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Radiographic measurement of leg-length change in the nonoperative leg during total hip arthroplasty: a potential indicator of imaging error?

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Abstract

Background: Anteroposterior (AP) pelvic radiographs are subject to errors that may cause measurement inaccuracy in total hip arthroplasty (THA). Such errors may be detected by measuring pre- to postoperative leg-length changes in the nonoperative leg, which experiences no physical changes during THA.

Methods: From AP pelvic radiographs, we measured pre- to postoperative leg-length changes (LLC) in the nonoperative legs of 67 patients who underwent primary THA using the trans-ischial line method.

Results: An LLC of 0 mm was observed in the nonoperative leg in only 14 cases (21%). A LLC $\geqslant$ 2 mm was observed in 27% (18/67) of cases, including 13% (9/67) with LLC $\geqslant$ 3 mm and 6% (4/67) with LLC $\geqslant$ 4 mm. A post-hoc analysis used a validated method to measure change in pelvic tilt between pre- and postoperative images and found that changes in pelvic tilt $\geqslant 4°$ in the anterior and posterior directions created apparent lengthening (2.0 ± 1.4 mm, $p < 0.001$ vs. 0–3° of tilt) and shortening (−2.1 ± 1.6 mm, $p < 0.001$ vs. 0–3° of tilt) of the nonoperative leg, respectively.

Conclusions: The current study provides evidence of measurement errors in leg length using AP pelvic radiographs following THA. Changes in pelvic tilt may be in part responsible for these errors, with the direction of change in pelvic tilt influencing the apparent lengthening or shortening of the lower limb. Ultimately, these findings may influence the radiographic measurement and interpretation of leg-length changes following THA.

Keywords

Leg-length change, total hip arthroplasty, radiographs, pelvic tilt, radiographic error

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Introduction

In total hip arthroplasty (THA), maximising component accuracy is important in ensuring long-term successful outcomes.[1–3] Preoperative planning and postoperative evaluation of acetabular component position and changes in leg length are key steps in this process, as is the increasing use of advanced technologies such as intraoperative computer-assisted navigation as an augment to standard practices. Given the consequences of component malalignment, i.e., instability, loosening, dislocation and revision surgery,[2,4,5] it is hoped that with these combined efforts to improve the accuracy of component positioning, outcomes in THA will continue to improve. The challenge, however, is that the evaluation of these various methods of improving accuracy and precision rely largely on plain film radiographs, an imaging modality known to be associated with several potential sources of error.[6–8] As such, the evaluation of component placement accuracy in THA – and the effectiveness of technologies such as navigation or

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patient-specific instrumentation (PSI) designed to improve component positioning accuracy – may be compromised by the accuracy limitations of the imaging itself.

Errors in patient positioning on radiographs are common, with a recent study suggesting that a perfectly aligned AP pelvic radiograph is only achieved between 30 and 56% of cases.[9] As a result, a substantial portion of imaging used to assess treatment success in THA is subject to error, which thus impacts the ability to accurately evaluate THA component position and outcome. This is especially pertinent in evaluating leg-length outcomes in THA, as errors such as rotation, flexion, adduction or abduction of the femur are known to alter the projection of landmarks onto the image and therefore create measurement errors.[10] This has a 2-fold impact on THA. It certainly impacts the ability to assess postoperative leg-length discrepancy (LLD), a critical aspect of THA, given the role of LLD in litigation.[11–13] Also of concern, however, is the impact of imaging error on the assessment of pre- to postoperative leg-length change (LLC). As these are central areas where navigation or PSI are purported to provide benefit, the potential for imaging error to adversely affect the evaluation of such technologies is very pertinent.

Evaluation of LLC in the operative leg is key to ensuring positive outcomes in THA, but this measurement, when applied to the nonoperative leg, provides a unique opportunity for evaluation of overall radiograph accuracy. Because the nonoperative leg undergoes no physical change, there should be no change between its pre- and postoperative leg-length measurements. Any observed changes would, therefore, be attributable to radiographic error (positioning, distortion, etc.) and would thus impact measurements of the operative leg as well. Quantifying the magnitude and prevalence of this type of error would provide important information on the expected measurement error when assessing postoperative outcomes in THA. To investigate this, we measured the changes in leg length in the nonoperative leg of patients who underwent THA. Our hypothesis was that in a minority of cases, there would be a significant difference between pre- and postoperative leg-length measurements in the nonoperative legs of THA patients.

Methods

Study design and primary outcome

This study was a retrospective analysis of anonymised pre- and postoperative AP pelvic radiographs of patients who underwent primary or revision THA between February 2016 and November 2017. Institutional ethical approval was received prior to image analysis (Veritas IRB, Montreal, Canada) and patients provided informed consent for the inclusion of their de-identified data and/or images in this study. The primary outcome for this study was the pre- to postoperative leg-length change (LLC) in the nonoperative leg as measured from radiographs. Standing images were used for both pre- and postoperative assessments, with postoperative imaging occurring at the 2-week follow-up visit. Radiographs were excluded from the analysis if any of the required landmarks (e.g. ischial tuberosities, lesser trochanters, etc.) were not visible on both pre- and postoperative images.

Measurement

All measurements were performed using TraumaCad software (version 2.5, BrainLab, Chicago, IL, USA). Measurements were performed by 2 trained reviewers, one an experienced clinician and the other a trainee, both of whom were trained in the evaluation of radiographic outcomes in hip arthroplasty. Leg length was measured in millimetres (mm) as the perpendicular distance between the trans-ischial line and the most medial aspect of the lesser trochanter. LLC was defined as the difference between the pre- and postoperative leg lengths. Measurements were repeated in triplicate and averaged to produce final measurements, with raw measurements rounded to the nearest whole number and the average calculated to 1 decimal point. Scaling of pre- and postoperative radiographs was performed by utilising a 25-mm scaling ball. In cases where no scaling ball was present, we used the known diameter of the implanted femoral head to scale the postoperative image. The nonoperative femoral head on the postoperative image was then measured to provide a reference measurement, which was then used to scale the preoperative image.

Data analysis

Data are presented as the absolute mean ± standard deviation. Mean values were compared via Student's *t*-test, with alpha set *a priori* at 0.05. Proportionality was evaluated using chi-square or Fisher's exact test, as appropriate based on group size. Intra- and inter-rater reliability were evaluated using the intraclass correlation coefficient (ICC).

Post-hoc pelvic tilt analysis

Following our initial analysis of LLC, we noted significant variability in pelvic tilt on the analysed images. As such, we performed a post-hoc measurement of pelvic tilt for each image, using a validated method,[14] to determine if pelvic tilt was correlated with LLC. Tilt measurements were completed in triplicate by 2 reviewers and the results averaged to determine both the magnitude and direction of tilt on individual radiographs but also the change in tilt noted between pre- and postoperative images for each participant. LLC was stratified according to pre- to postoperative absolute change in pelvic tilt of 0–3°, 4–6°, and ⩾7°

and differences in LLC between the groups were analysed using the Student's *t*-test. The effect of the direction of change in pelvic tilt (anterior/posterior) on LLC was also quantified with data presented as mean LLC ± standard deviation (SD).

Results

Leg-length change

A total of 134 radiographs were measured, representing 67 THA procedures. The nonoperative leg was the left leg in 57% of cases (38/67). The patient was female in 51% of cases (34/67). Agreement between raters was high. Intra-rater reliability for Rater 1 was 0.90 for leg-length measurements and 0.98 for pelvic tilt measurements, while that for Rater 2 was 0.89 and 0.93, respectively. Inter-rater reliability also showed strong consistency between raters (leg length: 0.89; pelvic tilt: 0.97).

The nonoperative leg was measured as unchanged (i.e., LLC = 0) in only 14 cases (21%). In 79% of cases (53/67), a LLC was measured in the nonoperative leg, which presented as a lengthening of the nonoperative leg in 40% of cases (27/67) and a shortening in 39% of cases (26/67). The absolute mean LLC in the nonoperative leg for the entire cohort was 1.3 ± 1.4 mm (range 0.0–6.3 mm). The majority of LLC were <2 mm in magnitude (49/67, 73%), although in 27% of cases (18/67), a LLC in the nonoperative leg of >2 mm was noted. Of these cases, 13% (n = 9) were measured at ⩾3 mm and 6% (n = 4) were ⩾4 mm (Table 1).

Pelvic tilt

The mean change in pelvic tilt between pre- and postoperative images across the entire cohort was −0.5° ± 4.8°; however, the absolute mean change was 3.8° ± 2.9° and a wide range of tilt measurements was observed (range −9.7–9.3°). In 48% of cases (32/67), the change in pelvic tilt indicated movement in the anterior direction, with a mean positive tilt of 3.7° ± 2.8° (range: 0.2°–9.3°) measured in this subgroup. In 45% of cases (30/67), the change in pelvic tilt indicated posterior movement, with a mean change of −4.5° ± 2.9° (range −0.5°–−9.7°). In only five cases (7%) was there no measured change in pelvic tilt.

We observed a linear relationship between the magnitude and direction of pelvic tilt and the resulting change in leg length (R^2 = 0.73), represented by the equation:

$Y = 0.33x + 0.05$, where y is the change in leg length and x is the pelvic tilt (Figure 1).

The magnitude and direction of pelvic tilt both contributed to apparent changes in leg length, with anterior pelvic tilt resulting in an apparent lengthening of the nonoperative leg, while posterior tilt resulted in an apparent shortening of the leg. A change in pelvic tilt of ⩽3° resulted in minimal change in apparent leg length (absolute mean = 0.6 ± 0.6 mm); however, when pelvic tilt was between 4–6°, there were significant increases in LLC (absolute mean LLC: 1.6 ± 1.0 mm; $p < 0.001$ vs. 0–3°). As pelvic tilt increased to ⩾7°, the apparent LLC likewise increased significantly (absolute mean LLC: 2.8 ± 1.7 mm, $p < 0.001$ vs. 0–3°; $p = 0.027$ vs. 4–6°) (Figure 2). The direction of tilt did not affect the magnitude of this relationship, only the direction, as noted above.

Table 1. Proportional analysis of absolute mean LLC in the nonoperative leg measured from pre- and postoperative AP pelvic radiographs of 67 THA patients.

Absolute mean LLC	Prevalence (%, *n*/*N*)
<1 mm	49.3, 33/67
1–2 mm	23.9, 16/67
2–3 mm	13.4, 9/67
3–4 mm	7.5, 5/67
⩾4 mm	6.0, 4/67

Discussion

Preoperative planning and postoperative evaluation of component position in THA largely utilise plain film radiographs as their main imaging modality. There is ample evidence, however, to suggest that error associated with radiographs – due either to improper patient positioning or artifact – can contribute to inaccuracy when measuring component orientation and/or change in leg length. We measured the change in leg length in the nonoperative legs of patients who underwent THA in order to determine the magnitude and prevalence of error associated with imaging measurements, based on the assumption that no changes should be present in the nonoperative leg length in THA patients. We found that in four of five cases, there was a measurable change in leg length in the nonoperative leg. In over one in four cases (27%), that change was >2 mm and in one in eight cases, it exceeded 3 mm. We further noted that these discrepancies were highly correlated with pelvic tilt, resulting in apparent lengthening and shortening of the lower limb with anterior and posterior tilt, respectively.

Tilt or rotation of the pelvis on imaging is known to affect the measurement of acetabular component position, predominantly anteversion,[15–18] while adduction/abduction or external/internal rotation of the femur can significantly affect the accurate measurement of leg length.[10] Importantly though, our study demonstrated that pelvic tilt can also adversely affect the measurement accuracy of pre- to postoperative leg-length change. In the context of achieving preoperative targets for leg lengthening, this is an important finding. While evaluation of leg-length discrepancy (i.e., operative vs. nonoperative leg) is important

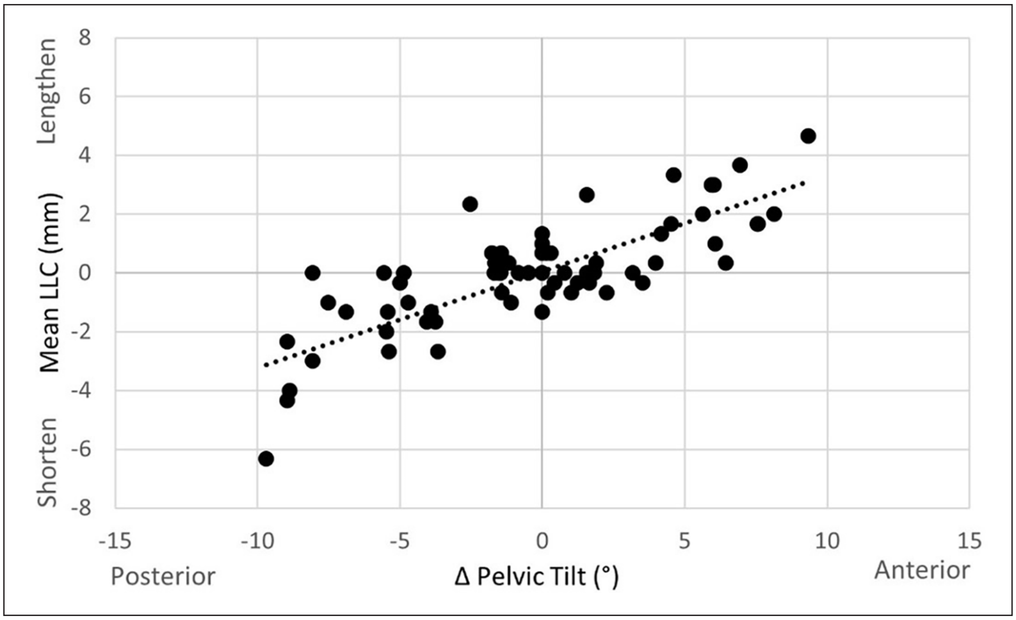

Figure 1. Direction of change in pelvic tilt (anterior/posterior) influences direction of apparent LLC (lengthen/shorten) in the nonoperative leg. A directional, linear relationship was noted between pelvic tilt and apparent change in nonoperative leg length, defined by the equation $y = 0.33x + 0.05$ ($R^2 = 0.73$).

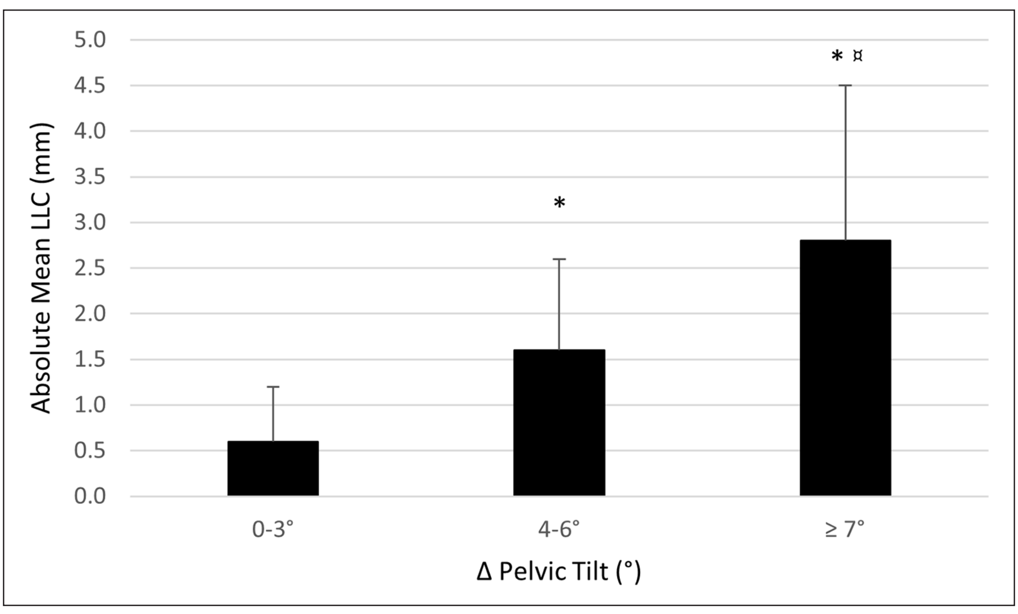

Figure 2. Change in pelvic tilt from preoperative to postoperative radiographs influences the absolute mean LLC (±standard deviation) in the nonoperative leg.
*Significant difference compared to 0–3°, $p < 0.001$. ¤Significant difference compared to 4–6°. $p < 0.05$.

with regards to patient satisfaction,[13,19,20] evaluation of pre- to postoperative change assesses the ability of the surgeon to achieve a preoperative target, and further evaluates the ability of assistive devices (robotics, navigation) to help reach these targets. Any unaccounted-for error will therefore compromise the ability to execute the preoperative plan.

Our study found an association between changes in pelvic tilt in the pre- and postoperative radiographs and the measured leg-length change in the nonoperative leg. When change in pelvic tilt was minimal (i.e., ⩽3°), there was minor error in the measurement of leg length; however, with larger changes in pelvic tilt (i.e., ⩾4°) the error in leg-length measurement increased significantly. This observed relationship between change in pelvic tilt and leg-length measurement was predictable, as changes in pelvic tilt in the anterior and posterior directions consistently created apparent lengthening and shortening of the nonoperative leg, respectively. This relationship is important as pelvic tilt can vary widely between radiographs of the same individual; for example, radiographic changes in pelvic tilt before and after THA have been reported to range from −26° to 15°.[21] As such, the presence of this amount and type of error and its consequent effect on leg-length measurements, while itself is not sufficient to surpass the threshold where patients are known to perceive leg-length inequalities,[19] nonetheless threatens to nullify any benefits gained from the careful planning of preoperative targets, or the use of assistive technologies to achieve these targets if their value cannot be accurately evaluated. The computer-assisted navigation and robotics systems used to improve component positioning can be associated with error of up to 3–5 mm.[22–25] If error also exists due to pre- to postoperative inconsistencies in patient positioning on imaging, as our findings suggest, a heightened awareness of this source of error should accompany postoperative radiographic evaluation. Standardisation of imaging protocols (i.e., use of a footboard) to avoid these inconsistencies may be a valuable method for minimising these problems moving forward. *In lieu* of that, though, it may prove prudent to measure both the operative and nonoperative legs when assessing postoperative LLC, in order to identify potential error caused by inconsistencies in patient positioning between pre- and postoperative imaging. This cross-check may prove valuable in ensuring that target lengthening is achieved and not misinterpreted due to measurement and/or imaging error.

Our study is not without limitations. The use of AP pelvic views (instead of full-leg views) may be considered a limitation; however, AP pelvic views are the standard of care for THA evaluation and as the THA procedure affects only the proximal femur, the affected region is adequately visible in the AP pelvic view.[26] Also, our study did not consider error caused by inconsistencies in abduction/adduction or internal/external rotation of the femurs on pre- and postoperative imaging, inconsistencies that may be magnified by our use of the trans-ischial line as our horizontal reference line. Future studies should also consider this factor, as these positioning inconsistencies can change the relative position or profile of the lesser trochanter and therefore affect LLC measurements. Finally, our relatively small sample size may also be limiting, although the images used are representative of the standard of care imaging for THA and therefore provide real-world evidence of measurement error. Overall, our results are generalisable and provide important evidence that pelvic tilt correction methods may be useful in identifying and interpreting potential measurement errors.[14]

Conclusion

In our study of pre- to postoperative LLC in the nonoperative leg of THA patients, we found that important errors occur present when measuring leg length using AP pelvic radiographs following THA. We observed that one in four cases had errors in leg-length measurement ⩾ 2 mm, and one in eight cases had errors ⩾ 3 mm. Our data indicate that changes in pelvic tilt may be in part responsible for these errors and that the direction of change in pelvic tilt influences the apparent lengthening or shortening of the lower limb. Ultimately, these findings may influence the interpretation of leg-length changes following THA. While this may not be applicable to postoperative evaluation of operative versus nonoperative leg-length discrepancy, in cases where evaluation of the pre- to postoperative change in leg length is desired – such as with the use of intraoperative technologies including robotics or navigation – assessment of pelvic tilt change to detect potential imaging error is recommended. Further investigation into the relationship between changes in pelvic tilt and other possible sources of error in the measurement of leg length is warranted.

Declaration of conflicting interests

The author(s) declared the following potential conflicts of interest with respect to the research, authorship, and/or publication of this article: KAF: and JMM: are employees of and hold stock options with Intellijoint Surgical.
WGP: has received consultancy fees from and holds stocks options with Intellijoint Surgical.

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