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Use of Intraoperative X-rays to Optimize Component Position and Leg Length During Total Hip Arthroplasty

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ABSTRACT

Proper femoral and acetabular component position and leg length equality are important intraoperative considerations during total hip arthroplasty. Unfortunately, traditional surgical techniques often lead to suboptimal component position, and such deviations have been associated with increased rates of prosthetic wear, dislocation, component loosening, and patient dissatisfaction. Although surgical navigation has been shown to improve reproducibility of component alignment, such technology is not universally available and is associated with significant costs and additional surgical/anesthetic time. In the current study, we found that a routine intraoperative pelvic radiograph could successfully identify malpositioned components and leg length inequalities and could allow for successful correction of identified problems. Unexpected component malposition and leg length inequality occurred in only 1.5% of cases where an intraoperative pelvic radiograph was utilized.

In the field of total hip arthroplasty (THA), there is universal agreement that proper component position is an important determinant to the ultimate success of the surgery. Although "optimal" alignment has yet to be precisely defined, there is general agreement that substantial deviation from accepted values is undesirable. Additionally, although there is no consensus as to how much leg length inequality is acceptable, there is agreement that significant deviation from neutrality is undesirable. Acetabular component ("cup") malposition has been associated with increased wear and greater propensity for dislocation [1–3]. Femoral varus has been associated with increased rates of prosthetic loosening, especially with cemented femoral components [4–9]. Leg length inequality is a substantial cause of patient dissatisfaction postoperatively. Several studies have suggested that conventional techniques fail to insure satisfactory alignment in a significant percentage of patients undergoing hip arthroplasty [10–13]. To date, few alternatives other than navigation have been proposed. Despite its potential utility, surgical navigation has had only limited adoption worldwide as the equipment is costly, requires skilled personnel, is not universally available, adds time to the surgical procedure (additional anesthesia time), and takes up space in the limited confines of the operating room. Unlike navigation, the availability of intraoperative radiographs (x-rays) is virtually universal in developed countries and does not require additional capital expenditures. Despite widespread availability of standard x-ray equipment, the utility of intraoperative x-rays for THA has rarely been evaluated. Although one study [14] has evaluated intraoperative radiographs for checking leg lengths during THA, the utility of such radiographs to guide component orientation has not been formally evaluated. The purpose of the present study was twofold. First, we wished to determine in what percentage of cases a single intraoperative AP pelvis x-ray would change the intraoperative management of THA patients. Second, we wished to determine whether such x-rays would reliably and reproducibly identify malpositioned components as well as uneven leg lengths such that the procedure could be altered and the final radiographic outcome optimized.

Methods

The Scripps institutional review board-approved outcomes database (PATS®, Axis Clinical Software Inc., Portland, OR) at our institution was used to identify 200 consecutive primary THAs (191 patients) performed at the author's hospital. All patients signed an IRB consent and HIPAA authorization for prospective data collection and retrospective review. Patient demographics and preoperative diagnoses were collected at the history and physical examination (Table 1), which occurred up to 30 days preoperatively. Noncemented fixation was used in 87% of cases. Mean body mass index (BMI) was 28 (range, 17–49). Seven patients had posttraumatic deformities.

All radiographs (x-rays) utilized for this study were digital images viewed on the Phillips–Stentor PACS system (Brisbane, CA). The PACS system incorporates digital goniometers and digital rulers for radiographic measurements. All measurements of leg length and

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Table 1
Patient Demographics and Reason for THA[a].

Means	*N*	Mean (SD)	Range
Age[b]	200	65.5 (11.7)	17–93
Height (in)	200	67.5 (4.5)	58–80
Weight (lbs)	200	188.3 (44.7)	86–340
BMI	200	28.0 (5.3)	17.4–48.8
Frequencies		***N***	**%**
Sex			
Female		100	50.0
Male		100	50.0
Primary diagnosis			
Osteoarthritis		169	84.5
Avascular necrosis		13	6.5
Post-trauma		7	3.5
Rheumatoid arthritis		5	2.5
SCFE/dysplasia		4	2.0
Ankylosing spondylitis		2	1.0

Study population: 200 hips (191 patients). Surgery dates: October 16, 2007–June 9, 2008. Staged bilateral: 8 hips (4 patients). Simultaneous bilateral: 10 hips (5 patients).
[a] Analyzed per hip, not per patient.
[b] Age at the time of surgery.

cup medialization mentioned in this manuscript were made without adjusting for magnification, and on average, are roughly 15% greater than the true values.

All THAs in this study were performed at one institution by one of five attending joint arthroplasty surgeons operating with a post-residency joint arthroplasty fellow (surgeon volume in Table 2). All hips were replaced through a posterolateral approach with the patient in a lateral decubitus position. Patients were held upright with padded posts positioned across the sacrum posteriorly and either the iliac crests or pubic symphysis anteriorly. Details of the procedure including implant type, surgery length, and complications were captured in the routine operative data collection form.

In all cases, a single anteroposterior (AP) pelvis x-ray was taken intraoperatively after final trial reduction with the permanent acetabular cup in position and the trial femoral broach, femoral head, and femoral neck in place. An example of the operating room set up for the intraoperative radiograph is shown in Fig. 1. A sterile drape is placed over the patient, and then a 14 × 17 inch x-ray cassette, held on a mobile stand, is positioned adjacent to the patient's pelvis with the 14-inch side of the x-ray cassette horizontal and the 17-inch side vertical. The AP pelvic radiograph is then taken in a cross-table fashion. The x-rays were evaluated for cup inclination, cup medialization, cup seating, femoral alignment, femoral sizing, leg length, and acetabular screw position (example, Fig. 2). After reviewing the x-ray, adjustments were made to the components, if necessary. Fig. 3 demonstrates correction of femoral varus; Fig. 4 demonstrates correction of vertical cup positioning; and Fig. 5 demonstrates correction of leg length inequality and excessively horizontal acetabular cup. At the conclusion of the surgery, the surgical team noted on the operative data form whether the x-ray changed the management. If the x-ray did change the management, the surgeons specified whether the change was directed at leg length, the femoral component, or the acetabular component. An additional (non-portable) x-ray was taken for each patient during the first routine postoperative office visit in our orthopedic clinic. The postoperative x-ray was used to determine "final alignment."

Table 2
Cases Contributed by 5 Surgeons.

Frequencies	*N*	%
Surgeon A	41	20.5
Surgeon B	47	23.5
Surgeon C	16	8
Surgeon D	68	34
Surgeon E	28	14

Fig. 1. (A and B) Example of intraoperative room set up during AP pelvic radiograph. The patient is in a lateral decubitus position. A temporary sterile drape is over the patient. The x-ray cassette is held on a portable stand with the longer side of the cassette vertical and the short-side horizontal. The x-ray is shot cross-table.

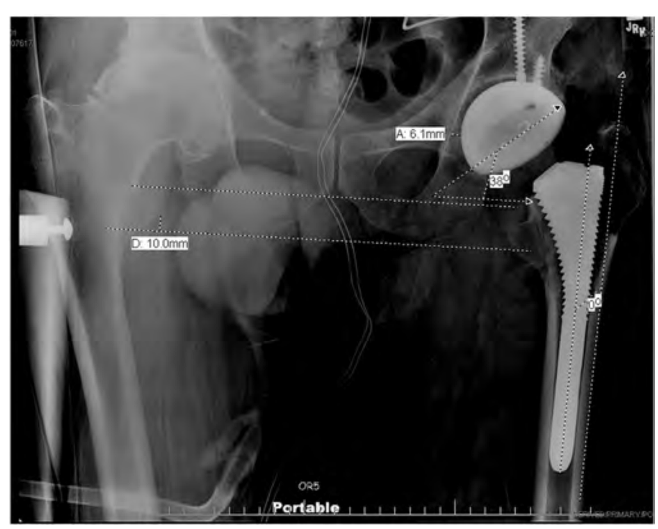

Fig. 2. Example of measurements made on intraoperative radiographs: acetabular cup inclination (38°), femoral varus/valgus (0°), distance from Kohler's line to acetabulum (cup medialization) (6.1 mm), leg length difference (10 mm), and cup seating (incomplete) screw position (intra-osseous).

Fig. 3. (A) Demonstrates femoral implant in 3° of varus intraoperatively. (B) Demonstrates correction made to femoral implant resulting in neutral alignment.

For the purposes of this study, a single-blinded reviewer evaluated the final postoperative x-rays for each patient without knowing whether intraoperative changes took place. In cases where the components were changed based on the intraoperative x-ray, and in cases where the final x-ray revealed an outlier, the intraoperative x-rays were also evaluated by the same reviewer. The review included a

Fig. 4. (A) Intraoperative radiograph demonstrating vertical acetabular inclination of 55°. (B) Postoperative radiograph showing improved acetabular inclination of 48°.

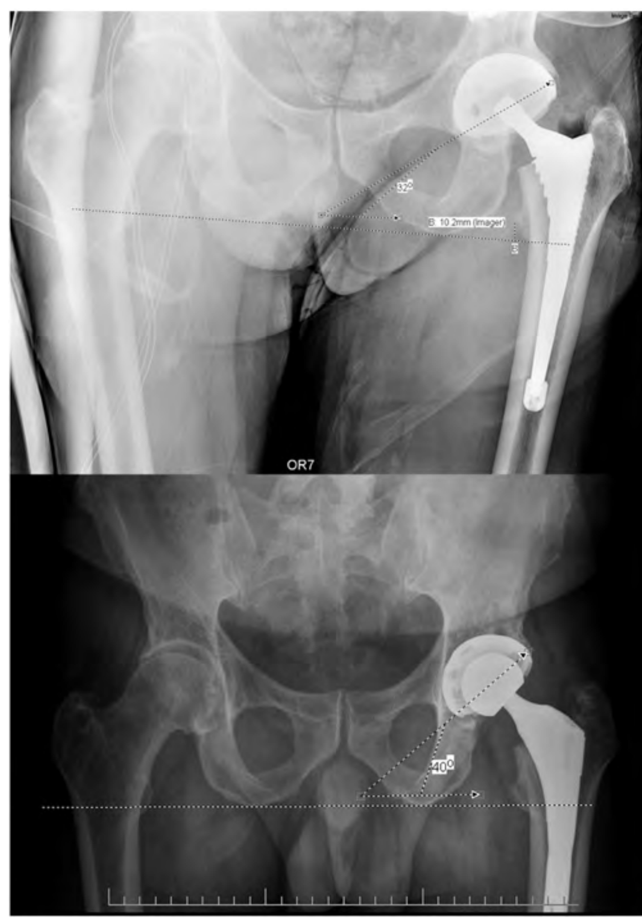

Fig 5. (A) Intraoperative x-ray showing trans-ischial line intersecting left lesser trochanter 10.2 mm more caudal than where the line intersects the right lesser trochanter (10.2-mm leg length inequality). Radiograph also demonstrates acetabular component excessively abducted (32°). (B) Postoperative radiograph showing trans-ischial line intersecting both lesser trochanters at similar levels, therefore equal leg lengths. Leg length corrected by resecting more femoral neck and seating femoral component more distally (acetabular alignment also improved from 32° to 40°).

measurement of the acetabular ("cup") abduction angle ("tilt"), acetabular medialization, leg length, and femoral alignment. In addition, x-rays were reviewed to ensure that the acetabular component was fully seated and all acetabular screws were intra-osseous. Cup tilt was measured in degrees against the trans-ischial line on the AP pelvis x-ray using a Stentor digital goniometer. If the trans-ischial line could not be clearly delineated, a line across the bottom of the obturator foramina was utilized. Cup medialization was measured in millimeters (mm) with respect to Kohler's ilio-ischial line. Leg length inequality was measured in mm (without correction for magnification) by comparing at what point the trans-ischial line intersected each femur with respect to the lesser trochanters. If the line intersects the left and right lesser trochanters at the same point, the leg lengths were judged to be equal. If the trans-ischial line was deformed from trauma or traction osteophytes, a line through the lowest point of the obturator foramina was used instead. Femoral alignment was measured by defining the angle between the long axis of the femur and the vertical axis of the femoral prosthesis. Varus angulation was measured in positive degrees; femoral valgus was measured in negative degrees.

For each parameter studied on the final x-ray, a determination was made whether the parameters fell within the target ranges, or whether an "outlier" occurred. Leg lengths were considered acceptable if they were within 6 mm without correcting for magnification (corresponding to roughly 5 mm with correction). Femoral alignment was considered acceptable if it fell within 2° of neutral. Each of the five surgeons had a different target range for cup abduction; therefore, the outliers were defined differently for each surgeon. The target ranges for cup tilt among the five surgeons was as follows: surgeon A 40°–50°; surgeon B 45°–55°; surgeon C 40°–50°; surgeon D 35°–50°; and surgeon E 35°–45°. Other than surgeon D, all surgeons wanted the cups medialized to at least within 4 mm of the lateral edge of the acetabular teardrop. Surgeon D wanted all cups medialized to within 5 mm of the medial edge of the acetabular teardrop.

The final x-rays were evaluated by the senior author to see if each radiographic parameter fell into the target range or not. If an outlier was identified, the parameter was checked against the intraoperative x-ray to see if the outlier was successfully identified intraoperatively but ignored by the surgeon, or whether the intraoperative x-ray failed to identify the outlier. Where possible, the operative reports of the cases with outliers were reviewed to determine why the surgeon chose not to alter an outlier that was successfully identified intraoperatively. It was hypothesized that surgeons may intentionally leave legs over-lengthened in cases of instability and may leave cups slightly vertical in dysplastic cases with poor superior acetabular bone coverage.

After reviewing postoperative and intraoperative x-rays, each radiographic parameter for each patient could be classified into one of four categories as follows: category A: intraoperative x-ray revealed proper position, confirmed on final x-ray; category B: intraoperative x-ray revealed improper position, successfully corrected on final x-ray; category C: intraoperative x-ray revealed improper position, but surgeon willfully ignored the x-ray based on other intraoperative patient-specific considerations; and category D: final x-ray revealed a problem not evident to the surgeon until after the completion of the case (intraoperative x-ray failed to reveal a problem, or attempt at correction of an identified problem was unsuccessful).

For cases falling into categories A, B, and C, the intraoperative x-ray was considered successful at identifying outliers and allowing correction where appropriate. Cases falling into category D were considered "unanticipated outliers" and represented a failure of the system to alert surgeons to alignment and length abnormalities.

Data were analyzed using SPSS version 13.0 (SPSS Inc., Chicago, IL).

Results

The mean alignment parameters and standard deviations for the entire cohort are summarized in Table 3. Data for cup abduction are broken down by surgeon, since each surgeon had a different target range for cup tilt. All surgeons had a mean cup abduction of 44°–46° with the exception of surgeon E, whose target range was 35°–45°. Surgeon E's mean cup abduction angle was 39°. All five surgeons had standard deviations of 4.0°–5.6° for cup abduction. Mean leg length inequality for the entire cohort was 1.5 mm (SD: 5.6 mm, not adjusted for magnification), mean cup position was 2.6 mm lateral to Kohler's line (SD: 4.1 mm), and mean femoral angulation was 0.1° varus (SD: 0.0).

Table 3
Postoperative X-ray Evaluation.

Variable	Target Cup Abduction (degrees)	*N*	Mean (SD)	Median	Range
Cup angle		200	43.7 (5.5)	44.0	27–55
Surgeon D	35–50	68	45.2 (5.6)	45.0	27–55
Surgeon B	45–55	47	43.6 (5.4)	45.0	32–53
Surgeon A	40–50	41	43.4 (4.4)	43.0	33–51
Surgeon E	35–45	28	39.0 (4.5)	38.5	29–48
Surgeon C	40–50	16	45.9 (4.3)	46.0	35–55
Leg length		192	1.5 (5.6)	0.0	−42 to 17
Cup medialization		199	2.6 (4.1)	2.0	−11 to 16
Femoral alignment		200	0.1 (0.0)	0.0	−2 to 3

The intraoperative x-ray led to a change in the intraoperative management in 50% of cases (Table 4). Among the 50% of cases where the x-ray changed the management, the changes included an alteration in cup position in 13%, changes to femoral alignment (generally reducing femoral varus) in 21%, and changes to leg length in 25%. The impact of the intraoperative x-ray is summarized in Table 5, which shows the percentage of cases that had optimal alignment on initial films (category A) contrasted with the percentage of cases that had optimal alignment on the final film (representing categories A and B). After making intraoperative changes based on the intraoperative x-ray, optimal femoral alignment was improved from 89% to 94%, optimal leg lengths were increased from 68% to 85%, and optimal cup angle was improved from 81% to 87%.

Interestingly, not all of the changes that were inspired by the intraoperative x-ray were due to components falling into the "outlying" zone. Although the x-ray led to changes in 100 of the 200 cases studied, only 65 of the cases were deemed true outliers. The other 35 changes represented attempts at trying to improve (perfect) alignment of a parameter that had already fallen into the acceptable zone. Of the 65 true outliers identified, successful correction of the problem was confirmed in 63. Therefore, outliers were successfully corrected 97% of the time when correction was felt to be indicated.

Evaluation of the final x-rays confirmed that the vast majority of patients had satisfactory alignment, although some outliers did occur. Very few outliers, however, were unanticipated (discussed below). The final x-ray demonstrated optimal alignment in 99.5% of femoral components, 96% of cups with respect to medialization, and 87% of cups with respect to abduction. 86% of leg lengths were deemed satisfactory (Table 5). There were no instances of screw malposition or incomplete cup seating.

Table 4
Intraoperative X-ray Evaluation.

Frequencies	*N*	%
Evaluation of x-ray changed operative plan		
No	100	50.0
Yes	100	50.0
Change in operative plan		
Cup position	26	13.0
Femur position	42	21.0
Leg length	49	25.0

Table 5
Impact of Intraoperative X-ray.

	Satisfactory on Initial Intraoperative X-ray	Satisfactory on Final X-ray
Femoral alignment	178/200 (89%)	199/200 (99.5%)
Leg length	128/189 (68%)	166/194 (86%)
Cup medialization	186/199 (94%)	190/199 (96%)
Cup abduction	161/198 (81%)	171/198 (86%)

In general, the intraoperative x-ray was successful in identifying outliers and allowing successful correction of the problem where appropriate. With six radiographic variables per patient studied (cup tilt, cup medialization, cup seating, leg length, femoral alignment, screw position), there was a total of 1200 data points. We identified just 3 "unanticipated outlying data points" (0.25%). The rate of unanticipated outliers for each variable individually was as follows (Table 6): unanticipated cup mal-seating 0%; unanticipated screw malposition 0%; unanticipated femoral malposition 0%; unanticipated cup medialization errors 0%; unanticipated leg length inequalities 1% (2/200); and unanticipated errors in cup abduction 0.5% (1/200).

Among the modest number of outliers identified on the final x-ray, virtually all were successfully identified on the intraoperative x-ray, yet the surgeon willfully chose to leave the components in the initial position. Such cases were deemed "planned outliers" and represent category C. Frequent observations in this group included legs that were left short due to long-standing complex deformities, legs that were left long in anticipation of upcoming contralateral hip arthroplasty, legs that were left long due to instability, and cups that were left vertical due to need for better coverage. Cups more horizontal than the target range also tended to be left in situ, if stability was satisfactory. In total "planned outliers" were seen in 0.5% of femoral components (1/200), 4.5% of cups with respect to medialization (9/200), and 13% of cups with respect to abduction (26/200). Thirteen percent (26/194) of patients had leg length differences greater than 6 mm that was clearly evident on the intraoperative films. These "planned outlier" cases constitute category C and do not represent failures of the x-ray to identify outliers. There were no planned outliers in the categories of screw position or cup mal-seating.

Discussion

Our data suggest that a single AP pelvis x-ray taken during trial reduction will identify most errors of alignment and leg length occurring during THA. The technique is quick, readily available in most operating rooms, and does not require capital expenditure or lengthy training. In our series, the use of x-rays identified deficiencies worthy of operative change in roughly half of cases reviewed. Changes to component position and leg length were easily corrected when identified by the x-ray. Interestingly, in many instances the operating surgeon felt that the clinical success of the implants mandated an alteration from the generic target values, and intentionally left the components outside of the target range, even when alerted intraoperatively that the components were not in the target position. This finding underscores the reality that any tool (x-ray, navigation, manual assessments) is only capable of alerting the surgeon as to the position of the components but is not capable of determining what the optimal position is for any given patient. This study enrolled a consecutive series of 200 patients undergoing primary total hip arthroplasty without any exclusions. Therefore, many patients would be expected to have deformities and other anatomical considerations that would mandate that deviation from generic target ranges take place, which was the case with this cohort.

Table 6
Unexpected Outliers.

Frequencies	*N*/Total *N*	%
Femoral angle outliers	0/200	0.0
Cup medialization outliers	0/200	0.0
Leg length outliers	2/200	1.0
Cup angle outliers	1/200	0.5
Screw position outliers	0/200	0.0
Cup seating outliers	0/200	0.0

Although alignment is felt to be important in a general sense by most surgeons, there are relatively little objective data from which to draw conclusions as to precisely what the target values for alignment should be. The recent literature has seen many authors, particularly those in strong favor of surgical navigation, calling for very narrow target ranges for cup alignment after THA. The concept of an acetabular safe zone was popularized in the 1970s by Lewinnek et al [3]. Although many contemporary authors and investigators still use Lewinnek's safe zone as the target alignment during THA, it is important to recognize how Lewinnek's values were established. These values (abduction 40° ± 10 and anteversion of 15° ± 10) were derived solely by evaluating dislocation rates in a cohort of 300 patients from over 30 years ago and did not take into account issues of wear, impingement, or the need to possibly alter the targets in hard bearings or large diameter bearings. Alternatively, Paterno et al [15], evaluated over 600 cases collected from 1983 to 1994 and found no association between abduction angle and dislocation rate, with cups ranging from 38° to 57°. D'Lima et al [16] used computer modeling for THAs with head diameters of 32 mm or less and found that range of motion (ROM) and stability would be optimized with cup abduction between 45° and 55° (5° more vertical than Lewinnek). Optimal anteversion, according to D'Lima was found to vary depending on femoral version and acetabular abduction; therefore, a single optimal value for anteversion was not feasible. Additional computer modeling studies have suggested 30°–50° of acetabular abduction, similar to Lewinnek, but 1°–30° of anteversion [17]. Another computer simulation recommended cup tilt of 45°–55° (similar to D'Lima) but with anteversion of 10°–20° [2]. Widmer and Majewski [18] evaluated the interplay of cup position with the neck-shaft angle of the femoral stem and indicated that optimal alignment required that the cup become 0.5° more vertical and 2° less anteverted for every1° decrease in femoral neck angle of the hip prosthesis. Investigators at CeramTec (Laurens, SC), a manufacturer of ceramic bearings indicated that with their articulation, optimal alignment should be less than 45° of abduction and anteversion of only 10°–15° [19]. Optimal alignment of metal on metal bearings is also a matter of unresolved debate. Regardless of what the theoretic optimal alignment may be, deviations from such targets are likely to be required in many patients. The wide variability of recommendations as to optimal cup position was reflected in the variable target values with which the surgeons in our group have chosen to adopt for their own cup implantations. Additionally, optimal alignment in vivo must take into account issues such as bony coverage of the cup, soft-tissue laxity, bony impingement, general flexibility, anticipated activities, type of bearing, femoral design, and fixed pelvic flexion/pelvic obliquity. These realities likely explain why the surgeons in this study frequently placed cups outside of their "target zone" and left them in such positions after the x-ray revealed a potential malposition. Whether one adopts broad or narrow alignment targets, and regardless of what target one adopts, our data suggest that an intraoperative x-ray will help the surgeon attain his/her target in the majority of cases.

Our study also investigated femoral alignment. In general, there was less variance in femoral alignment than there was for acetabular alignment. Femoral varus was a cause for alteration in the surgical procedure in 21% of cases. The majority of these stems were in 2° of varus or less prior to the correction, and one could reasonably argue that most of these probably would have had a successful outcome even if they were not corrected. Although mild femoral malalignment was felt to be an important cause of failure with cemented stems [4–9], it seems much less important with modern cementless stems. At least three contemporary studies have found no adverse effects of femoral varus up to 5° with modern tapered stem designs [20–22]. Nevertheless, at the present time it remains our practice to try to obtain neutral stem alignment.

Leg length inequality remains a common source of patient dissatisfaction after THA. There is no consensus as to how much leg length inequality can reasonably be accepted after THA [23]. Iagulli et al [24] utilized templating and intraoperative comparison to the contralateral leg to try to equalize leg lengths in a series of 700 THAs. They found 5% to have inequality of over 15 mm, although the majority were asymptomatic. In a smaller study of 86 THAs Hofmann et al [14] utilized intraoperative x-ray to gauge leg length, and all patients were within 6 mm of equal. In Hoffman's opinion, 6 mm was the cutoff for clinically significant, although the figure was derived empirically without any validation. Our results, like those of Hoffman, found the x-ray to be a reliable method of determining leg length. In several cases, however, the surgeon willingly left the leg long due to issues of instability. Because our cohort of patients also included some with complex leg length problems from ipsilateral and contralateral femoral fractures in addition to those with unstable prostheses, it was not unexpected that category C "planned outliers" were somewhat prevalent on review of final x-rays.

The last alignment parameter we chose to look at was medialization of the cup. Unfortunately, there are no published guidelines as to how medial the cup should be relative to fixed bony landmarks. The surgeons in this study adopted different target points for cup medialization, with some surgeons wishing to go to the medial edge of the tear drop and others wanting to stay slightly lateral to the lateral edge of the tear drop. Although we observed no cases of unanticipated outliers with respect to medial cup position, we did find 4.5% to be outside the target on final x-ray. While most of these cases involved cups that were felt during surgery to be at risk for femoral–pelvic impingement with further medialization, the surgeons chose to leave the cup slightly lateralized to preserve stability and offset. Despite these considerations, we did find the x-ray accurate in predicting the degree of medialization of the cup.

One limitation of our study was that we were not able to quantify acetabular anteversion intraoperatively through the use of our x-rays (although gross estimations were possible). Anteversion is clearly an important alignment parameter during THA, and not being able to quantify anteversion intraoperatively or postoperatively is the major shortcoming of the x-ray protocol utilized at our institution. Significantly improper anteversion would be expected to predispose to hip dislocation. Dislocation in this cohort of consecutive unselected patients was rare (2 patients, 1%), and it therefore seems unlikely that many cases of clinically important improper anteversion were present in this cohort. Surgical navigation has been promoted as a tool by which anteversion can be assessed intraoperatively [25–28]. Modern imageless navigation systems have produced mixed results in terms of providing reliable anteversion of acetabular components, largely due to variability with registering reliable landmarks to define the frontal plane of the pelvis [25,28]. Navigation systems utilizing computed tomography may be more reliable, although radiation exposure, time, and expense limit the utility of such systems. As discussed earlier, there is presently no consensus as to what constitutes optimal anteversion, and many surgeons vary the acetabular anteversion based on capsular laxity and femoral anteversion. Therefore, at the present time, given the lack of consensus as to what constitutes optimal anteversion, and given the need to alter anteversion on a case by case basis based on intraoperative considerations, we do not feel that inability to quantify anteversion intraoperatively detracts from the utility of intraoperative x-rays to optimize alignment of the prosthesis in general.

In summary, we found a single intraoperative AP pelvis x-ray to be a reliable, quick, and inexpensive means of determining acetabular abduction, acetabular medialization, leg length, and femoral alignment. Screw position and cup seating are also easily assessed with plain x-ray. Armed with such information, the surgeon can decide whether to change the position of the prosthesis before the conclusion of the case. In cases where changes are needed, reliable correction was produced in 97% of cases. In some instances, however, intraoperative considerations are such that these considerations will supersede generic alignment and leg length targets.

References

1. Biedermann R, Tonin A, Krismer M, et al. Reducing the risk of dislocation after total hip arthroplasty: the effect of orientation of the acetabular component. J Bone Joint Surg Br 2005;87:762.
2. Barrack RL. Dislocation after total hip arthroplasty: implant design and orientation. J Am Acad Orthop Surg 2003;11:89.
3. Lewinnek GE, Lewis JL, Tarr R, et al. Dislocations after total hip-replacement arthroplasties. J Bone Joint Surg Am 1978;60:217.
4. Star MJ, Colwell Jr CW, Kelman GJ, et al. Suboptimal (thin) distal cement mantle thickness as a contributory factor in total hip arthroplasty femoral component failure. A retrospective radiographic analysis favoring distal stem centralization. J Arthroplasty 1994;9:143.
5. Devitt A, O'Sullivan T, Quinlan W. 16- to 25-year follow-up study of cemented arthroplasty of the hip in patients aged 50 years or younger. J Arthroplasty 1997;12:479.
6. Ebramzadeh E, Sarmiento A, McKellop HA, et al. The cement mantle in total hip arthroplasty. Analysis of long-term radiographic results. J Bone Joint Surg Am 1994;76:77.
7. Sutherland CJ, Wilde AH, Borden LS, et al. A ten-year follow-up of one hundred consecutive Muller curved-stem total hip-replacement arthroplasties. J Bone Joint Surg Am 1982;64:970.
8. Bosch P, Kristen H, Zweymuller K. An analysis of 119 loosenings in total hip endoprostheses. Arch Orthop Trauma Surg 1980;96:83.
9. Pellicci PM, Salvati EA, Robinson HJ. Mechanical failures in total hip replacement requiring reoperation. J Bone Joint Surg Am 1979;61:28.
10. Haaker RG, Tiedjen K, Ottersbach A, et al. Comparison of conventional versus computer-navigated acetabular component insertion. J Arthroplasty 2007;22:151.
11. Nogler M, Kessler O, Prassl A, et al. Reduced variability of acetabular cup positioning with use of an imageless navigation system. Clin Orthop Relat Res 2004;426:159.
12. Parratte S, Argenson JN, Flecher X, et al. Computer-assisted surgery for acetabular cup positioning in total hip arthroplasty: comparative prospective randomized study. Rev Chir Orthop Reparatrice Appar Mot 2007;93:238.
13. Bosker BH, Verheyen CC, Horstmann WG, et al. Poor accuracy of freehand cup positioning during total hip arthroplasty. Arch Orthop Trauma Surg 2007;127:375.
14. Hofmann 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.
15. Paterno SA, Lachiewicz PF, Kelley SS. The influence of patient-related factors and the position of the acetabular component on the rate of dislocation after total hip replacement. J Bone Joint Surg Am 1997;79:1202.
16. D'Lima DD, Urquhart AG, Buehler KO, et al. The effect of the orientation of the acetabular and femoral components on the range of motion of the hip at different head–neck ratios. J Bone Joint Surg Am 2000;82:315.
17. Seki M, Yuasa N, Ohkuni K. Analysis of optimal range of socket orientations in total hip arthroplasty with use of computer-aided design simulation. J Orthop Res 1998;16:513.
18. Widmer KH, Majewski M. The impact of the CCD-angle on range of motion and cup positioning in total hip arthroplasty. Clin Biomech (Bristol, Avon) 2005;20:723.
19. Bader R, Willmann G. Ceramic cups for hip endoprostheses. 6: cup design, inclination and antetorsion angle modify range of motion and impingement. Biomed Tech (Berl) 1999;44:212.
20. Khalily C, Lester DK. Results of a tapered cementless femoral stem implanted in varus. J Arthroplasty 2002;17:463.
21. Berend KR, Mallory TH, Lombardi Jr AV, et al. Tapered cementless femoral stem: difficult to place in varus but performs well in those rare cases. Orthopedics 2007;30:295.
22. Abraham WD, Dimon III JH. Leg length discrepancy in total hip arthroplasty. Orthop Clin North Am 1992;23:201.
23. Min BW, Song KS, Bae KC, et al. The effect of stem alignment on results of total hip arthroplasty with a cementless tapered-wedge femoral component. J Arthroplasty 2008;23:418.
24. Iagulli 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.
25. Blendea S, Troccaz J, Merloz P. Accuracy measurements of acetabular cup positioning using CT less navigation. Rev Chir Orthop Reparatrice Appar Mot 2007;93:157.
26. Dorr LD, Malik A, Wan Z, et al. Precision and bias of imageless computer navigation and surgeon estimates for acetabular component position. Clin Orthop Relat Res 2007;465:92.
27. Kalteis T, Handel M, Bathis H, et al. Imageless navigation for insertion of the acetabular component in total hip arthroplasty: is it as accurate as CT-based navigation? J Bone Joint Surg Br 2006;88:163.
28. Wixson RL. Computer-assisted total hip navigation. Instr Course Lect 2008;57:707.