

Femoral offset is underestimated on AP pelvis radiographs but accurately assessed on AP hip radiographs in primary osteoarthritis

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Abstract

The aim of this retrospective cohort study was to evaluate differences in femoral offset (FO) when measured on corresponding pre-operative AP pelvis radiographs, AP hip radiographs and CT-scans of a consecutive series of 100 patients (43 males, 57 females, mean age 61 years, mean BMI 27 kg/m²) with primary end-stage hip osteoarthritis. Patients were positioned according to a standardised protocol to achieve reproducible projection and all images were calibrated. Inter- and intra-observer reliability was evaluated and measurement agreement between methods was assessed using Bland-Altman plots.

In the entire cohort, mean FO was 39.0 mm (95%CI: 37.4-40.6 mm) on AP pelvis radiographs, 44.0 mm (95%CI: 42.4-45.6 mm) on AP hip radiographs and 44.7 mm (95%CI: 43.5-45.9 mm) on CT scans. AP pelvis based FO was underestimated by 13% compared to CT ($p < 0.001$). No difference in mean FO between AP hip radiographs and CT was observed ($p = 0.191$).

The present study suggests that femoral offset is significantly underestimated on AP pelvis radiographs but can be reliably and accurately assessed on AP hip radiographs in patients with primary end-stage hip osteoarthritis. We therefore recommend to routinely obtain additional AP hip radiographs for pre-operative assessment of femoral offset in THA templating.

1 Introduction

Accurate restoration of physiological joint biomechanics in total hip arthroplasty (THA) provides patients with a better functional outcome in terms of improved abductor muscle strength^{1,2} and greater range of motion

(ROM)^{1,3-5} and helps to minimise the risk of post-operative complications such as limp, dislocation or wear-related implant failure in the long-term.^{3,6-8}

A mandatory pre-requisite for accurately restoring individual patient anatomy is precise pre-operative planning, in which femoral offset (FO) is an essential parameter. In clinical practice, pre-operative templating in THA is widely performed on anteroposterior (AP) pelvis radiographs even though several studies over the past two decades have described limited reliability for measuring FO on AP pelvis radiographs compared to computed tomography (CT)⁹⁻¹². Femoral anteversion (FA)^{10,11} and external rotational contractures in patients with end-stage osteoarthritis (OA)^{9,12} were identified as main reasons for underestimating FO on AP pelvis radiographs and consequently, some authors have proposed pre-operative CT as a standard procedure^{10,11}. Although CT is considered as gold standard for FO assessment^{13,14} its routine performance is questionable because of higher radiation doses, higher costs and limited availability.

To our knowledge, there are no previous studies in the literature that have investigated the accuracy and reliability of FO measurements on AP *hip* radiographs with reference to CT in pre-operative THA planning. The aim of the present study was to evaluate differences in FO when measured on standardised corresponding AP pelvis radiographs, AP hip radiographs and CT scans of patients with primary hip OA. Our first hypothesis was that FO measured on AP pelvis radiographs is significantly underestimated compared to FO measured on AP hip radiographs. We secondly hypothesised that there is no clinically relevant difference in mean FO measurements between AP hip radiographs and CT scans.

2 Materials and Methods

2.1 Cohort

Between July 2009 and December 2009 a consecutive series of 152 patients who had undergone primary THA for end-stage hip osteoarthritis (OA) with a custom-made cementless femoral implant¹⁵ was retrospectively reviewed. For each patient, a pre-operative AP pelvis radiograph, an AP hip radiograph and a CT scan of the affected hip had been routinely obtained and all images were retrieved in DICOM format from a picture archiving and communication system (PACS).

Patients with secondary forms of hip osteoarthritis, medication affecting bone metabolism or radiographs without calibration marker were excluded from the study. Patients in whom THA was performed bilaterally during the study period were only included with the first procedure side. Fifty-two patients were excluded according to the criteria stated above, leaving 100 patients (43 males, 57 females, mean age 61 (range: 45-74) years, mean body-mass-index (BMI) 27 (range: 20-45) kg/m², Table 1) that were included in the present study. In all cases, the diagnosis leading to THA was primary OA.

The study was approved by the institutional review board (reference S-272/2009).

2.2 Radiographic Protocol

In all patients, a standardised radiographic protocol was administered to achieve reproducible projection. Low-centered AP pelvis and AP hip radiographs (Figure 1) were taken in supine position. To correct for effects of magnification, a metal calibration sphere of 25 mm was positioned on the inner thigh at the anterior-posterior level of the femoral head. During the study period, two different x-ray tubes were in use: Canon CXDI series [Canon Inc., Tokyo, Japan] and Philips Bucky Diagnost VE VT [Royal Philips Electronics Inc., Amsterdam, Netherlands]. The tube-to-film distance was 1150 mm, with the tube orientation perpendicular to the table.

On AP pelvis radiographs, both legs were internally rotated by 15 degrees using a leg retainer and the crosshair of the beam was centred on the pubic symphysis.

For AP hip radiographs, the crosshair of the beam was directed to the midpoint between the anterior superior iliac spine and the symphysis to centre the beam on the centre of the femoral head of the diseased hip. The affected leg was internally rotated and retained so that the greatest prominence of the greater trochanter was palpated at its most lateral position to bring the femoral neck into the coronal plane. When internal rotation of the leg was not sufficient due to external rotation contracture, the affected hip was additionally elevated on the AP hip view using a wedge.

2.3 Computed Tomography Protocol

All hip CT scans were performed pre-operatively using a Toshiba Aquilion 16 CT scanner [Toshiba Corp., Tokyo, Japan]. Patients were positioned supine with legs in neutral rotation as confirmed by scout views. The scans were obtained in three sets: (1) from the cranial aspect of the acetabulum to below the lesser trochanter, (2) from below the lesser trochanter to a point 50 mm distally of the femoral isthmus and (3) 4-6 slices of the knee. Slice spacing of 4 mm, 8 mm and 2 mm were used, respectively. All scans were recorded with gantry tilt 0, 120 kV and a field of view (FOV) of 250 mm.

2.4 Radiographic measurements

A validated MATLAB programme [version 7.10, The MathWorks Inc., MA, USA] was used to determine the centre of the femoral head (HC), the head diameter (HD) and the femoral shaft axis on AP pelvis and AP hip views. On the femoral diaphysis, two points on the medial and lateral cortex 20 mm below the lesser trochanter, and two points on the medial and lateral cortex at the level of the femoral isthmus were defined. The midpoints of these point pairs determined the femoral shaft axis. A circle tool was used to define the head diameter and the co-ordinates of its centre. FO was calculated as the perpendicular distance from the centre of the femoral head to the femoral shaft axis. Measurements on AP pelvis radiographs were labeled FO_p and HD_p and on AP hip radiographs FO_h and HD_h , respectively (Figure 1). On AP pelvis radiographs, the distance from the midpoint of both tear drops to the centre of the femoral head (x) was calculated.

2.5 CT measurements

In addition to the 2D measurements, another validated MATLAB programme was used to measure FO and FA. The programme enabled the user to select points from pre-selected axial CT slices and performed calculations in the three dimensional (3D) co-ordinate system of the CT scanner (Figure 2).

For the 3D calculation of FO (FO_c) and head diameter (HD_c), three axial slices were selected ($s1$, $s3$, $s4$, Figure 3). HD_c and the centre of the femoral head were determined on the slice with the femoral head at its largest diameter ($s1$) using a circle tool. The femoral shaft axis was defined by the centroid of the proximal femoral

metaphysis^{16,17} (s3) and the centre of the isthmus (s4); FO_c was then calculated as the perpendicular distance from the femoral shaft axis to the centre of the femoral head.

For the calculation of FA, the femoral neck axis (s2, Figure 3) was defined using the single slice method as described by Sugano¹⁸, and the posterior condylar axis (s5) was defined by the most posterior aspects of the lateral and medial condyles. The angle between the femoral neck axis and the posterior condylar axis represented FA.

2.6 Measurement reliability

Intra- and inter-observer reliabilities for 20 randomly selected corresponding AP pelvis radiographs, AP hip radiographs and CT scans were evaluated by two independent and blinded observers using single-measure intra-class-correlation coefficients (ICC) with a two-way-random effects model for absolute agreement.

2.7 Statistical analysis

The distributions of variables were examined in exploratory data analysis, and tested for normality using Kolmogorov-Smirnov tests. All variables (FO_p, FO_h, FO_c, HD_p, HD_h, HD_c and FA) were normally distributed (range: p=0.06-0.20). For descriptive analysis, absolute mean values and differences of FO were expressed in mm with 95% confidence intervals (95%CI). FA was expressed in degrees with 95%CI. Distributions of FO values were compared using paired-samples *t*-tests for paired observations and independent-samples *t*-tests for unpaired observations. Pearson's correlation coefficient (*r*) was used to evaluate associations between continuous variables. Correlation was characterised as poor (0.00-0.20), fair (0.21-0.40), moderate (0.41-0.60), good (0.61-0.80), or excellent (0.81-1.00). Results with *p* values <0.05 were considered as significant, *p* values of <0.001 were considered as highly significant. Differences in FO measurements on all three modes of radiographic imaging were analysed using Bland-Altman plots¹⁹. Linear regression was performed to relate corresponding FO measurements. Statistical analysis was carried out using PASW Statistics 18 [SPSS Inc. an IBM company, IL, USA] and Sigmaplot 12.0 [Systat Inc., San Jose, CA, USA].

3 Results

3.1 Measurement reliability

Excellent intra-observer ICC was seen for all analysed parameters: FO_p (0.993), FO_h (0.990), FO_c (0.990), HD_p (0.886), HD_h (0.906), HD_c (0.933) and FA (0.984).

Inter- observer ICC also showed similar correlations for all parameters: FO_p (0.986), FO_h (0.977), FO_c (0.991), HD_p (0.812), HD_h (0.848), HD_c (0.866) and FA (0.950).

3.2 Radiographic findings

In the entire cohort, mean FO_p was 39.0 mm (95%CI: 37.4 to 40.6 mm), compared to mean FO_h of 44.0 mm (95%CI: 42.4 to 45.6 mm, Table 2). FO_p was significantly lower than FO_h ($p < 0.001$) with a mean difference of 5.0 mm (95%CI: 4.3 to 5.7 mm) or 11%, respectively (Table 3, Figure 4). The difference between FO_p and FO_h was slightly higher in males (5.8 mm, 14%) than in females (4.4 mm, 12%, $p = 0.45$, Table 3).

We observed a fair correlation between the difference in mean FO on corresponding radiographs and x ($r = 0.37$, $p < 0.001$). No correlation between the difference in mean FO on corresponding radiographs and FA ($r = 0.18$, $p = 0.07$) was found.

The observed difference between HD_p and HD_h (mean 1.0 mm, 95%CI: -0.6 to 1.4 mm) was not statistically significant ($p = 0.068$). In addition, HD_p and HD_h demonstrated an excellent correlation ($r = 0.89$, $p < 0.001$).

3.3 CT findings

Mean FO_c was 44.7 mm (95%CI: 43.5 to 45.9 mm, Table 2). FO_p was underestimated by 5.7 mm (95%CI: 4.5 to 6.9 mm) or 13% with reference to FO_c ($p < 0.001$). FO_c and FO_h were comparable ($p = 0.191$) with a mean difference of 0.7 mm (95%CI: -0.3 to 1.7 mm, Table 3, Figure 4). Comparing males and females, differences between FO_h and FO_c were similar ($p = 0.79$, Table 3).

We observed a good correlation between FO_p and FO_c ($r=0.687$, $p<0.001$) and between FO_h and FO_c ($r=0.767$, $p<0.001$, Figure 5). With reference to CT, disagreement in FO assessment was within ± 5 mm in 44 % (44 patients) of cases for AP pelvis radiographs and 74% (74 patients) for AP hip radiographs (Figure 6).

The mean femoral head diameter as measured on CT was lower than mean HD_p (mean difference -1.2 mm, 95%CI: -2.0 to -0.4 mm, $p=0.003$) and HD_h (mean difference -2.2 mm, 95%CI: -3.0 to -1.4 mm, $p<0.001$). Correlations between HD_c and HD_p ($r=0.62$, $p<0.001$) and HD_c and HD_h ($p=0.63$, $p<0.001$) were similar.

4 Discussion

Accurate and reliable assessment of FO is a key element in pre-operative planning for THA as it determines the selection and positioning of appropriate prosthetic components. Restoration of FO is essential to achieve a stable articulation²⁰ and to provide good range of motion¹, muscle function^{1,2}, and equal limb length³. The importance of FO restoration to prevent long-term adverse effects related to impingement²¹ and wear^{8,22} is well-accepted.

Despite the lower accuracy of plain radiography in comparison to 3D techniques based on CT¹⁰, AP pelvis radiographs are widely used for pre-operative templating in hip OA as they provide essential information regarding pelvic and contralateral hip anatomy, and allow evaluation of leg length discrepancies. It is well established that femoral rotation influences the radiographic appearance of proximal femoral anatomy²³ and that failure to correct for femoral anteversion and external rotation contracture results in underestimation of FO^{10,24}. Consequently, clear recommendations to optimise conventional radiographic projection of the femoral neck by internally rotating the lower limb during radiography have been made²⁵, but little attention has been given to potential differences in the accuracy of FO assessment on corresponding AP pelvis and AP hip radiographs. In contrast to AP pelvis views, AP hip radiographs theoretically allow a full correction of individual femoral version, even in the presence of external rotation contractures, as the hip can be elevated and symmetry is not an issue. Moreover, the centre of the beam is directed to the centre of rotation of the diseased hip which minimises effects of beam divergence.

The present study evaluated differences in FO measurements performed on standardised AP pelvis and AP hip radiographs in patients with primary end-stage hip OA and compared these measurements to true, 3D FO values obtained from corresponding CT scans. To minimise misleading projection effects of FA and external rotation contracture a standardised positioning protocol was used. All images were calibrated using a metal sphere which was reproducibly placed on the inner aspect of the thigh to compensate for potential errors of magnification in each radiograph. We observed a significant underestimation of FO with a mean of 5.0 mm (95%CI: 4.3 to 5.7 mm) comparing AP pelvis to AP hip views. Comparing AP hip to CT based FO values, a difference of 0.7 mm (95%CI: -0.3 to 1.7 mm) was seen. In 74% of cases AP hip derived FO measurements were within +/- 5mm of the CT measurements suggesting that FO measurements performed on standardised AP hip views allow an accurate representation of 3D FO.

We acknowledge the following limitations of the present study:

First, we cannot retrospectively quantify the effects of positioning and beam centration separately. Although a standardised positioning protocol was administered, the method for obtaining the radiographs remains a potential source of bias as both femoral rotation and positioning of the calibration marker depend on the judgment of the technician. Similarly, internal rotation of retroverted femora during patient positioning might have exaggerated measurement errors of FO. There were, however, only 7 retroverted femora in our cohort which showed a slight mean retroversion of -2.7 degrees (95%CI: -4.5 to (-0.9) degrees).

Secondly, the head diameter as determined on CT was lower than on corresponding radiographic measurements. It has been demonstrated that the femoral head is not a perfect sphere²⁶ and therefore, the present differences may be explained by the fact that HD was measured in the transverse plane on CT, but in the frontal plane on radiographs using least square fit circles. Moreover, the slice spacing of the present CT protocol (4 mm) aimed to reduce radiation exposure and to minimise artefacts caused by contralateral implants. This may have impeded the selection of the true level of the largest head diameter in some cases, potentially contributing to the lower HD values obtained from CT.

Thirdly, the true axis of the femoral neck to evaluate 3D FA can only be determined by means of a 3D reconstruction of the neck portion which was limited with the present CT protocol as a 1 mm slice interval is required for this purpose. However, the selected single slice method chosen in this study has demonstrated sufficient accuracy for FA measurements when the slice for determining the femoral neck axis is chosen just below the femoral head¹⁸. Moreover, we excluded patients with head or neck deformity associated with secondary OA.

Lastly, we did not use the long axis of the femur (centroid of metaphysis to centre of knee) as reported previously for FO measurements on CT²⁷. FO measurements in the present study were performed based on the longitudinal axis of the proximal femur (centroid of metaphysis to centre of isthmus) in order to replicate offset measurements as performed on plain radiography.

As a consequence of the reported limited accuracy and reliability of conventional radiographic measurements, the routine performance of CT scans for optimised preoperative FO assessment has been suggested^{10,11}. The results of the present study question this consideration for patients with primary OA, as we did not observe a clinically relevant difference in FO values comparing measurements made on AP hip radiographs compared to those made on CT. The obtained mean values for FO (44.0 mm) on AP hip views and FO (44.7 mm) and FA (14.9 degrees) on CT scans compare well to reported values in the literature^{10,28,29}. Moreover, the present study suggests that 3D FO may potentially be predicted from FO measurements performed on AP pelvis views with use of the provided regression equations. However, larger patient series are required to confirm this finding and to obtain more powerful correction factors for males and females separately. Because of the limited amount of data, we currently cannot recommend the general use of the derived equations.

A decrease in FO of approximately 12% was reported to cause abductor weakness² which indicates that the observed underestimation of FO (13%) comparing AP pelvis and AP hip views in our study is of clinical relevance. The difference between AP hip and CT values (2%) is of minor clinical importance. The observed differences in FO were consistent when considering male and female patients separately, suggesting that our findings are independent of gender related variability in proximal femoral anatomy^{30,31}.

In conclusion, the present study conclusively shows that compared to CT, femoral offset is significantly underestimated on AP pelvis radiographs, but can be measured with the same level of accuracy and reliability on AP hip radiographs in patients with primary osteoarthritis. AP hip radiographs allow a better control of femoral rotation, even in the presence of external rotation contractures, and additionally minimise adverse projection effects. In contrast to the suggested routine performance of CT for pre-operative assessment of FO, AP hip radiographs reduce radiation exposure and are a more cost-effective and available method to support the surgeon in the selection of appropriate implants. Although the ultimate decision of implant design, size and position must still be made intra-operatively, we recommend to routinely obtain additional AP hip radiographs for pre-operative assessment of femoral offset in patients with primary OA.

References

1. **McGrory BJ, Morrey BF, Cahalan TD, An KN, Cabanela ME.** Effect of femoral offset on range of motion and abductor muscle strength after total hip arthroplasty. *J Bone Joint Surg Br* 1995;77-6:865-9.
2. **Asayama I, Chamnongkitch S, Simpson KJ, Kinsey TL, Mahoney OM.** Reconstructed hip joint position and abductor muscle strength after total hip arthroplasty. *J Arthroplasty* 2005;20-4:414-20.
3. **Charles MN, Bourne RB, Davey JR, Greenwald AS, Morrey BF, Rorabeck CH.** Soft-tissue balancing of the hip: the role of femoral offset restoration. *Instr Course Lect* 2005;54:131-41.
4. **Matsushita A, Nakashima Y, Jingushi S, Yamamoto T, Kuraoka A, Iwamoto Y.** Effects of the femoral offset and the head size on the safe range of motion in total hip arthroplasty. *J Arthroplasty* 2009;24-4:646-51.
5. **Sakai T, Sugano N, Ohzono K, Nishii T, Haraguchi K, Yoshikawa H.** Femoral anteversion, femoral offset, and abductor lever arm after total hip arthroplasty using a modular femoral neck system. *J Orthop Sci* 2002;7-1:62-7.
6. **Lecerf G, Fessy MH, Philippot R, Massin P, Giraud F, Flecher X, Girard J, Mertl P, Marchetti E, Stindel E.** Femoral offset: anatomical concept, definition, assessment, implications for preoperative templating and hip arthroplasty. *Orthop Traumatol Surg Res* 2009;95-3:210-9.
7. **Patel AB, Wagle RR, Usrey MM, Thompson MT, Incavo SJ, Noble PC.** Guidelines for implant placement to minimize impingement during activities of daily living after total hip arthroplasty. *J Arthroplasty* 2010;25-8:1275-81 e1.
8. **Sakalkale DP, Sharkey PF, Eng K, Hozack WJ, Rothman RH.** Effect of femoral component offset on polyethylene wear in total hip arthroplasty. *Clin Orthop Relat Res* 2001-388:125-34.
9. **Rubin PJ, Leyvraz PF, Aubaniac JM, Argenson JN, Esteve P, de Roguin B.** The morphology of the proximal femur. A three-dimensional radiographic analysis. *J Bone Joint Surg Br* 1992;74-1:28-32.
10. **Sariali E, Mouttet A, Pasquier G, Durante E.** Three-dimensional hip anatomy in osteoarthritis. Analysis of the femoral offset. *J Arthroplasty* 2009;24-6:990-7.

11. **Sariali E, Mouttet A, Pasquier G, Durante E, Catone Y.** Accuracy of reconstruction of the hip using computerised three-dimensional pre-operative planning and a cementless modular neck. *J Bone Joint Surg Br* 2009;91-3:333-40.
12. **Sugano N, Ohzono K, Nishii T, Haraguchi K, Sakai T, Ochi T.** Computed-tomography-based computer preoperative planning for total hip arthroplasty. *Comput Aided Surg* 1998;3-6:320-4.
13. **Lee YS, Oh SH, Seon JK, Song EK, Yoon TR.** 3D femoral neck anteversion measurements based on the posterior femoral plane in ORTHODOC system. *Med Biol Eng Comput* 2006;44-10:895-906.
14. **Pasquier G, Ducharne G, Ali ES, Giraud F, Mouttet A, Durante E.** Total hip arthroplasty offset measurement: is C T scan the most accurate option? *Orthop Traumatol Surg Res* 2010;96-4:367-75.
15. **Akbar M, Aldinger G, Krahmer K, Bruckner T, Aldinger PR.** Custom stems for femoral deformity in patients less than 40 years of age: 70 hips followed for an average of 14 years. *Acta Orthop* 2009;80-4:420-5.
16. **Billing L.** Roentgen examination of the proximal femur end in children and adolescents; a standardized technique also suitable for determination of the collum-, anteversion-, and epiphyseal angles; a study of slipped epiphysis and coxa plana. *Acta Radiol Suppl* 1954;110:1-80.
17. **Murphy SB, Simon SR, Kijewski PK, Wilkinson RH, Griscom NT.** Femoral anteversion. *J Bone Joint Surg Am* 1987;69-8:1169-76.
18. **Sugano N, Noble PC, Kamaric E.** A comparison of alternative methods of measuring femoral anteversion. *J Comput Assist Tomogr* 1998;22-4:610-4.
19. **Bland JM, Altman DG.** Statistical methods for assessing agreement between two methods of clinical measurement. *Lancet* 1986;1-8476:307-10.
20. **Fackler CD, Poss R.** Dislocation in total hip arthroplasties. *Clin Orthop Relat Res* 1980-151:169-78.
21. **Malik A, Maheshwari A, Dorr LD.** Impingement with total hip replacement. *J Bone Joint Surg Am* 2007;89-8:1832-42.
22. **Little NJ, Busch CA, Gallagher JA, Rorabeck CH, Bourne RB.** Acetabular polyethylene wear and acetabular inclination and femoral offset. *Clin Orthop Relat Res* 2009;467-11:2895-900.
23. **Eckrich SG, Noble PC, Tullos HS.** Effect of rotation on the radiographic appearance of the femoral canal. *J Arthroplasty* 1994;9-4:419-26.
24. **Husmann O, Rubin PJ, Leyvraz PF, de Roguin B, Argenson JN.** Three-dimensional morphology of the proximal femur. *J Arthroplasty* 1997;12-4:444-50.
25. **Clohisy JC, Carlisle JC, Beaulé PE, Kim YJ, Trousdale RT, Sierra RJ, Leunig M, Schoenecker PL, Millis MB.** A systematic approach to the plain radiographic evaluation of the young adult hip. *J Bone Joint Surg Am* 2008;90 Suppl 4:47-66.
26. **Menschik F.** The hip joint as a conchoid shape. *J Biomech* 1997;30-9:971-3.
27. **Yoshioka Y, Siu D, Cooke TD.** The anatomy and functional axes of the femur. *J Bone Joint Surg Am* 1987;69-6:873-80.
28. **Noble PC, Alexander JW, Lindahl LJ, Yew DT, Granberry WM, Tullos HS.** The anatomic basis of femoral component design. *Clin Orthop Relat Res* 1988-235:148-65.

29. Unnanuntana A, Toogood P, Hart D, Cooperman D, Grant RE. Evaluation of proximal femoral geometry using digital photographs. *J Orthop Res* 2010;28-11:1399-404.

30. Nakahara I, Takao M, Sakai T, Nishii T, Yoshikawa H, Sugano N. Gender differences in 3D morphology and bony impingement of human hips. *J Orthop Res* 2010.

31. Atkinson HD, Johal KS, Willis-Owen C, Zadow S, Oakeshott RD. Differences in hip morphology between the sexes in patients undergoing hip resurfacing. *J Orthop Surg Res* 2010;5:76.

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Tables

	Entire cohort (n=100)	Males (n= 43)	Females (n= 57)
Age (years)	60.8 (45-74) (95%CI: 59.4- 62.2)	61.0 (45-72) (95%CI: 58.7- 63.3)	60.7 (45-74) (95%CI: 58.8-62.6)
Weight (kg)	79.7 (48.0-125.0) (95%CI: 76.6-82.9)	87.0 (60.0-125.0) (95%CI: 82.2-91.9)	74.2 (48.0-120.0) (95%CI:70.6-77.7)
Height (meters)	1.70 (1.53-1.91) (95%CI: 1.68-1.72)	1.77 (1.60-1.91) (95%CI: 1.75-1.79)	1.65 (1.53-1.76) (95%CI: 1.63-1.66)
BMI (kg/m²)	27.5 (20.3-44.6) (95%CI: 26.6-28.4)	27.7 (20.3-42.2) (95%CI: 26.3-29.1)	27.3 (20.5-44.6) (95%CI: 26.1-28.5)

Table 1. Demographic data (range) of the entire cohort, male patients and female patients with 95% CI.

	Entire cohort (n=100)	Males (n= 43)	Females (n= 57)
FO_p (mm)	39.0 (10.2-54.7) (95%CI: 37.4-40.6)	41.9 (18.4-54.7) (95%CI: 39.6-44.2)	36.8 (10.2-50.7) (95%CI: 34.7-38.9)
FO_h (mm)	44.0 (19.7-61.2) (95%CI: 42.4-45.6)	47.7 (26.2-61.2) (95%CI: 45.5-49.9)	41.2 (19.7-57.9) (95%CI: 39.3-43.2)
FO_c (mm)	44.7 (29.0-61.2) (95%CI: 43.5-45.9)	48.2 (40.2-61.2) (95%CI: 46.6-49.9)	42.0 (29.0-54.0) (95%CI: 40.7-43.3)
HD_p (mm)	47.2 (38.8-57.7) (95%CI: 46.4-48.1)	50.6 (43.7-57.7) (95%CI: 49.6-51.6)	44.7 (38.8-51.7) (95%CI: 43.9-45.4)
HD_h (mm)	48.2 (40.9-59.0) (95%CI: 47.3-49.1)	51.9 (45.2-59.0) (95%CI: 50.9-52.9)	45.4 (40.9-52.9) (95%CI: 44.6-46.3)
HD_c (mm)	46.0 (34.7-57.5) (95%CI: 45.0-47.0)	49.5 (36.8-57.5) (95%CI: 48.3-50.7)	43.3 (34.7-54.9) (95%CI: 42.3-44.4)
FA (degrees)	14.9 (-6.7-56.8) (95%CI: 12.6-17.1)	13.2 (-3.0-30.2) (95%CI: 10.5-15.9)	16.1 (-6.7-56.8) (95%CI: 12.7-19.6)

Table 2. Mean values (range) for FO, HD and FA with 95% CI for the entire cohort, male patients and female patients.

	Entire cohort (n=100)	Males (n= 43)	Females (n= 57)
FO_p to FO_h (mm)	5.0 (-2.1-16.5) (95%CI: 4.3-5.7)	5.8 (-0.8-16.5) (95%CI: 4.8-6.8)	4.4 (-2.1-15.2) (95%CI: 3.5-5.3)
FO_p to FO_h (%)	11	12	11
FO_p to FO_c (mm)	5.7 (-6.7-23.7) (95%CI:4.5-6.9)	6.3 (-5.2-21.8) (95%CI: 4.5-8.1)	5.2 (-6.7-23.7) (95%CI: 3.6-6.8)
FO_p to FO_c (%)	13	13	12
FO_h to FO_c (mm)	0.7 (-10.1-20.1) (95%CI:-0.3-1.7)	0.5 (-10.1-14.0) (95%CI: -1.1-2.2)	0.8 (-8.5-20.1) (95%CI: -0.5-2.1)
FO_h to FO_c (%)	2	1	2

Table 3 Mean differences in FO between AP pelvis (FO_p) and AP hip (FO_h) radiographs and between radiographs and CT (FO_c) given in absolute (mean (range), 95%CI) and relative (%) values.