Journal of Orthopaedics 16 (2019) 396–399

Contents lists available at ScienceDirect

Journal of Orthopaedics

journal homepage: www.elsevier.com/locate/jor

Restoring femoral offset and leg length; the potential of a short curved stem in total hip arthroplasty

Thom E. Snijders[a], Joost H.J. van Erp[a,b,*], Arthur de Gast[a,b]

[a] Clinical Orthopedic Research Center – mN, Diakonessenhuis Zeist, Zeist, the Netherlands
[b] Department of Orthopaedic Surgery, Diakonessenhuis, Utrecht, the Netherlands

ARTICLE INFO

Keywords:
Total hip arthroplasty
Femoral offset
Leg length
Prosthesis design
Template
Short straight stem

ABSTRACT

Background: Total hip arthroplasty (THA) is a very successful procedure in orthopedics. Still polyethylene wear and gait deficits are limiting the clinical success.

It is important to reconstruct leg length (LL) and femoral offset (FO) anatomically in order to have the best possible result of a THA. Gait deficits can arise due to leg length discrepancy as well as changes in the abductor moment arm. In THA, LL and FO are strongly determined by the orientation, size and geometry of the femoral stem.

Methods: This radio-anatomical study used the data of a prospective cases series of 112 patients who underwent 126 primary THAs and had completed a 1-year follow-up examination. FO and LL were compared between the conventional straight stem in vivo and a computed simulated implantation of a short curved stem, using the pre- and postoperative pelvic radiographs of the same patients.

Results: In this simulation of the short curved stem statistically significantly restored native FO ($p = 0.010$) and LL ($p = 0.000$) better, compared to the conventional straight stem.

Conclusions: Thus, the short curved stem restores FO and LL better, and could potentially prevent gait deficits.

1. Introduction

Total hip arthroplasty (THA) is very successful in improving patient's quality of life and good long term survival rates are reported.[1,2,3] The coming decades the number of patients in need for a THA will increase and these patients will have higher expectations on performance and durability.[4]

Despite advances in materials, implant design and surgical techniques, the revision burden remained unchanged over the past decades.[5] Among the most common causes of revision are wear, aseptic loosening and dislocation.[6] Furthermore, gait deficits are still frequently observed.[7,8] Femoral offset (FO) and leg length (LL) both, in addition to others, influence above mentioned issues.

FO is part of the abductor moment arm. Restoration of native FO increases range of motion, abductor muscle function and decreases PE wear.[9,10,11,12,13] Several studies even suggest that an increased FO has a beneficial effect on abductor muscle force and joint reaction forces.[14,15,16] Tanaka et al. correlated a Duchene gait with a decline in abduction moment.[17] However, the adverse effect of increased FO on thigh pain and abductor muscle function is not well understood.[15,10]

LL discrepancy, and especially lengthening of the leg, is associated with decreased walking distance, lower back pain, discomfort, instability, abnormal gait, nerve palsies, tension over the soft tissue structures and muscles, aseptic loosening of THA components, increased oxygen consumption and decreased patient satisfaction.[18,19,16,20]

A straight design stem is frequently used in THA, but due to its straight geometry it has limited ability to restore the FO. During surgery, the FO is determined by the depth and angle of reaming, the neck length and size of the stem, and the Caput-Collum-Diaphyseal (CCD) angle. The CCD angle is fixed, while the other three are surgeon dependent.

An orthopedic surgeon has only limited possibilities to reconstruct the FO and LL in primary THA. To overcome this, modular femoral components were developed. However, this resulted in a major increase in revision rate compared to non-modular stems.[21] The potential solution is a non-modular stem which allows restoration of the native FO and LL in conjunction with a modular head. A novel short curved stem is designed to be aligned along the calcar (medial part of the femoral neck) radius and is intended to restore the FO and LL anatomically. By adjusting the size and position of the short curved stem in the proximal femur, the surgeon can gradually adjust both the FO and LL to restore

* Corresponding author. Clinical Orthopedic Research Center – mN, Diakonessenhuis Zeist, Professor Lorentzlaan 76, 3707 HL, Zeist, the Netherlands.
E-mail addresses: tsnijders@diakhuis.nl (T.E. Snijders), jverp@diakhuis.nl (J.H.J. van Erp), adgast@diakhuis.nl (A. de Gast).

https://doi.org/10.1016/j.jor.2019.04.013
Received 21 January 2019; Accepted 15 April 2019
Available online 02 May 2019
0972-978X/

the restore the native anatomy.

By restoration of the FO without compromising LL, the surgeon is capable of optimizing the abductor muscle function and minimalizing polyethylene wear.[18],[14] The aim of this study is to test the hypothesis that a short curved stem has the better ability to restore FO and LL, than a conventional straight stem, in the same individual.

2. Material and methods

This is a radio-anatomical study of a cohort of 112 patients that underwent 126 primary total hip arthroplasties between December 2009 and August 2011. For this study, approval was given by the institutional review board (IRB) and informed consent was obtained from each patient. 73 (65%) patients were female and 39 (35%) were male. The mean age of patients was 63.46 years (range 39–86). Mean weight was 77.40 kg (range 51–132). The primary indication in 117 hips (92.8%) was osteoarthritis, 4 hips (3.2%) had congenital dysplasia, 3 hips (2.3%) had secondary osteoarthritis, 1 hip had osteonecrosis (0.8%) and 1 hip had a fracture (0.8%). Six patients were excluded. Of these, two hips were lost to follow-up, two hips had undergone revision because of late periprosthetic fractures and one patient had died. The latter was not related to the surgery. One hip was excluded because of a dynamic hip screw was in situ.

All patients received a THA with a non-cemented fully hydroxyapatite coated femoral stem, CCD-angle of 134° (Twinsys, Mathys Ltd. Bettlach), and a Vitamin E stabilized highly cross-linked polyethylene monoblock cup (RM Pressfit Vitamys cup, Mathys Ltd. Bettlach). Five experienced orthopedic surgeons performed the procedure using an anterolateral (3.2%), transgluteal (59.5%) or posterolateral (37.3%) approach. The surgeon could choose between standard (10 sizes), lateral (10 sizes) and two extra small femoral stems, in total 22 femoral stems.

Pre- and postoperative anteroposterior (AP) radiographs of the pelvis were taken in supine position and with the lower limb in 15° internal rotation, so the patella was situated in the frontal plane.

The measurements and templating were done by two medical students independently, using diagnostic Picture Archiving and Communication System (PACS) workstations (version 2.1.2.1, Centricity PACS; GE Healthcare Systems, Chalfont St. Giles, United Kingdom) with high-resolution monitors. The postoperative radiograph was calibrated using the size of the head in the THA, which was known from the patients' medical records. By measuring the diameter of the contralateral head of the femur postoperative, the preoperative radiograph could be calibrated. The oldest preoperative pelvic radiograph was used.

On the preoperative radiograph the center of rotation (CoR) was determined by the validated method of Patel et al.[22] The distance between the CoR and the tip of the greater trochanter was defined as the native FO. A method derived from Fessy et al.[23] was used to determine the distance of the X- and Y-axis of the tip of the greater trochanter to CoR. In this method the Y-coordinate is related to LL, because it represents the height of the tip of greater trochanter. The same procedure was repeated for the postoperative radiograph with the straight stem. Consecutively a template of the short curved stem, with a CCD-angle of 134°, was placed on the preoperative radiograph (Optimys by Mathys Ltd. Bettlach). This template was placed with primarily considering the cortical wall of the femur and following the calcar which resembles the procedure in a THA. The short curved stem is available in standard (12 sizes) and lateral (12 sizes) femoral stems. The size of the prosthetic femoral head (S, M, L, XL), which approximates the native CoR was chosen. In order to compare the FO and LL, the CoR has to be constant.

So any deviations from this templated CoR with respect to the native CoR, are measured in the X- and Y-direction and added to the X- and Y-coordinate of the native CoR. The final step is placing the X- and Y-axis of the short curved stem on the postoperative radiograph according to the CoR of the cup.

Table 1
Interclass correlation coefficients.

	Parameter	ICC	Range
Native	X	0.809	0.726–0.867
	Y	0.872	0.816–0.911
	FO	0.786	0.693–0.850
Short curved stem	X	0.666	0.499–0.774
	Y	0.765	0.657–0.838
	FO	0.678	0.508–0.785
Straight stem	X	0.873	0.812–0.914
	Y	0.818	0.738–0.873
	FO	0.896	0.851–0.928

Finally, the reconstructed FO of the templated short curved stem is measured. At the same time the Y-coordinate corresponds to LL.

The intra-observer reliability was evaluated with the two-way mixed ANOVA with absolute agreement. Differences of the X-, Y-axis and FO between the native, short curved stem and straight stem offset were determined, using the paired Student's *t*-test. Statistical analysis was performed using SPSS® 17.0 (SPSS Inc, Chicago, IL).

3. Results

The measurements showed interclass correlation coefficients between 0.666 and 0.896, displayed in Table 1. The differences of the x – (X), y-coordinate (Y) and FO between the short curved stems and the straight stems were normally distributed. The means in radiographic measurements in 120 hips (106 patients) of the X, Y and FO are shown in Table 2. Table 3 shows the mean deviations from the native X, Y and FO of the straight and short curved stem. The mean differences in the approximation of native X, Y and FO between the short curved stems and straight stems are shown in Table 4.

Statistical analysis showed a significantly better restoration of FO with the short curved stem. The short curved stem increases FO to a lesser extent than the straight stem (1.12 ± 4.790, $p = 0.010$).

There was a statistically significant difference between the Y-axis, showing an improved restoration with the short curved stem (-6.706 ± 6.934, $p = 0.000$) The X-axis was not statistically significant between the two stems.

4. Discussion

The findings in this study confirm our hypothesis. The short curved stem potentially has a statistically significant greater ability to restore FO compared to the straight stem, increases the FO to a lesser extent. Furthermore, the short curved stem restores LL statistically significantly better, compared to the straight stem.

The results show a wide variability. This is presumably because of the number of valgus hips in this cohort. The FO and LL in those hips increase considerably. In this cohort there are 17 patients whose FO increased with 10 mm or more (16%). Those hips have a steeper CCD angle, compared with the fixed CCD angle of 134° of the straight stem used. The effect of this increase on clinical outcome compared to normal and valgus hips, is not well documented in the literature. The neck-shaft angle and the geometry of the medullary canal, in relationship to the proximal femur, are major factors in influencing FO and LL. Lenaerts et al. and Pivec et al. showed us that THA implantation in a femur with a steep neck-shaft angle, a valgus configuration, increases FO, and that in a flared medullary canal, THA often results in increase of the LL.[10](6).

Until now, there is no adequate stem for these types of hips without increasing the FO vigorously. The short curved stem could be a solution compared to the existing options, especially with regard to LL.

Due to its short geometry and alignment along the calcar it is more easily adjustable to the specific anatomy of the individual patient.

Table 2
Means of the radiographically measured X-, Y and FO of the native hip, after implantation of the straight stem and after digitally templating the short curved stem.

	Native		Short curved stem		Straight stem	
	Mean Sd	Range	Mean Sd	Range	Mean Sd	Range
X	49.84 ± 5.96	32.1–61.7	51.91 ± 5.27	38.3–68.2	52.61 ± 6.42	37.6–66.7
Y	2.18 ± 5.57	−13.2–17.2	1.73 ± 5.59	−13.2–15.8	−5.32 ± 6.41	−24.2–10.8
FO	50.24 ± 6.11	32.0–61.1	52.23 ± 5.36	38.9–68.0	53.40 ± 6.25	38.7–67.1

Mean: millimeters (mm); Sd: standard deviation (SD); Range: millimeters (mm).

Table 3
Mean deviations of the native X, Y and FO for the straight and short curved stem.

	Straight stem – Native		Short curved stem – Native	
	Mean	Range	Mean	Range
X	2.64	−11.1–24.7	1.97	−3.6 - 21.2
Y	−7.14	−34 - 6.6	−0.43	−12.7–4.8
FO	3.01	−6.9 - 31.3	1,89	−5.2 - 34.7

Mean: millimeters; Range: millimeters.

Table 4
Differences in approximation of the native X-,Y and FO between the straight and short curved stem in X-, Y and FO.

	Mean Sd	Range	P-Value
X	0.666 ± 4.795	−16.8–14.1	0.122
Y	−6.706 ± 6.934	−34.0–7.8	0.000*
FO	1.12 ± 4.790	−10 - 16.4	0.010*

Mean: millimeters; Sd: standard deviation, millimeters; Range: millimeters; *: significant ($p < 0.05$).

As mentioned before, LL discrepancy after THA, mostly leg lengthening, can influence the patient's gait remarkable.[15,24,25] Furthermore, there is also a biomechanical effect of a lower position of the tip of the greater trochanter, relatively to the origin of the abductor muscles. The insertion of the abductor muscles is placed relatively more distal, which increases the angle between the FO and the abductor muscles. This increases the force of the abductors needed for a one-leg-stance progressively. The force of the abductors should increase with 11% for a one-leg-stance to compensate a 5° increase in angle between FO and the abductors resultant. Another example, an increase in FO of 5 mm gives a 9% force reduction needed for a one-leg-stance.

The effect is even greater if the angle between the abductor moment arm and FO is taken into account. This angle decreases when FO is increased. However, this effect is lost when LL is increased at the same time, which is typically seen when the straight stem is used. Our study showed an increase in FO with both the short curved stem and the straight stem. Abovementioned biomechanical presentation is simplified to the in vivo situation and calculated with a person of 79 kg. Decreasing the muscle force needed for the abductors could be of clinical relevance. Less force needed for the abductors could hypothetically mean that the patient can walk sooner, thereby speeding up the rehabilitation process. Furthermore, less force needed for abduction means less joint reaction forces on the THA. Less joint reaction forces could lead to a reduction in polyethylene wear and thus increased longevity of the THA.[13]

The most important limitation of this radio-anatomical study is the comparison between a simulated implantation of a short curved stem and a postoperative radiograph of a THA with a straight stem. The template is fitted perfectly following the cortical wall and calcar. The real THA is not placed perfectly in all patients. For instance, differences in the level of the femoral neck cut affect the positioning of the straight femoral stem.[26] This could lead to a different size of the straight stem, which influences the FO and LL directly. In the experience of Sariali et al. a wrong stem size could lead to 1 cm difference in LL.[27] Another important limitation of this study is the interobserver variability. The calculated intraclass correlation coefficient (ICC) resulted in values from “substantial” (0.61–0.8) until “almost perfect” (> 0,81), which confirms the reliability of our measurements.[28]

Evaluating radiographs of the pelvis comes with the following limitations. First the radiograph of the pelvis encounters magnification because of the radiation beam passes through. In this study this limitation is overcome by calibrating the radiographs by the size of head of the THA. The second limitation is the calibration of the preoperative radiograph. This radiograph is calibrated by the contralateral head of the femur, which could be measured on the postoperative radiograph. However this contralateral head could also be affected by deformation from osteoarthritis. The third limitation is determining of the CoR of the femoral head, which could be deformed by the osteoarthritis. To overcome this limitation the earliest available radiograph should be used, at the stage when the head is not, or the least affected.

Despite standardized radiographs, variations in internal and external rotation of the femur always shorten the measurement of FO.[6] The measurements are done according to a method derived from Fessy et al. which has not been validated.[23] However, Schofer et al. proved the method of Fessy et al. is the most accurate method available.[29] In this study the FO was determined in relation to the tip of the greater trochanter. The tip of the greater trochanter is not on the axis of the femur, like the definition of FO, however it is a clear reproducible point of the femur on the pre- and postoperative radiograph. Secondly it is the insertion point of the abductor muscles. And the third reason for using a derivative of Fessy et al. is the determination of both FO and LL in one simple measuring method.

Previous studies using a digital template, did not describe how the templates were oriented.[27](25) One of the strengths of this study is placing the template by following the surgical guidelines. The template was placed depending on the cortical wall and the calcar. The CoR was not used as a reference point because cup placement is responsible for CoR position.

Increasing FO seems beneficial because of an increased abductor moment arm. Secondly it gives less joint reaction forces and subsequently less PE wear, which prolongs longevity.[13] However, to what values increases in FO are beneficial, is unknown. A study of Barker et al. reported that in muscles of patients who underwent leg-lengthening, a process comparable to enlargement of FO, a small decrease in muscle strength and power was seen eventually.[30]

A too large increase of FO could cause thus weakness of the abductors and lateral trochanteric pain.

This radio-anatomical simulation shows the short curved stem can potentially restore FO and LL better than the straight stem used in this cohort of patients. Therefore, it has the potential to establish a superior restoration of hip joint biomechanics. Future studies should determine if the short curved stem shows better restoration of FO in vivo and whether this results in clinically relevant differences, with regard to gait deficits, polyethylene wear and implant survival.

Compliance with ethical standards

Authorship declaration

All authors listed meet the authorship criteria according to the latest guidelines of the International Committee of Medical Journal Editors, and all authors are in agreement with the manuscript.

Conflicts of interest

The authors declare that they have no relevant conflict of interest.

Funding

This study is funded by the Clinical Orthopedic Research Foundation, Diakonessenhuis Zeist.

Ethical approval

This study was approved by the local institutional review board.

Acknowledgments

The authors wish to thank dr. C.C.P.M. Verheijen, orthopedic surgeon, for his important additive and A. Eden, medical student, for collecting the data.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jor.2019.04.013.

References

1. Berry DJ, Harmsen WS, Cabanela ME, Morrey BF. Twenty-five-year survivorship of two thousand consecutive primary Charnley total hip replacements: factors affecting survivorship of acetabular and femoral components. *J Bone Jt Surg - Ser A.* 2002;84(2):171–177.
2. de Beer J, Petruccelli D, Adili A, Piccirillo L, Wismer D, Winemaker M. Patient perspective survey of total hip vs total knee arthroplasty surgery. *J Arthroplast.* 2012 Jun;27(6):865–869 e5.
3. King A, Phillips JRA. Total hip and knee replacement surgery. *Surg (United Kingdom).* 2016 May;34(9):468–474.
4. Kurtz SM, Lau E, Ong K, Zhao K, Kelly M, Bozic KJ. Future young patient demand for primary and revision joint replacement: national projections from 2010 to 2030. *Clin Orthop Relat Res.* 2009 Oct 10;467(10):2606–2612.
5. Bozic KJ, Kurtz S, Lau E, et al. The epidemiology of bearing surface usage in total hip arthroplasty in the United States. *J Bone Jt Surg - Ser A.* 2009 Jan;91(7):1614–1620.
6. Pivec R, Johnson AJ, Mears SC, Mont MA. Hip arthroplasty. *Lancet.* 2012 Nov 17;380(9855):1768–1777.
7. Foucher KC, Hurwitz DE, Wimmer MA. Preoperative gait adaptations persist one year after surgery in clinically well-functioning total hip replacement patients. *J Biomech.* 2007 Jan;40(15):3432–3437.
8. Perron M, Malouin F, Moffet H, McFadyen BJ. Three-dimensional gait analysis in women with a total hip arthroplasty. *Clin Biomech.* 2000 Aug;15(7):504–515.
9. Delp SL, Wixson RL, Komattu AV, Kocmond JH. How superior placement of the joint center in hip arthroplasty affects the abductor muscles. *Clin Orthop Relat Res.* 1996 Jul(328):137–146.
10. Lenaerts G, De Groote F, Demeulenaere B, et al. Subject-specific hip geometry affects predicted hip joint contact forces during gait. *J Biomech.* 2008;41(6):1243–1252.
11. Little NJ, Busch CA, Gallagher JA, Rorabeck CH, Bourne RB. Acetabular polyethylene wear and acetabular inclination and femoral offset. *Clin Orthop Relat Res.* 2009 Nov 2;467(11):2895–2900.
12. McGrory B, Morrey B, Cahalan T, An K, Cabanela M. Effect of femoral offset on range of motion and abductor muscle strength after total hip arthroplasty. *J Bone Joint Surg Br.* 1995 Nov;77–B(6):865–869.
13. Sakalkale DP, Sharkey PF, Eng K, Hozack WJ, Rothman RH. Effect of femoral component offset on polyethylene wear in total hip arthroplasty. *Clin Orthop Relat Res.* 2001 Jul(388):125–134.
14. Asayama I, Chamnongkich S, Simpson KJ, Kinsey TL, Mahoney OM. Reconstructed hip joint position and abductor muscle strength after total hip arthroplasty. *J Arthroplast.* 2005 Jun;20(4):414–420.
15. Cassidy KA, Noticewala MS, Macaulay W, Lee JH, Geller JA. Effect of femoral offset on pain and function after total hip arthroplasty. *J Arthroplast.* 2012 Dec;27(10):1863–1869.
16. Pakpianpairoj C. Perception of leg length discrepancy after total hip replacement and its impact on quality of life. *J Med Assoc Thail.* 2012 Oct;95(Suppl 1):S105–S108.
17. Tanaka Y. Gait analysis of patients with osteoarthritis of the hip and those with total hip arthroplasty. *Nippon Seikeigeka Gakkai zasshi.* 1993 Nov;67(11):1001–1013.
18. Gurney B, Mermier C, Robergs R, Gibson A, Rivero D. Effects of limb-length discrepancy on gait economy and lower-extremity muscle activity in older adults. *J Bone Jt Surg - Ser A.* 2001 Jun;83(6):907–915.
19. Longjohn D, Dorr LD. Soft tissue balance of the hip. *J Arthroplast.* 1998 Jan;13(1):97–100.
20. Röder C, Vogel R, Burri L, Dietrich D, Staub LP. Total hip arthroplasty: leg length inequality impairs functional outcomes and patient satisfaction. *BMC Muscoskelet Disord.* 2012 Jun 11;13:95.
21. Kop AM, Keogh C, Swarts E. Proximal component modularity in THA - at what cost? An implant retrieval study. *Clin Orthop Relat Res.* 2012 Jul 3;470(7):1885–1894.
22. Patel SR, Toms AP, Rehman JM, Wimhurst J. A reliability study of measurement tools available on standard picture archiving and communication system workstations for the evaluation of hip radiographs following arthroplasty. *J Bone Jt Surgery-American.* 2011 Sep 21;93(18):1712–1719.
23. Fessy MH, N'Diaye A, Carret JP, Fischer LP. Locating the center of rotation of the hip. *Surg Radiol Anat.* 1999;21(4):247–250.
24. Grisez BT, Calkins TE, Dietz MJ. Modular femoral stems in revision total hip arthroplasty. *Operat Tech Orthop.* 2017 Feb 24;27(3):178–185.
25. White SP, Shardlow DL. Effect of introduction of digital radiographic techniques on pre-operative templating in orthopaedic practice. *Ann R Coll Surg Engl.* 2005 Jan;87(1):53–54.
26. Mihalko WM, Saleh KJ, Heller MO, Mollard B, König C, Kammerzell S. Femoral neck cut level affects positioning of modular short-stem implant. *Orthopedics.* 2009 Oct 1;32(10/suppl):18–21.
27. Sariali E, Mauprivez R, Khiami F, Pascal-Mousselard H, Catonné Y. Accuracy of the preoperative planning for cementless total hip arthroplasty. A randomised comparison between three-dimensional computerised planning and conventional templating. *Orthop Traumatol Surg Res.* 2012 Apr;98(2):151–158.
28. Landis JR, Koch GG. The measurement of observer agreement for categorical data. *Biometrics.* 1977 Mar;33(1):159.
29. Schofer MD, Thomas P, Heyse TJ, Schmitt J, Boudriot U. Radiological determination of the anatomic hip centre from pelvic landmarks. *Acta Orthop Belg.* 2010 Aug;76(4):479–485.
30. Barker KL, Lamb SE, Simpson HRW. Recovery of muscle strength and power after limb-lengthening surgery. *Arch Phys Med Rehabil.* 2010 Mar;91(3):384–388.