Usefulness of Intraoperative Radiographs in Reducing Errors of Cup Placement and Leg Length During Total Hip Arthroplasty

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Abstract

Traditional methods of component placement during total hip arthroplasty (THA) can lead to errors in cup abduction angle and leg length.

Intraoperative radiographs were used to assess and correct errors during surgery in a consecutive series of 278 THAs performed by a single surgeon. After exclusions, 262 cases were available for cup abduction angle assessment and 224 for leg length discrepancy (LLD) assessment. Components were initially placed in a position determined as appropriate by the surgeon. Intraoperative radiographs were taken and appropriate corrections made. Postoperative radiographs were assessed at 6 weeks.

Mean abduction angle on intraoperative radiographs was 39.6°±5.9° versus 38.6°±4.1° on postoperative radiographs. Thirty-eight cups were outside the target abduction range on intraoperative radiographs versus 4 on postoperative radiographs. Mean LLD was 3.7 mm ± 3.6 mm on intraoperative radiographs and 2.5 mm ± 2.7 mm on postoperative radiographs.

Use of intraoperative radiographs is a valid, useful technique for minimizing errors in THA.

Correct acetabular component orientation and leg length restoration are integral to achieving positive outcomes in primary total hip arthroplasty (THA). Acetabular component position can affect dislocation rate, range of motion, pelvic osteolysis, and bearing surface wear.[1-7] Lewinnek and colleagues[1] correlated cup position with rates of dislocation and suggested a safe zone of 30°-50° of acetabular abduction and 5°-25° of acetabular anteversion. Since this landmark paper, several authors have demonstrated the importance of component position in obtaining optimal outcomes in THA.[2,3,7] While recommendations for ideal component position vary, there is little debate that cup position is critical to success of THA.[6]

Mechanical jigs are commonly used to aid in cup placement. However, these guides are based on the assumption that the surgeon can accurately predict the position of the patient's pelvis on the operating table. This is difficult and errors in cup position are common using these jigs.[8] More recently, computer assisted systems have been used for cup navigation in an attempt to reduce errors.[9-12]

Accurate leg length restoration is another important factor in hip function and patient satisfaction after THA.[13] Significant changes in leg length can adversely affect patient gait and hip function and stability.[14-16] Leg length discrepancy (LLD) is also a major cause of litigation following THA.[13] Consequently, there are multiple methods for measuring leg length change during surgery, including measurement of resected bone, mechanical devices, and computer assistance.[17]

Although there is no consensus on what angles constitute as ideal cup placement, there is consensus that extremes of positioning should be avoided and that the surgeon should have reasonable confidence in his/her cup placement.[6] There is also consensus on the importance of accurate leg-length restoration.[13-16] Intraoperative radiographs are an efficient technique to reduce errors in cup placement and leg length,[18] and are available in virtually all hospital settings.

The purpose of this study was to assess outcomes and error reduction in cup abduction angle inclination and leg length utilizing intraoperative radiographs in a consecutive series of patients undergoing primary THA. Our hypothesis was that use of intraoperative radiographs would result in significant reduction in errors of cup placement and leg length restoration.

Materials and Methods

From January 2005 through April 2008, one surgeon (MJC) performed 278 primary THAs on 260 patients. There were 121 men and 139 women patients, and 129 right and 149 left hips. The inclusion criterion was primary THA. Patients were excluded from assessment of cup inclination if there was any significant hip dysplasia and from the leg length assessment if there was any significant hip dysplasia, contralateral hip

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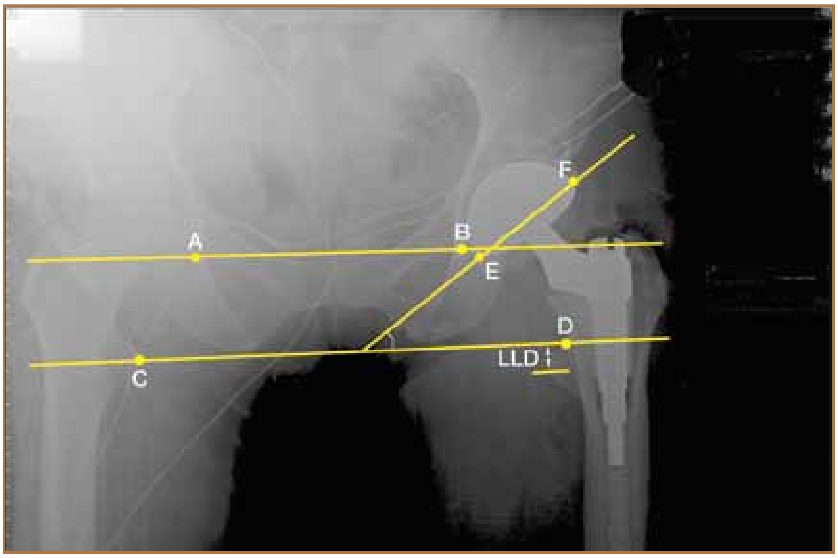

Figure. The cup abduction angle and leg length discrepancy (LLD) are measured as follows: (1) line AB is drawn through the inferior aspect of each teardrop of the pelvis; (2) line CD is drawn parallel to line AB through the center of the lesser trochanter of the non-operative leg; and (3) line EF is drawn from the inferior to the superior edge of the cup. The abduction angle is the angle subtended by lines CD and EF. The LLD is the distance between line CD and the center of the lesser trochanter of the operative leg.

pathology that would affect leg length measurement or need for proximal femoral osteotomy. After exclusions, there were 262 hips available for cup inclination assessment and 224 for length assessment. All patients consented for inclusion in this retrospective study and IRB approval was obtained.

The same surgical technique was used for each patient. Routine surgical technique was not altered for this study. Patient position and use of intraoperative radiographs are standard practice for the operating surgeon. Patients were positioned laterally with the anterior pelvic plane perpendicular to the surgical table. A posterior approach was used in all cases. Appropriate radiographic templating was performed prior to each case. The acetabulum was prepared in standard fashion and trialed. The acetabular component was then impacted with a goal abduction angle of 28°-45°. The abduction goal was set by the operating surgeon based on literature and experience. Angles above 45° were felt to increase risk of component wear. Angles below 28° were felt to increase risk of component impingement with range of motion. Attempt was made to match native anteversion. All cups were press-fit. A trial liner was placed. The femur was then prepared based on preoperative templating and intraoperative assessment. All final femoral components were press-fit. The final femoral trial was left in place and coupled with a neck of appropriate length and offset and headball. The hip was reduced and the field covered with a sterile drape.

Two crosstable intraoperative radiographs, anteroposterior (AP) pelvis and AP hip, were then taken sterilely. Measurements of cup abduction angle and leg length were recorded on AP pelvis radiographs. A horizontal line was drawn through the inferior aspect of each pelvic teardrop. A line was then drawn along the opening plane of the acetabular component. The angle subtended from the intersection of these 2 lines was classified as the cup abduction or inclination angle. For leg length, the interteardrop line was again used. Measurements were made from this line down orthogonally to the most proximal portion of the lesser trochanters (**Figure**). Any suspected film magnification was normalized using the known diameter of the cup. The AP hip radiograph was utilized to assess stem size and position in an attempt to avoid undersized stems and prevent varus stem placement.

Intraoperative values for inclination angle and LLD were noted. The hip was taken through standard intraoperative examination to assess stability, range of motion, and impingement. Based on radiographic measurements, appropriate changes were made. If the cup was outside the target inclination range of 28°-45°, a rubber coated tamp was used to make small changes in cup angle. This rarely altered the original press-fit stability of the cup. After changes were made, a final impaction was provided to the cup with a secondary impactor to insure that the cup was firmly seated. At this point acetabular screws were placed if desired and the final liner was inserted if using a modular cup.

Measured differences in leg length were assessed with the goal of creating equal lengths. Based on measured leg length, changes were made including altering femoral component size or position as well as changing neck length. Final femoral components were inserted and the hip was then reduced, irrigated thoroughly, and closed in a standard fashion. All patients had standard films taken including a supine AP pelvis 6 weeks postoperatively.

Two independent surgeons (MAW, JCM) reviewed intraoperative and 6-week postoperative films for all patients. Cup inclination and leg length were measured with the same method as above. This resulted in 2 datasets: intraoperative and postoperative. The intraoperative dataset was assumed to be a control, representing where the surgeon would have placed the components if not for the information yielded by the intraoperative radiograph. Mean and standard deviation for cup angle and LLDs were calculated for both datasets.

For study purposes, LLDs were recorded as an absolute number of millimeters from equal. Negative values were not used if the operative leg was short. Rather, the absolute difference in leg length was used (eg, if the leg was 3 mm short or long, the value recorded would be 3 mm). The number of outliers in each dataset was also calculated. This included number of cups with an abduction angle of 50° or more, number of cups outside the target abduction of 28°-45° and number of cases where postoperative LLD was greater than 10 mm. Statistical analysis included paired t-tests to compare means between the 2 datasets, F-tests to compare standard deviations and chi-square analysis to compare the number of outliers.

Results

Two hundred sixty-two hips were analyzed for cup abduction angle (**Table I**). Mean abduction angles were 39.6°±5.9° (range, 24°-60°) in the intraoperative dataset and 38.6°±4.1° (range, 28°-59°) in the postoperative dataset. The differences between means and standard deviations were statistically significant (P = .02 and P<.001, respectively). Cups in the postoperative dataset were slightly less vertical and demonstrated less variability in position.

The number of outliers from the target abduction angle range of 28°-45° was calculated for each dataset. In the intraoperative dataset, there were 38 cups (14.5%) outside the target range (35 cups >45° and 3 cups <28°). For the postoperative dataset, there were 4 cups (1.5%) outside the target range (all >45°). There were significantly fewer outliers in the postoperative dataset than in the intraoperative dataset (P<.001).

Extreme outliers with abduction angles greater than 50° were also assessed. There were 12 (4.5%) such values in the intraoperative dataset versus only 2 (0.8%) in the postoperative dataset. This difference was significant (P = .02). Furthermore, 1 of the 2 cups in the postoperative dataset with an abduction angle greater than 50° had clearly moved into a more vertical position from where it had been placed during surgery. The cup was inserted without screws and immediate postoperative films showed an abduction angle of 41°. This angle had increased to 59° on the 6-week film.

Overall, 224 hips were assessed for LLD (**Table II**). Mean LLD was 3.7 mm ± 3.7 mm (range, 0-15 mm) for the intraoperative dataset and 2.5 mm ± 2.7 mm (range, 0-9 mm) for the postoperative dataset. The differences between means and standard deviations were statistically significant (P<.001 for both). Overall, there was a smaller LLD and less variability in the postoperative dataset.

A LLD greater than 10 mm was considered to be an outlier. In the intraoperative dataset there were 16 hips (7.1%) with LLD greater than 10 mm. No hips in the postoperative dataset had LLD greater than 10 mm. This difference was significant (P<.001).

Table I. Intraoperative Versus Postoperative Cup Abduction Angle

	Intraoperative	Postoperative	P value
Number of Cups	262	262	-
Mean Abduction Angle (°)	39.6	38.6	.02
Standard Deviation (°)	5.9	4.1	<.001
Number of Cups >50°	12	2	.02
Number of Cups >45° or <28°	38	4	<.001

Table II. Intraoperative Versus Postoperative Leg Length Difference

	Intraoperative	Postoperative	P value
Number of Hips	224	224	-
Mean LLD (mm)	3.7	2.5	<.001
Standard Deviation (mm)	3.6	2.7	<.001
Number >10 mm	16	0	<.001

Abbreviation: LLD, leg length difference.

Discussion

Component position during THA has been shown to be a critical component of successful surgical outcome.[1-3,7] Unlike many independent patient factors such as preoperative health status or compliance with rehabilitation, component position is directly under the surgeon's control. Errors in component position can increase risk of dislocation, early wear, leg length inequality, and revision surgery.[1-3,7,13,14,16] Traditional cup placement using freehand techniques or mechanical guides leads to a significant rate of error.[11,12,19] This error rate can be increased even more when minimally invasive techniques are utilized.[20,21]

Most recommendations for cup placement are based on studies examining dislocation and wear rates. Lewinnek and colleagues[1] were one of the first to examine cup placement and its relation to dislocation rates. Using postoperative radiographs, he described a safe zone of 30°-50° of abduction and 5°-25° of anteversion. The dislocation rate for cups located outside this zone was 4 times higher than cups located within. Most present-day recommendations[6] are similar, although not identical, to Lewinnek's.

Schmalzried and colleagues[3] correlated polyethylene wear and osteolysis with cup abduction angle. Osteolysis of the ilium was associated with abduction of 50° or more. Risk of osteolysis rose incrementally as cups increased in abduction over 50°. Kennedy and colleagues[2] confirmed these findings, demonstrating that mean inclination of less than 50° led to significantly less polyethylene wear, osteolysis and cup migration versus mean inclination of 62°.

Significant LLD after THA is a considerable source of morbidity and patient dissatisfaction.[13-16] Gurney and colleagues[15] and associates demonstrated that significant LLD can lead to gait difficulties in older adults. Leg length differences of only 2 cm can lead to increased oxygen consumption and perceived exertion. A 3-cm difference can result in significant quadriceps fatigue. Older adults with preexisting medical conditions may have difficulty walking with LLD as small as 2 cm.

Konyves and colleagues[16] correlated true and perceived LLD with Oxford Hip Scores. He showed that perception of lengthening was related to true lengthening. Furthermore, patients with perceived lengthening had Oxford Hip Scores 18% lower at 1 year postoperatively than patients who perceived equal leg lengths. Incorrect femoral component placement was felt to be responsible for excessive lengthening in 98% of cases.

Hoffmann and colleagues[18] reported the use of intraoperative x-rays to reduce errors in leg length during THA. Eighty-six consecutive hips were assessed. Intraoperative x-rays were taken during all cases and appropriate changes made. On postoperative films mean LLD was 0.3 mm and no leg was lengthened or shortened by more than 6 mm.

Recognition of the importance of component position in THA has led to the recent rise in computer assistance or navigation.[10-12,19,22,23] DiGioia and colleagues[22] examined accuracy of cup placement using mechanical guides during THA. The cup was inserted and then its true position checked using an image-based computer navigation system. Seventy-eight percent of cups were found to be outside of the Lewinnek safe zone when using only a mechanical guide. They concluded that more accurate tools are needed for cup placement and explained the benefits of computer guidance.

Wixson and MacDonald[10] reported on 82 navigated THAs compared to a retrospective cohort of 50 hips done with conventional instruments. The computer system used was an imageless navigation system based on palpation and registration of bony landmarks. The computer-navigated group had significantly fewer errors in cup placement than the traditional group based on assessment of postoperative radiographs. Even with navigation, 45% of cups were outside the target abduction of 40°-45°. Wolf and colleagues[23] performed a computer simulation study to assess the accuracy of an imageless computer navigation system and showed that as little as 4 mm of error during registration of bony landmarks can lead to errors in version and abduction of ±10° and ±6°, respectively.

In the current study, we attempted to demonstrate that significant errors in cup abduction angle and leg length during primary THA can be minimized using intraoperative radiographs. Mean cup abduction angle was significantly different in the intraoperative dataset (39.6°) versus the postoperative dataset (38.6°). The higher angle in the intraoperative dataset reflects the observation that most significant errors in cup abduction are due to the cup being excessively vertical (higher abduction angle). In this study, the vast majority of changes made to cup position were to take the cup from a more vertical position to a more horizontal placement. The difference in mean abduction angle standard deviation between the 2 datasets was also significant. The lower standard deviation in the postoperative dataset reflects a clustering toward the mean with respect to cup abduction angle. We feel that this is directly due to corrections undertaken based on information gathered from intraoperative radiographs.

With respect to LLD, use of intraoperative radiographs again was associated with a significant reduction in error. Mean LLD in the intraoperative dataset was significantly higher than in the postoperative dataset. Information from intraoperative radiographs was used to make necessary corrections before final femoral components were placed, thereby reducing average LLD.

Perhaps the most meaningful results of this study involve the assessment of significant outliers. In the postoperative dataset, only 4 cups were outside the target abduction range. Furthermore, only 2 were extreme outliers with abduction of more than 50° and 1 of these was due to postoperative cup migration. This demonstrates significant reduction in error versus the intraoperative dataset and compares well with published rates of error using computer navigation.[10,12,19] Leenders and colleagues[19] reported on 50 hips done with computer assistance with 2 cups falling outside the target abduction of 40° to 55°. In the current study, only 4 of 262 cups were outside the target range of 28° to 45°.

In the postoperative dataset, there were no cases of the leg being lengthened or shortened by more than 10 mm, while there were 16 such cases in the intraoperative dataset. These initial errors were corrected based on information obtained from the intraoperative radiograph.

In addition to assessing cup abduction and leg length, intraoperative radiographs were also used to address several other factors. Femoral component position was assessed and any error of varus or valgus stem placement was corrected. Radiographs were also used to ensure that the stem was properly filling the femoral canal and that the cup was impacted all the way to the medial wall.

A potential criticism of utilizing intraoperative radiographs is the increased operative time necessary to take and analyze the films. Since use of radiographs is standard practice for the surgeon in this study, we found that additional operative time was minimal (approximately 4 minutes). This is because the operating room staff and surgeon were well versed in this technique. Radiographic cassettes were sterilely covered and waiting in advance and the x-ray technician was called to the room well ahead of time. Time during processing of the radiographs was utilized to assess hip stability, address contractures, obtain any necessary hemostasis, and potentially trial differing neck lengths. These are generally necessary steps that can be accomplished while the radiographs are processed. Radiographic lines were drawn by an experienced staff member and reviewed by the surgeon for accuracy. At this point, additional time was needed if any changes were necessary. However, we feel that time utilized to correct errors in component placement is obviously time well spent.

There are several limitations to this study. The most significant is that our method of using intraoperative radiographs to correct errors does not take into account cup anteversion. Pradhan[24] described a method to calculate cup anteversion based on AP pelvic radiographs. While we did not calculate cup anteversion, every effort was made to match native acetabular anteversion while simultaneously creating a stable hip. Cup version does not exist in isolation. It exists coupled with femoral version to yield the combined version of the prosthetic hip system.

Another limitation is that intraoperative films were taken with the patient in the lateral position whereas postoperative films were taken in the supine position. Several authors have shown that flexion and extension of the pelvis can have an effect on cup abduction measured on radiograph. This could have introduced error into our measurements.

This study demonstrates that use of intraoperative radiographs can lead to significant reduction in cup abduction and leg length errors during primary THA. While debate remains regarding optimal cup orientation, utilizing intraoperative radiographs allows the surgeon to reach his/her selected position more accurately. The operating surgeon in this series has extensive experience in THA. Despite this, there were many initial errors in cup placement and leg length that were noted and corrected based on intraoperative films. For less experienced surgeons or those using minimally invasive techniques, reduction in errors could be even more dramatic. Computer navigation is also a reasonable technique to enhance accuracy during THA. Our error rate using intraoperative radiographs compares well to those of several series using computer navigation. Furthermore, radiographs are readily available in almost every operating room while access to hip navigation is not as widespread.

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