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Proximal Femoral Asymmetry in Japanese Patients before Total Hip Arthroplasty

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Abstract

Templating is an important and established step in the preoperative planning process of total hip arthroplasty (THA) in order to select the size and position of the implant. In severely arthritic cases, the unaffected contralateral side is sometimes used as a reference to reconstruct morphological parameters of the planned implantation (ipsilateral) side, for example the femoral offset, the leg length or the antetorsion. Recent studies have shown that a significant side-to-side asymmetry of important proximal femoral parameters already exists in healthy subjects questioning the validity of the contralateral side as a reference. However, if preoperative asymmetry is larger than asymmetry in healthy subjects, preoperative planning can still make use of the contralateral side to target a postoperative result within the range of physiological asymmetry. Therefore, the specific objective of this study was to quantify the preoperative side-to-side asymmetry of five important morphological parameters of the proximal femur. Significant side-to-side differences between the ipsilateral side and the contralateral side were detected for the antetorsion, the offset, the neck length and the femoral length. The antetorsion is significantly higher for the ipsilateral side whereas offset, neck length and femoral length are significantly smaller. Mean and maximum difference in antetorsion is almost twice as high for the THA patients in comparison to healthy subjects. The same trend can be observed for the femoral length, less pronounced also for the caput-collum-diaphyseal angle. The comparison of proximal femoral side-to-side differences for subjects before THA and healthy subjects leads to the conclusion that contralateral templating can be a reasonable basis for THA planning of severely arthritic hips if the contralateral side shows no signs of osteoarthritis or developmental dysplasia.

1 Introduction

Templating is an important and established step in the preoperative planning process of total hip arthroplasty (THA) in order to select the size and position of the implant (Della Valle 2005). Two-dimensional templating with anterior-posterior radiographs of the pelvis is a widespread method in clinical praxis (Iorio 2009; Petretta 2015; Eggli 1998). Three-dimensional templating based on CT for navigated surgery or patient specific instrumentation (Spencer-Gardner 2016) is less common but more accurate than 2D templating (Sariali 2012). In severely arthritic cases, the unaffected contralateral side is sometimes used as reference to reconstruct morphological parameters of the planned implantation (ipsilateral) side, for example the femoral offset, the leg length or the antetorsion (Unnanuntana; Lecerf 2009; Cassidy 2012; Suh 2006; Pasquier 2010; van Embden 2015; Ranawat 1997; Della Valle 2005; Eggli 1998). Recent studies have shown that a significant side-to-side asymmetry of important proximal femoral parameters already exists in healthy subjects (Young 2013; Dimitriou 2016; Laumonerie 2018) questioning the validity of the contralateral side as reference (Laumonerie 2018). However, less is known about the amount of preoperative asymmetry of patients undergoing THA. If preoperative asymmetry is larger than asymmetry in healthy subjects, preoperative planning can still make use of the contralateral side to target a postoperative result within the range of physiological asymmetry. Therefore, the specific objective of this study was to quantify the preoperative side-to-side asymmetry of five important morphological parameters of the proximal femur: antetorsion, caput-collum-diaphyseal (CCD) angle, offset, neck length and femoral length. The antetorsion is also known as anteversion or femoral version. The CCD angle is also known as neck-shaft angle.

2 Material & Methods

2.1 Patient data

A database of 200 preoperative CT scans of the pelvis and both femora from Japanese patients undergoing total hip arthroplasty was available for this study. Pelvis and femora were semi-automatically segmented using thresholding and a manual post-processing in order to receive closed bone surface meshes. The bone surfaces of the contralateral joint were visually inspected for signs of osteoarthritis at the acetabulum and the proximal femur. Subjects with osteoarthritic changes of the contralateral joint were excluded from the study. Reasons for exclusion were subchondral cysts, osteophytes, an irregular acetabular rim or a closing up of the acetabular fossa.

2.2 Automatic femoral parametrization

All proximal femora were parametrized using a newly developed framework that automatically calculates a femoral coordinate system (FCS). The subject femur is transformed to its inertia system to detect the long axis in order to scale an annotated template femur. The distal part of the template is registered to the subject minimizing the deviations between the femoral condyles of the subject and the template. The antetorsion of the template is adapted to the subject's antetorsion using dual-quaternion skinning-transformations with bounded biharmonic weights (Jacobson 2014). Subsequently, the template is non-rigidly registered to the subject and the annotated areas, such as head, neck, shaft or condyles, are mapped to the subject. The origin of the FCS is defined by the femoral head center (FHC) and calculated by fitting a sphere to the vertices of the head. The orientation of the FCS is defined by the table top plane (Hartel 2016) and the mechanical axis. An iterative refinement algorithm of the most posterior points of the condyles and the most posterior point of the trochanteric crest calculates the table top plane. The normal of the table top planes describes the posterior-anterior axis. The mechanical axis, being the connection between the intercondylar notch and the FHC, is projected on the table top plane defining the inferior-superior axis. The medial-lateral axis is orthogonal to the posterior-anterior and the inferior-superior axis. The femoral neck axis is refined by iteratively changing the orientation of cutting planes through the neck. The normal of the cutting contour with the smallest perimeter defines the neck axis. The shaft axis is the main inertia axis of the vertices of the shaft. The five femoral parameters were calculated as follows: The antetorsion is the angle between the neck axis and the posterior condyle line, both projected on the transverse plane defined by the FCS. The CCD angle is the angle between neck axis and shaft axis. The offset is the distance between the FHC and its projection on the shaft axis. The neck length is the distance between the closest point of the neck axis to the shaft axis and the projection of the FHC on the neck axis. The femoral length is the distance between the intercondylar notch and the FHC.

2.3 Statistical analysis

The paired side-to-side differences of the parameters between the ipsilateral side and the contralateral side were tested for normal distribution using Kolmogorov-Smirnov test. As the test for normal distribution was rejected for all parameters, Wilcoxon signed rank test was used to identify significant differences between the ipsilateral side and the contralateral side. Significance level was set at $\alpha = 0.05$.

3 Results

The automatic parametrization of the femur ran without error for all 200 subjects. However, 6 subjects were excluded due to extreme preoperative deformations of the ipsilateral side causing misdetection of the neck axis or the FHC. 53 subjects were excluded from the analysis due to osteoarthritic changes of the contralateral side. Another 14 subjects were excluded due to coxa vara (CCD angle < 120°) or coxa valga (CCD angle > 135°) of the contralateral side. This means that 127 subjects were included in the analysis. Significant side-to-side differences between the ipsilateral side and the contralateral side were detected for the antetorsion, the offset, the neck length and the femoral length. The antetorsion is significantly higher for the ipsilateral side whereas offset, neck length and femoral length are significantly smaller (Figure 1).

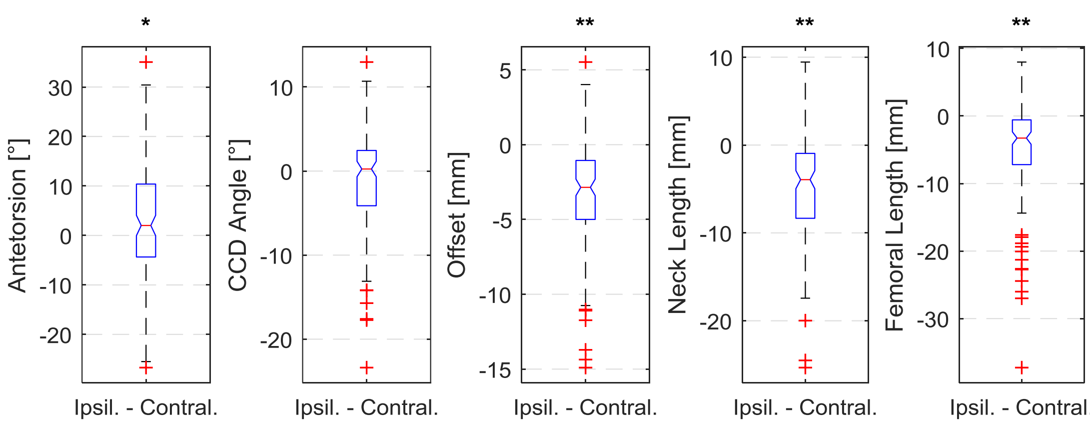

Figure 1: Boxplots of paired side-to-side differences (n = 127). Ipsilateral side minus contralateral side.

* → $p<0.01$, ** → $p<0.0001$.

The absolute differences were calculated in order to compare the results with previous studies of healthy subjects without osteoarthritic changes reported by Laumoniere et al. (Laumonerie 2018) and Dimitriou et al. (Dimitriou 2016) (Table 1).

Absolute differences	**Mean (standard deviation; minimum to maximum)**		
	Preoperative THA	**Healthy (Laumonerie 2018)**	**Healthy (Dimitriou 2016)**
Number of subjects	127	345	61
Antetorsion [°]	10.0 (7.8; 0.2 to 35.0)	5.1 (4.1; 0.0 to 18.7)	4.3 (-; 0.2 to 17.3)
CCD Angle [°]	4.4 (4.2; 0.0 to 23.4)	2.9 (2.4; 0.0 to 18.5)	2.3 (-; 0.2 to 14.9)
Offset [mm]	3.9 (3.2; 0.1 to 14.9)	3.8 (3.2; 0.0 to 15.4)	2.5 (-; 0.1 to 10.3)
Neck Length [mm]	5.8 (5.2; 0.1 to 25.3)	-	-
Femoral Length [mm]	6.0 (6.5; 0.1 to 37.3)	3.6 (2.9; 0.0 to 17.3)	2.9 (-; 0.0 to 8.5)

Table 1: Absolute paired side-to-side differences.

4 Discussion

Table 1 shows the difference in proximal femoral side-to-side differences between patients before THA and healthy subjects. Mean and maximum difference in antetorsion is almost twice as high for the THA patients. The same trend can be observed for the femoral length, less pronounced also for the CCD angle.

Some limitations of this study have to be considered. This analysis is limited to Japanese subjects. Laumoniere et al. reported that Asians have a higher CCD angle asymmetry than a Middle-Easterner population and Caucasians (Laumonerie 2018). Manual segmentation and reconstruction of the bone surfaces is subject to an intra- and inter-observer variability that may affect the automatic parametrization of the femur. Only the bone surfaces were used for the visual exclusion of contralateral femora with osteoarthritic changes. The grey level volume data of the CT scans should also be included into the exclusion process that should be based on an established grading system for osteoarthritis and developmental dysplasia in adult of the hip. The newly developed framework for parametrization of the femur proved to be a robust method. However, the automatic parametrization has to be validated against a manual approach. In this study, the results of the automatic approach were visually reviewed for misdetections. Extreme decrease in neck length or osteophytes at the neck can cause a misdetection of the neck axis or the FHC. To avoid these misdetections, the adaptation of the template femur could be improved by varying the neck length and the CCD angle in addition to the antetorsion.

5 Conclusion

The comparison of proximal femoral side-to-side differences for subjects before THA and healthy subjects leads to the conclusion that contralateral templating can be a reasonable basis for THA planning of severely arthritic hips if the contralateral side shows no signs of osteoarthritis or developmental dysplasia. Target parameters of the ipsilateral side can be planned within the limits of a physiological side-to-side asymmetry in consideration of the alignment of the cup. However, intraoperative deviations from the preoperative plan might be necessary to achieve an optimal soft tissue tension around the hip avoiding pain and a limited range of motion after THA. Providing an appropriate intraoperative guidance is one aspect of our ongoing research.

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