be identifiable from any publications or presentations.	☐
I consent to being video recorded.	☐
I consent to being audio recorded.	☐

Use of quotations: Please indicate your preference (select *one* option): a) I do not wish to be quoted. **or** b) I agree to the use of quotations in research outputs if I am not identifiable.	☐ ☐
I understand how to raise a concern or make a complaint.	☐
I agree to take part.	☐

_____	dd / mm / yyyy	_____
Name of participant	Date	Signature
_____	dd / mm / yyyy	_____
Name of person taking consent	Date	Signature

Appendix F: Pre-data collection questionnaire.

Pre data collection:

Please note that you may only participate in this survey if you are 18 years of age or over.
☐ I certify that I am 18 years of age or over
If you have read the information above and agree to participate with the understanding that the data (including any personal data) you submit will be processed accordingly, please tick the box below to start.
☐ Yes, I agree to take part

Demographics
Year of birth:
Gender: woman/ man / diverse
Height: cm
Weight: kg
Handedness: right/ left/ ambidextrous

Experience with spinal manipulation
Select one:
Student>> Which year of your chiropractic studies are you currently in: check box 4/5/6

How often do you deliver thoracic spine manipulation per week (in practice or skills class):

Do you have any experience delivering spinal manipulation to a manikin? y/n & if y: how many times:

Appendix G: Hand contacts used during kinetic data collection.



© Luana Nyirö

Appendix H: Post-data collection questionnaire.

Post data collection:

Do you think you applied thoracic spine manipulation similarly between the human volunteers and manikin? y/n-> why?

If 6 year student: Was your treatment of the human volunteers comparable to the treatments you deliver in clinical practice? y/n -> why? -> Was this different for different vignettes (i.e. 20-25yo woman, 50-55yo man)?

Was your treatment of the manikins comparable to the thoracic spine treatments you deliver in clinical practice? y/n -> why?

Do you think you modulated the (peak) forces that you applied to the different vignettes (i.e. 20-25yo woman, 50-55yo man)? y/n -> how?

What do you think this research study was investigating?

Any further comments regarding data collection or anything else you would like to share with us? free text

Appendix I: Focus-group interview question guide.

Topic Guide

Section	Questions/Content	Prompts
Ethics Statement	Thank you for consenting to join this focus group. I am Lindsay and will facilitate the FG. I will sometimes take notes, keep track of time, and monitor the chat. Can I confirm that you all have read and understood the information sheet? I'll start with some ground rules and instructions: This focus group will last about 60 minutes and will be video and audio-recorded (the chat will also be recorded). Please have your camera and microphone on at all times. Feel free to mute yourself in case you have background noise, but please unmute yourself as soon as the noise is gone. To avoid distractions, please make sure you are in a quiet environment, that you have your phone on silent and any other programs or applications on your computer (e.g., emails) closed. If you drop from the call, please connect again as soon as possible. All information shared today will be kept strictly confidential and I'll ask you to please not share any information you hear here today with anyone. You have the right to not answer a question if you do not wish to, but we will give everyone an opportunity to voice their opinions and we would like to hear everyone's opinions. If, at any time, you are unsure about what is being asked or discussed, please let us know. So, the aim of today's focus group is to explore your thoughts, perceptions and opinions on the use of manikin-based simulation in chiropractic technique skills classes. Therefore, there are no right or wrong answers and all thoughts and opinions are welcome. Before we start do you have any questions?	
Introductory Questions	1. Lets start with some introductions… we'll go around and if you could state your name, background and which year group you are in (if the year groups are mixed)? • [Lindsay to introduce herself first] • Keep it succinct: name, research background, year group i. ["name, background and year group" to be sent in the chat]	
Manikin-based simulation	Manikin-based simulation has been increasingly used for the development and acquisition of chiropractic technique skills. However, I see a new role for manikins in our classrooms – to provide a bridge between skills classes and your clinical practice in the Lehrklinik. We are currently undergoing a review of the entire chiropractic technique skills program, from years 1 to 5 and I am interested to know your opinions and beliefs about the use of manikin-based simulation in the classroom.	
Main Questions	1. Let's start with the manikins. You have all used the PAT manikin in the classroom and in a couple of research projects. What are your thoughts about PAT? [PAUSE – give them time to think]	• *What do you like or don't like about PAT?* • *Do you think something about PAT could be improved?*

Focus group question interview guide, Version 1.0, 03.02.2025

		• *Do you think PAT is more lifelike than the other/HAM manikin?* • *Have your thoughts related to PAT changed as you use it more?* • *Did the feedback related to other participants' responses influence your reflection on PAT?*
	[Summarize or not the discussion – depending on how it goes] Now let's change topics: 2. What do you see as the advantages to using manikin-based simulation in the classroom – not only for skills acquisition and development, but also as a scaffold into clinical practice? [PAUSE – give them time to think]	
	3. What do you see as the challenges to using manikin-based simulation in the classroom? [PAUSE – give them time to think]	
	4. Do you think it is possible for manikin-based simulation to be systematically and longitudinally integrated into the chiropractic medicine program? [PAUSE – give them time to think]	• *Why/why not?*
	5. How do you see manikin-based simulation as being systematically and longitudinally integrated into the chiropractic medicine program? [PAUSE – give them time to think]	
Conclusion	That's all the questions, is there anything else you would like to add regarding PAT and/or the use of manikin-based simulation in the chiropractic skills technique curriculum? The focus group has now finished. We will be conducting other focus groups and will combine the feedback you have provided with that gathered in the other groups. I will circulate a copy of today's interview to everyone once it is finished, so that everyone has the opportunity to check it for accuracy and provide any further thoughts/comments that might arise between today and then. Thank you for participating in this study, we really appreciate your time and input.	