Arthroplasty Today 30 (2024) 101492

Contents lists available at ScienceDirect

Arthroplasty Today

journal homepage: http://www.arthroplastytoday.org/

Original Research

Intraoperative Fluoroscopy Decreases Magnitude and Incidence of Leg-Length Discrepancy Following Total Hip Arthroplasty

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A R T I C L E I N F O

Article history:
Received 22 January 2024
Received in revised form
7 June 2024
Accepted 23 July 2024
Available online 14 October 2024

Keywords:
Total hip arthroplasty
THA
Leg-length discrepancy
Intraoperative fluoroscopy
Direct anterior approach

A B S T R A C T

Background: Leg-length discrepancy (LLD) can lead to patient dissatisfaction and decreased function after total hip arthroplasty (THA). This study examines the impact of intraoperative fluoroscopy on the magnitude and incidence of LLD after THA.
Methods: Patients undergoing primary THA were identified and stratified into cohorts based on one out of 4 surgical approaches and intraoperative fluoroscopy use. The most recent 100 patients matching each cohort were included. Preoperative and postoperative LLD was assessed radiographically via an inter-teardrop reference line to lesser trochanter measurement.Magnitude of LLD and the proportion of patients in each cohort with LLD >5 mm, >10 mm, and 15 mm were analyzed.
Results: Four hundred patients were stratified into 4 equal cohorts. Overall, THA done with fluoroscopy yielded fewer leg length discrepancies than THA done without fluoroscopy. The anterior-based muscle sparing (ABMS) approach with fluoroscopy had significantly less postoperative LLD than the posterior approach without fluoroscopy (3.4 vs 5.1 mm, $P < .01$) and the ABMS approach in the lateral position without fluoroscopy (3.4 vs 4.8 mm, $P = .03$). For LLD >5 mm, the ABMS approach with fluoroscopy cohort had significantly fewer patients compared to the ABMS approach without fluoroscopy (23 vs 41, $P < .01$). For LLD >10 mm, the ABMS approach with fluoroscopy cohort had significantly fewer patients compared to the posterior approach without fluoroscopy (2 vs 15, $P < .01$). For LLD >15 mm, relative to the posterior approach without fluoroscopy, all other cohorts had significantly fewer outliers ($P < .02$).
Conclusions: This study supplies evidence that use of intraoperative fluoroscopy is likely beneficial in reducing the magnitude of LLD following THA and reducing the incidence of outlier LLDs >5 mm, >10 mm, and <15 mm.

Introduction

Leg-length discrepancy (LLD) following total hip arthroplasty (THA) is a known cause of poor patient satisfaction and, if severe, can impact patient gait, causing significant limitation to functional status [1-3]. Additionally, large postoperative LLD can lead to low back pain, degenerative knee changes, and chronic pain [4].

Mean LLD values reported in the literature for patients after unilateral THA range from 3 mm to 17 mm, but a true definition of LLD is not widely agreed upon [5]. Sykes *et al.* reported that more than 74% of patients with discrepancies greater than 5 mm are aware of the difference [6]. Konyves *et al.* found that Oxford Hip Scores were 27% worse at 3 months in patients who perceived that their limb had been lengthened following THA [7]. Dissatisfaction due to LLD after THA is also the most common source of litigation toward orthopaedic surgeons [8-10].

Therefore, minimization of LLD should be a consistent goal during implant positioning in THA. This study aims to examine the impact that the use of intraoperative fluoroscopy has on

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https://doi.org/10.1016/j.artd.2024.101492

the magnitude of LLD. A secondary aim of the study is to compare the LLD of various common surgical approaches used in THA.

Material and methods

Approval from the institutional review board was obtained prior to the start of this study (Protocol IRB-AAAT1981). Patients who had undergone THA with one of 4 fellowship-trained arthroplasty surgeons were identified from an institutional arthroplasty database. The electronic health record (EHR) was examined to screen patients for inclusion in this study. Inclusion criteria were patients with a primary diagnosis of osteoarthritis who underwent primary unilateral THA. Exclusion criteria were patients with primary diagnoses other than osteoarthritis, prior or planned contralateral THA, severe-graded contralateral osteoarthritis, lack of follow-up radiographs, or preoperative LLD >2 cm. The EHR was reviewed in order to collect basic demographic information, surgical approach during THA, and determine use of intraoperative fluoroscopy. Basic demographic information collected included age, gender, American Society of Anesthesiologists (ASA) class, and body mass index (BMI). The most recent 100 patients undergoing each approach (posterior without intraoperative fluoroscopy, anterior-based muscle sparing (ABMS) without intraoperative fluoroscopy in the lateral position, ABMS with intraoperative fluoroscopy in the supine position, direct anterior with intraoperative fluoroscopy) who satisfied all inclusion criteria were included in this study. Patient preoperative and postoperative radiographs were sourced from the EHR. Standard anteroposterior radiographs with a 25-mm marker ball at the level of the greater trochanter were used. Preoperative and postoperative LLD was assessed using the interteardrop reference line method described by Ranawat *et al.* [3]. Specifically, this was a reference line that was drawn passing through the inferior margin of the radiographic teardrop bilaterally. A vertical line between the most prominent point of the lesser trochanter and the reference line was measured on each side. The difference in length between the surgical and nonsurgical legs was recorded as the LLD. See Figure 1. Analysis was based on the absolute value of this measurement except where otherwise noted. All measurements were made by a single, trained researcher blinded to surgical approach and use of fluoroscopy.

Surgical approach was determined independently by the operating surgeon. Choice of approach and position was chosen based on training, learning curve, and patient factors. All patients had a similar radiographic protocol, with standing anteroposterior pelvis radiographs preoperatively and postoperatively. All of these radiographs were done with 25 mm marker balls to confirm consistency and accuracy. Any patient without properly done radiographs at any time point was excluded from the study. Similarly, all patients, irrespective of surgical approach, underwent preoperative surgical templating prior to THA with a consistent goal of equalizing LLD. This was done based on radiographic in addition to clinical factors including apparent LLD based on physical exam findings. Intraoperative determination of LLD was done differently for the different surgical approaches. For the ABMS and direct anterior approaches, intraoperative fluoroscopy was utilized and compared to preoperative templating and intraoperative radiographic landmarks, specifically recreating the interteardrop line and measuring leg lengths clinically. For patients positioned in the lateral position, intraoperative measuring tools including the center of femoral head to lesser trochanter distance and the "spike and suture" method [5]

Statistical analysis

One-way analysis of variance (ANOVA) was used to analyze continuous demographic variables including age and BMI, as well as preoperative and postoperative LLD. Pearson's chi-square test was used to analyze categorical variables, including gender and ASA class, as well as the proportion of patients in each cohort with >5 mm, >10 mm, or 15 mm postoperative LLD. Post-hoc tests were performed using Tukey's method after statistical significance was determined via ANOVA and using post-hoc chi-squared tests with Bonferroni correction after statistical significance was determined via initial chi-squared tests. All demographic analyses were performed utilizing the Excel data analysis tool version 16.0 (Microsoft, Inc., Redmond, WA). ANOVA and post-hoc Tukey tests were performed using SPSS version 24 (IBM Corp., Armonk, NY).

A priori sample size analysis

To achieve 80% power and alpha 0.05 in detecting a 1 mm difference in a direct comparison of 2 cohorts, 100 patients in each cohort would be needed. Thus, a total of 400 patients were studied, with 100 per group.

Results

Eight hundred seventy-one total patients were screened for inclusion in this study. Four hundred sixty-five did not meet inclusion criteria. Patients were excluded for prior/scheduled contralateral THA (272), fracture (78), presence of contralateral severe osteoarthritis (59), lack of available follow-up radiographs (46), prior surgery on the operative limb (11), preoperative LLD >2 cm impacting surgical plan (4), and presence of tumor at the operative site (1).

Patient demographics are summarized in Table 1. BMI was significantly higher in the posterior approach without fluoroscopy cohort (30.4 vs 27.4, 27.7, and 28.5, $P < .01$). No significant differences were observed between the cohorts with regard to age, sex, ASA class, and magnitude of preoperative LLD.

The magnitude of postoperative LLD varied between the cohorts. The posterior and ABMS cohorts done in the lateral position, not utilizing intraoperative fluoroscopy had LLD of 5.1 and 4.8 millimeters respectively. The direct anterior and supine ABMS cohort that did utilize fluoroscopy had LLD of 3.8 and 3.4 millimeters, respectively. ANOVA analysis demonstrates a significant

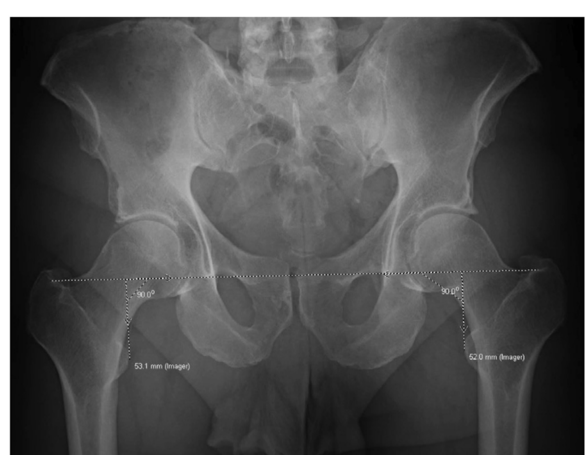

Figure 1. Measurement of the preoperative leg-length discrepancy relative to the interteardrop reference line.

Table 1
Patient demographics and preoperative LLD.

Data point	Posterior approach without fluoroscopy	ABMS approach without fluoroscopy	ABMS approach with fluoroscopy	Direct anterior approach with fluoroscopy	*P*-value
n	100	100	100	100	
Age (y)	62.9 ± 13.4	65.0 ± 13.8	66.7 ± 14.2	65.0 ± 13.6	.22
BMI	30.4 ± 6.0	27.7 ± 5.0	28.5 ± 5.6	27.4 ± 5.1	**<.01**[a]
Female, n (%)	44 (44.0)	54 (54.0)	53 (53.0)	59 (59.0)	.20
ASA score					.80
I	7 (7.0)	7 (7.0)	5 (5.0)	7 (7.0)	
II	55 (55.0)	56 (56.0)	66 (66.0)	55 (55.0)	
III	37 (37.0)	37 (37.0)	29 (29.0)	37 (37.0)	
IV	1 (1.0)	0 (0)	0 (0)	1 (1.0)	
Preoperative interteardrop LLD (mm)	5.8 ± 5.1	5.1 ± 4.0	4.6 ± 3.3	4.6 ± 4.0	.15

Bold value indicates significance at $P < .05$.
[a] Denotes significance at $P < .05$.

difference among the cohorts ($P < .01$) (Table 2). Post-hoc Tukey tests found that the ABMS approach with fluoroscopy had significantly less postoperative LLD than the posterior approach without fluoroscopy (3.4 vs 5.1, $P < .01$) and the ABMS approach done in the lateral position without fluoroscopy (3.4 vs 4.8, $P = .03$). Direct anterior with fluoroscopy did not reach significance when compared to posterior approach without fluoroscopy ($P < .06$). Between direct anterior and both ABMS with and without fluoroscopy, there was no significant difference ($P < .85$ and $P < .21$, respectively) (Table 3).

Chi-squared analysis demonstrates that a significant difference exists among the cohorts with regard to the proportion of patients with postoperative LLD >5 mm ($P = .04$) and >10 mm ($P < .01$) (Table 2). Post-hoc chi-squared tests were performed, and Bonferroni correction applied to determine significance as $P \leq .008$. For LLD >5 mm, the ABMS approach done supine with fluoroscopy cohort had significantly fewer patients as compared to the ABMS approach done in lateral position without fluoroscopy cohort (n = 23 vs 41, $P < .008$). For LLD >10 mm, the ABMS approach done supine with fluoroscopy cohort had significantly fewer patients as compared to the posterior approach without fluoroscopy cohort (2 vs 15, $P < .008$). For LLD >15 mm, the anterior approach with fluoroscopy, the ABMS with fluoroscopy, and the ABMS without fluoroscopy had significantly fewer patients as compared to the posterior approach without fluoroscopy (0 vs 7, $P < .01$, vs 7, $P < .01$, 1 vs 7, $P < .02$, respectively). Other comparisons did not achieve statistical significance (Table 4).

Discussion

LLD after THA is linked to poor patient outcomes and increased litigation toward orthopaedic surgeons [1-6,8-12]. Given the importance of mitigating LLD after THA, numerous techniques for doing so have been trialed. In addition to preoperative templating, there have been as many as 20 intraoperative techniques for measuring LLD described in the literature [5]. Despite the effort put forth to mitigate LLD after THA, a gold-standard nonradiographic intraoperative technique for LLD assessment does not exist [11]. Despite the measures taken, LLD can still occur after THA, with a mean LLD value for patients following unilateral THA reported to range from 3 mm to 17 mm [5]. Fluoroscopy may provide an ideal tool to evaluate LLD intraoperatively.

The results of the presented analysis support the use of intraoperative fluoroscopy to decrease the likelihood of a postoperative leg length discrepancy. With the ABMS approach, fewer patients had LLD >5 mm when fluoroscopy was used in the supine position compared to no fluoroscopy used in the lateral position. Fewer patients had LLD >10 mm when comparing ABMS with fluoroscopy vs posterior approach without fluoroscopy. However, there was no difference when comparing direct anterior with fluoroscopy to either of the nonfluoroscopic THA techniques.

Few other studies assess the effect of intraoperative fluoroscopy on LLD. The results of these prior analyses are mixed, and the analyses were limited in several ways. A report by Leucht et al. compared primary posterior THA without fluoroscopy to primary anterior THA with fluoroscopy and found the latter group to have less mean LLD [12]. The authors, however, acknowledged the difficulty of isolating the impact of fluoroscopy because of other differences between the approaches. Bingham et al. found no significant difference in LLD between anterior THA with and without fluoroscopy [13]. Though this analysis controlled for surgical approach, intersurgeon variables were not controlled as each group was performed by one of 2 different surgeons. Our study, in one analysis, compared the same surgical approach (ABMS) with and without fluoroscopy to better isolate the effect of fluoroscopy. There was, however, a difference in patient positioning between lateral decubitus and supine, which allows the additional option of ankle palpation. Additionally, our study includes patients from 4 surgeons, with 2 surgeons performing the ABMS approach, improving the external validity of these comparisons.

Though possible, there is some difficulty using fluoroscopy in posterior THA. Furthermore, with any approach, both component

Table 2
Mean postoperative LLD and number of patients with LLD >5 or >10 mm.

Leg length discrepancy	Posterior approach without fluoroscopy	ABMS approach without fluoroscopy	ABMS approach with fluoroscopy	Direct anterior approach with fluoroscopy	*P*-value
Postoperative interteardrop LLD (mm)	5.1 ± 4.5	4.8 ± 3.7	3.4 ± 2.5	3.8 ± 3.1	**<.01**
Patients with LLD >5 mm (n, %)	37 (37.0)	41 (41.0)	23 (23.0)	31 (31.0)	**.04**
Patients with LLD >10 mm (n, %)	15 (15.0)	10 (10.0)	2 (2.0)	6 (6.0)	**<.01**
Patients with LLD >15 mm (n, %)	7 (7.0)	1 (1.0)	0 (0.0)	0 (0.0)	**<.01**

ANOVA showing significance.
Bold value indicates significance at $P < .05$.

Table 3
Post-hoc Tukey test for postoperative LLD.

Comparison	*P*-value
Posterior approach W/O fluoroscopy vs ABMS approach W/O fluoroscopy	.93
Posterior approach W/O fluoroscopy vs ABMS approach W/ fluoroscopy	**<.01**[a]
Posterior approach W/O fluoroscopy vs direct anterior approach W/ fluoroscopy	.06
ABMS approach W/O fluoroscopy vs ABMS approach W/ fluoroscopy	**.03**[a]
ABMS approach W/O fluoroscopy vs direct anterior approach W/ fluoroscopy	.21
ABMS approach W/ fluoroscopy vs direct anterior approach W/ fluoroscopy	.85

W/O, without; W/, with.
Bold value indicates significance at $P < .05$.
[a] Denotes significance at $P < .05$.

positioning the extent of soft tissue disruption will impact the lengthening required to achieve stability. It is possible that future improvements in robotic surgery may impact the incidence of LLD via posterior approach. Robotics have become increasingly utilized in an attempt to improve component positioning and lower rates of dislocation and instability [14]

This study has several limitations. As noted, different approaches involve different soft tissue releases that may alter both intraoperative stability and the surgeon's ability to evaluate LLD intraoperatively. Notably, our analysis showed no difference in LLD when looking at the ABMS and posterolateral approaches without fluoroscopy. Additionally, technique-specific differences may influence our results since a small number of surgeons are included in this study and the cohorts were not equally distributed among the surgeons. Also, as a radiographic study only, this study did not take into account any other pre-existing differences in femur or tibia length among the patient cohorts, possibly further contributing to skeletal leg length differences. Additionally worthy of mention, fluoroscopy can be misleading relative to an alternative of intraoperative plain radiography, which, despite its potentially increased difficulty of use, may produce higher quality images and ultimately reduce radiation exposure.[15]. And finally, pelvic obliquity and scoliotic deformities could have also contributed to apparent leg length discrepancies, further complicating the outcomes.

Table 4
Post-hoc chi-square test for proportion of patients with LLD >5 mm and >10 mm.

Comparison	*P*-value
>5 mm	
Posterior approach W/O fluoroscopy vs ABMS approach W/O fluoroscopy	.56
Posterior approach W/O fluoroscopy vs ABMS approach W/ fluoroscopy	.03
Posterior approach W/O fluoroscopy vs direct anterior approach W/ fluoroscopy	.37
ABMS approach W/O fluoroscopy vs ABMS approach W/ fluoroscopy	**<.008**[a]
ABMS approach W/O fluoroscopy vs direct anterior approach W/ fluoroscopy	.14
ABMS approach W/ fluoroscopy vs direct anterior approach W/ fluoroscopy	.20
>10 mm	
Posterior approach W/O fluoroscopy vs ABMS approach W/O fluoroscopy	.29
Posterior approach W/O fluoroscopy vs ABMS approach W/ fluoroscopy	**<.008**[a]
Posterior approach W/O fluoroscopy vs direct anterior approach W/ fluoroscopy	.04
ABMS approach W/O fluoroscopy vs ABMS approach W/ fluoroscopy	.02
ABMS approach W/O fluoroscopy vs direct anterior approach W/ fluoroscopy	.30
ABMS approach W/ fluoroscopy vs direct anterior approach W/ fluoroscopy	.15

W/O, without; W/, with.
Bonferroni correction applied identifies $P \leq .008$ as significant. Bold value indicates significance at $P < .05$.
[a] Denotes significance at $P \leq .008$.

Conclusions

We found that intraoperative fluoroscopy decreases LLDs in THA. Its use appears to decrease both total LLDs as well as large (>10 mm) LLDs. The use of intraoperative fluoroscopy is an important aid in evaluating leg lengths during THA.

Conflicts of interest

H. J. Cooper is a speaker bureau of 3M; is a paid consultant for 3M, Canary, DePuy, Polaris, and Zimmer-Biomet; has stock options in Polaris; receives research support from Smith & Nephew; is an editorial board member of Journal of Bone and Joint Surgery-American; and is a board/committee member of AAOS and Eastern Orthopaedic Association. J. A. Geller receives royalties from Smith & Nephew; is a speaker bureau of Smith & Nephew; is a paid consultant for Nimble Health and Smith & Nephew; has stock options in Zimmer; receives research support from Orthopaedic Scientific Research Foundation, OrthoSensor, and Smith & Nephew; and is an editorial board member of Clinical Orthopaedics and Related Research, Journal of Arthroplasty, and Journal of Bone and Joint Surgery-British. R. P. Shah is a paid consultant for Link Orthopaedics, Monogram, and Zimmer; is an unpaid consultant for OnPoint; has stock options in Parvizi Surgical Innovations; and is a board/committee member of the American Association of Hip and Knee Surgeons and the U.S. Food and Drug Administration. All other authors declare no potential conflicts of interest.

For full disclosure statements refer to https://doi.org/10.1016/j.artd.2024.101492.

CRediT authorship contribution statement

Christopher L. Blum: Writing – original draft, Investigation, Formal analysis, Data curation. **Andrew J. Luzzi:** Writing – original draft, Investigation, Formal analysis, Data curation. **Jeremy S. Frederick:** Writing – original draft, Investigation, Formal analysis, Data curation. **H. John Cooper:** Writing – review & editing, Validation, Supervision, Project administration, Investigation. **Roshan P. Shah:** Writing – review & editing, Validation, Supervision, Project administration, Investigation. **Jakub Tatka:** Supervision, Project administration, Investigation. **Jeffrey A. Geller:** Writing – review & editing, Validation, Supervision, Project administration, Investigation, Conceptualization. **Carl L. Herndon:** Supervision, Project administration, Investigation.

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