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Digital Fluoroscopic Navigation for Limb Length Restoration During Anterior Total Hip Arthroplasty

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ABSTRACT

Background: Restoration of limb length is important in total hip arthroplasty. Clinical evaluation and preoperative templating establish the intended lengthening. The purpose of this study was to assess whether digital fluoroscopic navigation (DF) improved the accuracy of planned lengthening in direct anterior approach total hip arthroplasty (DAA-THA).

Methods: Planned lengthening measurements on 100 consecutive unilateral DAA-THA patients, along with patient characteristics, were prospectively collected by 2 surgeons. One surgeon utilized DF to achieve intended length (n = 50), while the other utilized unaided standard fluoroscopy (SF; n = 50). A third surgeon blinded to the procedures assessed actual limb length using an ipsilateral overlay technique on the 6-week postoperative radiograph. The difference between the mean planned and actual limb lengthening stratified by DF and SF was assessed using bivariate and multivariate statistics.

Results: The mean (standard deviation) planned lengthening in DF and SF groups was 3.96 (2.1) and 3.47 (2.2) mm, respectively. The mean (standard deviation) actual lengthening in DF and SF groups was 3.11 (4.0) and 0.68 (4.6) mm, respectively. After accounting for age, sex, body mass index, laterality, and the Bone Index, multivariate regression results showed that the average difference between planned and actual limb lengthening in the DF group was significantly lower than that in the SF group ($\beta = -1.92$; 95% confidence interval: −3.51, −0.33; $P < .02$). A greater percentage of patients in the DF group (66% vs 40%) were within 3 mm of the intended plan ($P < .01$).

Conclusions: Fluoroscopy helps achieve the intended surgical lengthening in DAA-THA. The use of DF resulted in more accurate execution of lengthening.

Introduction

Limb length discrepancy (LLD) after THA is an undesirable outcome, and its incidence in the literature varies between 1% and 27% [1]. It can lead to patient dissatisfaction and secondary complications including gait disturbance, low-back pain, neuritis, component instability, and early component loosening [2–7]. Additionally, patients' perception of LLD is well-known to be a leading cause of litigation following THA [8–11].

Preoperative templating establishes a proposed plan to achieve the intended lengthening. Acetabular cup position first determines the intended center of rotation of the hip. Femoral stem size and position relative to the greater and lesser trochanters further dictates the level of the intended proximal femoral neck osteotomy to achieve desired lengthening. The final template provides an approximate value for planned limb lengthening, which is then carried out and can be confirmed intraoperatively with various techniques [4,12–14].

Specific to the anterior approach, fluoroscopy allows visualization of common landmarks around the hip. Length may be grossly assessed by comparing the relationship of the inferior ischial line or inferior teardrop line to the superior aspect of the lesser trochanter or tip of the greater trochanter (Fig. 1). This technique is limited by beam asymmetry and femoral abduction or rotation differences

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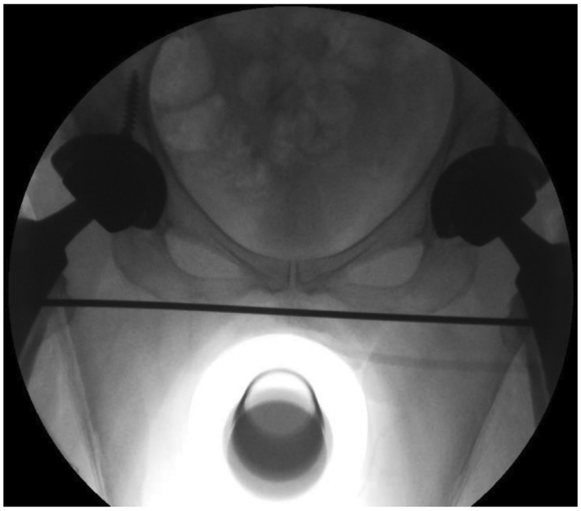

Figure 1. A superimposed instrument demonstrates the relationship between the inferior ischial line and lesser trochanters.

(Fig. 2). An alternative technique espoused by Matta et al. involves utilizing an overlay view to compare the surgical and contralateral hip and visualizing differences in length and offset [12]. This is performed by manually superimposing the printed radiographs for comparison (Fig. 3). Improved accuracy is obtained when both images are an exact match. Pelvic rotation, femoral abduction, and other positional changes are factors that influence the outcomes of this method. Enabling technologies have been developed to enhance the accuracy of fluoroscopy when evaluating changes in leg length and offset [13] (Fig. 4) and can also produce rapid overlay comparisons intraoperatively and correct for differences in femur abduction and adduction (Fig. 5).

In recent years, there has been an increased interest in standard fluoroscopy as a result of its increased utilization in conjunction with direct anterior approach total hip arthroplasty (DAA-THA). Its use is largely supported by prior studies; however, the clinical benefit and ability to prevent postoperative LLD has not yet been clearly defined [14,15]. Digital fluoroscopic navigation (DF) has been introduced to enhance fluoroscopy capabilities in improving component positioning and leg length determination. However, demonstration of its superiority remains in question. The purpose of this clinical study was to compare the accuracy of intended leg lengthening between standard unaided fluoroscopy (SF) and DF used in primary DAA-THA, by comparing measurements of anticipated lengthening with executed lengthening. We hypothesize that actual limb lengthening produced by DF is more accurate (to intended limb lengthening) than that by SF.

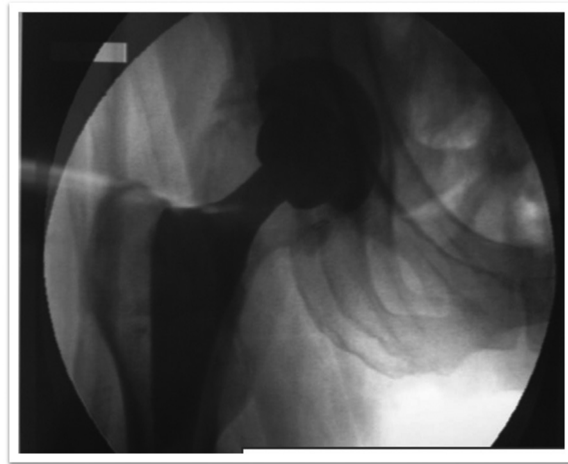

Figure 3. An illustration of the contralateral overlay technique with printed radiographs (not properly aligned).

Material and methods

Study design and participant population

This research is a retrospective comparative cohort study of prospectively collected data of patients undergoing DAA-THA at a community hospital between May and September 2020.

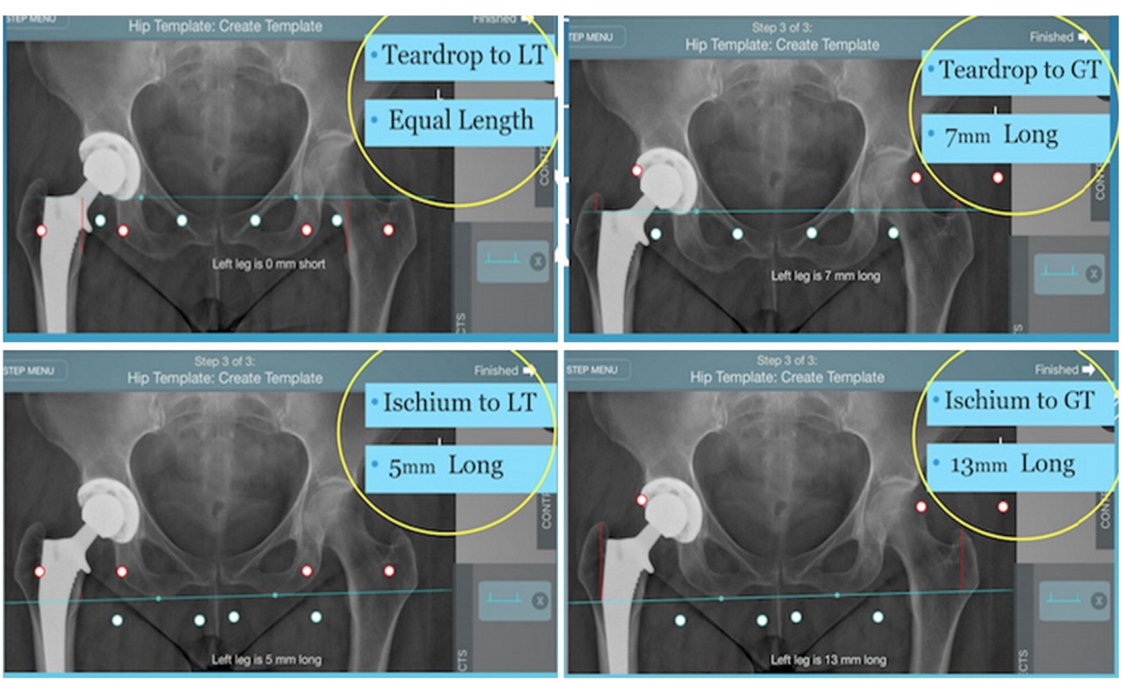

Figure 2. Repeated measurements of the same radiograph using different reference points. GT, greater trochanter; LT, lesser trochanter.

Figure 4. OrthoGrid Hip software system. OrthoGrid Hip creates superimposed grid lines parallel to the inferior tear drop line and lesser trochanter to aid in limb length assessment.

Consecutive patients during this period were included in the study based on the following criteria:

- age ≥18 years,
- underwent primary unilateral total hip arthroplasty by one of the two surgeons,
- had preoperative template measurements of desired surgical lengthening,
- have received postoperative radiographs at their outpatient follow-up visit, and
- not undergoing a revision surgery or arthroplasty for fracture.

We performed a sample size calculation and power analysis and determined that the study needed a minimum sample of 100 subjects (50 per group) to achieve a power of at least 0.8.

Data collected on all patients preoperatively included patient characteristics such as age, sex, body mass index (BMI), cortical diameters, and bone index.

Assessment of leg lengthening

Two surgeons employed distinct intraoperative radiologic techniques, each using one of SF or DF, for the assessment of leg length. The surgeons who performed the procedures collected the information on intended limb-lengthening prospective data preoperatively. Preoperative templating provided intended lengthening for anatomical restoration of the hip joint. The procedure for SF used OrthoView (Meridian Technique Limited, Southampton, UK) for preoperative templating, and DF used VELYS Hip Navigation (DePuy Synthes, Raynham, MA) for both templating and intraoperative interpretation. Both templating software systems employed perform a measurement calibration based on a standard radiograph calibration marker used for all patients.

The surgeons also used different techniques when assessing intraoperative leg length change. The surgeon utilizing unaided fluoroscopy relied on soft-tissue tension as well as template execution such as femoral neck cut and the distance from the tip of greater trochanter to the shoulder of prosthesis, considering acetabular center of rotation. The surgeon utilizing digital fluoroscopic navigation relied on soft-tissue tension as well as the ipsilateral radiograph overlay technique. This technique superimposes the preoperative image with the intraoperative one after appropriate registration. The software adjusts for femoral position and provides information regarding leg length and both femoral and global offset. For both surgeons, only anterior stability was assessed with range of motion up to 90 degrees of external rotation and 30 degrees of extension.

A third surgeon, blinded to the 2 study groups, assessed achieved limb lengthening using the 6-week postoperative radiographs for each patient included in the study. Achieved/actual surgical lengthening was assessed with an ipsilateral overlay technique utilizing the VELYS Hip Navigation software. This process involves the registration of specific anatomic landmarks of the preoperative and postoperative radiographs, which guides the

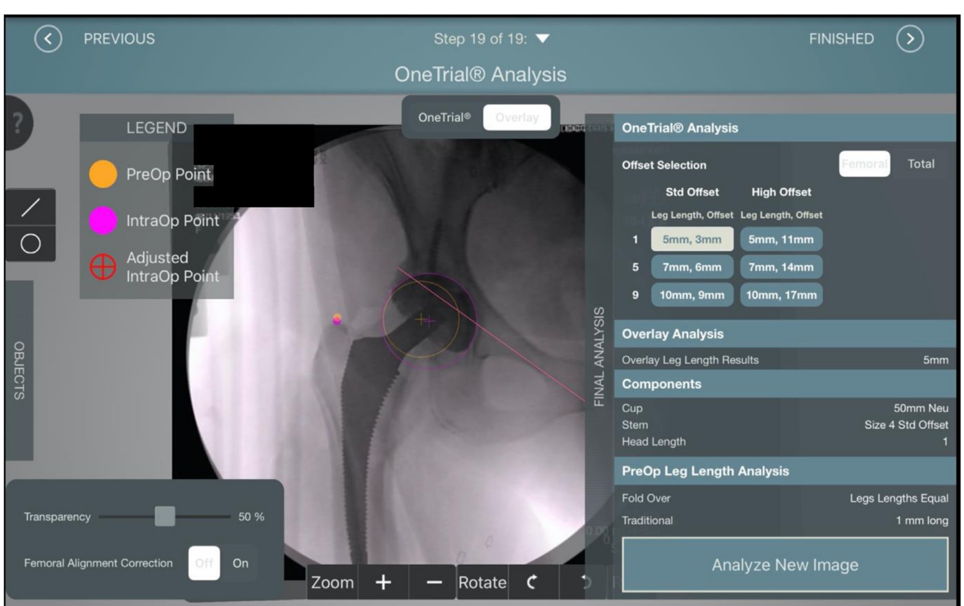

Figure 5. Digital ipsilateral overlay technique using VELYS Hip Navigation.

superimposition of the images. It also determines changes after accounting for differences in femur abduction and adduction.

Statistical analysis

We examined all variables for normality using the Shapiro-Wilk test. Descriptive statistics were calculated for all variables of interest. Continuous variables were reported as means and standard deviations (SD), and categorical variables were reported as frequencies and percentages (%). The primary outcome of interest was difference in mean planned and actual limb length. We categorized this difference (in absolute terms) into 6 categories: up to 1 mm, 1-2 mm, 2-3 mm, 3-4 mm, 4-5 mm, and greater than 5 mm.

Depending on the normality of distribution of variables, differences in continuous variables were evaluated using t-test or nonparametric methods. We also assessed categorical variables and proportions with the chi-square or Fisher's exact test as appropriate. Multivariable multivariate regression models (logistic or linear mixed models) were utilized to examine associations among the dependent variables. Statistical significance was set at alpha 5% level ($P < .05$). We performed all statistical analyses using STATA SE Version 17 (StataCorp LLC, College Station, TX) and R software version 4.1.3 (The R Foundation for Statistical Computing, Vienna, Austria).

Results

One hundred eligible patients were included in the study. There were 49 men and 51 women were enrolled in this study ($n = 100$). The mean (SD) age was 65.0 (9.7) years (range, 46-87). Osteoarthritis was the diagnosis in 95%, while avascular necrosis was seen in 5%. Both groups had similar demographic characteristics (Table 1). Sixty-seven procedures were right-sided, and 33 procedures were of left laterality. The mean (SD) BMI for patients in DF and SD groups was 29.72 (6.5) and 29.39 (11.8), respectively, and the difference in mean BMI between the 2 groups was not statistically significant. The mean (SD) length of stay (LOS) for cases belonging to the DF group was shorter, 0.36 (0.5) days, than the average LOS of 0.92 (0.7) days in the SF group. This mean difference in LOS between the 2 groups was statistically significant ($P < .001$). The mean differences in outer and inner cortical diameters (in mm) between the 2 groups were not statistically significant. The mean (SD) planned lengthening in DF and SF groups were 3.96 (2.1) and 3.47 (2.2) mm, respectively. The mean (SD) actual lengthening in DF and SF groups was 3.11 (4.0) and 0.68 (4.6) mm, respectively. The mean difference in planned and actual lengthening between the 2 groups was statistically significant ($P < .05$). A greater percentage of patients in the DF group (66% vs 40%) were within 3 mm of the intended plan ($P < .01$). Results from the generalized linear mixed model analysis showed that after accounting for age, sex, BMI, laterality, and the Bone Index, the average difference between planned and actual limb lengthening in the DF group was significantly lower than that in the SF group ($\beta = -1.74$; 95% CI: -3.28, -0.20; $P < .027$).

Discussion

Total hip arthroplasty has proven to be a successful and widely accepted procedure for the treatment of end-stage arthritis. Surgical methods and techniques of THA have evolved over time in order to improve the accuracy of component positioning and to achieve optimal length and offset of the reconstructed hip. In recent years, fluoroscopy has become a useful tool utilized by surgeons during THA, and the introduction of enabling technologies has significantly enhanced the utility of standard fluoroscopy. This study sought to compare the radiographic outcomes of 2 patient groups, one using SF and one using DF. We questioned whether intraoperative DF resulted in more accurate planned limb lengthening than SF in DAA-THA. Our data show a statistically significant difference between the 2 groups, where the DF group

Table 1
Descriptive analysis.

Characteristic	DF	SF	P value
Age (y)	63.58 (9.6)	66.36 (9.7)	.15
Sex			.32
Male	27 (54%)	22 (44.0%)	
Female	22 (46%)	28 (56.0%)	
Laterality			.523
Right	32 (64.0%)	35 (70.0%)	
Left	18 (36.0%)	15 (30.0%)	
Height (cm)	169.73 (11.48)	166.69 (20.98)	.639[a]
Weight (Kg)	86.78 (24.3)	79.60 (24.6)	.15
BMI	29.72 (6.5)	29.39 (11.8)	.195[a]
Outer cortical diameter (mm)	27.46 (3.4)	27.34 (3.1)	.86
Inner cortical diameter (mm)	11.45 (1.9)	11.09 (1.7)	.33
Bone index	0.58 (0.06)	0.59 (0.06)	.619[a]
Lengthening (mm)			
Planned (P)	3.96 (2.1)	3.47 (2.2)	.241[a]
Actual (A)	3.11 (4.0)	0.68 (4.6)	.006
Difference (P-A)	0.85 (3.8)	2.79 (4.0)	.014
Absolute difference (P-A)	3.03 (2.4)	4.09 (2.6)	.020[a]
Lengthening categories (P-A)			.166
0-1 mm	12 (24.0%)	6 (12.0%)	
>1-2 mm	13 (26.0%)	9 (18.0%)	
>2-3 mm	8 (16.0%)	5 (10.0%)	
>3-4 mm	3 (6.0%)	9 (18.0%)	
>4-5 mm	6 (12.0%)	9 (18.0%)	
>5 mm	8 (16.0%)	12 (24.0%)	
≤3 mm	33 (66%)	20 (40%)	.009
>3 mm	17 (34%)	30 (60%)	

Values are given as mean (SD) and n (%).
[a] *P* value for non-parametric tests of equality.

demonstrates a smaller difference between planned and actual length. Additionally, a greater percentage of patients in the DF group (66% vs 40%) were within 3 mm of the intended plan ($P < .01$). These results support the hypothesis that DF may help surgeons more closely reconstruct the desired planned limb length when performing THA and help a surgeon to replicate their preoperative plan more closely. We believe this may help to reduce the incidence of unintended LLD. To the best of our knowledge, no previous study has compared the radiographic outcomes of digital fluoroscopic navigation against those of standard fluoroscopy.

The use of fluoroscopy has been largely favored in recent clinical studies when utilized during the anterior approach [14,16]. Leucht et al. compared the use of fluoroscopy during the direct anterior approach with that in patients undergoing posterior-approach THA without fluoroscopy and found a statistically significant decrease in postoperative LLD when using fluoroscopy (0.7 vs 2.7 mm) [15]. Additional studies also support that fluoroscopy used during the direct anterior approach may improve consistency of acetabular component orientation [17]. Recent studies have also shown contradictory results. Bingham et al. found no significant difference in acetabular component positioning or postoperative LLD when comparing patients undergoing DAA-THA with and without fluoroscopy [14]. These results suggest that fluoroscopy may be a useful tool, but factors such as surgical approach and surgeon experience have a large impact on controlling LLD.

Although fluoroscopy has been useful in providing surgical information to execute a plan, it is not without limitations. For example, in relation to the inferior ischial line or inferior teardrop line and its relationship to specific anatomical locations in the femur, leg length is commonly assessed using the superior aspect of the lesser trochanter or tip of the greater trochanter. This technique is limited by radiograph asymmetry as well as femoral abduction and adduction and rotation differences. Alternatively, using radiographs of the normal contralateral hip joint and comparing it to the surgical hip via an overlay technique can provide information on differences in leg length and offset. This technique can provide an accurate assessment of both leg length and offset as long as the overlaid images are a mirror image of each other accounting for pelvic rotation and femoral abduction/adduction variations. This technique can be executed by printing the images and superimposing them and assessing the relationships of the femoral outlines (Fig. 4). Similarly, an ipsilateral overlay of the presurgical image with one with the trials in place can also be used to assess changes in leg length and offset. Improved accuracy is obtained when both images are similar. Regardless of the technique utilized, understanding the limitations of fluoroscopy and ways of minimizing them can enhance the information provided in order to make sound intraoperative decisions. Furthermore, other variables such as parallax and distortion affect the image quality of fluoroscopy and can affect its interpretation. Digital fluoroscopic navigation allows for ipsilateral overlay and tries to minimize variability with landmark registration and adjusting for differences in femur abduction and adduction (Fig. 5).

We acknowledge that the present study has several limitations. It was a retrospective analysis of prospectively collected data with its inherent biases. Additionally, we examined the radiographic outcomes of 2 experienced surgeons employing 2 different techniques. Therefore, extrapolation of these results to all surgeons is speculative. As noted above, accuracy of actual lengthening and measurements is dependent on consistent intraoperative fluoroscopic imaging and recognition of necessary adjustments. We were unable to acquire patient-reported outcome measures, which would have given more insights and possibly helped to differentiate DF from SF in clinical terms with the clinical benefits. Lastly, it is difficult to clearly define the clinical significance of our data. Our results showed a significantly larger percentage of patients within 3 mm of planned lengthening when using digital fluoroscopic navigation; however, the clinical impact of this value on perception of LLD as well as overall patient outcomes is unknown.

Conclusions

The use of fluoroscopy in DAA-THA helps achieve intended limb lengthening. Enhancement with digital navigation resulted in more accurate execution of planned limb lengthening. Clinical significance of this finding should be further studied.

Conflicts of interest

Dr. Suarez receives royalties from Corin USA, is in the speakers' bureau of or gave paid presentations for Depuy, is a paid consultant for Depuy, has stock or stock options in Cuptimize, and is on the editorial board of *Arthroplasty Today*. All other authors declare no potential conflicts of interest.

For full disclosure statements refer to https://doi.org/10.1016/j.artd.2022.08.021.

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