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Are there clinically relevant anatomical differences of the proximal femur in patients with mild dysplastic and primary hip osteoarthritis?

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A CT-data based matched pairs cohort study

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Abstract

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

Methods: This retrospective radiographic CT-data based study investigated the proximal femoral anatomy in a consecutive series of 84 patients with secondary hip OA due 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°; $p<0.001$), while 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 higher neck shaft angle (128° ± 7° vs. 123° ± 4°; $p<0.001$). 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 for both groups.

Conclusion: Patients with secondary hip OA due to mild DDH can be equally treated with cementless stem designs compared to primary hip OA, however subtle anatomical differences of the proximal femur should be respected.

Keywords: anatomy, proximal femur, hip, osteoarthritis, dysplasia

Level of evidence: Diagnostic Level IV

Introduction

Total hip arthroplasty in secondary forms of 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 anatomic 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 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 osteoarthritis, 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 to debate as to what the optimal method choice of femoral implant is for such patients in order to achieve secure endosteal fit.

Therefore, this study aims 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), specifically asking:

1) How do the anatomic parameters for femoral head size, femoral offset, femoral anteversion, neck shaft angle, femoral canal torsion and leg torsion differ between both groups of patients?
2) Are there specific patterns of proximal femur canal shapes and rotational alignment of the lower extremities comparing both groups of patients?

Patients and Methods

Study Cohort

This retrospective radiographic matched-pairs cohort study investigated preoperative computed tomography (CT) scans of a consecutive case series of 84 patients with end stage osteoarthritis due to mild developmental dysplasia of the hip (Crowe type I/II) and 84 matched patients with primary hip osteoarthritis. All patients gave informed consent and the study was approved by the institutional review board (S-272/2009). 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 Diakonie-Klinikum Stuttgart, Germany. We included all European/White Caucasian consecutive patients in the study cohort with the diagnosis of advanced osteoarthritis of the hip due to developmental dysplasia of the hip (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-centered anteroposterior (AP) radiographs of the pelvis: center-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 “mild” developmental dysplasia and end stage secondary OA of the hip were identified. These patients were matched to patients with the diagnosis of primary osteoarthritis 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 standardized preoperative CT scans of the affected hip[11]. Demographic patient data is presented in table 1.

Table 1: Patient demographics and distribution of study and control group; mean (SD)

Variable	Study group (Secondary OA due to DDH)	Control group (Primary OA)	p value
Number of hips	84	84	-
Gender (F:M)	54 : 30	54 : 30	-
Age at surgery (yrs.)	54.0 (8.2)	55.1 (7.6)	0.385
Body mass index (kg/m²)	27.5 (6.8)	26.8 (5.5)	0.446

Radiographic Assessment

Preoperative digital low-centered calibrated anteroposterior (AP) radiographs of the pelvis were taken with the patient in the supine position, legs in 15° internal rotation and centered 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 standardized with TraumaCad software (Version 2.2, Voyant Health, Petach-Tikva, Israel)[12].

Preoperative CT scans were performed with a Toshiba Aquilion 16 CT scanner (Toshiba, Tokyo, Japan) in all patients and supine position with their 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 distal to the femoral isthmus, and (3) four to six slices of the knee (slice spacings 4, 8 and 2 mm, gantry tilt 0°, 120 kV, field of view 250 mm)[11].

Standardized CT measurements were performed using a validated software (Matlab, version 7.10; The MathWorks, Natick, Massachusetts)[11]. The femoral shape was determined by analyzing the manually set "best fit" circle, oval or axis on the following axial CT slices in each patient on twelve standardized 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 (Figure 1 A & B).

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 scanner[8,11]. Femoral offset was defined as the distance between the center of rotation of the femoral head and proximal femoral shaft axis, connecting the mid points of the slices at the center of the metaphysis (s4) and the isthmus of the femur (s10). 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&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&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 center of the femoral head and the centroid of the metaphysis (slices 2&4) and the proximal femoral shaft axis (FSA). In order to analyze the three-dimensional endosteal shape of the proximal femur and endosteal femoral torsion, the area of each ellipse on the levels s4-s10 was measured in cm^2 (Figure 2). Furthermore, the Canal Flare Index (CFI) was calculated for the slices s4-9 to quantify the endosteal increment of the proximal femur canal size as illustrated by the green and purple line in Figure 1 (CFI_x = area $slice_x$/area $slice_{10}$; with x ranging from 4 to 9).

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

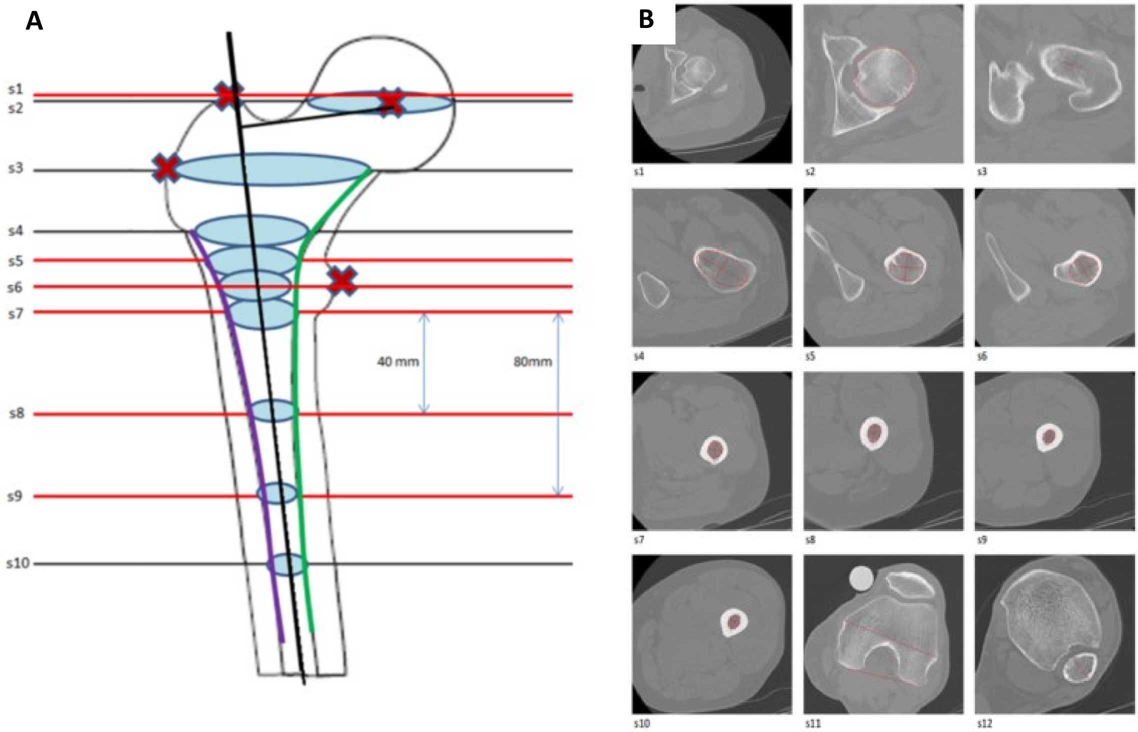

Figure 1 A & B illustrating the three-dimensional analysis of the shape of the proximal femoral torsion measuring the rotation and area of each ellipse on the levels s4-s10.

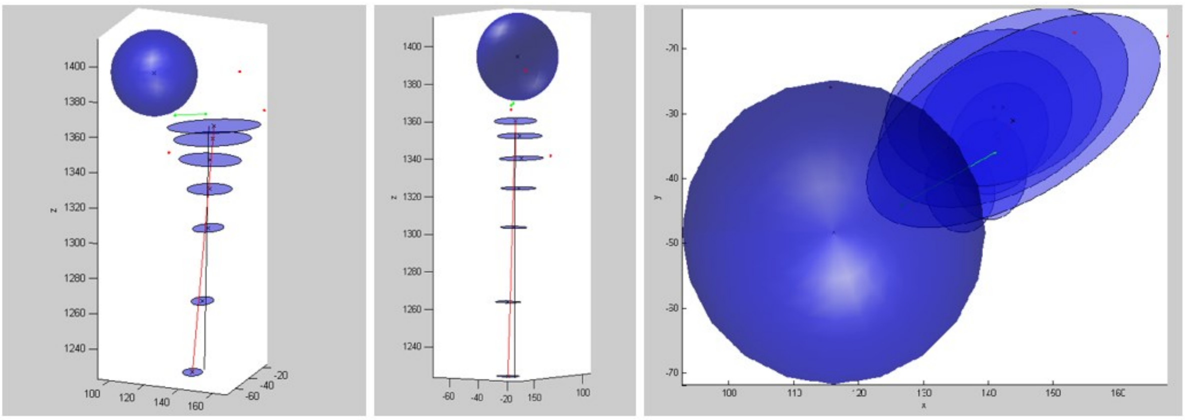

Figure 2 illustrating the three-dimensional model describing the shape and geometry of the proximal femoral measuring the rotation and area of each ellipse on the levels s4-s10.

Statistical analysis

Continuous variables were expressed as mean values in millimeters or degrees including standard deviations (SD). Variables were tested for normal distribution using a 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 inter-observer 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 % CI; 0.53 – 0.91) to 0.99 (95 % CI; 0.97 – 0.99).

Comparing both groups, only minor differences were observed. 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).

Table 2: Radiographic measurements for the study and control group; mean (SD)

	Study group (Secondary OA due to DDH)	Control group (Primary OA)	p value
Head diameter (all patients)	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)	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)	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 antetorsion (all patients)	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)	-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)	-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 ($p < 0.05$)

Analyzing the three-dimensional shape of the proximal femur (s4-10), 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 (s6: +0.4 cm^2; p=0.047), while the femoral canal showed a less pronounced narrowing distally (s8: +0.2 cm^2; p=0.010; s9: +0.1; p=0.023) Both groups showed a comparable pattern pattern of endosteal femoral torsion, however a high inter-individual variability for both groups at the meta-diaphyseal level was observed(S7: 10.3°, SD 43.4 & 5.6°, SD 49.1) (Table 3 & Figure 3 A-C).

Table 3: Three-dimensional measurements for femoral canal torsion, canal size and canal flare index (CFI) for each ellipse on the levels s4-s10 of the proximal femur for the study and control group; mean (SD)

	Study group (Secondary OA due to DDH)	Control group (Primary OA)	p value
Femoral Canal Torsion in °			
S4 (Centroid)	4.5 (36.4)	4.9 (4.5)	0.632
S5	0.6 (9.8)	-1.5 (11.3)	0.208
S6 (Lesser trochanter)	-14.4 (21.2)	-17.5 (21.9)	0.355
S7	10.3 (43.4)	5.6 (49.1)	0.504
S8	59.0 (21.8)	60.1 (18.0)	0.724
S9	71.2 (16.2)	70.7 (19.2)	0.858
Femoral Canal Size in cm²			
S4 (Centroid)	9.9 (2.1)	9.8 (1.9)	0.826
S5	9.1 (2.2)	8.7 (1.7)	0.185
S6 (Lesser trochanter)	6.3 (1.6)	5.9 (1.2)	0.047*
S7	3.5 (1.0)	3.3 (0.8)	0.125
S8	2.1 (0.6)	1.9 (0.4)	0.102
S9	1.5 (0.5)	1.5 (0.5)	0.417
Femoral Canal Flare Index			
S4 (Centroid)	8.7 (2.9)	8.4 (2.6)	0.536
S5	8.0 (2.8)	7.5 (2.3)	0.185
S6 (Lesser trochanter)	5.5 (1.7)	5.0 (1.5)	0.064
S7	3.0 (1.0)	2.8 (0.7)	0.068
S8	1.7 (0.5)	1.6 (0.3)	0.010*
S9	1.3 (0.3)	1.2 (0.1)	0.023*

* indicating significance ($p < 0.05$)

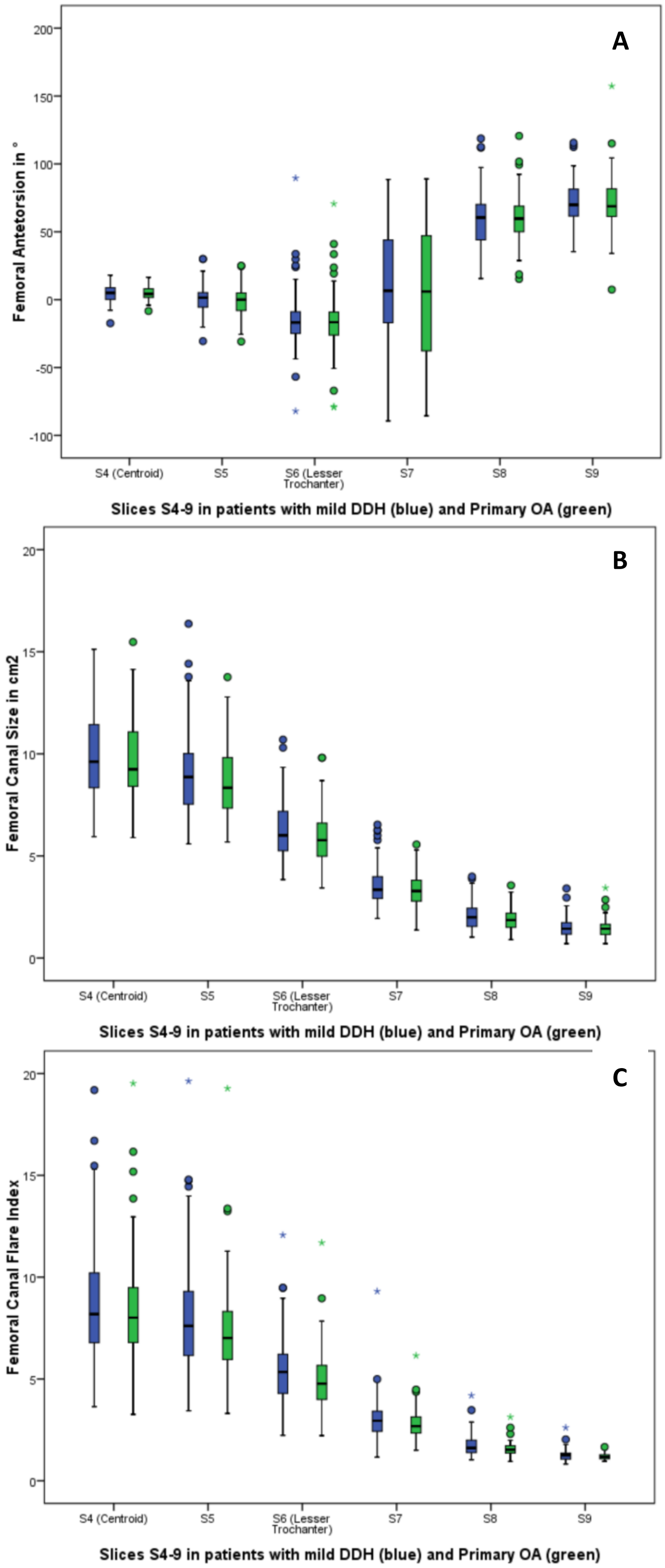

Figure 3: Boxplots illustrating A: Femoral Canal Torsion, B: Femoral Canal Size in cm^2 and C: Femoral Canal Flare Index for the slices S4-9 in patients with mild DDH (blue) and Primary OA (green).

Discussion

There an ongoing debate in which proportion of patients with advanced OA due to mild DDH standard straight stems or short stems can be safely used to achieve secure endosteal stem fit and joint geometry reconstruction. Therefore, knowledge of 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 complications like instability, stem subsidence or intraoperative periprosthetic femoral fractures[19,20].

Answering our research questions, our study found limited and rather small anatomical differences of the proximal femur and the endostealcanal shape in patients with mild dysplastic compared to those with primary hip osteoarthritis. However, a high inter-subject variability for femoral canal torsion in both groups at the meta-diaphyseal level was observed.

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. We tried to minimize this by including all patients with the 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. Our 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. However the fact that a substantial number of patients with DDH have a history of prior surgery patients at the time of THA, this can also be interpreted as a strength of the study.

Interpreting our results with regard to clinical relevance in context of the literature, the most important limitation is that only two CT-data based studies exist and have investigated the anatomy of the proximal femur in DDH patients compared to matched healthy controls but excluded patients with osteoarthritis[7,8]. In our study, we could not detect any differences between DDH Crowe type I/II and primary OA patients for femoral version, endosteal isthmus canal width and diameter in the 3D 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]. We presume that 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 our 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 36.0 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[21,22]. 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 center of rotation is necessary during cup preparation.

Conclusion

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

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