

In Situ Leg Length Measurement Technique in Hip Arthroplasty

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Abstract: In situ femoral preparation refers to implanting a femoral component before the femoral neck osteotomy and without dislocating the hip joint, which allows the implanted femoral component to be used to measure leg length and offset. One hundred hip arthroplasty surgeries among 93 patients were compared with a control group of 15 patients. A modular neck femoral component was implanted in a technique similar to implanting a femoral nail. The differences between the in situ measurements and the preoperative and postoperative radiograph measurements averaged -0.1 mm for leg length ($r = 0.89$) and -0.37 mm for offset ($r = 0.57$). In situ leg length measurement allows accurate measurement of leg length and offset and guides surgeons in selecting appropriate modular components to attain a near anatomical hip arthroplasty.

Keywords: leg length, offset, hip arthroplasty, in situ measurement.

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Leg length discrepancy is a well-recognized source of patient dissatisfaction after hip arthroplasty. Multiple techniques have been described to restore leg length and offset during hip arthroplasty, including preoperative templating, intraoperative palpation of bony landmarks and tensioning of soft tissue, intraoperative measurement devices, intraoperative radiographs, and computer navigation [1-3]. The intraoperative measurement devices typically measure the distance between a pin inserted into the ilium and a point marked on the greater trochanter, as originally described by Harris [4-12].

The in situ measurement technique uses the unique features of hip anatomy that allow for in situ femoral preparation without disrupting the anatomical relationship between the femur and pelvis. In situ femoral preparation implants the femoral broach and/or prosthesis without cutting the femoral neck or dislocating the hip joint and is analogous to implanting an ante-grade femoral nail. The soft tissue interval is similar to a Kocher-Langenbock approach. In situ femoral preparation was developed by Stephen Murphy [13] as part of his superior approach to hip arthroplasty. Because the femoral component is implanted before the native anatomical relationship between the femur and pelvis

is altered, the femoral component serves as the primary reference point in measuring the preoperative and postoperative leg length and offset.

The primary goal of this study was to compare the change in the leg length and offset measured during surgery with the in situ measurement technique to the change in leg length and offset measured on preoperative and postoperative radiographs. The secondary goal was to compare the change in leg length and offset measured with the in situ technique to the patients' desired change in leg length and offset. The final goal was to compare the patients' desired change in leg length and offset to the change in leg length and offset measured on the preoperative and postoperative radiographs.

Materials and Methods

The following study is a prospective cohort of 100 consecutive total hip arthroplasty in 93 patients. Institutional review board approval was obtained. Enrollment in this study was offered to all of the author's patients who were scheduled for hip arthroplasty. During the study enrollment, 12 hip arthroplasty patients did not participate in the study for reasons listed below. One patient was excluded for being younger than 18 years. One patient was excluded for being a non-English speaker. The first-generation prototype of this in situ leg length device threaded only into a press-fit Wright Medical Profemur Renaissance stem; therefore, 2 patients requiring a cemented femoral component were excluded. Two patients were excluded because their preoperative hip ankylosis severely limited their hip adduction, which would have made the in situ femoral preparation too difficult.

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Two patients were excluded for body weight greater than 280 lb because of the possibility of modular neck fatigue failure [14]. One patient met the inclusion criteria but refused participation. Three patients were excluded because they were seen only at a rural satellite clinic without consistent magnification on the preoperative and postoperative radiographs.

There were 44 men and 49 women in this study. The average age of the patients was 60 years, with a range of 31 to 86 years. The average femoral head size was 40.4 mm, with a range of 28 to 56 mm. Sixty-five bearing surfaces were metal on metal, 29 were metal on polyethylene, and 6 were ceramic on ceramic. Seventy-four patients did not perceive any leg length discrepancy preoperatively; thus, the surgical goal for these patients was to leave their leg length unchanged, not necessarily to match the leg length of the contralateral hip on the preoperative radiograph. Preoperatively, 26 patients perceived their operative leg was shorter than the contralateral leg and requested their operative leg to be lengthening by an average of 4 mm (range, 3-13 mm). Blocks and radiographic measurements were used to help these 26 patients select a desired amount of lengthening, which was documented in their chart. Preoperatively, no patients perceived that their operative leg was longer than the contralateral leg. Restoration of the native total offset was the goal for every patient; however, in situations in which both leg length and offset could not both be restored, leg length restoration took priority. All patients were informed preoperatively that poor hip stability might require deliberate lengthening of the leg.

Preoperative templating was done with low anteroposterior radiographs of the pelvis. Each x-ray was taken with the patient's feet pointed forward and their legs placed in a neutral abducted position. Templates with 15% magnification were used to determine the implant sizes, the modular neck preference, and the distance from the tip of the greater trochanter to the shoulder of the femoral component. In addition, a line perpendicular to the femoral axis was drawn 5 cm above the femoral prosthesis into the ilium to represent the site at which the cannulated screw would enter the ilium when the femoral component was properly positioned.

The superior approach surgical technique for hip arthroplasty has been previously described by Murphy [13]. The patient was positioned in the lateral decubitus position. The leg was positioned in approximately 60° of flexion, maximum adduction, and about 20° of internal rotation. The foot was placed on a Mayo stand, and the knee was left unsupported off the anterior side of the operating table. Typically, an 8 cm incision was made proximal to the greater trochanter. After dissecting posterior to the abductors and down to the superior hip capsule, the piriformis tendon was tagged and released. The hip capsule underneath the piriformis

tendon was opened from the superior femoral neck to the edge of the acetabulum and then anteriorly along the rim of the acetabulum. Retractors were placed inside the hip capsule along the anterior and posterior sides of the femoral neck. A sharp-tipped cylindrical reamer was inserted into the piriformis fossa and used to open the femoral canal. Sequential cylindrical reamers were used to expand the femoral canal. An osteotomy was used to cut a channel in the lateral femoral head and the medial femoral neck metaphyseal bone. Sequential broaches were inserted to machine the femoral metaphyseal bone until the distance from the shoulder of the broach to the tip of the greater trochanter corresponded with the templated distance. The modular neck femoral prosthesis was then implanted into the femoral canal. The leg length device was threaded into the femoral prosthesis. The leg length device was used to guide a smooth wire perpendicular to the femoral axis into the ilium either 5 or 6 cm above the shoulder of the femoral prosthesis (Fig. 1). A temporary cannulated screw was then implanted over the guide wire into the ilium (Fig. 2). The preoperative leg length measurement was set by the location of the screw in the ilium. The preoperative offset measurement was determined by inserting a stylus into the cannulated screw to measure the distance



Fig. 1. Leg length device guides wire into ilium.



Fig. 2. Cannulated screw inserted over guidewire.

between the head of the cannulated screw and the leg length device (Fig. 3). The leg length device was removed from the femoral prosthesis.

All of the above steps were performed while the femoral head remained in the acetabular socket. The in situ femoral neck cut started at the superior lateral neck and extended medial and inferior using the femoral prosthesis to guide the osteotomy. The blunt Homan retractors inside the anterior and posterior capsule protected the capsule from the saw blade. The femoral head was removed with a threaded Steiman pin drilled into the femoral head. The acetabulum bone was prepared either using the 45° angled acetabular reamers and insertion handle as described by Murphy [13] in the superior approach or using a percutaneous assisted approach as described by Penenberg [15]. The acetabular component was implanted, and a trial acetabular liner, head and neck, was inserted into the acetabular and femoral components. The leg length device was again threaded into the femoral prosthesis, and the change in vertical and horizontal distances between the leg length device and screw head were determined using a stylus inserted into the cannulated screw (Fig. 4). Adjustments in the modular head and neck were made to restore leg length and offset. An in situ hip reduction

was performed with the final modular components by implanting the liner, then placing the head in the liner, then implanting the modular neck into the femoral prosthesis, and finally engaging the end of the modular neck into the femoral prosthetic head by manipulating the leg. The cannulated screw was removed from the ilium. An intraoperative fluoroscopy radiograph was obtained on all patients to assess the position of the components. The final change in leg length and offset was recorded in the operative note at the end of each case.

The postoperative change in leg length and offset was measured using the preoperative and postoperative anteroposterior pelvic radiographs. The radiographic technician attempted to recreate the same hip abduction for every radiograph, given that even small variations in hip abduction have a large potential impact on the measurements. To correct for any positioning error, outlines of the femoral bone (specifically the lesser and greater trochanters and the femoral shaft) were made on both the preoperative and postoperative radiographs, and the center of rotation of the prosthetic hip was marked. Using a light box, the 2 femoral outlines were overlapped, and the location of the center of rotation of the prosthetic hip was translated onto the preoperative radiograph. The teardrops and other pelvic landmarks



Fig. 3. Initial leg length and offset measurement taken.



Fig. 4. Final leg length and offset measurement taken.

were then outlined on both the preoperative and postoperative radiographs. The pelvic outlines of the operative side were then overlapped, and the vertical and horizontal distances between the center of rotation of the prosthesis hip and the mark on the preoperative radiograph were measured and recorded as the postoperative change in leg length and offset. This radiographic measurement technique corrected for any

change in leg abduction between radiographs by allowing the 2 radiographs to rotate around the center of rotation of the hip. It did not, however, correct for any change in offset due to a change in internal or external rotation. At 6-weeks, 3-month, and 1-year follow-up appointments, patients were asked to discuss their perception of leg length. Harris hip scores were obtained preoperatively and at 1 year. Statistical analysis was performed using Microsoft Excel.

A retrospective cohort of 15 hip arthroplasty patients in whom this leg length device was not used was selected as a control group. Eight patients had surgery before this device was available, 4 patients had a cemented hip arthroplasty, and 3 patients had ankylosed hip joints that made the in situ femoral preparation impossible. All patients in the control group had preoperative templating and intraoperative radiographs to help restore leg length and offset.

Results

The primary goal of this study was to compare the change in the leg length and offset measured with the in situ technique to the change in leg length and offset measured on preoperative and postoperative radiographs. The in situ measured leg length accuracy (Fig. 5) was defined as the difference between the intraoperatively measured change in leg length using the in situ technique and the postoperatively measured change in leg length using the preoperative and postoperative radiographs. The in situ measured leg length accuracy averaged 0.0 mm with a 1.68-mm standard deviation (range, -4 to 6 mm) and had a correlation coefficient of 0.89. Ninety-one percent and 98% of the in situ measured leg lengths and radiographic leg lengths were within 3 and 5 mm of each other, respectively. The in situ measured offset accuracy (Fig. 5) averaged -0.4 mm with a standard deviation of 2.69 mm (range, -7 to 9 mm) and had a correlation coefficient of 0.57.

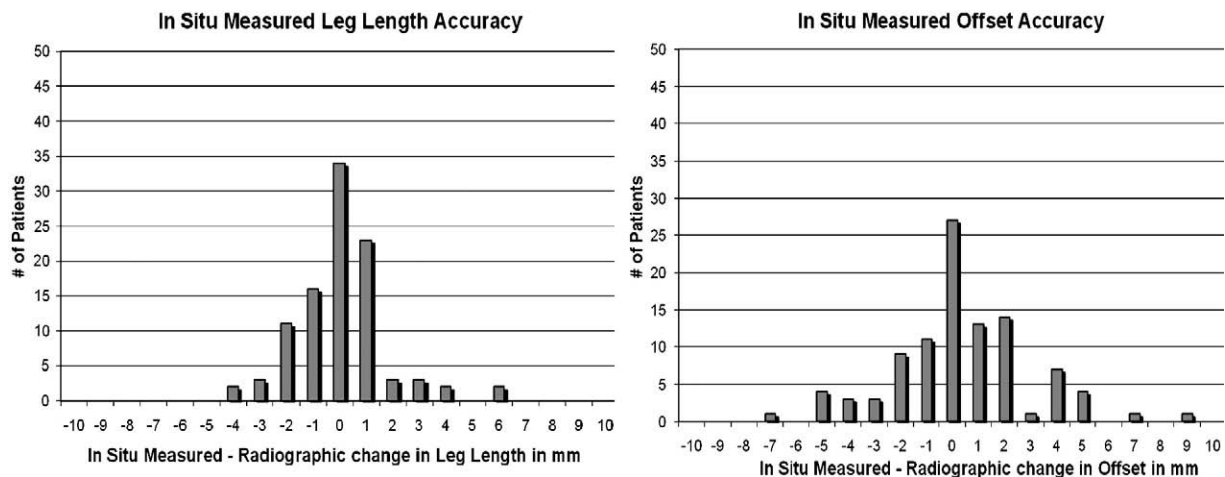


Fig. 5. In situ measurement accuracy.

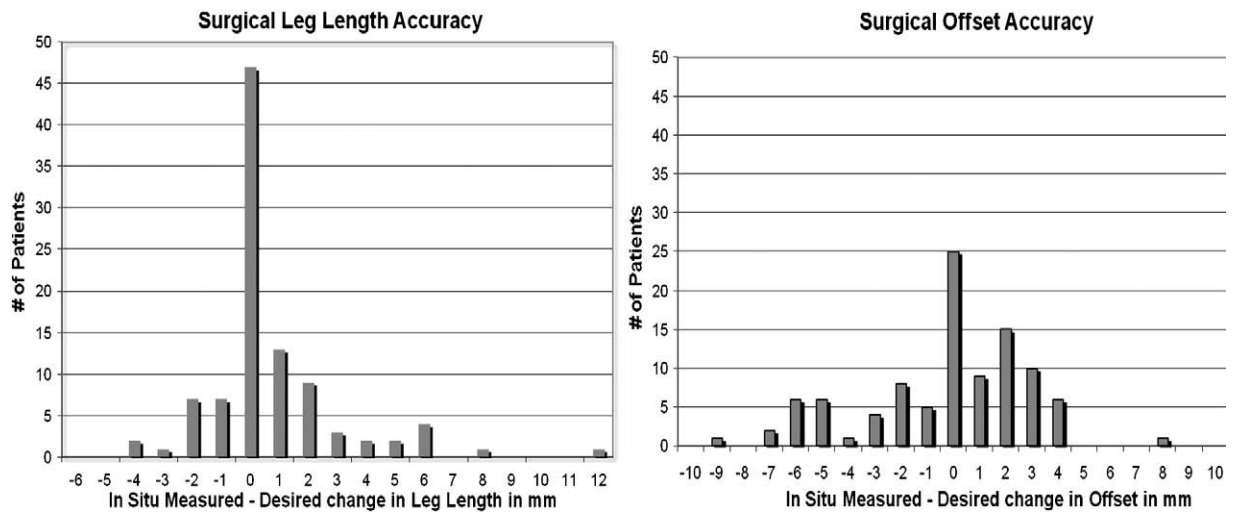


Fig. 6. Surgical accuracy.

The secondary goal was to compare the patients' desired change in leg length and offset to the in situ measurements. This surgical leg length accuracy was defined as the difference between the patients' desired change in leg length and the in situ measured change in leg length. The surgical leg length accuracy accounted for intraoperative deviations from the planned change in leg length to improve hip stability or to improve the diaphyseal fill of the femoral component, which resulted in a slightly proud femoral component and known lengthening of the leg. The surgical leg length accuracy (Fig. 6) averaged 0.7 mm with a 2.3-mm standard deviation (range, -4 to 12 mm) and had a correlation coefficient of 0.74. Eighty-eight percent and 94% of the desired leg lengths and in situ measured leg lengths were within 3 and 5 mm of each other, respectively. Two patients requested 10 and 12 mm of lengthening but were lengthened only 6 and 8 mm, respectively, due to tight soft tissue structures (4 mm short of their desired leg length). Six patients were deliberately lengthened (4, 5,

6, 6, 8, and 12 mm) to improve hip stability. A larger femoral prosthesis was selected in 4 patients to improve the diaphyseal fill but inadvertently resulted in a proud femoral prosthesis that lengthened these patients' leg 4, 5, 6, and 6 mm despite selecting the shortest head and neck. Because the planned change in offset was zero for every patient, the offset surgical accuracy equaled the in situ measured change in offset and averaged -0.2 mm with a 3.1-mm standard deviation (range, -9 to 8 mm).

The final goal of this study was to compare the patients' desired change in leg length and offset to the change in leg length and offset measured on the preoperative and postoperative radiographs. The overall leg length accuracy was defined as the difference between the patients' desired change in leg length and the radiographic change in leg length. The overall accuracy incorporates any errors from the in situ measurement technique, deviations from the surgical plan, and inability to achieve both leg length and offset request. The overall leg length accuracy (Fig. 7) averaged 0.7 mm with a 2.9-mm

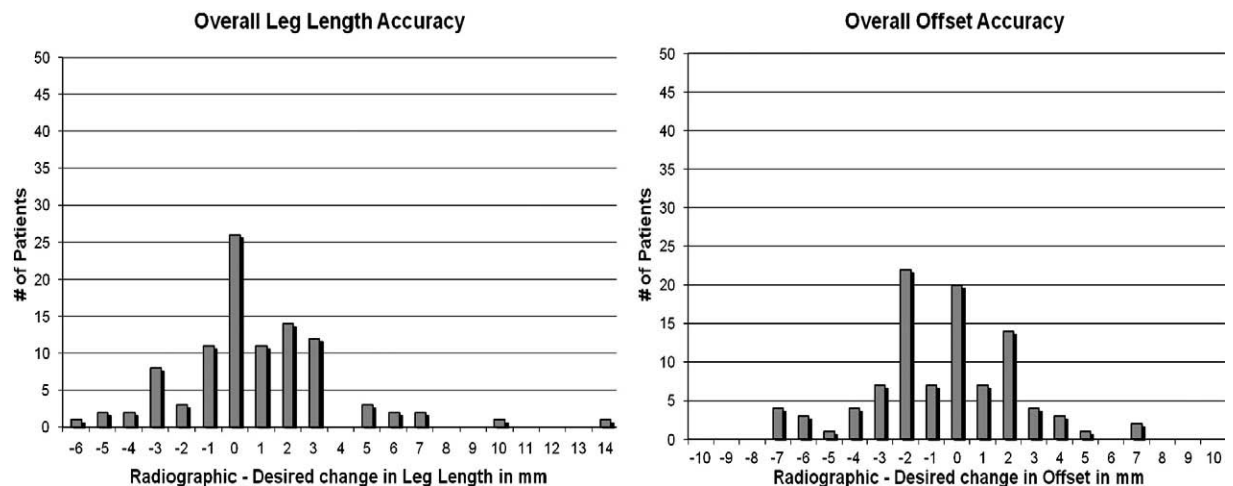


Fig. 7. Overall accuracy.

standard deviation (range, -6 to 14 mm) and had a correlation coefficient of 0.64. Eighty-one percent and 92% of the desired leg lengths and radiographic leg lengths were within 3 and 5 mm of each other, respectively. The overall offset accuracy averaged -0.6 mm with a 2.8-mm standard deviation (range, -7 to 7).

The 93 study patients were compared with the 15 control patients. The mean changes between the preoperative plan and the postoperative radiograph in leg length and offset were 4.5 and 2.8 mm for the control group and 0.7 and -0.6 mm for the study group. A Welch-Satterthwaite *t* test for unequal variances was used to compare the overall leg length and offset accuracy between the control patients and the study patients. The overall leg length in the study group was statistically more accurate ($P = .0004$). The overall offset in the study group trended to being more accurate but failed to reach statistical significance ($P = .17$).

Two patients reported feeling longer in their operative leg after surgery and are shown in Fig. 6 and 7, as the 2 patients with leg length changes greater than 8 mm. One patient inadvertently received a mislabeled +3.5-mm head ball instead of a -3.5-mm head ball due to a packaging error by the manufacturer. The in situ leg length measurement for this patient was 3 mm, but with a femoral head being 7 mm longer than anticipated, the adjusted in situ measurement was 8 mm. The change in leg length on her radiographs was 10 mm. Another patient with hip dysplasia requested only 4 mm of leg lengthening despite being 11 mm short on the preoperative hip radiograph; however, intraoperatively, her hip instability required lengthening her leg by 16 mm according to the in situ measurement. The radiographic change in leg length was 18 mm resulting in her operative leg being 7 mm longer than her nonoperative leg on her postoperative radiograph. This patient uses a shoe lift and is pleased with her hip arthroplasty.

One intraoperative calcar fracture required cables. Another femur fracture occurred 2 weeks after the surgery and required cables without changing components. One patient had a pathologic acetabular fracture that required conversion to a cup/cage construct. Three patients with metal-on-metal articulation (2 monoblock shells and 1 modular acetabular component) had revisions to a ceramic on polyethylene articulation for pain of unknown origin 2 years after their original surgery. There were no identifiable problems with their hip joints preoperatively or at the time of the revision surgery. One polyethylene liner dislodged from the acetabular shell 2 years postoperatively due to excessive rim wear. The acetabular component had a 60° abduction angle and was revised.

In 3 patients, the cannulated screw in the ilium was removed before the acetabular component was inserted because the screw threads were visible after reaming the acetabular bone. In these instances, a trial femoral head

of the same diameter as the intended acetabular component was used to obtain a leg length and offset measurement before the screw was removed. There were no dislocations, infections, or complications from the leg length device or cannulated screw. The Harris Hip scores improved from a preoperative average of 46 (range, 14-83) to a 1-year postoperative average of 89 (range, 36-100).

Discussion

In situ femoral preparation allows implantation of the femoral component before the anatomical relationship between the femur and pelvis is altered in much the same way, as an antegrade femoral nail is implanted. The femoral component then becomes the primary reference point for establishing the preoperative leg length and offset. The firm foundation of the implanted femoral prosthesis allows the surgeon to build off that foundation with different sizes of modular head and neck components to restore the desired leg length and offset. A similar technique is used in revision femoral hip arthroplasty, where the modular stem is implanted to a firm end point, and then a modular femoral body and head are selected to restore the desired leg length and offset.

Another benefit of the in situ femoral preparation includes easier preparation of the femoral canal because the intact femoral head in the acetabulum stabilizes the entire femur during reaming and broaching. The intact femoral neck maintains femoral offset, which makes entering the femoral canal with the broaches often easier than if the femoral head was rotated out of the socket, and the neck was cut. The machining of the proximal femur is performed while directly observing the femoral head, so restoring the femoral anteversion is easily accomplished. In addition, the change in femoral anteversion can be ascertained by observing the angle between the cannulated screw and the leg length device at the end of the case. Corrections to the femoral anteversion are possible at the end of the case by selecting an anteverted or retroverted modular neck. Machining the femoral canal with an intact femoral neck may dissipate hoop stresses in the proximal femur more efficiently and reduce fractures, although 2 femoral fractures did occur in this study. Lastly, this technique eliminates the intraoperative hip dislocation, which may help prevent a postoperative hip dislocation.

Most leg length devices in the literature are some variation of Harris's technique of inserting a Steiman pin in the ilium [4-11]. Woolson and Harris [5] described using a caliper attached to the Steiman pin to measure the distance to a point on the greater trochanter. McGee and Scott [6] suggested bending the Steiman pin until it touched the greater trochanter. Jasty et al [7] reported the use of a caliper attached to the Steiman pin with 87% of his 85 patients within 5 mm of the contralateral

side. By comparison, 92% of the patients in our study were within 5 mm of the patients' desired leg length. Bose described using both a caliper and a level attached to the Steiman pin to measure leg length [8]. Mihalko et al [9] used a screw in the ilium and a screw driver to measure the distance to the greater trochanter. Shiramizu et al [10] reported his use of an L-shaped caliper attached to a Steiman pin to restore leg length. Ranawat et al [12] placed a temporary pin in the infracotyloid notch to mark the greater trochanter and reported that 84% of his patients were within 3 mm of the predicted leg length with a correlation coefficient of 0.82. In our study, 92% of the patients were within 3 mm of the predicted leg length with a correlation coefficient of 0.89.

One source of possible error for leg length devices is the failure to return the leg to the same position for both measurements. Sarin et al [16] showed that a 5° change in abduction results in an 8-mm change in leg length. To minimize this error, Ranawat et al [12] stressed the importance of obtaining the measurement as close to the center of rotation of the hip as possible. The in situ leg length device measures the change in leg length along the femoral axis, which is approximately 3 to 5 cm away from the center of rotation of the hip. Returning the leg to the same position (flexion and abduction) for both measurements is confirmed by making the cannulated screw (ie, the stylus) and the leg length device perpendicular to each other at the final measurement. Both the femoral and pelvic markers with this device are vectors that convey direction and therefore allow for a verification of the same leg position for both measurements. Another possible source of error with leg length devices is the inadvertent dislodging of the Steiman pin from the ilium. Our device attaches to the solidly implanted femoral component and is removed during most surgery so that it is not inadvertently dislodged.

Our study limitations include the following. Many studies have shown excellent leg length restoration with preoperative templating and intraoperative radiographs [1,2]. Preoperative templating and intraoperative radiographs were also performed in this study, which may explain some of the favorable results. Our technique requires that the surgeon implant the femoral component in a reasonable position and then use the modular components to fine tune the leg length and offset. Our study also used large diameter femoral heads, which improved hip stability and likely decreased the need for deliberate lengthening of the leg to gain hip stability. Preserving the posterior hip capsule and eliminating the intraoperative hip dislocation might also improve hip stability and decrease the need for deliberate lengthening. Some of the patients in our control group had more complicated hip arthroplasty surgeries, which may have biased this group. Comparison of our study to previous studies is complicated by the fact that our leg length goal

was based on the patient's preoperative perception of leg length and not the contralateral hip radiograph. For this reason, the desired leg length in this study may have been slightly shorter than the desired leg length in previous studies. The radiographic measurement technique used in this study has not been validated but is intended to correct for changes in leg position between the preoperative and postoperative radiographs.

The 2 patients who perceived a leg length discrepancy after surgery were the 2 furthest outliers on the overall accuracy figure at 10 and 14 mm; however, 1 patient only complained of the discrepancy after I informed her of the manufacturing mistake. The clinical relevance of the surgical accuracy of leg length is therefore difficult to state as many factors likely contribute to the patient's perception of their postoperative leg length. However, in my opinion, a detailed preoperative conversation with patients about their desired change in leg length greatly improves the patient's postoperative perception of the leg length.

The in situ measurement technique used in this study has evolved to allow its use with traditional nonmodular neck femoral prosthesis and cemented femoral prosthesis. This second-generation device can attach to many different femoral broaches and gives the surgeon an opportunity to adjust the final femoral component position after a leg length measurement is made. Because both the femoral and iliac markers are vectors, this second-generation device does not require a trial reduction of the hip joint to make the leg length, offset, or femoral anteversion measurements. This in situ technique may also be used with pinless femoral navigation of hip arthroplasty.

There are many effective techniques and tools available to orthopedic surgeons to restore leg length and offset in hip arthroplasty. Most current techniques and devices obtain enough accuracy to satisfy most patients. It remains to be seen if any subtle improvements in leg length and offset accuracy might offer any improved clinical outcomes.

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