Does stem design influence component positioning in total hip arthroplasty using a minimal invasive posterolateral approach?

Wenzel Waldstein · Christian Merle ·
Tom Schmidt-Braekling · Friedrich Boettner

Received: 7 January 2014 / Accepted: 7 February 2014 / Published online: 7 March 2014
© Springer-Verlag Berlin Heidelberg 2014

Abstract

Purpose Limited data exist for the reconstructive potential of short bone-preserving stems in THA using a minimal invasive posterolateral approach. Our study aim was to assess the effect of stem design on the reconstruction of hip offset and leg length in MIS posterolateral THA.

Methods This retrospective consecutive single-surgeon study compares hip offset and leg length, as well as acetabular component positioning (cup anteversion; inclination) of 129 THAs with a cementless standard-length stem (Synergy®) and 143 THAs with a cementless short bone-preserving stem (Trilock®).

Results In reference to the contralateral side, the mean difference in hip offset was 0.9 mm ($p=0.067$) for the standard stem and 0.1 mm ($p=0.793$) for the short stem, respectively. Leg-length discrepancy was 0.7 mm (Synergy®) and 0.9 mm (Trilock®), respectively. A total of 233 (86 %) acetabular components fell within the target zone for anteversion and inclination.

Conclusion Accurate component positioning in MIS posterolateral approach THA is possible and is not influenced by the type of stem.

Keywords Stem design · Short stem · MIS total hip arthroplasty · Reconstruction · Acetabular component positioning

Introduction

Accurate component positioning and reconstruction of physiologic joint mechanics with equal leg length are essential goals of contemporary total hip arthroplasty (THA). Various surgical factors have been reported to influence the occurrence of impingement, dislocation, and wear following primary THA, including surgical experience [1], operative approach [1], and design, position and orientation of prosthetic components [2, 3]. Over the last decade, minimally invasive surgical (MIS) approaches using bone preserving stem designs have been introduced because of their potential advantages associated with reduced intra-operative soft-tissue trauma [4]. It could be postulated that the reconstruction of hip offset and leg length is more challenging using a ‘broach only’ short stem compared to a standard ‘ream and broach’ stem since reaming allows alignment of the stem along the femoral diaphysis and therefore standardizes the reconstruction of joint biomechanics [5]. In addition, it has been suggested that minimally invasive implantation techniques may be more prone to intra-operative component malpositioning, compromised fixation or neurovascular injury [6]. Despite the growing popularity of minimally invasive implantation techniques and bone preserving stem designs, there is only limited data on the accuracy of component positioning and the reconstructive potential of these implants when a minimally invasive surgical approach is used. Additionally, there are subtle differences in implant design between hip implant manufactures. In some designs, stem offset is decreased and acetabular component offset is increased, compared to others. It has not been studied if this affects the reconstruction of hip offset.

We sought to determine (1) how a short bone-preserving stem compares to a straight standard-length stem in the reconstruction of hip offset and leg length in MIS posterolateral THA, and (2) whether a MIS posterolateral approach allows

W. Waldstein · T. Schmidt-Braekling · F. Boettner (✉)
Orthopaedic Surgery, Hospital for Special Surgery, New York, NY,
USA
e-mail: boettnerf@hss.edu

C. Merle
Department of Orthopaedic and Trauma Surgery, University Hospital
Heidelberg, Heidelberg, Germany

for accurate positioning and orientation of the acetabular component with reference to reported target zones.

Materials and methods

We retrospectively studied a consecutive single-surgeon series of 325 hips in 290 patients who underwent primary THA between January 2011 and April 2012 for end-stage hip disease. The inclusion criteria were osteoarthritis, rheumatoid arthritis, post traumatic arthritis, avascular necrosis or developmental hip dysplasia (Crowe grade 1) who received either a cementless straight standard length femoral component (group 1: Synergy, Smith&Nephew, Memphis, TN, Fig. 1a) or a cementless short bone preserving femoral component (Group 2: Tri-Lock, DePuy, Warsaw, IN, Fig. 1b). Both stem designs offer the option of a standard and high offset neck configuration and were implanted in combination with a hemispheric press-fit acetabular component (group 1: R3, Smith&Nephew, Memphis, TN; group 2: Pinnacle, DePuy, Warsaw, IN). There is a subtle difference between both manufactures in that the implants in group 1 have approximately 2 mm more offset for the neutral acetabular component and less offset for the femoral component. Exclusion criteria were (1) cemented fixation or (2) patients with developmental hip dysplasia (Crowe grades ≥ 2). Fifty-three hips were excluded as they did not

meet the defined inclusion criteria, leaving 243 patients (272 hips: 143 right and 129 left) in the study cohort. There were 123 men and 120 women, who underwent 214 unilateral 19 bilateral and ten staged bilateral procedures. The mean age at time of surgery was 61 years (range, 22–87 years) and the mean BMI was 28.8 kg/m² (range, 19.8–48.4 kg/m²). In all patients, a minimally invasive posterolateral approach in lateral position was used as previously described [7]. During cup implantation, the surgeon (FB) aimed for a cup position with 20° of anteversion and 40° of inclination and attempted to restore hip offset according to the opposite side. The senior author reamed to the floor of the fovea acetabuli to reproduce preoperative templating (tear drop) and avoid excessive medialisation of the centre of rotation [8]. Leg length was intra-operatively determined by measuring the distance between the lesser trochanter and the centre of the femoral head. No intra-operative radiographs or image-based navigation were used. The study was approved by the institutional review board.

For all patients, anteroposterior (AP) pelvis and cross-table lateral radiographs were taken pre-operatively and at eight weeks postoperatively following standardized institutional protocols. A metal calibration sphere of 25 mm was positioned on the inner thigh to correct for effects of magnification. The crosshair of the beam was centered on the pubic symphysis in supine position and both legs were internally

Fig. 1 The two stems compared in this study. **a** A cementless straight standard-length stem (group 1: Synergy®, Smith&Nephew, Memphis, TN). **b** A cementless short bone-preserving stem (group 2: Tri-Lock®, DePuy, Warsaw, IN)

rotated by approximately 15° to position the femoral neck in the coronal plane.

Postoperative AP pelvic radiographs of all patients were reviewed and radiographic measurements were performed on a picture archiving and communication system (PACS) with commercial planning software (Sectra IDS7; Sectra, Linköping, Sweden). Cup version (CV) was analysed on AP pelvic films as described by Lewinnek et al. [9] and recently validated by Lu et al. [10]. Using a best fit ellipse tool (ImageJ software v1.46, NIH) cup version was calculated as arcsin of the short versus the long leg of the ellipse. Relative ante- or retroversion was also assessed on cross-table lateral radiographs utilizing the technique described by Yao et al. [11]. Cup inclination (CI) was measured in relation to the horizontal interteardrop reference line. The target zones for anteversion and inclination were defined as $10\text{--}30^\circ$ and $30\text{--}50^\circ$, respectively. Femoral offset (FO) was measured as perpendicular distance from the center of the femoral head to the femoral shaft axis [12]. For measurements of acetabular offset a vertical line through the teardrop perpendicular to the interteardrop reference line was drawn and the perpendicular distance from this line to the center of the femoral head was measured (Fig. 2). Hip offset (HO) was defined as the sum of acetabular and femoral offset [13].

For measurements of leg-length discrepancy, the interteardrop line was used as horizontal reference. The difference between the vertical distances from the reference line to the most prominent point on each lesser trochanter defined the leg-length discrepancy (Fig. 2). Values were reported with reference to the contralateral hip, with positive values indicating relative lengthening and negative values indicating relative shortening of the operated side. The contralateral hip was

Fig. 2 Standardized anteroposterior radiographs of the pelvis of a 77-year-old man with well aligned cementless straight standard-length stem, showing the measurements of femoral offset, acetabular offset and leg length discrepancy

classified as (1) hip without or minimal joint space narrowing (Tönnis grade ≤ 1), (2) hip with joint space narrowing (Tönnis grade ≥ 2) or (3) contralateral THA.

Intra- and interobserver reliabilities for repeated measurements were assessed by two independent and blinded observers for 20 randomly selected sets of radiographs. Intra- and interobserver reliabilities for the grading scores were evaluated by two independent blinded observers for all radiographs. For intra-observer reliabilities, grading and measurements were performed at two occasions separated by a minimum of four weeks. For repeated measurements, intraclass correlation coefficients (ICC) were calculated using a two-way mixed model with 95 % CIs. Single measures are given for intra-observer calculations and average measures for the interobserver calculations.

For statistical analysis, absolute mean values are expressed in mm (FO, AO, HO) or degrees (CI, CV) with 95 % confidence intervals (95%CI). Differences in mean FO were expressed in absolute (95%CI) and relative (%) values. The Kolmogorov-Smirnov test was performed to test for normal distribution of variables. As not all variables met the criteria for normal distribution, the Mann Whitney *U*-test was used to compare the distribution of variables. Results with *p* values <0.05 were considered as statistically significant, and *p* values of <0.001 were considered as highly significant. Scatter plots and were used to evaluate associations between continuous variables. Statistical tests were carried out using SPSS® 17.0 software for Windows® (SPSS Inc, Chicago, IL, USA).

Results

Excellent interobserver and intra-observer intra-class-correlation coefficients were observed for all analyzed parameters (Table 1).

Accurate reconstruction of hip offset and leg length was observed for both stem designs. There was no

Table 1 Interobserver and intraobserver ICC for analysed parameters

Parameter	Interobserver ICC	Intraobserver ICC
Cup inclination ($n=20$)	0.981	0.961
Cup version ($n=20$)	0.985	0.997
Reconstructed AO ($n=20$)	0.960	0.973
Reconstructed FO ($n=20$)	0.937	0.927
Reconstructed HO ($n=20$)	0.961	0.953
Contralateral AO ($n=20$)	0.853	0.890
Contralateral FO ($n=20$)	0.981	0.974
Contralateral HO ($n=20$)	0.899	0.926
Leg length discrepancy ($n=20$)	0.929	0.950

ICC intraclass correlation coefficient, AO acetabular offset, FO femoral offset, HO hip offset

significant ($p=0.460$) difference between the mean hip offset on the operated side and the mean contralateral hip offset in group 1. Similarly in group 2, no significant ($p=0.916$) difference between the mean operated side hip offset and the mean contralateral hip offset was observed (Table 2).

In 260 hips (96 %) the femoral component was positioned neutral to 3° of varus with reference to the femoral shaft axis. One stem was in 6° of valgus. The remaining 11 were positioned between 4° of varus and 9° of varus.

For the entire cohort, the operated side was relatively lengthened by a mean of 0.8 mm (95%CI 0.5–1.1). Leg length was similarly ($p=0.973$) reconstructed in both groups with mean LLD of 0.7 mm (95%CI 0.2–1.2) in group 1 and mean LLD of 0.9 mm (95%CI 0.5–1.3) in group 2, respectively. After exclusion of cases ($n=79$) with contralateral joint space narrowing, leg length was reconstructed within the range of –2 mm (short) to 2 mm (long) in 159 (82 %) cases. When a leg length discrepancy of ≤ 4 mm (short or long) was chosen as cut-off, 183 (95 %) cases were reconstructed in this range.

The minimally invasive posterolateral approach allowed for safe and accurate positioning of the acetabular component. For the entire cohort, mean inclination was 45.7° (95%CI 45.2–46.2) and mean cup anteversion was 23.3° (95%CI 22.7–23.9). Inclination ranged from 32° to 57° and cup anteversion from 7.9° to 38.1°, respectively. There were 248 (91 %) acetabular cups that fell within the optimal inclination range of 30° to 50°, and 257 (95 %) cups that fell within the optimal version range of 10° to 30°. A total of 233 (86 %) cups fell within the optimal range for both inclination and anteversion (Fig. 3).

Discussion

Although straight standard length cementless stems have successfully been used over the last two decades [14], short bone preserving cementless stems have become increasingly popular to address some of the limitations encountered with longer stem designs. Short stems potentially preserve more bone stock, improve proximal load transfer, optimize bone remodeling especially in the older population and decrease stress shielding [15, 16]. Furthermore, short stems may be easier to insert through smaller, minimally invasive incisions. Despite the popularity of those short bone preserving femoral implants, there is, to the best of our knowledge, no study in the literature that critically assessed the accuracy to reconstruct hip offset and leg length using a minimal invasive posterior approach.

Our study is the first to demonstrate that both stems allow for accurate reconstruction of the center of rotation, acetabular offset and femoral offset with reference to the contralateral side. The study also shows that acetabular offset was

Table 2 Mean values for hip offset, acetabular offset and femoral offset for groups 1 and 2

Measure	Group 1 (Synergy; $n=129$)			Group 2 (Tri-lock; $n=143$)		
	Reconstructed hip	Contralateral hip	Differences in offset	Reconstructed hip	Contralateral hip	Differences in offset
Overall hip offset (mm)	69.0 (95%CI 67.8–70.3)	69.9 (95%CI 68.5–71.3)	0.9 (95%CI –0.1 to 1.8)	73.7 (95%CI 72.5–75.0)	73.8 (95%CI 72.5–75.2)	0.1 (95%CI –0.6 to 0.8)
Acetabular offset (mm)	28.9 (95%CI 28.4–29.5)	38.1 (95%CI 36.9–39.2)	9.1 (95%CI 8.0–10.3)	29.4 (95%CI 29.0–29.9)	40.1 (95%CI 39.0–41.3)	10.7 (95%CI 9.7–11.7)
Femoral offset (mm)	40.1 (95%CI 39.1–41.1)	31.8 (95%CI 31.1–32.6)	–8.3 (95%CI –9.3 to –7.2)	44.4 (95%CI 43.4–45.3)	33.7 (95%CI 32.9–34.5)	–10.7 (95%CI –11.7 to –9.7)
Differences in offset = offset contralateral hip – offset reconstructed hip

Fig. 3 A scatter plot of inclination versus anteverision angles for each acetabular cup with a window for the optimal orientation. The majority (86%) of cups were placed within the range of 30–50° inclination and 10–30° anteverision

consistently reduced by using the floor of the fovea acetabuli as a landmark for medialisation of the acetabular component (Table 2). The floor of the fovea acetabuli is a reference point that can easily be visualized both during pre-operative templating and intra-operative cup preparation. It also improves equatorial cup press-fit, primary mechanical stability [17] and secondary osteointegration [18]. Consequently, femoral offset was increased to reconstruct overall hip offset. Furthermore, the study demonstrates that leg length was restored in the majority of patients.

These findings are of clinical relevance as the association between reconstruction and implant failure is well understood but longer follow ups for short stems are still rare [19, 20]. In a RSA migration study Röhrle et al. [21], reported on the two-year results of a short femoral component and concluded that the low migration would suggest a favourably long-term outcome. Lombardi et al. [22] published the promising results for a short tapered stem at a mean followup of 7.3 months. For standard length stems, several studies have demonstrated that using a MIS approach does not compromise the long-term clinical and radiographic outcome when compared with conventional incision techniques [23, 24]. With regard to the reconstruction of leg length, our results compare favorably with a report of Licini et al. [25] who described 0.3-mm leg lengthening using navigation.

This is the first study to describe the cup position with reference to the reported target orientation for inclination and anteverision using a MIS posterolateral approach in a large number of patients. In the majority (86 %) of cases the MIS posterolateral approach allowed for safe and accurate positioning of the acetabular component without the use of

navigation. Recently, there has been much debate about ‘safe’ and accurate positioning of the cup. DiGioia et al. [26] reported that only 22 % of acetabular cups implanted in primary THA using a standard posterolateral approach were within the suggested Lewinnek safe zones of 30–50° inclination and 5–25° anteverision. This is in contrast to a report of Bosker et al. [27] who stated that 71 % of implanted cups were positioned within the safe zone. Wenz et al. [28] defined optimal inclination between 35° and 55° and could demonstrate that via a MIS posterolateral approach 94 % of cups were implanted within the targeted range. Wenz et al. [28] were the first to report on cup inclination using a MIS approach to the hip but they did not measure cup version. In the present study, we defined the target zone for cup anteverision between 10° and 30° which is in contrast to Lewinnek’s suggested safe zone of 5° to 25°. The slightly higher targeted anteverision reflects the surgeon’s goal to achieve 20° anteverision in an attempt to reduce the incidence of posterior dislocation.

Our study has the following limitations: first, we only assessed acetabular version but not femoral version because there was no three-dimensional imaging available; second, measurements of component positioning on AP pelvic radiographs are based on the coronal plane of the pelvis on the table. There was no device used to bring the anterior pelvic plane parallel to the film as originally described by Lewinnek et al. [9]. Thus, obliquity due to spinal deformities and pelvic tilt are not accounted for which might affect the measurement accuracy for cup version [29]. However, Lu et al. [10] demonstrated that standard AP pelvic radiographs without the use of such a device allow for reliable and accurate measurements of acetabular orientation in relation to computed tomography (CT). Postoperative cross-table lateral radiographs were used to validate the degree of cup anteverision/retroversion [11]. Standardization of cross-table lateral radiographs can be challenging because of the necessity to flex the contralateral hip and because of the effect of pelvic tilt on cup version. Despite these potential sources of error, Ghelman et al. [30] demonstrated that measurements of cup version on radiographs correlated with those on computed tomography with radiographs resulting in a mean of 8.7° more anteverision. Therefore given that the lowest version was 18.7° in the present study, it is very likely that all cups were actually placed in anteverision.

In conclusion, the current findings suggest that both straight and bone preserving stem designs enable accurate reconstruction of hip offset and leg length using a MIS posterolateral approach. The present study further demonstrates that the used minimally invasive posterolateral approach allows for accurate positioning of the acetabular component with reference to reported target zones for cup version and inclination.

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

References

- Callanan MC, Jarrett B, Bragdon CR, Zurakowski D, Rubash HE, Freiberg AA, Malchau H (2011) The John Charnley Award: risk factors for cup malpositioning: quality improvement through a joint registry at a tertiary hospital. *Clin Orthop Relat Res* 469:319–329. doi:10.1007/s11999-010-1487-1
- Jasty M, Goetz DD, Bragdon CR, Lee KR, Hanson AE, Elder JR, Harris WH (1997) Wear of polyethylene acetabular components in total hip arthroplasty. An analysis of one hundred and twenty-eight components retrieved at autopsy or revision operations. *J Bone Joint Surg Am* 79:349–358
- Kennedy JG, Rogers WB, Soffe KE, Sullivan RJ, Griffen DG, Sheehan LJ (1998) Effect of acetabular component orientation on recurrent dislocation, pelvic osteolysis, polyethylene wear, and component migration. *J Arthroplasty* 13:530–534
- Howell JR, Garbuz DS, Duncan CP (2004) Minimally invasive hip replacement: rationale, applied anatomy, and instrumentation. *Orthop Clin North Am* 35:107–118. doi:10.1016/S0030-5898(03)00112-3
- DiGiovanni CW, Garvin KL, Pellicci PM (1999) Femoral preparation in cemented total hip arthroplasty: reaming or broaching? *J Am Acad Orthop Surg* 7:349–357
- Berry DJ, Berger RA, Callaghan JJ, Dorr LD, Duwelius PJ, Hartzband MA, Lieberman JR, Mears DC (2003) Minimally invasive total hip arthroplasty. Development, early results, and a critical analysis. Presented at the Annual Meeting of the American Orthopaedic Association, Charleston, South Carolina, USA, June 14, 2003. *J Bone Joint Surg Am* 85-A:2235–2246
- Bottnar F, Delgado S, Sculco TP (2006) Minimally invasive total hip replacement: the posterolateral approach. *Am J Orthop (Belle Mead NJ)* 35:218–224
- Merle C, Grammatopoulos G, Waldstein W, Pegg E, Pandit H, Aldinger PR, Gill HS, Murray DW (2013) Comparison of native anatomy with recommended safe component orientation in total hip arthroplasty for primary osteoarthritis. *J Bone Joint Surg Am* 95:e172. doi:10.2106/JBJS.L.01014
- Lewinnek GE, Lewis JL, Tarr R, Compere CL, Zimmerman JR (1978) Dislocations after total hip-replacement arthroplasties. *J Bone Joint Surg Am* 60:217–220
- Lu M, Zhou YX, Du H, Zhang J, Liu J (2013) Reliability and validity of measuring acetabular component orientation by plain anteroposterior radiographs. *Clin Orthop Relat Res* 471:2987–2994. doi:10.1007/s11999-013-3021-8
- Yao L, Yao J, Gold RH (1995) Measurement of acetabular version on the axiolateral radiograph. *Clin Orthop Relat Res* 316:106–111
- Merle C, Waldstein W, Pegg E, Streit MR, Gotterbarm T, Aldinger PR, Murray DW, Gill HS (2012) Femoral offset is underestimated on anteroposterior radiographs of the pelvis but accurately assessed on anteroposterior radiographs of the hip. *J Bone Joint Surg (Br)* 94:477–482. doi:10.1302/0301-620X.94B4.2806794-B/4/477
- Dastane M, Dorr LD, Tarwala R, Wan Z (2011) Hip offset in total hip arthroplasty: quantitative measurement with navigation. *Clin Orthop Relat Res* 469:429–436. doi:10.1007/s11999-010-1554-7
- Aldinger PR, Jung AW, Breusch SJ, Ewerbeck V, Parsch D (2009) Survival of the cementless Spotorno stem in the second decade. *Clin Orthop Relat Res* 467:2297–2304. doi:10.1007/s11999-009-0906-7
- Molli RG, Lombardi AV Jr, Berend KR, Adams JB, Sneller MA (2012) A short tapered stem reduces intraoperative complications in primary total hip arthroplasty. *Clin Orthop Relat Res* 470:450–461. doi:10.1007/s11999-011-2068-7
- Patel RM, Smith MC, Woodward CC, Stulberg SD (2012) Stable fixation of short-stem femoral implants in patients 70 years and older. *Clin Orthop Relat Res* 470:442–449. doi:10.1007/s11999-011-2063-z
- Zweymuller KA, Lintner FK, Semlitsch MF (1988) Biologic fixation of a press-fit titanium hip joint endoprosthesis. *Clin Orthop Relat Res* 235:195–206
- Haddad RJ Jr, Cook SD, Thomas KA (1987) Biological fixation of porous-coated implants. *J Bone Joint Surg Am* 69:1459–1466
- Fackler CD, Poss R (1980) Dislocation in total hip arthroplasties. *Clin Orthop Relat Res* 151:169–178
- Little NJ, Busch CA, Gallagher JA, Rorabeck CH, Bourne RB (2009) Acetabular polyethylene wear and acetabular inclination and femoral offset. *Clin Orthop Relat Res* 467:2895–2900. doi:10.1007/s11999-009-0845-3
- Rohrl SM, Li MG, Pedersen E, Ullmark G, Nivbrant B (2006) Migration pattern of a short femoral neck preserving stem. *Clin Orthop Relat Res* 448:73–78. doi:10.1097/01.blo.0000224000.87517.4c
- Lombardi AV, Jr., Berend KR, Adams JB (2009) A short stem solution: through small portals. *Orthopedics* 32(9). doi:10.3928/01477447-20090728-09
- Floren M, Lester DK (2006) Durability of implant fixation after less-invasive total hip arthroplasty. *J Arthroplasty* 21:783–790. doi:10.1016/j.arth.2005.11.001
- Swanson TV (2005) Early results of 1000 consecutive, posterior, single-incision minimally invasive surgery total hip arthroplasties. *J Arthroplasty* 20:26–32. doi:10.1016/j.arth.2005.05.017
- Licini DJ, Burmikel DJ, Meneghini RM, Ochsner JL (2013) Comparison of limb-length discrepancy after THA: with and without computer navigation. *Orthopedics* 36:e543–547. doi:10.3928/01477447-20130426-13
- Digioia AM 3rd, Jaramaz B, Plakseychuk AY, Moody JE Jr, Nikou C, Labarca RS, Levison TJ, Picard F (2002) Comparison of a mechanical acetabular alignment guide with computer placement of the socket. *J Arthroplasty* 17:359–364
- Bosker BH, Verheyen CC, Horstmann WG, Tulp NJ (2007) Poor accuracy of freehand cup positioning during total hip arthroplasty. *Arch Orthop Trauma Surg* 127:375–379. doi:10.1007/s00402-007-0294-y
- Wenz JF, Gurkan I, Jibodh SR (2002) Mini-incision total hip arthroplasty: a comparative assessment of perioperative outcomes. *Orthopedics* 25:1031–1043
- Meftah M, Yadav A, Wong AC, Ranawat AS, Ranawat CS (2013) A novel method for accurate and reproducible functional cup positioning in total hip arthroplasty. *J Arthroplasty* 28:1200–1205. doi:10.1016/j.arth.2012.09.018
- Ghelman B, Kepler CK, Lyman S, Della Valle AG (2009) CT outperforms radiography for determination of acetabular cup version after THA. *Clin Orthop Relat Res* 467:2362–2370. doi:10.1007/s11999-009-0774-1