acta orthopaedica belgica, 2024, 90, 581-587

doi.org/10.52628/90.4.13095

Rectangular femoral stems can successfully accommodate the medullary canal in patients with severe hip dysplasia operated on with total hip arthroplasty and a shortening osteotomy: A morphometric study

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The current study aimed to objectively evaluate the fit of a rectangular, tapered stem to the severely dysplastic hips on the basis of the proximal femoral anatomy and the dimensional properties of the stem. It was hypothesized that the stem size planned with accordance to the diaphyseal canal width alone can accommodate the distal femur successfully with no sizing mismatch.

Forty-six patients (53 hips) suffering from secondary osteoarthritis due to hip dysplasia scheduled for total hip arthroplasty (THA) with a subtrochanteric transverse shortening osteotomy were included. All hips were Crowe type 4. All patients underwent preoperative computed tomography imaging. Height of femoral head center (HCH) was determined. Medullary canal diameter measurements at different levels were made. These were made at a level (1) 35% of HCH above the lesser trochanter (DT +35), (2) 70% of HCH below the lesser trochanter (DT -70), and (3) at the level of isthmus (Di). Medullary canal flare indices were calculated from the individual parameter ratios. Similar measurements were carried out for the different sizes of the femoral stem.

The mean DT +35 was 41.9 ± 6.4 mm, the mean DT-70 was 17.3 ± 2.2 mm, and the mean Di was 12.8 ± 1.9 mm. In all femurs, the width of the isthmus was wider than that of the corresponding femoral stem isthmus. The femoral stem sizes established with respect to the diaphyseal width of the femur were all compatible with the isthmus width of the femur.

Tapered and rectangular stems can accommodate the proximal femur above and below the osteotomy level in Crowe type IV hip dyplasia patients, thereby constituting a viable option as the femoral stem in this patient group with technically demanding difficulties.

Keywords: Total hip arthroplasty, developmental dysplasia of the hip, subtrochanteric osteotomy, rectangular stem, Zweymuller.

INTRODUCTION

Developmental dysplasia of the hip (DDH) is among the leading causes of secondary osteoarthritis of the hip joint (Engesæter et al., 2008; Jacobsen et al., 2005). Total hip arthroplasty (THA) is the most effective treatment for relieving pain, restoring joint function, and correcting leg-length discrepancies in patients with severe coxarthrosis secondary to DDH (Engesæter et al., 2008). Due to the disrupted anatomy of the proximal femur and altered shape of the acetabulum, THA in patients with severe dysplasia raises technical challenges. Restoration of the hip center of rotation in an anatomical position has been shown to yield good biomechanical results (Bicanic et al., 2009). To accomplish this purpose, a shortening osteotomy is needed. Transverse, oblique, step-cut, double-chevron, and V-shaped osteotomies have been shown to yield successful clinical results in this regard (Ahmed et al., 2015; Krych et al., 2010).Of these methods, subtrochanteric transverse osteotomy (STO) is an easier technique, which enables simultaneous shortening of the femur, correction of excessive anteversion, and preservation of the proximal femoral metaphysis (Chareancholvanich et al., 1999).

Regarding the femoral implant, variabilities in dysplastic proximal femoral anatomy may compromise implant stability, when a fit-and-fill component in applied. A rectangular, tapered, cementless stem with its fit-without-fill design could constitute an ideal option for dysplastic hips with its low price and proven primary and secondary stability (Mu et al., 2016).However, a lack of knowledge exist regarding the stem measurements and it's relevance to individual patient's morphometric properties with respect to the proximal femoral anatomy.

The present study aimed to quantitatively verify the better fit of this implant type to dysplastic bone by determining relevant parameters of intramedullary canal flare measurements at different levels on proximal femur. Accurate fit of the femoral component to dysplastic bone and therefore sufficient rotational stability at the osteotomy site in patients with Crowe type IV dysplasia would further support the use of these implants in this patient group.

The hypothesis was that rectangular, tapered femoral stem would successfully accommodate the proximal femur in dysplastic hips with a transverse osteotomy, given that[1] the stem size determination is made with respect to proximal diaphyseal level measurements, where rectangular stem primarily anchors, and[2] width of the stem is narrower than the canal diameter at the isthmus level.

SUBJECTS AND METHODS

As per the routine follow-up protocol, authors collected computed tomography (CT) scans of the bilateral hips of DDH patients. From January 2011 to December 2018, 249 THAs were performed on patients with DDH, and the results were retrospectively analyzed. The study included 46 patients (53 hips) with secondary osteoarthritis due to severe dysplasia, which corresponded to type IV as proposed by Crowe et al.[8]. All patient were operated on with THA and subtrochanteric transverse osteotomy using a tapered, rectangular, press-fit femoral component (Zweymuller stem, SL-PLUS femoral hip stem; Smith & Nephew, Andover, MA, USA). Patients who had been operated on the affected hip prior to the study were excluded from the study group. Of the participants, 44 were female (51 hips) and two were male (two hips). The mean age at the time of surgery was 41.5 ± 7.0 years (range: 24–50).

Parameter measurements

A standard imaging protocol was followed preoperatively for all patients, including pelvic AP views, AP and lateral views of the affected hip, a full-length view of the lower extremities, and computed tomography (CT) imaging of the pelvis and proximal femurs (Somatom Sensation Cardiac, Siemens, Erlangen, Germany). All CT scans were conducted with the patient lying symmetrically in a supine position. The pelvis was positioned neutrally, with the anterior iliac crests and pubic symphysis evenly resting on the table. The scanning area extended from the fourth lumbar vertebra down to the distal third of the femur, with a slice thickness of 1.0 mm and an inter-slice space of 1.0 mm. Images were imported in DICOM format into the Virtuoso software (Siemens Medical Systems)[9] and axial CT images were used for measurements.

Measuring the canal flare indices

The center and diameter of the femoral head was determined with the best filling circle. excluding severely deformed regions from the calculation[10]. The head center height (HCH), defined as the vertical distance from the center of the lesser trochanter (LT) to the center of the femoral head, was measured. The mediolateral (ML) and anteroposterior (AP) widths of the medullary canal were measured at three levels relative to the LT in the preoperative CT images LT +35 level: A transverse slice at 35% of the HCH above the LT, corresponding to the collum osteotomy level in THA.

At the LT +35 level, the ML width exceeded the AP width, so an ellipse was used to measure the internal diameter of the canal. At the other levels, a best-fitting circle provided the most accurate canal width measurement (Figure 1). The diameters at each level were determined as DT +35, DT -70, and Di, with DT +35/Di representing the overall canal flare index, DT +35/DT -70 the metaphyseal canal flare index, and DT -70/Di the diaphyseal canal flare index. The vertical distance from the LT center to the isthmus was recorded as the isthmus position[11].

Acetate templates from SL-Plus implants were scanned and imported into SketchUp (Trimble

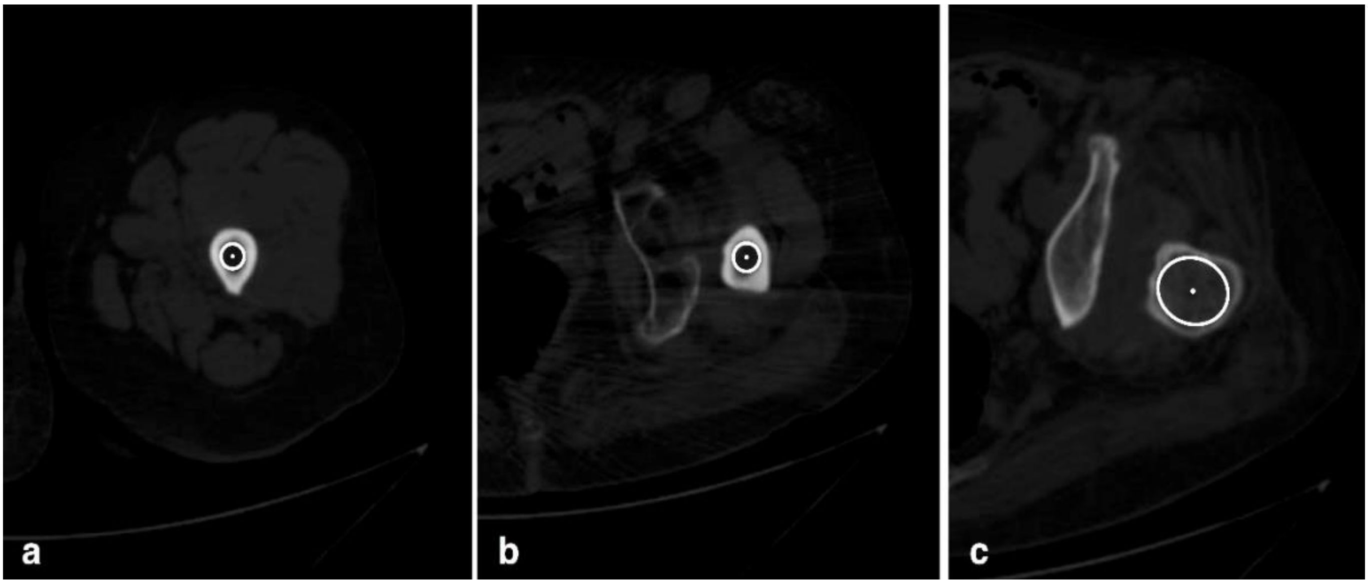

Fig. 1 — Axial CT images showing the plane of the isthmus (Ti) (a), DT−70 (b), and DT+35 (c) for the right hip of a 47-year-old woman.

Inc., Sunnyvale, CA, USA) as PNG files. Similar measurements and indices were calculated using the software (Figure 2).

Next, stem size was determined for each femur based on the diaphyseal width at the DT +70 level to ensure cortical anchorage. Optimal anchorage was achieved by matching the diaphyseal width of the bone to the stem size. Stem flare indices (SFI) were also calculated: (1) overall SFI (DT +35 / Di), (2) metaphyseal SFI (DT +35 / DT +70), and (3) diaphyseal SFI (DT +70 / Di)[12].

Finally, the stem sizes used during surgery were noted from patient records, and complications, including union status at the osteotomy site, were investigated in follow-up radiographs[13].

Statistical analysis

A musculoskeletal radiologist measured the canal flare indices using the CT images. The means, ranges, and standard deviations of the measurements were calculated. SPSS ver. 17.0 for Windows (SPSS, Chicago, IL, USA) was used in all analyses. G*Power, version 3.1.9 (University of Kiel, Germany) was used to determine sample sizes.

RESULTS

The results of power analysis showed that 3 hips for each size were required to reveal differences at a 5% significance level with 80% power, using a large effect size (0.8). Table I and Table II show the results for stem measurements and all intramedullary parameters, including the position of the isthmus, DT+35, DT−70, and Di.

In all femurs, the width of the isthmus was ≥ 2 mm wider than that of the corresponding femoral stem isthmus (Appendix). Moreover, in these femurs, the femoral stem sizes established with respect to the metaphyseal width of the femur were compatible with the proximal metaphyseal flare index to ensure anchorage around the metaphysis (Table III).

Retrospective analysis revealed that the preoperatively determined stem sizes using CT images were identical to those used during surgery in all patients. Two patients (three hips) experienced intraoperative fractures, which consisted of one acetabular, one proximal, and one distal femoral fracture. Plate insertion was used to treat the acetabular fracture, and cerclage bands were applied to treat the femoral fractures. All fractures healed with no further complications. The six-month follow-up radiographs of the patients showed that union occurred at the osteotomy site in all patients (Figure 3).

DISCUSSION

The current study was able to show, that rectangular, tapered stems can successfully accommodate the proximal femur in the presence of a transverse osteotomy. This conclusion was made available with the morphometrical measurements obtained at three different levels of the proximal femur and the corresponding dimensional properties of the femoral component. Canal flare indices along with stem flare indices revealed that the stem size planned with accordance to the diaphyseal canal width alone can accommodate the femur successfully with no sizing mismatch in a Crowe type IV group of patients.

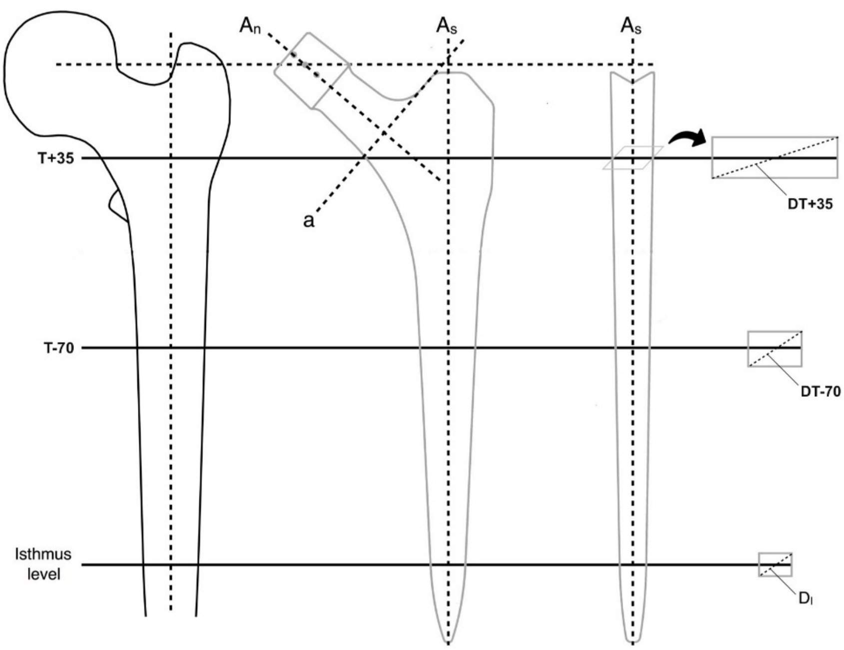

Fig. 2 — Axis of the neck (An): Two transverse lines (proximal and distal) were drawn across the neck connecting the superior and inferior edges. A line connecting the midpoints of the two cross-neck lines was defined as the axis of the neck.
Axis of the stem: Two transverse lines (proximal and distal) were drawn across the stem connecting the lateral and medial edges. A line connecting the midpoints of the two cross-stem lines was defined as the axis of the stem (As).
A line was drawn through the base of the neck perpendicular to the axis of the neck (a). The intersection of the line with the medial edge of the stem was defined as T+35. The ML and AP widths of the stem were measured at this level, and the diagonal length was calculated (DT+35).
Two lines perpendicular to the axis of the stem from the center of the femoral head and T+35 were drawn, and the length between the two intersection points was defined as 65% of the height of the femoral head from the center of the lesser trochanter (HFH) [13]. Below 70% of HFH from T+35 was defined as T−70 [13]. The ML and AP widths of the stem were measured at this level, and the diagonal length was calculated (DT−70).
The level at which the conicity of the stem tip begins was defined as the isthmus of the stem. The ML and AP widths of the stem were measured at this level, and the diagonal length was calculated (Di). Below 35% of HFH from T+35 was defined as the level of the lesser trochanter (T) [13]. The vertical distance from T to the isthmus was defined as the position of the stem isthmus.

In THA without a STO, the early stability of the cementless femoral stem, in particular its rotational stability, can be established using either a proximally, a distally, or both proximally and distally fitting stem. To establish rotational stability at the osteotomy site after STO, the stem should be able to obtain sufficient fit both proximally and distally.

An important issue in addition to establishing a post-STO rotational stability is fixating the osteotomy site. Distal fit of stem below the osteotomy site should obtain four point contact on endosteal cortices for better primary fixation. Previous studies have shown excellent result with the use of the rectangular femoral stem without the need for an additional fixation method or graft at the osteotomy site[14].

Of note, the femoral stem sizes used in dysplastic hips are relatively smaller than primary total hip arthroplasty cases. A previous study reported that the majority of patients with dysplastic hips were operated on with the use of smallest stems, similar to the finding of this study[14,15].

Therefore, the proximal medullary canal was examined on two separate regions as above and below the osteotomy level with metaphyseal and diaphyseal flare indices. Metaphyseal width measurements at LT−70 level was used for stem size determination and distal flare measurements

Table I. — Parameters (n = 53 hips).

Parameters	Mean ± Standard deviation	Minimum	Maximum
DT+35 (mm)	41.9 ± 6.4	31.9	52.7
DT−70 (mm)	17.3 ± 2.2	14.0	21.6
Di (mm)	12.8 ± 1.9	9.8	16.3
Position of isthmus (mm)	77.0 ± 6.4	66.2	90.0
Overall CFI (DT+35/ Di)	3.3 ± 0.3	2.8	4.4
Metaphyseal CFI (DT+35/ DT−70)	2.4 ± 0.2	2.1	3.3
Diaphyseal CFI (DT−70/Di)	1.4 ± 0.0	1.3	1.5

CFI, canal flare index.

Table II. — Dimensional properties of the femoral component.

Implant Size	DT+35 (mm)	DT−70 (mm)	Di (mm)	Position of isthmus (mm)	Overall SFI (DT+35/ Di)	Metaphyseal SFI (DT+35/ DT−70)	Diaphyseal SFI (DT−70/Di)
S01	26,9	13,2	8,6	64,8	3,13	2,04	1,53
S0	27,7	13,8	9	66,7	3,06	2,01	1,52
S1	28,7	14,4	9,6	67,7	2,99	1,99	1,5
S2	29,8	15	10,3	69,6	2,89	1,98	1,46
S3	31,1	16,1	10,8	72,7	2,89	1,93	1,49
S4	32,3	17	11,7	73,7	2,76	1,9	1,45
S5	33,6	18	12,4	77,5	2,72	1,86	1,46
S6	35	19,1	13,4	78,7	2,61	1,83	1,42
S7	36,5	20,2	14,4	81	2,54	1,81	1,41
S8	38	21,4	15,4	83,2	2,47	1,78	1,39
S9	39,7	22,8	16,5	86	2,4	1,75	1,38
S10	41,4	24,1	17,7	88,7	2,33	1,72	1,36
S11	43,4	25,6	19,3	90,1	2,24	1,69	1,32
S12	45,3	27,4	20,8	93,9	2,18	1,65	1,32

SFI, stem flare index.

Table III. — Femoral component sized and patient distribution.

Femoral component size	-1	0	1	2	3	4	5	6	7	8
Number (%) of patients	19 (36%)	10 (19%)	10 (19%)	4 (8%)	3 (6%)	2 (4%)	2 (4%)	1 (2%)	1 (2%)	1 (2%)

confirmed bone-prosthesis fit below this level in all patients without outliers. This conformity is important in terms of rotational stability and hence, fixation of the osteotomy.

The level of the canal isthmus (Ti) was at least 66.2 mm below the STO level (DT−70). Considering that approximately a 4 cm length of bone is shortened intraoperatively[16,17] wherefore the removed segment is understood to be above the level of the isthmus. This fact further empowers the conclusion deduced from the flare indices in this study.

In this study, isthmus widths of the applied prosthesis were narrower than that of the intramedullary canal diameters at the isthmus level in all patients. The stem is more "tapered" than the medullary canal width flare, as indicated by diaphyseal canal flare index measurements of individual femurs and stem flare indices of the corresponding stem sizes. Thus, it is possible to fixate the osteotomized proximal femur regardless of the amount of shortening, and the stem design will provide four-point rotational support on the axial plane.

In this study, most severe drop in the medullary canal diameters occurred between T+35 and T−70 levels, whereas the minimum drop occurred between the T−70 and Di levels, as indicated by the values

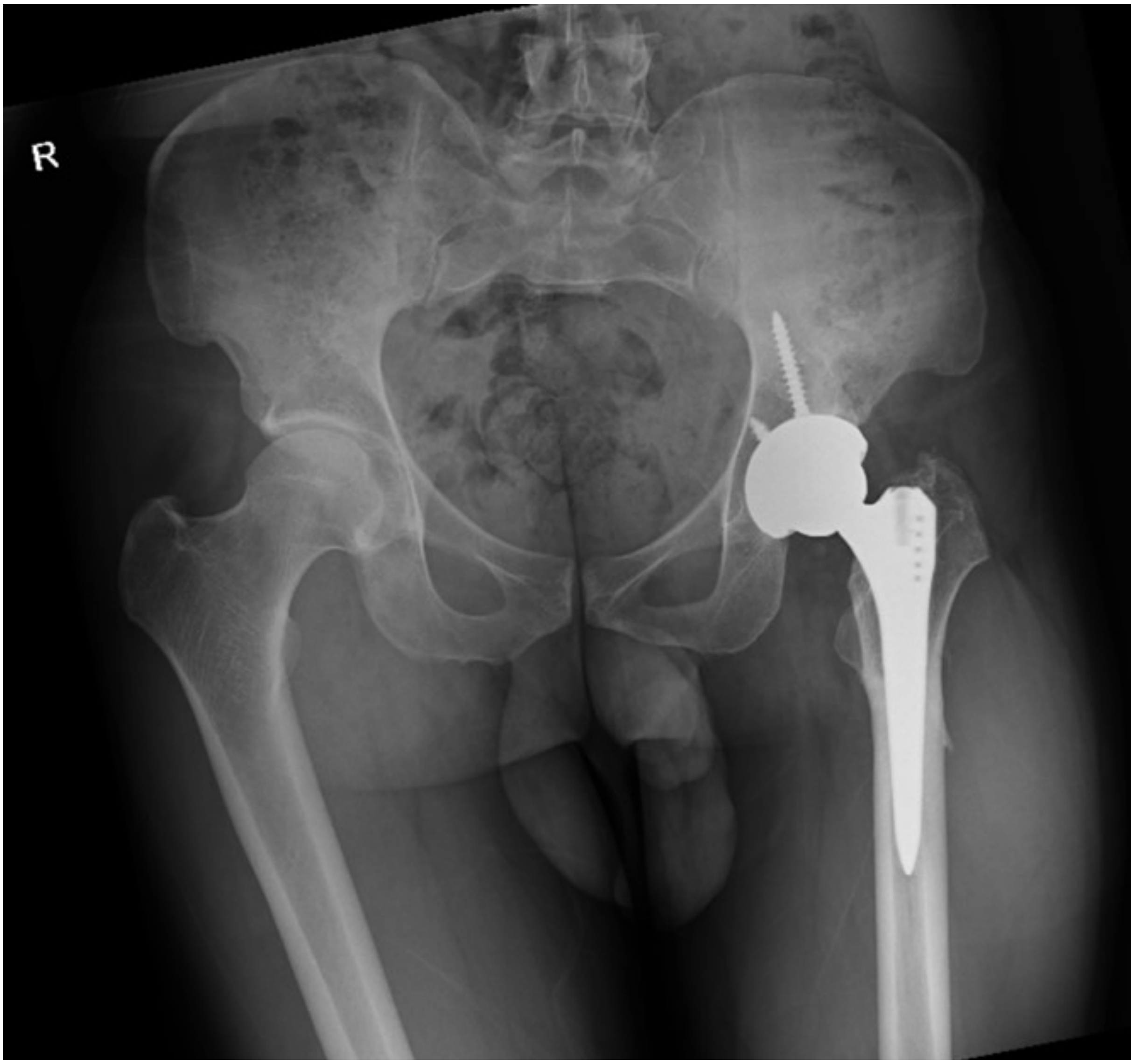

Fig. 3 — Postoperative x-ray image of a patient.

of the metaphyseal and diaphyseal flare indices, which are 2.4 and 1.4, respectively. In other words, narrowing predominantly occurred at the metaphyseal and proximal diaphyseal levels, the segment in which the rectangular cross-section of the Zweymuller stem obtains three-point fixation[16]. Further below there is a straight canal, where the Zweymuller cross-section provides four-point rotational support (Philip C Noble 1, 2003; Zweymuller & Semlitsch, 1982).

The Zweymuller stem is rectangular, tapered, and grit-blasted. The ability to acquire fixation to bone along it's entire length renders it an appealing option for fixation in the presence of a shortening osteotomy[18]. In this study, an applicable method was employed to derive the canal flare indices for THA with subtrochanteric osteotomy. The width of the medullary canal at different levels was measured in both below and above the osteotomy level. Moreover, using the diameter of the best filling circle to depict the contour of the medullary canal on the slices distal to the osteotomy can counteract the effects of medullary canal rotation on the canal flare index after the osteotomy.

The cross-sectional shape of the medullary canal in dysplastic femurs was remarkably similar: For the sections through the proximal metaphysis, medullary canal had larger ML widths than AP widths, for the rest of the proximal femur, the ML and AP widths of the medullary canal were considerably similar. This finding contradicts the observations of Sugano, who reported that the DDH canal was narrower in the sagittal plane than it was in the frontal plane[10].

There are limitations to this study. First, these findings are limited to the specific femoral component used in this study. Although its design is not dissimilar to many other tapered, rectangular, press-fit implants currently available, these findings may not be generalizable to other total hip designs. Second, the authors did not obtain repeatability or intraobserver variability data for the CT measurements, although similar studies reported good agreements. Third, the retrospective design of the study causes a selection bias. Finally, and most importantly, in clinical practice, plain radiography is a routine examination method. However, because of flexion contracture and malrotation of the hip, plain radiography often fails to reveal the real anatomical characteristics of the hip joint in DDH. Three-dimensional studies can overcome this obstacle.

CONCLUSION

Tapered and rectangular stems can accommodate the proximal femur in the presence of a transverse shortening osteotomy in Crowe type IV hip dysplasia patients, thereby constituting a viable option as the femoral stem in this patient group with technically demanding difficulties. A femoral stem size planned with accordance to the canal width at LT -70 alone is indicative of a successful accommodation even on more distal regions with no size mismatch below this level.

Conflict of Interest: The authors declare that they have no conflict of interest.

Funding: There is no funding source.

Ethical approval: This article does not contain any studies with human participants or animals performed by any of the authors.

Informed consent: Informed consent was obtained from all individual participants included in the study.

Acknowledgements: There is no acknowledgement.

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