Arthroplasty Today 22 (2023) 101154

Contents lists available at ScienceDirect

Arthroplasty Today

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

Original Research

Accuracy of Leg Length and Hip Offset Measurements Using a Fluoroscopic Grid During Anterior Approach Total Hip Arthroplasty

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A R T I C L E I N F O

Article history:
Received 28 February 2023
Accepted 8 May 2023
Available online xxx

Keywords:
Total hip arthroplasty
Grid
Limb length
Hip offset
Discrepancy

A B S T R A C T

Background: Minimizing leg length (LLD) and hip offset (OD) discrepancies is critical for tissue tension and implant longevity in total hip arthroplasty (THA). The direct anterior approach (DAA) helps surgeons recreate these values under fluoroscopy. Several methods to accomplish this have been described, with no consensus on which is superior. This study evaluated the ability to minimize LLD and OD using a surgeon-controlled, adjustable fluoroscopic grid. We hypothesized that this tool would recreate parameters to within 10 mm of the contralateral side.
Methods: One hundred eleven primary THAs performed with an adjustable radiopaque grid to equalize leg length and hip offset were retrospectively reviewed. These values were measured on postoperative radiographs and compared to the contralateral hip. Patients were excluded if they had inadequate imaging, revision arthroplasty, preexisting deformities, or underwent approaches other than DAA.
Results: Mean age was 59.1 ± 11.1 years, 63.1% of patients were female, and average body mass index was 27.8 ± 7.0. Mean LLD was 3.7 ± 3.0 mm, while mean OD was 4.6 ± 3.6 mm. 95.5% of hips showed LLD < 10 mm, while 93.7% of hips had OD < 10 mm. Furthermore, 76.6% of hips had LLD < 5 mm, while 62.2% of hips had OD < 5 mm.
Conclusions: The described technique restored limb length and hip offset during DAA THA. This technique yields consistent results and offers an inexpensive alternative to costly digital software and more cumbersome fixed grid systems.

Introduction

Total hip arthroplasty (THA) is a reliable treatment for end-stage degenerative disease of the hip joint as well as displaced femoral neck fractures. It is a cost-effective procedure demonstrating consistent improvement in pain scores, patient-reported outcomes, and quality of life [1,2]. Its success is reflected in its increasing incidence, with recent data projecting a 71% increase to 635,000 surgeries annually in 2030 [3]. A crucial goal in THA is to properly position the femoral and acetabular components when reestablishing limb length and hip offset, 2 parameters that directly influence soft tissue tension, implant longevity, and patient satisfaction.

Limb length (LLD) and hip offset discrepancies (OD) are associated with prosthetic dislocations, increased wear rates, and decreased patient satisfaction [4,5]. Since its introduction, the direct anterior approach (DAA) for THA has grown in popularity and has been shown to be associated with lower pain severity, lower narcotic usage, and improved hip function through 90 days [6,7]. Many advocates of DAA support the use of intraoperative fluoroscopy (IF) to guide component positioning. While a number of methods using IF to reestablish leg length and hip offset have been described, there is no clear distinction as to which method is superior [8].

This study sought to evaluate the effect of a reusable, freely adjustable radiopaque grid on restoration of leg length and hip offset while performing DAA using IF. We hypothesized that using this convenient tool would enable the surgeon to consistently recreate these parameters to within 10 mm of the contralateral side without the use of preoperative or intraoperative digital templating.

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https://doi.org/10.1016/j.artd.2023.101154

Material and methods

From July 2015 through February 2020, 2 investigators retrospectively reviewed 145 primary DAA total hip arthroplasties performed by the senior author at a single institution. In each surgery, the senior author utilized a handheld, freely adjustable radiopaque grid under IF to help guide the restitution of leg length and hip offset. Demographic data was collected, including age, gender, body mass index (BMI), and presenting diagnosis. Presenting diagnoses included osteoarthritis, femoral neck fracture, posttraumatic arthritis, and avascular necrosis (AVN). Surgical time was also recorded. Exclusion criteria included patients without adequate preoperative and postoperative imaging for measurement, patients undergoing revision arthroplasty, patients with a preexisting congenital deformity of the hip joint, or any arthroplasty performed using approaches other than the DAA. Patients with a previous history of THA in the contralateral hip were included, assuming adequate imaging was available and no other exclusion criteria were met. Institutional review board approval was required for this study.

For the intraoperative protocol, all patients were positioned on a Hana fracture table in the supine position (Mizuho OSI, Union City, CA). A single THA system was used in all cases (Polarstem and R3 acetabular system, Smith and Nephew, Memphis, TN). During the placement of trial components, an anterior-posterior (AP) fluoroscopic image of the pelvis was obtained. This was accomplished by centering the C-arm over the pubic symphysis and adjusting tilt until the coccyx was centered 2-3 cm above the symphysis and both obturator foramen and teardrops were symmetric. Both femora were rotated until the lesser trochanters were both on profile and equal in size. The grid, composed of orthogonal vertical and horizontal lines 1 cm apart, was placed in a sterile X-ray cassette bag and held in place anterior to the pelvis by the surgeon with the C-arm lowered as far as possible. The grid was positioned to ensure vertical and horizontal reference lines bisecting the pubic symphysis and touching both acetabular teardrops, respectively (Fig. 1). Limb length was estimated by counting the number of grid boxes from the apex of the lesser trochanters to the horizontal reference line. Similarly, offset was estimated by counting the number of grid boxes from the apex of the lesser trochanters to the symphyseal vertical reference line.

All patients were seen in the clinic 2 weeks postoperatively, at which time AP radiographs of the pelvis were obtained. Similar to the technique described by Dastane et al. [9], leg length and offset of both the surgical and contralateral hips were measured using the home institution's picture archiving software (Fig. 2). For leg length, this required creating a horizontal reference line through the teardrops. From this line, the distance was measured to the apex of the lesser trochanters. Offset was determined by first establishing the femoral center of rotation. From there, 2 vertical lines were measured from the center of rotation to the medial aspect of the teardrop and to the anatomic axis of the femur. Adding these 2 distances yielded a hip offset.

Measurements were compared to the contralateral hip to determine LLD and OD. Goal LLD and OD was < 10 mm, and each THA being evaluated was considered within the respective goal or outside of it. BMI was compared in those patients with LLD < 10 mm and LLD > 10 mm as well as OD < 10 mm and OD > 10 mm. Percentage of LLD and OD less than 10 mm and less than 5 mm were calculated. Fisher's exact test was used to look for any association between LLD and OD under 10 mm and under 5 mm. Preoperative diagnoses were reviewed, and Fisher's exact test was used to check for any association between preoperative diagnoses and LLD and OD. Wilcoxon rank sum checked for differences in BMI between groups. Statistical analysis was performed using SAS software (SAS System for Windows version 9.4 or higher, Cary, NC).

Results

Of the 145 direct anterior total hip arthroplasties originally studied, 111 hips from 104 patients met the inclusion criteria. The surgery was carried out on a total of 63 right hips and 48 left hips. The mean age of patients was 59.1 ± 11.8 years, with 70 patients (63.1%) being females. The average BMI of all patients reviewed was 27.8 ± 7.0, and the average time of surgery was 126 ± 21.3 (86-187) minutes. Indications for surgery consisted of osteoarthritis (58.6% of hips), AVN (9.0% of hips), posttraumatic arthritis (7.2% of hips), and femoral neck fracture (24.3% of hips). Additionally, there was one patient with an acetabulum and femoral head fracture (0.9% of hips) (Table 1).

Mean LLD was 3.7 ± 3.0 mm, while mean hip OD was 4.6 ± 3.6 mm. A total of 95.5% of the hips produced less than 10 mm LLD, while 93.7% of the hips produced less than 10 mm OD. Furthermore, 76.6% of the hips produced LLD of less than 5 mm, while 62.2% of hips produced OD of less than 5 mm. Leg length and hip offset were also examined together. Ninety-nine out of 111 hips (89.2%) demonstrated both LLD and OD of less than 10 mm. Additionally, 52

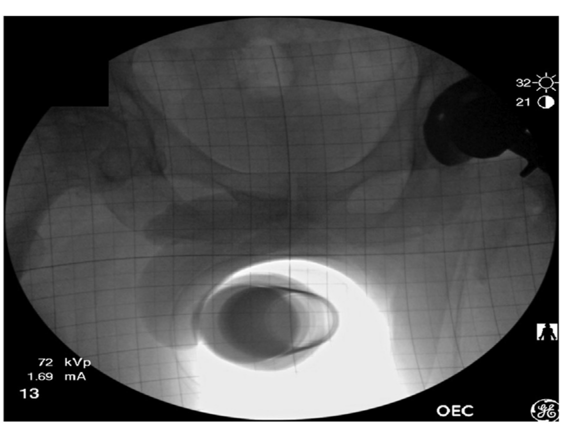

Figure 1. Intraoperative view of adjustable fluoroscopic grid for limb length analysis and hip offset with trial implants. Horizontal markings aligned with bilateral teardrops and bilateral lesser trochanters. Vertical marking aligned down the pubic symphysis.

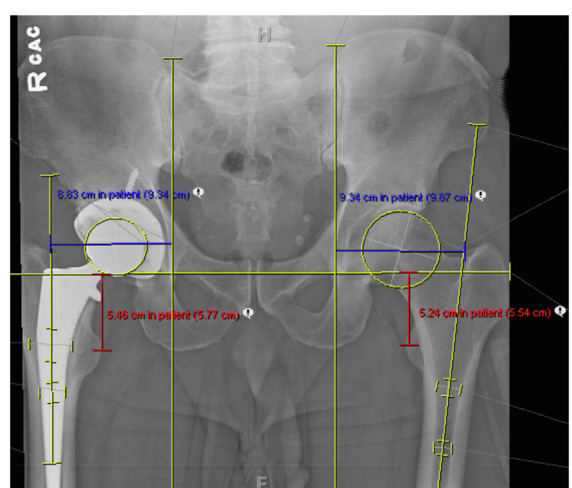

Figure 2. Postoperative assessment of hip offset (blue lines and measurements) and limb length (red lines and measurements) demonstrated.

Table 1
Demographics and preoperative diagnoses.

Variable	THA (n = 111)
Mean age (y)	59.1
Gender	70 F (63.1%)
	41 M (36.9%)
BMI (kg/m^2)	27.8
Preoperative diagnosis	
Osteoarthritis	65 (58.6%)
Avascular necrosis	10 (9.0%)
Posttraumatic arthritis	8 (7.2%)
Femoral neck fracture	27 (24.3%)
Acetabulum + femoral head fracture	1 (0.9%)

THA, total hip arthroplasty.
Data are presented as absolute number of patients with percentages in parentheses.

out of 111 hips (46.9%) demonstrated both OD and LLD of less than 5 mm (Table 2).

Regarding preoperative diagnosis, 100% (10/10) of patients with AVN, 100% (27/27) patients with femoral neck fracture, 93.8% (61/65) of patients with osteoarthritis, and 100% (8/8) patients with posttraumatic arthritis demonstrated a LLD of less than 10 mm. One hundred percent (10/10) of patients with main diagnosis of AVN, 92.6% (25/27) of patients with femoral neck fractures, 92.3% (60/65) of patients with osteoarthritis, and 87.5% (7/8) of patients with posttraumatic arthritis demonstrated an OD of less than 10 mm. When evaluating for discrepancies under 5 mm, 90.0% (9/10) of patients with AVN, 74.1% (20/27) of patients with femoral neck fracture, 73.8% (48/65) of patients with osteoarthritis, and 100% (8/8) of patients with posttraumatic arthritis demonstrated LLD less than 5 mm. Additionally, 90.0% (9/10) of patients with AVN, 59.3% (16/27) of patients with femoral neck fractures, 56.9% (37/65) of patients with osteoarthritis, and 75.0% (6/8) of patients with posttraumatic arthritis demonstrated OD of less than 5 mm.

When examining the effects of preoperative diagnosis on outcome, analysis revealed no association between preoperative diagnosis and LLD or OD under 10 mm (P = .56 and P = .65, respectively). There was also no effect of preoperative diagnosis on LLD or OD under 5 mm (P = .27 and P = .17, respectively). One patient was not included in the preoperative diagnosis analysis as they were the only patient with an acetabulum fracture, and therefore the diagnosis group was not large enough for analysis.

When considering demographics, there were no differences in BMI for LLD or OD under 10 mm (P = .34 and P = .85, respectively). This was calculated based on the Wilcoxon rank sum test.

Discussion

THA is a successful, reproducible procedure leading to relief and restoration of function in most patients with end-stage arthritis of the hip joint [10]. Optimizing outcomes and patient satisfaction after THA are, in part, dependent on restoration of leg length and hip offset. Leg length inequality after THA has been associated with numerous complications, including nerve palsies, lumbar pain, altered gait mechanics, increased cardiovascular demand, increased patient dissatisfaction, and high litigation rates [11–13]. Previous investigations have shown that LLD confirmed by radiograph often correlates with patient perception of a symptomatically longer or shorter limb, especially when the surgical limb is lengthened by 6 mm or shortened by 10 mm [14]. Likewise, it has been demonstrated that failure to restore hip offset leads to increased force requirements by the abductor musculature, increased joint reactive forces, and early component wear and failure [9,15]. Therefore, optimizing these parameters is paramount in maximizing patient satisfaction as well as implant longevity. Harnessing IF as a guide in reconstituting these crucial values remains an allure of the DAA, with some authors finding it superior for component placement compared to freehand technique [5].

Table 2
Postoperative limb length and hip offset discrepancies.

Variable			THA (n = 111)
	Mean[a] (mm)	<10 mm[b]	<5 mm[b]
LLD	3.7 (3.0)	95.5% (106)	76.6% (85)
OD	4.6 (3.6)	93.7% (104)	62.2% (69)

THA, total hip arthroplasty; LLD, leg length discrepancy; OD, hip offset discrepancy.
[a] Numbers in parentheses represent standard deviation.
[b] Numbers in parentheses represent absolute number of patients.

In this study, we found that the senior author's use of a reusable, freely adjustable radiopaque grid was able to achieve excellent results in restoring leg length and hip offset during DAA THA using IF. While the majority of patients undergoing THA have less than 10 mm of discrepancy postoperatively, previous reports note that differences of 5-10 mm after THA are generally well tolerated by patients [16–18]. In our study, we achieved a LLD ≤ 10 mm in 96% of hips and ≤ 5 mm in 77%, suggesting that most of our patients should be satisfied with their leg lengths postoperatively. Similarly, there are several publications evaluating hip offset, with most reporting ≤10 mm as the upper limit of what is desirable [5,16,19,20]. Using our described technique, we achieved an OD < 10 mm and < 5 mm in 94% and 62%, respectively. These results are consistent with previously published experiences in using IF to restore abductor tension and optimize joint reactive forces across the implant.

Since Matta and colleagues first described their original image overlay technique to estimate leg length and offset, several methods to assess and recreate these variables using IF have been evaluated [6]. Matta's original method involves obtaining and printing an AP fluoroscopic image of the unaffected hip, then overlaying this image onto a subsequent AP of the operative hip with trial implants in place. Austin and colleagues compared a variation of Matta's technique to a freely adjustable transverse rod positioned in line with both ischial tuberosities. The authors found that 85/94 of overlay THAs and 101/106 of transverse rod THAs had LLD < 10 mm (90.4% vs 95.3%, respectively, P = .179). Additionally, 84/94 of overlay THAs and 94/106 transverse rod THAs had offset discrepancies <10 mm (89.3% vs 88.7%, P = .878) [16]. The authors concluded that each technique yields excellent results in keeping both parameters within acceptable limits. Similar to the transverse rod technique, our grid system is surgeon-controlled, quickly adjustable, and does not rely on printing an image preoperatively.

This study is not the first to use a grid system while attempting to establish leg length and hip offset. Gilliland et al. retrospectively compared cohorts undergoing DAA using IF during component positioning [8]. Thirty-nine THAs had components placed using a radiopaque grid fixed to the operative table, compared to 60 THAs with components placed visually using IF alone. Using the same goal parameters of LLD and OD < 10 mm, the authors found 39/39 (100%) and 35/39 (85%) patients were within the 10 mm goal for leg length and hip offset, respectively. This was statistically significant compared to using IF alone, with 53/60 (88%) and 40/60 (67%) patients under goal for LLD and OD (P = .04 and P = .047, respectively). They additionally found that utilizing a grid led to a significant reduction in surgical time. Our results are consistent with their findings and support the conclusion that their grid improves accuracy and operative workflow. The described technique in this study may offer an additional advantage to the surgeon, as it does not require fixation to the table preoperatively, can be introduced and removed from the fluoroscopic field of view with minimal disruption to workflow, is positionally fine-tuned with maximal surgeon control intraoperatively, and incurs the only additional cost of a disposable sterile X-ray cassette bag.

Recently, digital gridding systems have been developed in attempts to mitigate against human error in component positioning that may arise from image distortion while using IF. Proponents argue the ability of a digital system to consistently acquire bony landmarks automatically could lead to decreased fluoroscopic usage during surgery, improve the accuracy of component positioning, and increase overall efficiency. Thorne and colleagues recently compared length and offset parameters in 98 DAA THAs using a digital grid system to 111 hips reconstituted using a manual grid similar to the one described in this study [20]. Despite a statistically significant decrease in global hip offset (GHO) discrepancy using the manual system (4.24 ± 2.77 mm vs 3.47 ± 2.41 mm, $P = .002$), both cohorts showed excellent postoperative LLD and GHO parameters. The manual grid system yielded an overall accuracy of 99.2% and 99.2% for achieving LLD and GHO ≤ 10 mm, whereas the digital grid system was 97.8% and 98.8%, respectively. With the apparent equivalence of both systems in accurately recreating leg length and hip offset, the commensurate results of the manual grid do invite the question of increased cost, increased time for templating, and the added burden of introducing a software system into the surgical workflow.

Strengths of our study include incorporation of a single experienced surgeon's patient cohort at a high-volume institution. Additionally, we used a single THA system. These factors help minimize interobserver variability in surgical technique, use of fluoroscopy in obtaining quality imaging, positioning of the grid, and subtle differences in arthroplasty systems that could theoretically affect measurement of LLD and OD.

Limitations of our study include its retrospective design, lack of control group, and the inherent human error associated with freely positioning any measurement tool. In addition, due to an interruption in clinical follow-up secondary to the COVID-19 pandemic, patient-reported outcomes were unable to be consistently obtained and were therefore not included in this study. Admittedly, this technique also only addresses 2 parameters under consideration during component placement in THA. Recreation of hip offset is critical to restoring abductor function, minimizing joint reactive forces, and improving stability. However, both acetabular cup abduction and version angles have been shown to affect range of motion, risk of impingement, and risk of dislocation [21]. Thus, the importance of accurate positioning in all planes in addition to an appropriate offset should be stressed to maximize stability [21]. These were not addressed in the current study, as the grid does little to help guide the version and does not offer a reference line for abduction angle. Indeed, Matta et al. showed excellent results in placing the cup within the established "safe zone" of 40 ± 10 degrees during DAA, and this has been recreated using a radiopaque grid in subsequent studies [6,8,19]. Further considerations for our grid could include modifying it to include a reference line reflecting the abduction angle goals commonly used.

Conclusions

Overall, the technique we describe is simple, reproducible, and accurate in reconstituting leg length and hip offset in the setting of DAA THA using IF. Our results are consistent with other previously published reports and offer a surgeon-controlled, cost-effective, and nimble method of intraoperatively assessing these critical parameters while precluding the need for expensive digital overlay software.

Conflicts of interest

The authors declare there are no conflicts of interest.

For full disclosure statements refer to https://doi.org/10.1016/j.artd.2023.101154.

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