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Are there clinically relevant anatomical differences of the proximal femur in patients with mild dysplastic and primary hip osteoarthritis? A CT-based matched-pairs cohort study

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AIM: To investigate the three-dimensional anatomy and shape of the proximal femur, comparing patients with secondary osteoarthritis (OA) due to mild developmental dysplasia of the hip (DDH) and primary hip OA.

MATERIALS AND METHODS: This retrospective radiographic computed tomography (CT)-based study investigated proximal femoral anatomy in a consecutive series of 84 patients with secondary hip OA due to mild DDH (Crowe type I&II/Hartofilakidis A) compared to 84 patients with primary hip OA, matched for gender, age at surgery, and body mass index.

RESULTS: Men with DDH showed higher neck shaft angles (127±5° vs. 123±4°; $p<0.001$), whereas women with DDH had a larger femoral head diameter (46±4 vs. 44±3 mm; $p=0.002$), smaller femoral offset (36±5 vs. 40±4 mm; $p<0.001$), decreased leg torsion (25±13° vs. 31±16°; $p=0.037$), and a higher neck shaft angle (128±7° vs. 123±4°; $p<0.001$) compared to primary OA patients. Similar patterns of the three-dimensional endosteal canal shape of the proximal femur, but a high inter-individual variability for femoral canal torsion at the meta-diaphyseal level were found for DDH and primary OA patients.

CONCLUSION: Standard cementless stem designs are suitable to treat patients with secondary hip OA due to mild DDH; however, high patient variability and subtle anatomical differences in the proximal femur should be respected.

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Introduction

Total hip arthroplasty (THA) in secondary forms of osteoarthritis (OA) continue to pose a clinical challenge as patients are of younger age and proximal femoral anatomy is highly variable in patients with hip dysplasia.[1–3] Cementless femoral reconstruction with standard or short stems may hence be technically challenging as anatomical variations may compromise primary stem stability, increase the risk for intraoperative periprosthetic fractures and make the reconstruction of offset and leg length more difficult, which are essential for functional outcome.[4–6]

Few studies have evaluated the three-dimensional anatomy in patients with hip dysplasia, reporting substantial differences between dysplastic and healthy femora, particularly with respect to femoral neck version, neck length, rotational deformities and size.[7,8] These studies have concluded that in femora with a higher degree of deformity (Crowe >II, Hartofilakidis B/C) modular or specially designed stems may be necessary to accommodate for the dysplastic abnormalities of joint geometry and endosteal canal shape.[7] As these studies excluded patients with OA, there is a paucity of data on potential differences in femoral anatomy between patients with primary hip OA and patients with secondary OA due to mild DDH (Crowe I/II, Hartofilakidis A). This leads the debate as to what the optimal choice of femoral implant is for such patients in order to achieve a secure endosteal fit. Therefore, the present study was undertaken to investigate the three-dimensional anatomy and shape of the proximal femur, comparing patients with end-stage primary hip OA and secondary OA due to mild DDH (Crowe type I/II, Hartofilakidis A). Two questions were specifically asked: how do the anatomical parameters for femoral head size, femoral offset, femoral anteversion, neck shaft angle, femoral canal torsion, and leg torsion differ between both groups of patients; and are there specific patterns of proximal femur canal shapes and rotational alignment of the lower extremities comparing both groups of patients?

Materials and methods

Study cohort

This retrospective radiographic matched-pairs cohort study investigated preoperative computed tomography (CT) examinations of a consecutive case series of 84 patients with end-stage OA due to mild developmental dysplasia of the hip (Crowe type I/II) and 84 matched patients with primary hip OA. All patients gave informed consent and the study was approved by the institutional review board. The study was conducted according to the Helsinki Declaration of 2008.

Between June 2008 and December 2009, a total of 597 primary cementless THAs were performed at the Department of Orthopaedic Surgery, Diakonie Klinikum Stuttgart, Germany. All European/White Caucasian consecutive patients were included in the study cohort with a diagnosis of advanced OA of the hip due to DDH Crowe type I and II/Hartofilakidis A.[3,9] In patients with bilateral THA, only the first hip to undergo THA was included in the study cohort. Patients with mild DDH were identified according to the following radiographic criteria evaluated on digital low-centred anteroposterior (AP) radiographs of the pelvis: centre-edge angle <25° (CEA), sharp angle (SA) >42°, acetabular index (AI) <38°.[10] Patients with prior hip surgery were not excluded from the study cohort. Eighty-four patients with end-stage secondary OA of the hip due to "mild" DDH were identified. These patients were matched to patients with a diagnosis of primary OA without any deformity of the hip according to gender, age at surgery, and body mass index.[7] Patients with secondary osteoarthritis due to trauma, infection, rheumatic disease, osteonecrosis of the femoral head, Legg–Calvé–Perthes disease or slipped capital femoral epiphysis were excluded from the study cohort. In all patients, a cementless custom-made titanium femoral component was implanted, which was manufactured on the basis of standardised preoperative CT examinations of the affected hip.[11] Demographic patient data are presented in Table 1.

Radiographic assessment

Preoperative digital low-centred calibrated AP radiographs of the pelvis were taken with the patient in the supine position, legs in 15° internal rotation and centred X-ray beam on the symphysis pubis. Radiographic measurements of the CEA, SA and AI, indicating the acetabular inclination, depth, and coverage of the femoral head were performed standardised with TraumaCad software (Version 2.2, Voyant Health, Petach-Tikva, Israel).[12]

Preoperative CT examinations were performed with a Toshiba Aquilion 16 CT system (Toshiba, Tokyo, Japan) in all patients in the supine position with their legs in neutral rotation as confirmed by scout views. The scans were obtained in three sets: from the cranial aspect of the acetabulum to below the lesser trochanter, from below the lesser trochanter to a point 50 mm distal to the femoral isthmus, and four to six slices of the knee (slice spacing: 4, 8 and 2 mm, gantry tilt: 0°, 120 kV, 250 mm field of view).[11]

Standardised CT measurements were performed using a validated software (Matlab, version 7.10; The MathWorks, Natick, MA, USA).[11] The femoral shape was determined by analysing the manually set "best fit" circle, oval, or axis on the following axial CT sections in each patient on 12

Table 1
Patient demographics and distribution of study and control group.

Variable	Study group (secondary OA due to DDH)	Control group (primary OA)	*p*-Value
No. of hips	84	84	–
Gender (F:M)	54 : 30	54 : 30	–
Age at surgery, mean (SD) (years)	54.0 (8.2)	55.1 (7.6)	0.385
Body mass index, mean (SD) (kg/m^2)	27.5 (6.8)	26.8 (5.5)	0.446

standardised levels: most cranial point of the major trochanter, maximum diameter of the femoral head, transition femoral head to neck, centroid of the metaphysis, upper edge of the lesser trochanter, maximum diameter of the lesser trochanter, lower edge of the lesser trochanter, 40 and 80 mm below the lesser trochanter, femoral isthmus, distal femur with the most prominent posterior aspect of the lateral and medial condyles, ankle with medial and lateral malleolus (Fig 1).

From these slices, femoral head diameter, offset, anteversion, shank torsion, leg torsion, NSA and distal femoral canal shape were calculated in the three-dimensional coordinate system of the CT machine.[8,11] Femoral offset was defined as the distance between the centre of rotation of the femoral head and proximal femoral shaft axis, connecting the midpoints of the slices at the centre of the metaphysis (slice 4) and the isthmus of the femur (slice 10). Femoral anteversion was measured as the angle between the femoral neck axis and the posterior condylar axis. The femoral neck axis was defined using the single-slice method as described by Sugano *et al.*[8] and the posterior condylar axis as the line between the most posterior aspect of the lateral and medial condyles (slices 3 and 11). Shank torsion was measured as the angle between posterior condylar axis of the knee and the axis of the ankle, connecting the most prominent aspect of the medial malleolus and the midpoint of the syndesmotic lateral tibial groove (slices 11 and 12). Leg torsion was calculated as the sum of femoral anteversion and shank torsion. The neck–shaft angle (NSA) was measured between the femoral neck axis in the coronal plane, defined by the line connecting the centre of the femoral head and the centroid of the metaphysis (slices 2 and 4) and the proximal femoral shaft axis (FSA). In order to analyse the three-dimensional endosteal shape of the proximal femur and endosteal femoral torsion, the area of each ellipse on the levels slices 4–10 was measured in square centimetres (Fig 2). Furthermore, the Canal Flare Index (CFI) was calculated for the slices 4–9 to quantify the endosteal increment of the proximal femur canal size as illustrated by the green and purple line in Fig 1 (CFI_x = area $slice_x$/area $slice_{10}$; with x ranging from 4 to 9).

Measurements were performed by one reviewer (W.W.), who was not involved in index surgery. A second analysis was performed by two reviewers (W.W., C.M.) 4 weeks after initial radiographic analysis for 20 randomly selected data sets in a blinded fashion. Intra- and interobserver reliabilities were calculated, using single-measure correlation coefficients with a two-way random effects model for absolute agreement.[13]

Statistical analysis

Continuous variables were expressed as mean values in millimetres or degrees including standard deviations (SD). Variables were tested for normal distribution using a

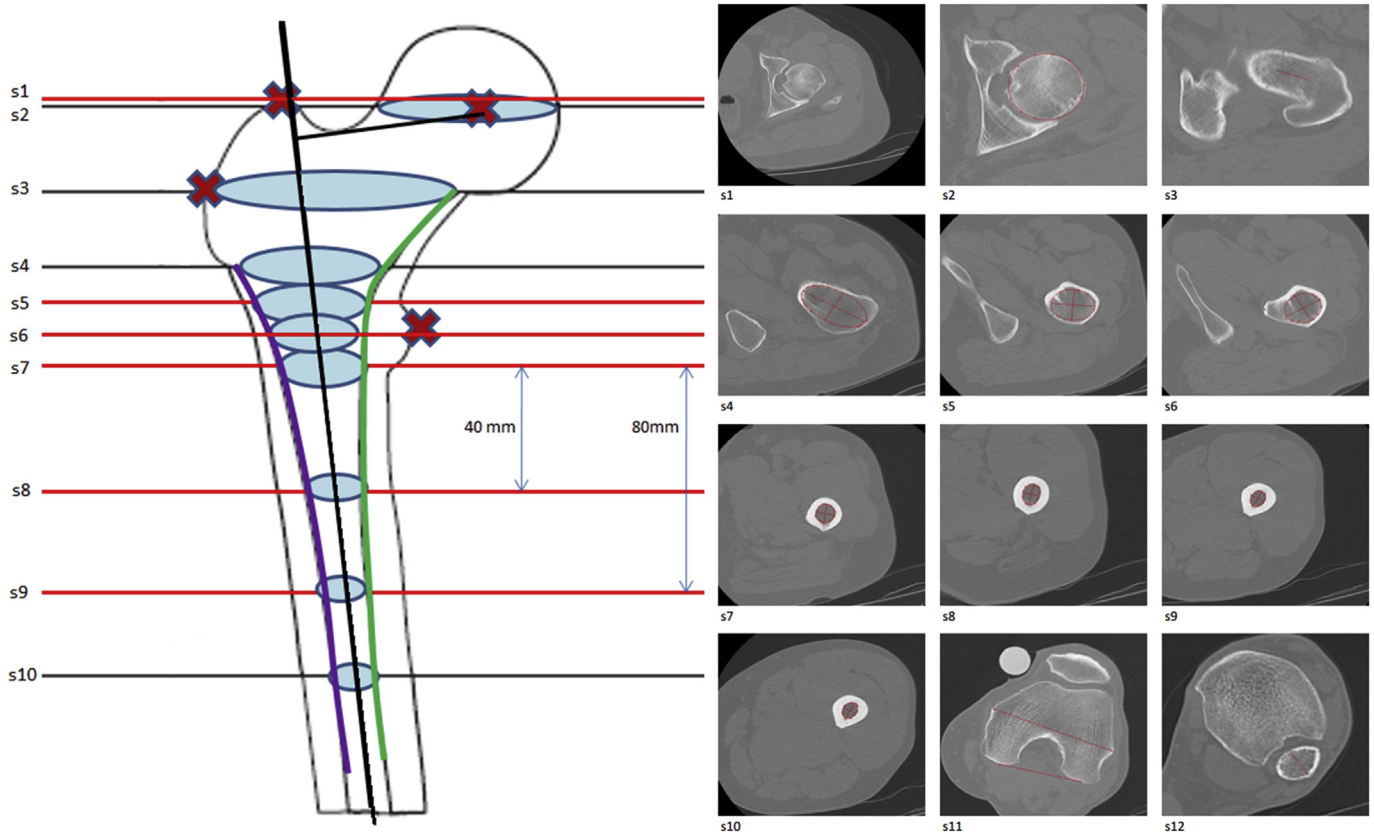

Figure 1 Three-dimensional analysis of the shape of the proximal femoral torsion measuring the rotation and area of each ellipse on the levels slices 4–10.

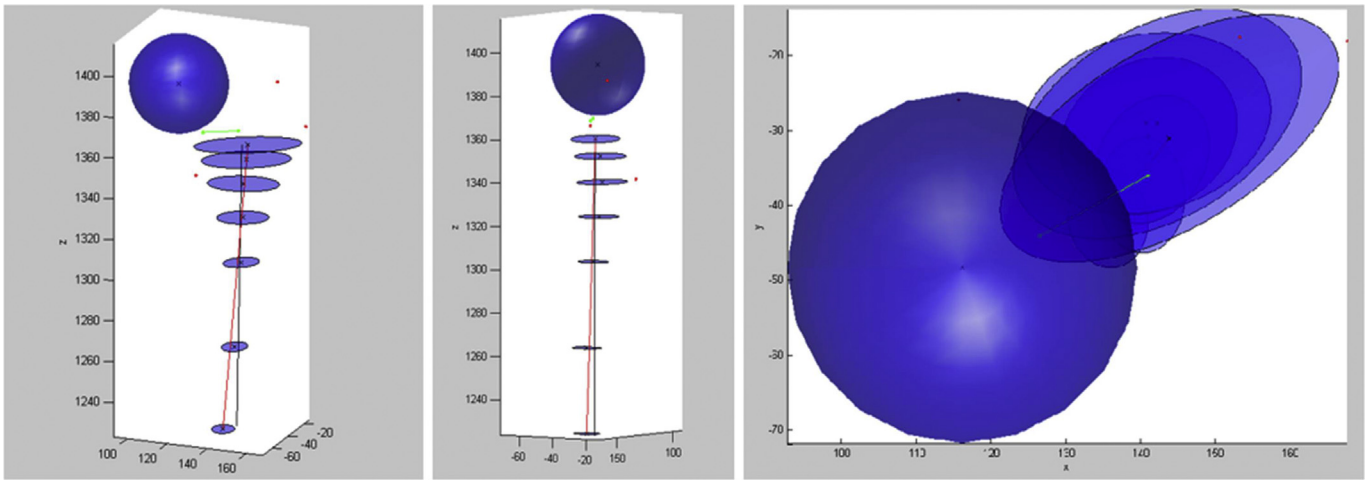

Figure 2 Three-dimensional model describing the shape and geometry of the proximal femoral measuring the rotation and area of each ellipse on the levels slices 4–10.

Kolmogorov–Smirnov test and parametric tests were used. Spearman correlation coefficients (rs) were used to evaluate associations among continuous variables. Both research questions were tested by using parametric tests (*t*-test). *p*-Values of <0.05 were considered significant. Statistical analysis was performed using SPSS software (Version 21.0, IBM SPSS Statistics, Chicago, IL, USA).

Results

The interobserver and intra-observer correlation coefficients were classified as "good" for HD, NSA and "very good" for all other radiographic measurements, with coefficients ranging from 0.79 (95% confidence interval [CI]: 0.53–0.91) to 0.99 (95% CI: 0.97–0.99).

Only minor differences were observed on comparing both groups. Patients with DDH showed a slightly larger femoral head diameter, smaller femoral offset and a higher NSA. Analysis by gender demonstrated a higher NSA in males with DDH compared to primary OA. Females with DDH had a significantly larger femoral head diameter, smaller femoral offset, a higher NSA and decreased leg torsion compared to females with primary OA (Table 2).

Analysing the three-dimensional shape of the proximal femur (slices 4–10), a slightly larger absolute cross-sectional size of the medullary canal was detected on the level of the lesser trochanter in DDH patients compared to primary OA patients (slice 6: $+0.4$ cm^2; $p=0.047$), whereas the femoral canal showed a less pronounced narrowing distally (slice 8: $+0.2$ cm^2; $p=0.010$; slice 9: $+0.1$; $p=0.023$) Both groups showed a comparable pattern of endosteal femoral torsion; however, a high inter-individual variability for both groups at the meta-diaphyseal level was observed (slice 7: 10.3°, SD 43.4 and 5.6°, SD 49.1; Table 2, Fig 3).

Discussion

There is an ongoing debate regarding which patients with advanced OA due to mild DDH can safely use standard straight stems or short stems to achieve a secure endosteal stem fit and joint geometry reconstruction. Therefore, knowledge regarding potential anatomical differences of the proximal femur in patients with secondary osteoarthritis due to mild DDH is of high clinical relevance, to achieve a high primary press-fit stability and to avoid

Table 2
Radiographic measurements for the study and control group.

	Study group (Secondary OA due to DDH)	Control group (Primary OA)	*p*-Value
Head diameter (all patients), mean (SD)	47.9 (4.5)	45.9 (3.6)	0.002*
Men	50.5 (3.4)	49.0 (2.8)	0.072
Women	46.4 (4.4)	44.2 (2.7)	0.002*
Femoral offset (all patients), mean (SD)	38.6 (6.2)	41.8 (4.4)	<0.001*
Men	43.3 (5.7)	44.9 (3.9)	0.232
Women	36.0 (4.8)	40.1 (3.7)	<0.001*
Neck shaft angle (all patients), mean (SD)	127.7 (6.2)	123.1 (3.5)	<0.001*
Men	127.2 (5.1)	122.8 (3.6)	<0.001*
Women	127.9 (6.8)	123.2 (3.5)	<0.001*
Femoral anteversion (all patients), mean (SD)	16.1 (12.6)	14.8 (11.2)	0.447
Men	11.3 (9.9)	12.4 (8.4)	0.646
Women	18.7 (13.2)	16.1 (12.3)	0.285
Shank torsion (all patients), mean (SD)	−43.7 (9.2)	−43.9 (12.4)	0.892
Men	−43.6 (9.9)	−38.5 (14.2)	0.113
Women	−43.7 (8.9)	−46.9 (10.2)	0.088
Leg torsion (all patients), mean (SD)	−27.6 (13.1)	−29.2 (14.8)	0.476
Men	−32.3 (12.3)	−26.1 (13.1)	0.064
Women	−25.0 (12.9)	−30.8 (15.5)	0.037*

*Indicating significance ($p<0.05$).

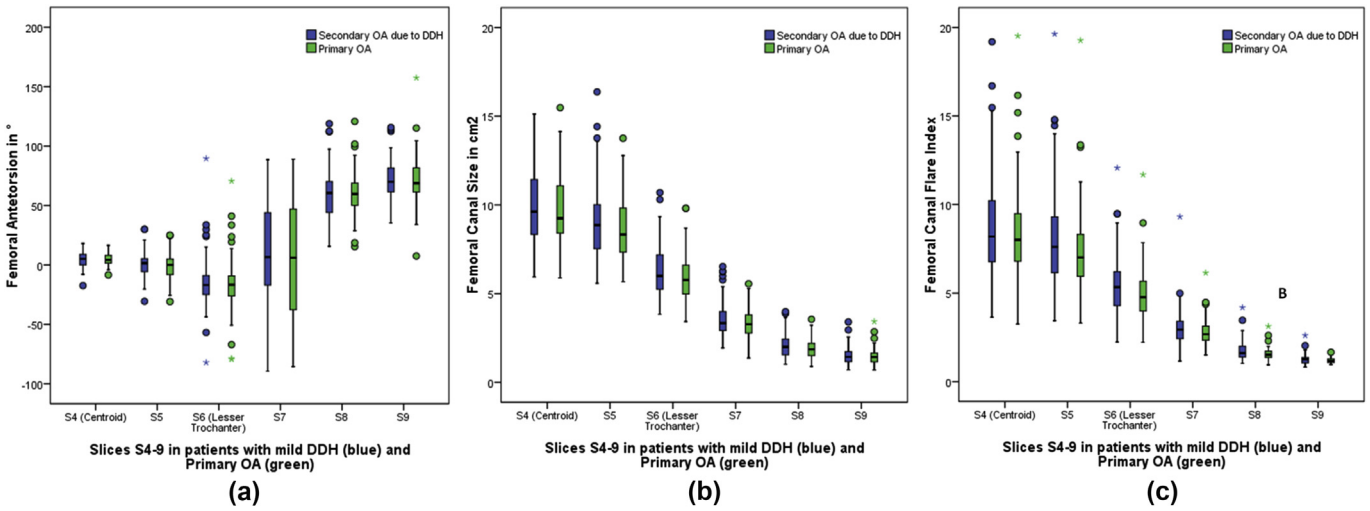

Figure 3 Boxplots illustrating (a) femoral canal torsion, (b) femoral canal size in square centimetres, and (c) femoral canal flare index for the slices S4–9 in patients with secondary OA due to mild DDH (blue) and primary OA (green).

complications such as instability, stem subsidence, or intraoperative periprosthetic femoral fractures.[14,15]

To answer this question, the present study found limited and rather small anatomical differences of the proximal femur and the endosteal canal shape in patients with secondary OA due to mild DDH compared to primary hip OA; however, a high inter-subject variability for femoral canal torsion was observed in both groups at the meta-diaphyseal level.

There are several limitations of the present study that have to be acknowledged. Due to the retrospective cohort study design, the first and most important limitation is a potential selection bias. This was minimised by including all patients with a diagnosis of advanced secondary OA of the hip due to DDH Crowe type I/II, independent of prior hip surgery from a consecutive series of patients. The present study cannot provide information on anatomical differences of the proximal femur in severe DDH Crowe type III/IV, because these patients were excluded from the present study. Furthermore, the inclusion of DDH patients with prior hip surgery might have biased the results; however, the fact that a substantial number of patients with DDH have a history of prior surgery patients at the time of THA, can also be interpreted as a strength of the study.

Interpreting the present results with regard to clinical relevance in context of the literature, the most important limitation is that only two CT-based studies exist and have investigated the anatomy of the proximal femur in DDH patients compared to matched healthy controls, but excluded patients with OA.[7,8] In the present study, no differences were detected between DDH Crowe type I/II and primary OA patients for femoral version, endosteal isthmus canal width, and diameter in the three-dimensional analysis[7,8]; however, minor differences for the NSA in males, and femoral head diameter, femoral offset, leg torsion, and NSA in females were found. Patients with DDH Crowe type I/II had significantly higher NSAs compared to primary OA (127.7±6.2° vs. 123.1±3.5°; $p<0.001$). The NSA angles for patients with DDH Crowe Type I compare well to recent studies.[7,8] The reported difference for the NSA angle between DDH and control group patients may be attributable to the presence of advanced OA, the difference between each study's control group (healthy vs. primary OA patients), distribution of gender, and study cohort size. In contrast to the present study, two prior studies reported a highly selected study population (only women from an Asian sub-population), comparing the femoral anatomy of patients with all grades of DDH (Crowe I–IV) to a matched healthy cohort without primary OA. The present study consisted of patients from a European/White Caucasian population with 64% females and a matched control group with primary OA. The fact that the present study only included patients with end-stage OA is a particular strength and these differences in study populations should be acknowledged when interpreting the present results.

With regard to the implantation of cementless stems, the present data suggest that in women with secondary OA due to DDH Crowe type I/II with a mean femoral offset of 36 mm and a neck shaft angle of 127.9° hip anatomy can be restored using standard cementless stems that offer a low-offset stem design. As there were no clinically relevant rotational differences in patients with DDH compared to those with primary OA, off-the-shelf implants appear to be a suitable option for most patients with mild DDH; however, surgeons need to be aware of the high inter-individual variability for femoral canal torsion in both groups of patients at the meta-diaphyseal level and slightly less pronounced narrowing of the distal femoral canal in DDH patients in order to decrease the risk for intraoperative periprosthetic femoral fractures or under-sizing of the femoral stem as this has been reported to be a risk factor for late aseptic loosening.[16,17] This finding highlights the importance of preoperative planning in all cases to identify potential outliers in advance. Moreover, conical or modular stem designs need to be available as back-up option in case a sufficient fixation or restoration of offset and leg length

cannot be achieved, especially when a secure press-fit cannot be obtained or an excessive alteration of the centre of rotation is necessary during cup preparation.

In conclusion, the present study demonstrates that gender-specific subtle anatomical differences of the proximal femur exist between patients with secondary OA due to Crowe type I/II DDH and end-stage primary OA. The findings are of clinical relevance, as they suggest that patients with both secondary OA due to mild dysplasia and primary OA demonstrate a highly variable joint geometry and proximal femoral canal shape; however, most patients with mild DDH seem appropriate for cementless femoral reconstruction with off-the-shelf implants when multiple offset and size options are available. Outliers need to be identified during preoperative planning for optimal implant choice.

Conflict of interest

The authors declare no conflict of interest.

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