Common Errors in the Execution of Preoperative Templating for Primary Total Hip Arthroplasty

Krishna R. Tripuraneni, MD,† Michael J. Archibeck, MD,*
Daniel W. Junick, MD,* Joshua T. Carothers, MD,* and Rick E. White*

Abstract: We reviewed 75 primary total hip arthroplasty preoperative and postoperative radiographs and recorded limb length discrepancy, change in femoral offset, acetabular position, neck cut, and femoral component positioning. Interobturator line, as a technique to measure preoperative limb length discrepancy, had the least amount of variance when compared with interteardrop and intertuberosity lines (Levene test, P = .0527). The most common error in execution of preoperative templating was excessive limb lengthening (mean, 3.52 mm), primarily due to inferior acetabular cup positioning (Pearson correlation coefficient, P = .036). Incomplete medialization of the acetabular component contributed the most to offset discrepancy. The most common errors in the execution of preoperative templating resulted in excessive limb lengthening and increased offset. Identifying these errors can lead to more accurate templating techniques and improved intraoperative execution. **Keywords:** templating, errors, hip, arthroplasty.

Meticulous preoperative templating before primary total hip arthroplasty (THA) aids in the restoration of limb length, femoroacetabular offset, and the prediction of appropriate implant types and sizes. Although many studies have examined optimal component positioning [1-5], few have examined the accuracy of execution of preoperative planning [6-8]. Our impression is that a few common errors in the execution of such templating account for the majority of resultant inaccuracies. We therefore sought to systematically compare our preoperative plans with our postoperative radiographs to identify and specifically quantify these common errors.

The purpose of this study was to retrospectively review the reproducibility of measuring limb length discrepancy (LLD) techniques and to identify common errors in the execution of preoperative planning.

Materials and Methods

We reviewed 75 routine consecutive primary hip arthroplasties performed between September 2006 and July 2007. Twenty-five were performed by each of 3 high-volume surgeons at our institution. Patients in whom bilateral hips were performed or in whom complex procedures were required (osteotomies, bone grafting, etc) were excluded from the evaluation. We retrospectively reviewed the preoperative radiographs and the associated templating, which was performed before the procedure. We then reviewed first postoperative radiographs (6 weeks) for each patient.

All surgeries were planned with a standard preoperative templating technique used by all surgeons at our institution. All radiographs reviewed in this study were standard analog films. Preoperative radiographs included an anteroposterior (AP) view of the pelvis and an AP and lateral view of the proximal femur obtained with a standard magnetic magnification markers. The AP pelvis images were obtained with the x-ray tube 1 m from the tabletop and centered over the pubic symphysis in an attempt to obtain magnification of 20% ± 6% (2 SDs) [9]. The AP images of the hip were obtained with 10° to 15° of internal rotation of the limb centered over the hop in an effort to obtain a true AP of the femoral neck.

Templating Technique

The templating was supervised or carried out by the respective attending orthopedic surgeon, then recorded on an index card before the surgery, and followed a standard protocol. First, LLD was determined on the AP pelvic radiograph; a horizontal line through one of two radiographic landmarks (inferior aspect of the ischial tuberosities [used by two surgeons] or the inferior aspect of the obturator foramina [used by one surgeon]) was

*From the *New Mexico Orthopaedic Associates, Albuquerque, New Mexico; and †University of New Mexico Health Sciences Center, Department of Orthopaedic Surgery, Albuquerque, New Mexico.*
Submitted April 13, 2009; accepted October 10, 2009.
No benefits or funds were received in support of the study.
Reprint requests: Michael Archibeck, MD, 201 Cedar St., NE Suite 6600, Albuquerque, NM 87106.

0883-5403/2508-0010$36.00/0
doi:10.1016/j.arth.2009.10.004

drawn. The distance between this line and the most medial aspect of the lesser trochanters was recorded. The difference between the 2 sides, as measured with a 20% magnified ruler, was defined as our radiographic LLD. This value and the clinically measured LLD were used to determine a surgical goal for limb lengthening intraoperatively. This goal was recorded and used for comparison of our actual lengthening obtained.

We then performed the remainder of the templating on the AP hip radiograph using 20% magnified templates. Using an acetabular transparency, the anticipated acetabular component position and size were determined. The inferior border of the acetabulum was positioned to the level of the inferior aspect of the teardrop and positioned with abduction in line with the superolateral aspect of the acetabulum, while accounting for intraoperative removal of peripheral osteophytes. The center of rotation (COR) of the acetabular component was then marked on the radiograph. We then drew a horizontal line proximal to the acetabular COR of distance equivalent to the desired limb lengthening. Next, we templated the appropriate size and positioning of the femoral component. The size was determined by appropriate fit and fill of the proximal femur. The proximal/distal position was determined by placing the template such that the standard (+ zero) femoral head transected the previously drawn line. If executed properly, this would give us the desired limb lengthening. We then evaluated the femoroacetabular offset gained or lost with this proposed construct. If a loss in offset was anticipated, an extended offset femoral template was used.

Postoperative Radiographic Evaluation

Postoperatively, a complete radiographic review was performed by a single, unbiased reviewer not involved in any of the surgical procedures (KRT). Our primary goal was to review the execution outcomes of the preoperative planning. To identify any significant variations in the determination of LLD, we remeasured LLD of all postoperative radiographs using three different radiographic landmarks an average of 12 months after initial measurements. To minimize recall bias, KRT did all remeasurements, whereas the attending surgeon performed all LLD measurements preoperatively. Horizontal lines were drawn through the inferior aspect of the teardrops (interteardrop line), the inferior aspect of the obturator foramina (interobturator line), and the inferior aspect of the ischial tuberosities (intertuberosity line). Limb length discrepancy was recorded with respect to each of these radiographic landmarks for each patient, both on preoperative and postoperative AP pelvis radiographs, and statistically reviewed. In addition, we evaluated on both preoperative and postoperative radiographs the templated and actual positions of the acetabular component, femoral component, neck cut level, depth of femoral component insertion, change in offset, and component sizes.

Various statistical methods were used to analyze the collected data. Limb length discrepancy measuring techniques were evaluated using a Levene test, Pearson correlation coefficients, and linear regression models. Linear regression models were also used to determine the templating results for execution of offset and to quantify how much each component contributed to LLD, if any.

Results

Our final demographics included 20 men and 55 women with an average body mass index of 27.3 (range, 22.4-36.3); average height was 67 in (range, 60-74 in). There were a total of 47 patients with a preoperative diagnosis of osteoarthritis, 15 with rheumatoid arthritis, 9 with avascular necrosis, and 4 with posttraumatic degenerative joint disease.

Femoral components used in these 75 hips included 35 standard-offset ML Tapers, 23 extended-offset ML Tapers, 9 standard-offset reduced-neck ML Tapers, 3 extended-offset reduced-neck ML Tapers, 1 standard-offset Epoch II, 2 extended-offset Epoch II, 1 Versys Heritage, and 1 Versys beaded fullcoat (all Zimmer, Warsaw, Ind). Implanted acetabular components included 38 Trilogy cluster components and 37 Trabecular Metal cluster components (all Zimmer). Acetabular liners implanted consisted of 51 standard liners and 24 ten-degree elevated rim liners.

Limb Length Evaluation

To demonstrate which of the three horizontal lines (among interobturator, interteardrop, and intertuberosity) had the least amount of variation in measuring LLD, we used the Levene test, which demonstrated weak evidence (P = .0527) that variances were not similar among the three radiographic lines used to measure LLD. Interobturator line had the least amount of variation (SD = 1.71), whereas interteardrop had the most amount of variation (SD = 2.53); and intertuberosity fell in between these two values (SD = 1.99). Pearson correlation coefficients were also calculated, with the most correlation present between the

Table 1. Correlation Coefficients of Radiographic Lines to Measure LLD

Preoperative Radiographic Lines Used to Determine LLD
Pearson Correlation Coefficients, N = 75
Prob > |r| Under H0: $\varrho = 0$

	Intertuberosity	Interteardrop	Interobturator
Intertuberosity	1.00000		
Interteardrop	0.58565 *	1.00000	
Interobturator	0.83806 *	0.64723 *	1.00000

Correlation coefficients for intertuberosity, interteardrop, and interobturator line; the highest correlation in our study is with the interobturator line.
* P < .0001.

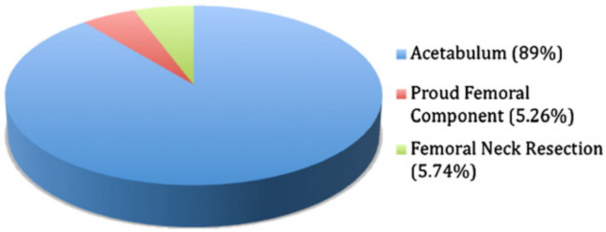

Fig. 1. Contributions to excessive limb lengthening.

interobturator and interteardrop lines (0.83, $P < .0001$). We found that the most precise and reproducible radiographic line to determine LLD for our cases was the interobturator line. A summary of the correlation coefficients is seen in Table 1.

Execution of Templating

Limb Length

Using a linear regression model for each of the interobturator, interteardrop, and intertuberosity lines, all three lines demonstrated a similar execution outcome with respect to LLD. For the interobturator line (our most precise, reproducible LLD method), the mean postoperative LLD, when compared with the preoperative goal, was 3.52 mm (range of 15 mm of shortening to 18 mm of lengthening, standard deviation of 6.76 mm).

The acetabular component position contributed most significantly to errors in the execution of desired postoperative limb length (Pearson correlation coefficient, $P = .04$). Neither the position of the femoral component ($P = .38$) nor the femoral neck resection level ($P = .34$) contributed in a statistically significant manner to limb length errors. A multiple regression model of acetabular component contribution, femoral component contribution, and femoral neck resection on postoperative LLD was performed and is represented in Fig. 1.

Offset

Femoroacetabular offset was on average 0.4 mm greater than desired, with a range from 16 mm of reduced offset to 21 mm of increased offset (SD = 6.8 mm). Lateral placement of the acetabular component relative to the templated position contributed a mean of 1.4 mm (range, −18 to 13 mm) to offset discrepancy, whereas the femoral component geometry contributed a mean of −1.0 mm (range, −23 to 19.5 mm); median values were 1.5 and −0.5 mm, respectively.

Discussion

The goals of THA are to obtain a well-functioning, long-lasting, pain-free reconstruction [10,11]. An integral part of this reconstruction includes correcting any LLD, improving hip mechanics, and providing hip stability. Preoperative templating is of critical importance toward accomplishing these goals. Errors in the execution of preoperative planning occur and are felt by the authors to be relatively reproducible and similar among surgeons. The purpose of this review was to identify, if possible, the most reproducible and reliable technique for measuring preoperative LLD and to identify common errors in the execution of preoperative templating.

Our study demonstrates, without statistical significance, that LLD is best measured in a reproducible manner using the interobturator line (Pearson correlation coefficient, 0.84), more so than the interteardrop or interischial lines. Many studies have examined the interteardrop line [12,13]. There have been no specific studies demonstrating which radiographic line has the best reproducibility. Intraoperatively, Ranawat et al [14] have been a proponent of the infracotyloid groove as a static anatomical landmark to assess LLD; meanwhile, others have referenced the well limb [15] or used intraoperative radiographs [16]. Other studies have scrutinized postoperative LLD equalization attempts as well. Suh et al stated in their study that it was not successful to equalize limb lengths while maintaining appropriate offset [7]. Their postoperative results showed a lengthening of 3.1 mm for all patients on the affected side, whereas the same limb was short 5.6 mm preoperatively, using the intertuberosity line; their study also did not include functional LLD. More recently, Unnanuntana et al published a similar study using the interteardrop line, noting a mean postoperative LLD of 0.9 mm, compared with a preoperative mean value of 4.7 mm. As evidenced with this recent review of the literature, along with our results, there are numerous ways to measure LLD; and in the future, we may be able to determine the best radiographic method using comparative studies.

Although our templating technique is quite similar to the article by Gonzalez Della Valle et al [17] and other surgeons, we found the interobturator line to be more reproducible, as opposed to their suggestion of a radiographic line through the inferior border of the teardrops or ischial tuberosities. Although other studies have found the interteardrop to be more useful because of its proximity to the hip COR [18,19], our data suggest, although not statistically significant, that this line has the most variability. No studies specifically have examined the sole use of the interobturator line alone; its benefit has not been borne out, and its advantage may be yet to be determined.

We found that the most common errors in the execution of preoperative planning were excessive limb lengthening and increased total femoroacetabular offset. Although both of these tendencies may be used by the surgeon to improve intraoperative hip stability, they can lead to patient dissatisfaction with respect to the possible need for a shoe lift in the case of limb lengthening and a prominent lateral hip or trochanteric bursitis in the case of increased offset. We found that the mean error in obtaining our desired limb lengthening was 4.83 mm, with a range of −8 to 16 mm. We found that, on average, inferior acetabular positioning relative to our templating technique contributed most significantly to this error (89%), with placement of femoral neck cut and proud positioning of the femoral component to be less common (combined, 11%). We found that the contributing errors to offset execution were more so a lateralized acetabular component rather than a malpositioned femoral component. The absolute values of the alterations in offset were generally small and perhaps of minimal clinical significance.

Many prior studies have examined the best method to minimize limb length inequalities, both preoperatively and intraoperatively [8,13,14,16,20]. Two other studies have also examined the role of component positioning. Eggli et al [12] noted 1.5 mm inferior and 3.4 mm medial placement of acetabular components in their series. Knight and Atwater [21] found 1 mm inferior and 5 mm medial postoperative positioning of their acetabular components in relation to the radiographic teardrop. Preoperative templating for predicting component size has demonstrated variable results. Unnanuntana et al [22] demonstrated 42.2% accurate prediction of cementless acetabular size and 68.8% for cementless femoral size. Their mean postoperative LLD was 0.9 ± 6.8 mm. Eggli et al [12] also found 90% accurate prediction of acetabular components and 92% for cemented femoral components, with radiographic LLD of 2 mm ± 1 mm.

In a 2005 study by Gonzalez Della Valle et al [6], they retrospectively demonstrated that implant size, position, alignment, COR restoration, and equalization of limb length are all important reasons to perform preoperative templating for THA. Furthermore, they determined acetabular component positioning preoperatively using the inferior border of the teardrop and the superolateral border of the acetabulum; they were able to accurately predict 87% of cemented cup sizes and 65% of cementless cups. Although their study is of significant value, we sought to address cementless cups only in this study to normalize these implant results.

Although there is similar methodology in our study to the article of Unnanuntana et al [22], our study has a few differences worth noting from their two primary goals. First, their study primarily focused on determining the accuracy in the prediction of component size—a feature we sought not to examine given the literature reviewed here. Their second goal of evaluating clinical usefulness of one specific method of preoperative templating to establish limb length equality and hip offset was examined here and expanded upon. We were able to identify our most reproducible radiographic line with the least amount of variability in determining LLD and quantify the degree to which each component contributes to LLD and offset.

A large constraint of this study is our exclusion of functional limb length discrepancy, while only examining radiographic differences preoperatively and postoperatively. Many studies have examined both radiographic and functional LLD and their respective importance [14,17,23,24]. Although we do routinely measure functional LLD preoperatively, we do not routinely measure this in our patients postoperatively unless they continue to complain of that symptom or have a noteworthy limp on clinical examination. In addition, Gonzalez Della Valle et al [23]. showed that patients with increasing age tend to perceive functional LLD to a smaller degree than younger patients postoperatively and thus have a less likely need for shoe lifts. For this reason, it may be useful to gauge radiographic LLD alone as an independent objective criterion in evaluating postoperative LLD. The patients included in this study all had an attempt at equalization of radiographic LLD only.

In addition, despite using a standard templating technique, as mentioned earlier, errors in execution of templating may occur from human measurement differences and rotation differences comparing preoperative and postoperative radiographs.

Whereas the retrospective nature of this study is a limitation, several important findings are of clinical significance. First, our comparison of the three different techniques for measuring radiographic LLD demonstrated the most reproducible one to be the interobturator line. We have therefore gone to using this line routinely in our templating. Second, the most common errors in the execution of preoperative templating result in an increased limb length and increased femoroacetabular offset. The placement of the acetabular component contributes most significantly to this error. We feel this common error results from a natural tendency to ream medially preferentially over superiorly secondary to the direction of force applied to the reamers. We found that we were templating to remove equal bone circumferentially but rarely did so during surgery. Thus, we now template the acetabular component more inferiorly while still removing adequate superior bone to obtain bleeding, subchondral bone (ie, template to remove 1-2 mm of superior bone). The issue of femoroacetabular offset demonstrates the tremendous variability in patient anatomy relative to that available with standard femoral components. Although lateral acetabular component positioning contributed to this error (1.4 mm), only the large differences are felt to be clinically significant. Whereas a slight increase in femoral offset can improve hip biomechanics and reduce joint reactive force, larger amounts can result in a cosmetic deformity or increase the likelihood of trochanteric bursitis [10,11,20].

References

1. Carter LW, Stovall DO, Young TR. Determination of accuracy of preoperative templating of noncemented femoral prostheses. J Arthoplasty 1995;10:507.

2. Hayakawa K, Minoda Y, Aihara M, et al. Acetabular component orientation in intra- and postoperative positions in total hip arthroplasty. Arch Orthop Trauma Surg 2008 [Epublication].
3. Kummer FJ, Shah S, Iyer S, et al. The effect of acetabular cup orientations on limiting hip rotation. J Arthroplasty 1999;14:509.
4. McCollum DE, Ray WJ. Dislocation after total hip arthroplasty. Causes and prevention. Clin Orthop Relat Res 1990;261:159.
5. Patil S, Bergula A, Chen PC, et al. Polyethylene wear and acetabular component orientation. J Bone Joint Surg 2003;85-S:56.
6. Gonzalez Della Valle A, Slullitel G, Piccaluga F, et al. The precision and usefulness of preoperative planning for cemented and hybrid primary total hip arthroplasty. J Arthroplasty 2005;20:51.
7. Suh KT, Cheon SJ, Kim DW. Comparison of preoperative templating with post-operative assessment in cementless total hip arthroplasty. Acta Orthop Scand 2004;75:40.
8. Woolson ST. Leg length equalization during total hip replacement. Orthopedics 1990;13:17.
9. Clarke IC, Gruen T, Matos M, et al. Improved methods for quantitative radiographic evaluation with particular reference to total hip arthroplasty. Clin Orthop Relat Res 1976;121:83.
10. Bombelli R. Osteoarthritis of the hip: pathogenesis and consequent therapy. Berlin: Springer-Verlag; 1976.
11. Pauwels F. Gesammelte abhandlungen zur funktionellen anatomiedes bewegungsapparates. Berlin: Springer-Verlag; 1965.
12. Eggli S, Pisan M, Muller ME. The value of preoperative planning for total hip arthroplasty. J Bone Joint Surg Br 1998;80:382.
13. Woolson ST, Hartford JM, Sawyer A. Results of a method of leg-length equalization for patients undergoing primary total hip replacement. J Arthroplasty 1999;14:159.
14. Ranawat CS, Rao RR, Rodriguez JA, et al. Correction of limb-length inequality during total hip arthroplasty. J Arthroplasty 2001;16:715.
15. Johnston RC, Brand RA, Crowninshield RD. Reconstruction of the hip. A mathematical approach to determine optimum geometric relationships. J Bone Joint Surg 1979;61:639.
16. Hoffman AA, Bolognesi M, Lahav A, et al. Minimizing leg-length inequality in total hip arthroplasty: use of preoperative templating and an intraoperative x-ray. Am J Orthop 2008;37:18.
17. Gonzalez Della Valle A, Padgett DE, Salvati EA. Preoperative planning for primary total hip arthroplasty. JAAOS 2005;13:455.
18. Goodman SB, Adler SJ, Fyhrie DP, et al. The acetabular teardrop and its relevance to acetabular migration. Clin Orthop Relat Res 1998;236:199.
19. Ilchmann T, Franzen H, Mjoberg B, et al. Measurement accuracy in acetabular cup migration: a comparison of four radiologic methods versus roentgen stereophotogrammetric analysis. J Arthroplasty 1992;7:121.
20. Iaqulli ND, Mallory TH, Berend KR, et al. A simple and accurate method for determining leg length in primary total hip arthroplasty. Am J Orthop 2006;35:455.
21. Knight JL, Atwater RD. Preoperative planning for total hip arthroplasty: quantitating its utility and precision. J Arthroplasty 1992;274:12.
22. Unnanuntana A, Wagner D, Goodman SB. The accuracy of preoperative templating in cementless total hip arthroplasty. J Arthroplasty 2009;24:180.
23. Gonzalez Della Valle A, Zoppi A, Peterson MGE, et al. Age affects the perception of limb length discrepancy in patients with and without a total hip arthroplasty. Hip Intl 2004;14:249.
24. Ranawat CS, Rodriguez JA. Functional leg-length inequality following total hip arthroplasty. J Arthroplasty 1997;12:359.