Minimizing Leg-Length Inequality in Total Hip Arthroplasty: Use of Preoperative Templating and an Intraoperative X-Ray

Aaron A. Hofmann, MD, Michael Bolognesi, MD, Amit Lahav, MD, and Stephen Kurtin, MD

Abstract

Leg-length inequality after total hip arthroplasty remains a controversial issue. In the study reported here, we sought to determine whether significant leg-length discrepancies (>6 mm) can be minimized with use of an intraoperative x-ray. In each case, preoperative templating was carefully performed, an intraoperative pelvis x-ray was obtained to assess accuracy, and appropriate adjustments were made. Eighty-six consecutive primary total hip arthroplasties and their associated x-rays were retrospectively reviewed. Mean postoperative leg-length discrepancy was 0.3 mm (SD, 2.6 mm; range, –6 to +6 mm). No legs were lengthened or shortened by more than 6 mm. Significant leg-length discrepancies can be minimized with use of an intraoperative pelvis x-ray.

Leg-length inequality (LLI) after total hip arthroplasty (THA) persists as a controversial issue for the orthopedic community. The technique used in the present study was a simple protocol using preoperative planning and intraoperative x-rays as a means of preventing excessive lengthening or shortening of the operative extremity.

The range of LLI after hip arthroplasty is as diverse as the techniques reported for evaluating leg lengths are numerous. Precise preoperative templating was used to control against significant leg-length discrepancy (LLD) in several studies.[1-4] Investigators have reported mean postoperative limb lengthening of as little as 1 mm and as much as 15.91 mm, with an even larger range of discrepancies. However, preoperative templating alone has some limitations when components are not placed exactly where preoperative plans dictate.

Some authors have used mechanical devices to check length during surgery—a fixed reference point such as a reference pin in the ilium and a limb-length caliper,[5] a reference pin placed in the infracotyloid groove,[6] a guide wire inserted below the iliac crest and bent at 90° to allow the reference tip to lie distal to the greater trochanter,[7] a 3-pronged iliac reference device with an adjustable caliper,[8] and a pin with malleable segments that allows trochanteric referencing.[9] All these reference devices were limited by the reality that they can move during surgery and thereby distort measurements.

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Surgeons are advised to warn all THA candidates of the possibility of postoperative LLI and to document their conversations on the topic. The American Academy of Orthopaedic Surgeons Committee on Professional Liability reported that postoperative neuropathy, LLI, and infection are the leading causes for post-THA litigation[10] and further recommended that surgeons document conversations and consider using custom THA consent forms to demonstrate that these issues were discussed.

All the techniques described in the literature allow surgeons some control over postoperative LLD and therefore some hope that its associated difficulties can be avoided. Dr. Hofmann used a combination of a strict and precise preoperative templating protocol and use of an intraoperative x-ray for final component selection.

Materials and Methods

We report on 86 consecutive primary THAs (43 right, 43 left) involving a single type of prosthesis that is well known to Dr. Hofmann. Of the 86 patients, 37 were

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women and 49 men. Mean age was 61 years (range, 19-86 years). The study group included patients who had a contralateral THA and were previously operated on by Dr. Hofmann. The first replaced hip was excluded, as there was no referencing normal hip against which to template; instead, the plan for restoration of equal leg length and offset was based on the prior contralateral THA. Preoperative diagnoses in the 86 patients included osteoarthritis, rheumatoid arthritis, avascular necrosis, developmental dysplasia, Perthes disease, and posttraumatic arthritis (Table I). Of the 86 prostheses, 77 were placed with a press-fit technique (femur and acetabulum, porous-coated prosthesis) and 9 with a cement technique. Both types of prosthesis were included, as component type does not influence evaluation of leg-length results. These components were available in standard and 6-mm-increased-offset designs used in varus hips. All acetabular components were porous-coated and implanted with a press-fit technique.

Preoperative LLI was assessed radiographically with low anteroposterior (AP) x-rays of the pelvis distal to the iliac wings, focusing on the hips. Each x-ray was taken with patient's feet pointed forward to standardize rotation of the lower extremities. Legs were placed in a neutral position to prevent abduction or adduction of the limb. Horizontal lines passing through the most inferior points on the ischium were drawn. The vertical distance between the most proximal point on the lesser trochanter and the transischial line was measured on both sides using 18% magnified templates (Figure 1). X-rays obtained at our institution have an approximate 18% magnification; a magnification change should be considered for very thin or obese patients. The difference between the 2 sides was documented as preoperative LLI. Before surgery, all patients received a complete physical examination focusing on the hip, knee, ankle, and back. Range of motion of the back and lower extremity was assessed. Any other symptoms (or history) of trauma were discussed and evaluated. As assessed from history and x-rays, no patient had any significant anatomical deformity, including shortening defect distal or proximal to the hip, fixed pelvic obliquity, or major scoliosis.

Preoperative planning was done with the standard AP pelvis x-ray using templates specific for the implants to be used. This technique, similar to that initially described by Muller,[11] was detailed by Hofmann and Skrzynski.[12] These templates allowed determination of size and placement of the acetabular component, level of the femoral osteotomy, and size and type (standard or offset) of the femoral stem. The goal was to restore the center of rotation of the hip joint and to reproduce the anatomical head and neck length offset. Placement of the acetabulum in the correct position allows the center of rotation to be restored. Leg length and offset are then determined further on the femoral side. The distance between the center of the head and the top of the lesser trochanter was noted on both sides. These measurements were considered when determining the neck cuts and the femoral implant sizes. Dr. Hofmann aimed to equalize the distance between the center of the head and the top of the lesser trochanter on both hips. This distance was determined by assuming that the acetabular component was placed in the appropriate anatomical position resting on the cortical floor of the cotyloid notch with the inferior portion of the acetabular template on the distal portion of the teardrop. The component template was just lateral to the teardrop but did not violate the teardrop or the ilioischial line (Kohler line). The center of the contralateral head was identified with the femoral template to reproduce this length and offset, and the length of the neck cut was noted in order to reproduce this anatomical relationship. The contralateral hip was used to template the femur so as to reproduce the normal anatomy of the normal hip. Paying careful attention to detail during this preoperative interval allowed for a predetermined surgical plan for component size, design (standard or offset), neck length, and level of osteotomy (Figures 2A–2C).

Figure 1. Preoperative anteroposterior pelvis x-ray shows that the hip to be operated on is shorter than the hip previously operated on. The patient's right side was lengthened when the total hip arthroplasty was performed.

All surgeries were performed with the patient placed in a lateral position held with a radiolucent Montreal hip positioner (OSI, Union City, CA), and all used a standard posterolateral approach. Hip exposure was carried out distally enough to expose the top of the lesser trochanter. This exposure allowed for direct measurement (with a sterile ruler) for neck-level resection relative to the lesser trochanter and afforded

Table I. Diagnosis at Primary Arthroplasty

Original Diagnosis	n (%)
Osteoarthritis	64
Avascular necrosis	10
Dysplasia	4
Rheumatoid arthritis	3
Trauma/fracture	3
Perthes disease	2

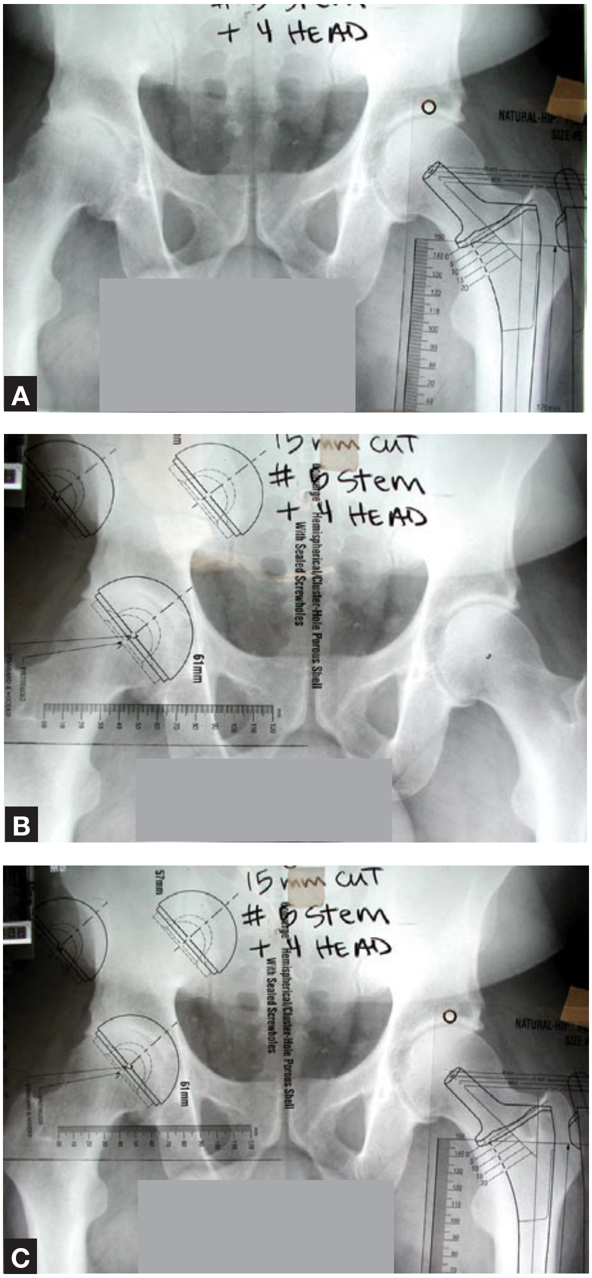

Figure 2. Preoperative anteroposterior pelvis x-rays of right total hip arthroplasty show **(A)** femoral component templated, **(B)** acetabular component templated, **(C)** acetabular and femoral components templated together.

the surgeon the opportunity to reevaluate neck length after calcar planing and subsequent fine-tuning of the neck cut. An intraoperative low AP pelvis x-ray was obtained with a 14×17-in cassette placed vertically on a cassette holder after placement of the appropriately sized stem. As the x-ray equipment was portable, the operative team assisted the radiology technician with cassette height and cephalocaudal positioning in order to ensure that an acceptable x-ray would be obtained. The patient's feet were again positioned pointing forward, as done for the preoperative x-ray, so that the lesser trochanter could be seen in the same rotational profile. Neutral positioning of the legs to prevent excess abduction or adduction was done with a pillow and blankets between the legs, once again for relative accurate comparison with the preoperative x-ray. All adjustments on the acetabular side, the femoral side, or both sides of the hip joint were made after this x-ray was interpreted (Figure 3). These adjustments included changing prosthetic neck length (head implant selection), changing femoral neck cut by calcar planing the femoral neck, changing from a 6-mm-offset stem to a standard stem, changing cup version, and placing a protrusio liner. For calcar planing, the prosthesis was removed with a slap hammer and then reinserted.

Table II. Preoperative and Postoperative Leg-Length Inequalities

Measurement	Leg-Length Inequality (mm) Preoperative	Postoperative
Mean	–3.7	0.3
SD	7.0	2.6
Minimum	–20	–6
Maximum	16	6

All hips were also given an intraoperative physical examination: Assessments were made of anterior impingement with internal rotation, tightness of the anterior capsule with full extension and external rotation, and hip stability with internal rotation and hip flexed to 90° (neutral abduction-adduction); leg length was grossly evaluated and directly compared with that of the nonoperative leg using foot and knee as reference points; and preoperative and postoperative "kick test" results were compared. Kick tests were performed by holding the hip in an extended and slightly abducted position and then flexing the knee back to approximately 90°. The lower extremity is then allowed to extend. Estimation of the amount of "kick" that the examiner appreciates is then recorded. A lengthened extremity should demonstrate more kick. As an arthritic hip joint tends to be shorter owing to loss of cartilage, lengthening can produce a kick, but excessive kick can mean significant lengthening. Physical examination findings and interpretation of the intraoperative x-ray were assimilated to determine final implant selection. After the final implants were placed, the short external rotators and capsule were attached to the greater trochanter region using No. 5 Mersiline tape through drill holes.

For all patients, a postoperative portable supine AP pelvis x-ray was obtained in the recovery room to confirm component position and joint location. X-rays used for critical evaluation of leg lengths were acquired at follow-up (3-6 months).

Preoperative and postoperative radiographic measurements included vertical distance from the transischial line and the most proximal point on the lesser trochanter. The difference in this number between each side was recorded as postoperative LLI (Figure 4).

An effort to evaluate the accuracy of this technique was made by comparing intraoperative x-rays with x-rays obtained at follow-up. Ten pairs of x-rays were compared to evaluate the consistency of the technique. Leg lengths were measured on both, and the values were compared.

Results

Preoperative LLI ranged from –20 mm (short) to +16 mm (long); the mean was –3.7 mm (SD, 7 mm). Mean LLI at follow-up (3-6 months) was +0.3 mm. Postoperative leg lengths ranged from –6 mm to +6 mm (Table II). No patient had to use shoe lifts for equalization of leg lengths, and no patient complained of a noticeable LLI. All 86 patients had an LLI of 6 mm or less. Thirteen patients had a postoperative LLI indicating a shortened extremity (range, –6 to –2 mm). Leg length was fine-tuned during surgery in almost 50% of cases. Components were modified or repositioned from preoperative x-ray templating according to intraoperative component positioning. Preoperative templating placement of the prosthesis is based on accurate placement of the prosthesis consistent with templating. Preoperative templating alone has some limitations when components are not placed exactly where preoperative plans dictate. An intraoperative x-ray allows for this determination and the ability to alter component position to obtain better placement.

To evaluate the accuracy of this technique, in 10 cases intraoperative x-rays were compared with x-rays acquired at follow-up. Leg lengths were measured on both, and the values were compared. Mean intraoperative LLI was 0.6 mm, and mean postoperative LLI was 0.1 mm. There was no significant difference between these measurements, and no difference between the paired x-rays was ever larger than 1 mm. The small difference may be a cause of internal or external rotation of the hip showing more or less of the lesser trochanter, even with standardization of x-rays and patient position. These results suggest that the technique was effective in reproducing leg-length measurements.

“[Our] technique...demands consideration of length, offset, and stability, as the combination of these factors determines operative results.”

Discussion

Limb-length inequality after THA is a problem often encountered by orthopedic surgeons. In the literature, recent attention toward minimizing LLI characterizes the perceived significance of this problem. The true consequence of limb-length inequality, however, remains unclear, despite the efforts that most surgeons make to avoid leaving a patient long or short. White and Dougall[13] recently suggested that leg length is not critically important. They prospectively studied 200 patients undergoing unilateral THA. Results showed no statistical association between LLD and functional outcome or patient satisfaction. Their study group included 41 patients with lengthening of more than 10 mm.

Traditional goals for hip arthroplasty are pain elimination, function restoration, and hip stability, but restoration of equal leg lengths has become increasingly important as well. The surgeon therefore often faces a difficult intraoperative decision between length and stability. The general assumption is that increased length translates directly into increased stability. The technique outlined in the present study demands consideration of length, offset, and stability, as the combination of these factors determines operative results.

Despite the findings of White and Dougall,[13] it seems likely that most surgeons continue to try to

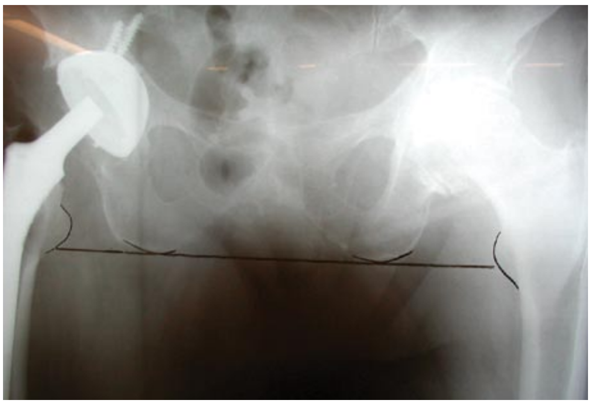

Figure 3. Intraoperative pelvis x-ray shows shortened right lower extremity with decreased offset, which during surgery can be corrected with a longer femoral head to obtain acceptable restoration of appropriate leg length and offset.

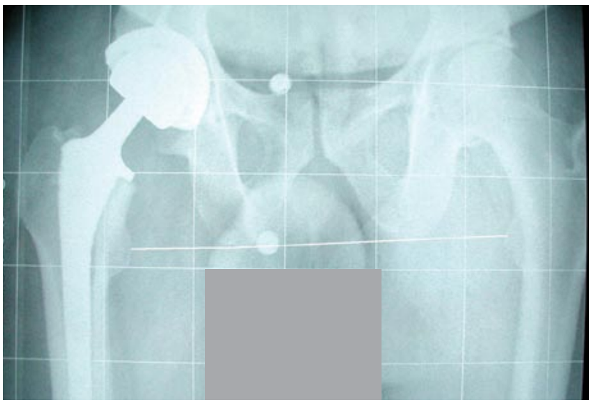

Figure 4. Postoperative anteroposterior pelvis x-ray shows excellent restoration of appropriate leg lengths.

Table III. Comparison of Results: Other Studies Versus Present Study

Study	Leg-Length Inequality (mm) Mean Postoperative	% >6 mm
Woolson[1]	2.8	11
Ranawat et al[6]	1.9	11
Woolson et al[3]	1.0	14

maintain equal leg lengths after hip arthroplasty. Literature reports highlighting concerns about the negative aspects of lengthening suggest this. The most feared effect of overlengthening is partial or complete sciatic nerve palsy. Its prevalence has been reported to be as high as 13% (31/243) after primary hip replacement.[14] Most reports suggest it occurs in approximately 2.0% to 2.5% of cases; its occurrence seems more likely when lengthening is more than 2.5 cm.[15]

More recently, efforts to minimize postoperative LLI have been more successful. Woolson[1] and Woolson and colleagues,[3] in particular, reported very favorable numbers. Woolson (84 patients) found a mean postoperative LLI of 2.8 mm, with 11% of cases lengthened more than 6 mm. Woolson and colleagues followed up with a larger study (351 patients, 408 hips) and good results (mean lengthening, only 1 mm), but 14% of cases were lengthened more than 6 mm and 3% more than 1 cm. Woolson used a precise preoperative templating technique that relies on replacing the amount of femoral head and neck and remaining joint cartilage that is removed with prosthetic implants that are the same height in order to attain equal leg lengths. This attention to detail and measurement during templating was the focus of the technique used in the present study. Ranawat and colleagues[6] placed a pin in the infracotyloid groove to assist with intraoperative leg-length determination and reported a postoperative LLI of 1.9 mm, but still 11% of cases were lengthened more than 6 mm. The range reported in their study was –7 to +8 mm.

“[Maloney and Keeney[22]] concluded that the preoperative plan should be executed in the operating room using appropriate intraoperative cues. The useful technique that we recommend is the intraoperative x-ray.”

Edeen and colleagues[16] interviewed and examined 68 patients for LLI, which was determined by orthoroentgenography and compared with clinical measurements of leg length. Mean inequality was 9.7 mm. In the large group (32%) that was aware of this inequality, mean LLI was 14.9 mm. Edeen and colleagues concluded that clinical measurements of LLI correlated poorly with values determined orthoroentgenographically.

Back pain associated with LLD must also be considered. As suggested in the spine literature, increased limb lengths may be related to low back pain.[17,18] A need for shoe lifts was not reported in all series, but this can be an important consideration, as some patients are not satisfied with the outcome of their procedure.

Lengthening seems to raise the most challenging issues. One of the earliest attempts to determine postoperative LLD after THA was by Williamson and Reckling,[19] whose study is often cited for its high mean LLI (15.91 mm), high incidence of sciatic nerve injury (3.3%), and high percentage of patients requiring a shoe lift after surgery (27%). Turula and colleagues[2] performed 55 cemented THAs and noted mean radiographic LLIs of 8.74 mm (unilateral group) and 11.55 mm (bilateral subset), which seem to be improvements on those reported by Williamson and Reckling. However, Turula and colleagues’ ranges (–20 to +16 mm for unilateral; 2 to 23 mm for bilateral) are fairly wide compared with those of Williamson and Reckling.

Several other authors[5,7-9] have proposed fixed reference points, such as the one used by Ranawat and colleagues.[6] There is some variability in pin design, pin placement, and specific reference points for length measurement. There are also some obvious concerns about these techniques—including need for separate incision for pin placement for some methods, variability in leg position during measurement, and consistency of pin position during the procedure. Among the authors who have attempted to address these issues are Woolson and Harris,[8] who proposed using a 3-pronged iliac reference device with an adjustable caliper. This device allows for placement of 3 smooth pins in the iliac wing and likely improved stability of the measuring device but increases some surgeons’ concern about placing pins in the ilium. Huddleston[9] described using a VacPac to create an operative-leg cradle that allows placement of the leg back to or near its initial position at time of measurement. His measurement technique included using a pin with malleable segments that allows trochanteric referencing.[9] Other studies highlight novel approaches used by different surgeons as they attempt to solve this problem. Bose[20] described a carpenter’s level that allows for optimization of thigh position, and Affatato and Toni[21] proposed a noninvasive ultrasound system for measuring leg lengths and resultant changes during surgery.

Maloney and Keeney[22] wrote that minor LLD (<1 cm) is common after THA and usually well tolerated. In some patients, however, even such small discrepancies are a source of dissatisfaction. The authors concluded that the preoperative plan should be executed in the operating room using appropriate intraoperative cues. The useful technique that we recommend is the intraoperative x-ray.

Our study data compare favorably with those in the literature (Table III). Mean LLI was 0.3 mm (range, –6 mm to 6 mm). Thirteen patients had an LLI indicating a shortened extremity. These data support our inference from Woolson's studies that careful preoperative templating is critical during the preoperative planning period. Adding the intraoperative x-ray improves the accuracy and reproducibility of this technique.

There is skepticism about using an intraoperative x-ray during THA. Some orthopedic surgeons cite increased cost as a deterrent, but many simply doubt that the x-ray will be used to make an intraoperative decision. For stability, these surgeons rely more on physical examination or some other referencing technique. Results from our retrospective review and data from our radiographic review suggest otherwise. We identified a subset of patients in an effort to definitively document if and when a change in implant selection (ie, operative plan) was made after the intraoperative x-ray. We found that a change was made about half the time—a finding that supports the role of the intraoperative x-ray in the present methodology.

Conclusions

Results indicate that this technique provided a reliable means of achieving equal leg lengths while avoiding the need for a fixed reference point or additional intraoperative device designed for limb-length measurement. There may be a concern about extrapolating 2-dimensional x-rays to the 3-dimensional issue of offset and leg length, but, with proper positioning and standardization of the patient and x-ray cassette, this can be minimized. As computer navigation systems become user-friendlier, readily available, and financially viable, they may further improve implant positioning with regard to LLI and 3-dimensional analysis. These systems already allow surgeons to monitor leg length in real-time display during surgery. Until this practice becomes common, we propose pairing precise preoperative templating with an intraoperative x-ray. It is of utmost importance that the x-ray be stringently evaluated and critiqued during surgery so that the appropriate decision can be made regarding final component selection. We offer an additional technique that provides a simple means of avoiding significant discrepancies.

Authors' Disclosure Statement

Dr. Lahav and Dr. Kurtin report no actual or potential conflict of interest in relation to this article.

Dr. Hofmann wishes to note that he holds a patent for a health-care-related product(s) or category of products named in this article. He also wishes to note that he is a paid consultant to a health-care-related company whose product or category of products is mentioned in this article.

Dr. Bolognesi wishes to note that he is a paid consultant for the Knee Navigation Project for Zimmer, Inc. He also wishes to note that he is a recipient of the Zimmer/OREF Career Development Award.

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