Femoral antetorsion after calcar-guided short-stem total hip arthroplasty: A cadaver study

Josef Hochreiter1,2 | Gernot Böhm3 | Johann Fierlbeck4 | Conrad Anderl1 | Marco Birke5 | Peter Münger6 | Reinhold Ortmaier1,2,7

1Department of Orthopedic Surgery, Ordensklinikum Linz GmbH, Barmherzige Schwestern Hospital, Linz, Austria
2Department of Orthopedics and Traumatology, Paracelsus Medical University, Salzburg, Austria
3Department of Diagnostic and Interventional Radiology, Ordensklinikum Linz GmbH, Linz, Austria
4Institute for Clinical Innovation, Paracelsus Medical University, Salzburg, Austria
5Institute of Anatomy and Cell Biology, Paracelsus Medical University, Salzburg, Austria
6Mathys Ltd Bettlach, Bettlach, Switzerland
7Research Unit of Orthopedic Sports Medicine and Injury Prevention, Institute for Sports Medicine, Alpine Medicine and Health Tourism, UMIT Private University for Health Sciences, Medical Informatics and Technology GmbH, Hall in Tirol, Austria

Correspondence
Josef Hochreiter, Department of Orthopedic Surgery, Ordensklinikum Linz GmbH, Barmherzige Schwestern, Seilerstätte 4, 4010 Linz, Austria.
Email: Josef.Hochreiter@ordensklinikum.at

Abstract
Calcar-guided short stems in total hip arthroplasty (THA) permit surgeons to successfully reconstruct postoperative femoroacetabular offset, accurately restore leg length, and adequately re-establish a wide range of caput-collum-diaphyseal angles. However, their effect on femoral antetorsion is less known. Indeed, controlling antetorsion of the femoral stem can be challenging because of the differences in individual femoral geometry and curvature. Therefore, we investigated if calcar-guided short-stem THA alters femoral antetorsion and compared it with conventional-stem THA. Using 12 Thiel-fixed, full-body cadaver specimens from donors without known hip disorders, we compared an uncemented calcar-guided femoral short-stem prosthesis with an uncemented conventional straight-stem prosthesis. In a paired study setup, each specimen received a calcar-guided short stem on one side and a conventional stem on the other. On the acetabular side, all specimens received a press-fit, monobloc acetabular cup. Femoral antetorsion angles were measured using the Waidelich method, and pre- and post-operative angles of both sides were recorded. The mean preoperative femoral antetorsion angles were similar in both groups (24.8° ± 7.5° vs. 23.8° ± 6.1°, p = 0.313). Mean postoperative femoral antetorsion angles were 23.0° ± 5.5° in short-stem and 13.5° ± 7.1° in conventional-stem hips. Short-stem hips had a small but nonsignificant difference in femoral antetorsion angles pre- and post-operatively (1.8° ± 3.2°, p = 0.109), while the difference for conventional-stem hips was much larger and highly significant (10.3° ± 5.8°, p < 0.001). Calcar-guided short-stem THA effectively restores femoral antetorsion. However, how this affects long-term clinical outcomes and complications warrants further exploration.

KEYWORDS
cadaveric study, calcar-guided short stems, femoral antetorsion, total hip arthroplasty
INTRODUCTION

The goal of total hip arthroplasty (THA) is to restore normal hip anatomy and biomechanics. To achieve this objective, crucial factors affecting the patient’s anatomy, including leg length, caput-collum-diaphyseal (CCD) angle, femoroacetabular offset, and femoral antetorsion, must be considered.1-4

To date, several hip prosthesis designs have been developed to accurately reconstruct the hip joint. Among them are calcar-guided short stems, which were designed to optimally adapt to the proximal femur’s anatomy and restore hip biomechanics. Their curved design renders individual stem positioning possible in a wide range of varus and valgus alignments.5 A conclusion confirmed by a clinical study in which calcar-guided short-stem prostheses allowed for accurate hip joint reconstruction in the studied patient population.6 In addition, calcar-guided short stems permit surgeons to successfully reconstruct postoperative femoroacetabular offset, accurately restore leg length, and adequately re-establish a wide range of CCD angles in most patients, contributing to the restoration of anatomical hip geometry and favorable midterm clinical outcomes.1,5-11

In addition to the abovementioned parameters referring to the anteroposterior view, antetorsion of the femoral component also plays an important role in proper hip stability.2,4,12,13 Both excessive antetorsion and retrotorsion can lead to impingement and instability.13 Correct component torsion is therefore necessary to achieve an impingement-free range of motion and prevent well-known complications of THA such as instability, dislocation, and component wear.2,13,14

Conventional stems have led to substantial reduction in femoral antetorsion angles after THA compared with preoperative values.4 However, to our knowledge, the long-term clinical significance of this has not been studied. Although calcar-guided short stems allow good anatomical reduction in the anteroposterior view, their effect on femoral antetorsion is less known.

For this reason, we carried out an in vitro study to examine (1) whether calcar-guided short-stem THA alters postoperative femoral antetorsion and (2) how calcar-guided short-stem THA compares with conventional-stem THA. We hypothesized that the femoral antetorsion angle would not change significantly from preoperative values after calcar-guided short-stem THA.

METHODS

Selection and preparation of cadaver specimens

The study included 12 Thiel-fixed full-body cadaver specimens from donors without known hip disorders, such as dysplasia, fracture sequelae, and proximal femoral bone defects, used according to institutional guidelines. The cadavers were prepared according to the standard protocol described by Thiel,15 using modified Thiel solutions.16

Surgical approach and implants

An anterolateral approach was used in the supine position without a traction table in all cadaver specimens. In all procedures, the hip was externally rotated. With 90° of knee flexion, the ipsilateral lower leg thus ended up in the horizontal plane, parallel to the operation table.

Both conventional and short stems were implanted according to the accompanying surgical techniques. In conventional stems, the implants were inserted with an antetorsion perpendicular to the lower leg, and the femoral neck did not guide the implant during insertion. In short stems, the implants were inserted along the partially preserved femoral neck (so-called “calcar-guided” implant insertion), which determined the final position of the implant.

Three senior orthopedic surgeons (J.H., C.A., and R.O.) from the same clinic operated on four cadaver specimens each (left and right side). The three surgeons had operated on over 100 cases using both implants included in this study, and therefore, no learning curve was associated with calcar-guided short-stem implantation.17

On the femoral side, an uncemented calcar-guided femoral short-stem prosthesis (optimys stem; Mathys Ltd Bettlach) was implanted and compared with an uncemented conventional straight-stem prosthesis similar to the Zweimüler design (CBH stem; Mathys Ltd Bettlach). Instead of actual implants, three-dimensionally printed stems made of polylactide and 28-mm trial heads made of polyphenylsulfone18 were used to minimize image artifacts. However, the implant bed was prepared using standard instruments. On the acetabular side, a press-fit, monobloc acetabular cup (RM Pressfit; Mathys Ltd Bettlach) was implanted in all cases.

All cadaver specimens were randomly assigned to the surgeons (four specimens each). In a paired study setup, calcar-guided short-stem implants were implanted on one side and conventional-stem implants on the other based on random side allocation, making sure that both groups had the same number of left and right implants.

Image acquisition and measurement of femoral antetorsion angles

All pre- and post-operative measurements were recorded with a computed tomography (CT) scanner (Somatom Emotion 6, Siemens) using the corresponding three-dimensional imaging software (Syngo Via, Siemens). All scans were performed helically with a vertical gantry using a layer thickness of 1.25 mm. We centered the specimens with feet parallel in a supine position and scanned them from the iliac crest to the knee joint. All images were reconstructed with an overlapping reconstruction technique to obtain images with a slice thickness of 0.8 mm. We used a hard kernel (UH90) and a bone window setting to obtain high-quality images for radiographic evaluation.

Femoral antetorsion was measured with the Waidelich method, which uses superimposed CT transverse slices.19 Femoral antetorsion was calculated as defined previously by measuring the angle between two lines: The first line connected the center of the femoral head or the head of the implanted prosthesis to the center of an ellipse.
around the greater trochanter. The second line connected the posterior aspect of the medial and lateral femoral condyles. To summarize briefly: we began by drawing a circle around the femoral head or the implanted prosthesis head, and then drew a straight line along the dorsal edge of the femoral condyles in the distal femoral area (Figure 1). Next, we drew an ellipse in the greater trochanter area where the posterior protrusion is clearly defined, transferred the head circle and condylar line to the height of the ellipse, and then drew a second straight line between the center of the ellipse and the center of the circle. Finally, we measured the angle between the lines, representing the femoral neck axis and the epicondylar axis, and documented the femoral anteversion angle.

2.4 | Statistical analysis

We used descriptive statistics (means, SDs, and 95% confidence intervals) to describe specimen characteristics and outcome variables at the measurement point. Paired t tests were used to determine pre- and post-operative differences in each specimen, and the Shapiro–Wilk test was applied to test for normality. The sample size was determined based on a paired scenario assuming a within-patient correlation of 0.85, yielding power of 80%. Statistical analysis was performed with SAS version 9.4 (SAS Institute Inc). A value of \( p < 0.05 \) (two-sided) was considered statistically significant.

3 | RESULTS

Baseline characteristics of the donor population are described in Table 1. The mean preoperative femoral antetorsion angles were similar in both short-stem and conventional-stem hips (24.8° ± 7.5° vs. 23.8° ± 6.1°, \( p = 0.313 \)).

The mean postoperative femoral antetorsion angle was 23.0° ± 5.5° in short-stem and 13.5° ± 7.1° in conventional-stem hips (Table 1). Short-stem hips had a small but nonsignificant difference in femoral antetorsion angles pre- and post-operatively (1.8° ± 3.2°, \( p = 0.109 \)). In sharp contrast, the difference between pre- and post-operative femoral antetorsion angles in conventional-stem hips was much larger and highly significant (10.3° ± 5.8°, \( p < 0.001 \)) (Figure 2).

**FIGURE 1** Pre- and post-operative CT scans of one specimen showing femoral antetorsion angles (°) using the Waidelich method. A Short-stem prosthesis was implanted in the right hip (A, C); a conventional straight-stem prosthesis was implanted in the left hip (B, D). The circles represent the femoral head or the implanted prosthesis head, the ellipses the greater trochanter area where the posterior protrusion is clearly defined, and the bold straight lines the measured femoral neck and epicondylar axes. CA, condylar axis; FNA, femoral neck axis.
FIGURE 2  Mean pre- and post-operative differences in femoral antetorsion angle (°) with 95% CI in short-stem and conventional-stem THA. THA, total hip arthroplasty

4 | DISCUSSION

In this paired in vitro study, we examined whether calcar-guided short-stem THA altered postoperative femoral antetorsion in the same way as conventional-stem THA. The results confirmed our hypothesis that the femoral antetorsion angle did not change significantly from preoperative values after calcar-guided short-stem THA.

Numerous studies exist about the effects of short-stem THA on primary stability, clinical scores, implant survival, and accurate anatomical reconstruction of the hip with the restoration of postoperative femoroacetabular offset, CCD angles, and leg length. Many of these have shown excellent mid-term clinical outcomes in these areas. However, only limited evidence is available on the effect of short-stem THA on femoral antetorsion. Addressing this topic, we found that short-stem THA preserved postoperative femoral antetorsion angles better than conventional-stem THA. Confirming our results, the authors of a recently published cadaveric study also found better restoration of femoral antetorsion with a metaphyseally anchored short-stem prosthesis compared with a short straight-stem and a conventional-stem prosthesis implanted in femoral specimens. However, in contrast to Ezechieli et al., our study was performed on full-body cadavers, which represents a more realistic model taking into account the effect of the soft tissues on the femoral antetorsion during implant bed preparation and insertion. Further in line with our findings, Müller et al. also found that conventional-stem THA resulted in a significantly lower postoperative femoral antetorsion angle than the preoperative value (7.4° vs. 24.9°, \( p < 0.001 \)). Although the loss of femoral antetorsion did not affect 1-year clinical outcomes in their study, long-term clinical significance of this phenomenon remains unknown.

Due to the curved design in calcar-guided short stems, an individual stem positioning is possible in a wide range of different varus and valgus alignments alongside the medial calcar. Moreover, the curved design of the short-stem prosthesis used in this study allows for better restoration of the physiological femoral offset than conventional stems. Implant positioning usually spares the femoral neck, with the implant guided along the calcar. This anatomical landmark, with metaphyseal fixation, makes it possible to adapt to particular anatomical situations.

With conventional stems, the surgeon’s estimation of the femoral component antetorsion is only approximate, and the surgeon can influence the antetorsion by twisting the stem more anteriorly. With short stems, however, implantation is guided more by the preserved femoral neck. In addition, femoral antetorsion is influenced by factors such as the anterior bowing, individual anatomy, and original
IMPROPER COMPONENT TORSION OF THE HIP IS KNOWN TO LIMIT THE RANGE OF MOTION AND INCREASE THE RISK OF COMPLICATIONS, SUCH AS IMPINGEMENT, INSTABILITY, DISLOCATION, AND COMPONENT WEAR.13,14,26 SHORT FEMORAL STEMs MAY REDUCE THE RISK OF THESE COMPLICATIONS DUE TO THEIR NONPOROUS SURFACE, A GOOD PRESS FIT AND THE ABSENCE OF DISEASE TRANSMISSION.28 THIEL‐FIXED cadavers are therefore considered suitable for use in orthopedic applications.28 Third, because femoral antetorsion can largely depend on the surgical technique, results may vary across clinics. Finally, we used three‐dimensionally printed short stem trials to minimize imaging artifacts, and therefore, our results may be applicable only to the stems evaluated. However, we did use the same procedures, approach, and instrumentation as in a standard in vivo THA, making the procedure comparable to a real‐life clinical scenario. Although polyphenylsulfone stems are smoother than metallic stems due to their nonporous surface, a good press‐fit can be achieved when using the right size. In this study, the appropriate size of the implants was chosen preoperatively.

Nevertheless, our study has several strengths. In particular, all surgeons involved in this study practice in the same clinic and therefore use the same surgical technique, limiting any technical differences. Additionally, we followed the Waidelich method for femoral antetorsion measurement using CT images in transverse planes. Due to the fixed anatomical landmarks, available both pre‐ and post‐operatively, this method is known to have high accuracy and reproducibility, as well as low intra‐ and inter‐observer variability.20

In conclusion, our study demonstrated that calcar‐guided short stem THA effectively restored femoral antetorsion. However, whether the lower dislocation rates of short‐stem implants result from the good restoration of femoral antetorsion warrants further exploration.

ACKNOWLEDGMENTS

We thank Dr. Dominik Pfluger at numerics data GmbH for the statistical analysis, Mathys Ltd. for partially funding this study, and Medical Minds GmbH for medical writing and editorial support. The work was partially supported by Mathys Ltd Betlach. Funded sponsored statistical analysis through an independent consultant as well as medical writing and editorial support from a medical writing agency. No other external sources were involved. Mathys Ltd. Betlach had no role in the analysis or interpretation of the data, or the decision to submit results.

AUTHOR CONTRIBUTIONS

All authors contributed equally to data collection, analysis, and write‐up. All authors have read and approved the final submitted manuscript.

CONFLICT OF INTERESTS

The authors declare that there are no conflict of interests.

ORCID

Josef Hochreiter http://orcid.org/0000-0002-5378-1811

REFERENCES

1. Kutzner KP, Kovacevic MP, Roeder C, Rehbein P, Pfeil J. Reconstruction of femoro‐acetabular offsets using a short‐stem. Int Orthop. 2015;39:1269‐1275.
2. Renkawitz T, Haimerl M, Dohmen L, et al. The association between Femoral Tilt and impingement‐free range‐of‐motion in total hip arthroplasty. BMC Musculoskelet Disord. 2012;13:65.
3. 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;24:646‐651.
4. Müller M, Abdel MP, Wissilew G, Duda G, Perka C. Do post‐operative changes of neck‐shaft angle and femoral component antversion have an effect on clinical outcome following uncemented total hip arthroplasty? Bone Joint J. 2015;97 b:1615‐1622.
5. Kutzner KP, Freitag T, Donner S, Kovacevic MP. Bieger R. Outcome of extensive varus and valgus stem alignment in short‐stem THA: clinical and radiological analysis using EBRA‐FCA. Arch Orthop Trauma Surg. 2017;137:431‐439.
6. Jerosch J. Short stems are different—a classification of short stem designs. Orthopädische und Unfallchirurgische. Praxis. 2012;1:304‐312.
7. Erivan R, Muller AS, Villatte G, et al. Short stems reproduce femoral offset better than standard stems in total hip arthroplasty: a case‐control study. Int Orthop. 2020;44:45‐51.
8. Hochreiter J, Mattiassich G, Ortmair R, Steinmair M, Anderl C. Femoral bone remodeling after short‐stem total hip arthroplasty: a prospective densitometric study. Int Orthop. 2020;44:753‐759.
9. Kutzner KP, Donner S, Loweg L, et al. Mid‐term results of a new‐generation calcar‐guided short stem in THA: clinical and radiological follow‐up of 216 cases. J Orthopaedics Traumatol. 2019;20:31.
10. Mittelstaedt H, Hochreiter J, Anderl C, et al. Calcar‐guided short stems in total hip arthroplasty: a two‐year prospective multicentre study. Open Orthopaedics J. 2020;14:33‐38.
11. Snijders TE, van Erp JHJ, de Gast A. Restoring femoral offset and leg length; the potential of a short curved stem in total hip arthroplasty. J Orthop. 2019;16:396‐399.
12. Sendtner E, Tibor S, Winkler R, Wörner M, Grifka J, Renkawitz T. Stem torsion in total hip replacement. Acta Orthop. 2010;81:579‐582.
13. Zahar A, Rastogi A, Kendrick D. Dislocation after total hip arthroplasty. Curr Rev Musculoskelet Med. 2013;6:350‐356.
14. Wines AP, McNicol D. Computed tomography measurement of the accuracy of component version in total hip arthroplasty. J Arthroplasty. 2006;21:696-701.
15. Thiel W. The preservation of whole corpses in natural colors. Annals Anatomy—Anatomischer Anzeiger. 1992;174:185-195.
16. Thiel W. Ergänzung für die Konservierung ganzer Leichen nach W. Thiel. Annals Anatomy—Anatomischer Anzeiger. 2002;184:267-269.
17. Loweg L, Kutzner KP, Trost M, et al. The learning curve in short-stem THA: influence of the surgeon’s experience on intraoperative adjustments due to intraoperative radiography. Eur J Orthopaedic Surgery Traumatol. 2018;28:269-275.
18. 3d-printerstore.ch. ProFill Premium Filament PLA-TEC Data Sheet, available from https://www.3d-printerstore.ch/Filamente/3D-Filament-1-75-mm/PLA-Filament-1-75mm/ProFill-PLA-TEC-1-75mm:::49_51_138_210.html
19. Waidelich HA, Strecker W, Schneider E. Computed tomographic torsion-angle and length measurement of the lower extremity. The methods, normal values and radiation load. RoFo: Fortschritte auf dem Gebiete der Rontgenstrahlen und der Nuklearmedizin. 1992;157:245-251.
20. Kaiser P, Attal R, Kammerer M, et al. Significant differences in femoral torsion values depending on the CT measurement technique. Arch Orthop Trauma Surg. 2016;136:1259-1264.
21. Bieger R, Ignatius A, Reichel H, Dürselen L. Biomechanics of a short stem: In vitro primary stability and stress shielding of a conservative cementless hip stem. J Orthopaedic Res. 2013;31:1180-1186.
22. Kutzner KP, Ried E, Donner S, Bieger R, Pfeil J, Freitag T. Mid-term migration pattern of a calcar-guided short stem: a five-year EBRA-FCA-study. J Orthopaedic Sci. 2020;25:1015-1020.
23. Lidder S, Epstein DJ, Scott G. A systematic review of short metaphyseal loading cementless stems in hip arthroplasty. Bone Joint J. 2019;101-b:502-511.
24. Santori FS, Santori N. Mid-term results of a custom-made short proximal loading femoral component. J Bone Joint Surg Br. 2010;92:1231-1237.
25. Ezechiel M, Windhagen H, Matsubara M, Budde S, Wirries N, Sungu M. A neck-preserving short stem better reconstructs the centre of rotation than straight stems: a computed tomography-based cadaver study. Arch Orthop Trauma Surg. 2021.
26. Mayeda BF, Haw JG, Battenberg AK, Schmalzried TP. Femoral-acetabular mating: the effect of femoral and combined anteversion on cross-linked polyethylene wear. J Arthroplasty. 2018;33:3320-3324.
27. National Joint Replacement Registry Australia (AOANJRR). 2019. Australian Orthopedic Association.
28. Yiasediou M, Roberts D, Glassman D, Tomlinson J, Biyani S, Miskovic D. A multispecialty evaluation of thiel cadavers for surgical training. World J Surg. 2017;41:1201-1207.

How to cite this article: Hochreiter J, Böhm G, Fierlbeck J, et al. Femoral antetorsion after calcar-guided short-stem total hip arthroplasty: A cadaver study. J Orthop Res. 2022;40:2127-2132. doi:10.1002/jor.25228