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Leg length discrepancy assessment in total hip arthroplasty: is a pelvic radiograph sufficient?

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Aims

Leg length discrepancy (LLD) is a common pre- and postoperative issue in total hip arthroplasty (THA) patients. The conventional technique for measuring LLD has historically been on a non-weightbearing anteroposterior pelvic radiograph; however, this does not capture many potential sources of LLD. The aim of this study was to determine if long-limb EOS radiology can provide a more reproducible and holistic measurement of LLD.

Methods

In all, 93 patients who underwent a THA received a standardized preoperative EOS scan, anteroposterior (AP) radiograph, and clinical LLD assessment. Overall, 13 measurements were taken along both anatomical and functional axes and measured twice by an orthopaedic fellow and surgical planning engineer to calculate intraoperator reproducibility and correlations between measurements.

Results

Strong correlations were observed for all EOS measurements ($r_s > 0.9$). The strongest correlation with AP radiograph (inter-teardrop line) was observed for functional-ASIS-to-floor (functional) ($r_s = 0.57$), much weaker than the correlations between EOS measurements. ASIS-to-ankle measurements exhibited a high correlation to other linear measurements and the highest ICC ($r_s = 0.97$). Using anterior superior iliac spine (ASIS)-to-ankle, 33% of patients had an absolute LLD of greater than 10 mm, which was statistically different from the inter-teardrop LLD measurement ($p < 0.005$).

Discussion

We found that the conventional measurement of LLD on AP pelvic radiograph does not correlate well with long leg measurements and may not provide a true appreciation of LLD. ASIS-to-ankle demonstrated improved detection of potential LLD than other EOS and radiograph measurements. Full length, functional imaging methods may become the new gold standard to measure LLD.

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Keywords: total hip arthroplasty, leg length discrepancy, LLD, EOS, pelvic radiograph, preoperative planning

Introduction

Leg length discrepancy (LLD) is a common pre- and postoperative issue in total hip arthroplasty (THA) patients. Significant postoperative LLD occurs in up to 32% of patients after THA,[1] with consequences including dislocation,[2,3] abnormal gait,[4] sciatica and back pain,[5-7] patient dissatisfaction,[8] and litigation.[9] As acknowledged by Hofman et al,[9] the main causes of LLD after THA are insufficient preoperative planning and errors in surgical execution. Despite a wealth of literature on the subject, several key questions remain over which variables to measure and how to best measure them.

Broadly, LLD can be measured clinically or radiographically.[10] Clinical measurements include block measurements and tape measurements between anatomical surface landmarks, whereas radiological measurements include plain radiography and CT.[10] Studies have compared these two methods

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Table I. Summary of landmarks and axes used for our LLD measurements with their corresponding descriptions.

Landmark or axis	Type	Definition
Functional axis	Axis	Measured vertically from the superior landmark to a point level with the inferior landmark
Anatomical axis	Axis	Measured directly from landmark to landmark
Head centre	Landmark	Defined by drawing a bet-fit circle around the femoral head and taking the centre of the circle
Distal femur	Landmark	Centre of trochlea groove
Tibial eminence	Landmark	Junction of eminence (centre of tibial baseplate when a knee arthroplasty is present)
Ankle	Landmark	Cortical border of distal tibia; tibial plafond
ASIS	Landmark	Symmetrical landmarks on anterior iliac crest
Floor	Landmark	The floor; a functional measurement
Adduction	Landmark	Angle between femoral mechanical axis and the vertical axis
Obliquity	Landmark	Angle between Bi-ischial line and the horizontal

ASIS, anterior superior iliac spine; LLD, leg length discrepancy.

Table II. Summary of all measurements taken on either weightbearing anteroposterior radiograph or EOS.

Measurement	Imaging modality	Axis
Inter-teardrop to LT	WB AP radiograph	N/A
ASIS-to-ankle	EOS	Functional
ASIS-to-ankle	EOS	Anatomical
ASIS-to-floor	EOS	Functional
Head centre-to-ankle	EOS	Functional
Head centre-to-ankle	EOS	Anatomical
Head centre-to-floor	EOS	Functional
Femur length	EOS	Functional
Femur length	EOS	Anatomical
Tibia length	EOS	Functional
Tibia length	EOS	Anatomical
Hip adduction	EOS	(Angular)
Pelvic obliquity	EOS	(Angular)

EOS scans (EOS Imaging, France).
AP, anteroposterior; ASIS, anterior superior iliac spine; LT, lesser trochanter; N/A, not applicable; WB, weightbearing.

and found radiological measurements to be no more accurate than clinical measurements.[11-15]

To further complicate matters, there are also two etiologies of LLD: a 'true' LLD (tLLD) and an 'apparent' LLD (aLLD).[16] A tLLD is caused by differences in the actual lengths of bony and soft-tissue anatomy, whereas an aLLD is caused by hip/knee contractures or altered mechanics of the spine, leading the patient to perceive a difference in leg lengths while their bony and soft tissue anatomy may be equal lengths.[17] Nakanowatari et al[16] found that an aLLD is perceived by almost four times as many patients as tLLD. Similarly, in a sample of 1,114 patients, Wylde et al[18] demonstrated that 30% reported aLLD, but only 36% of these patients had a tLLD. Additionally, 17% of patients who did not perceive any LLD in fact had a tLLD.

To have a complete understanding of pre- and postoperative LLD, Sabharwal and Kumar[10] proposed that the ideal measurement for assessing LLD should have three qualities. First, accuracy; the measurement targets what is perceived by the patient (aLLD). Second, precision; the measurement has high repeatability and reproducibility. And third, affordability and availability. However, we propose a fourth quality is needed; granularity, in that the measurement can isolate the specific sources of LLD to understand the limitations of correction from surgery.

A conventional radiological technique for measuring LLD when planning a THA has been to draw a line through the inferior aspect of the teardrops on a weightbearing (WB) anteroposterior (AP) pelvic radiograph and measure the vertical distance of the most prominent point on each lesser trochanter (LT) to this inter-teardrop line[19-23] (inter-teardrop to LT). This measurement normalizes pelvic obliquity in favour of determining anatomical differences that exist at the ipsilateral and contralateral hips, such as acetabular cartilage degeneration and femoral head wear. Despite limitations, such as internal femoral rotation resulting in difficulty landmarking the lesser trochanter (LT) and magnification error,[24] this method is popular. However, it fails to capture other sources of LLD beyond the pelvis and proximal femur, including scoliosis, flexion contractures at the hip or knee, adduction contractures, anatomical variation in femoral and tibial lengths, and ankle deformities.[10] An illustration of these sources of LLD can be seen in Figure 1. Hip and knee flexion contractures may cause apparent shortening of the limb, while abduction contractures or equinus deformity of the ankle may lead to an apparent lengthening of the affected hip.[10] These factors are likely to influence a patient's perception of their LLD and an accurate assessment should include consideration of all of them. In fact, Piyakunmala and Sangkomkamhang[25] found poor agreement between radiological methods and patient perception. Therefore, it may be said that the pelvic AP radiograph has low accuracy,[25] moderate granularity, and high precision.[21]

To better capture all the possible sources of LLD, other methods of measuring LLD include long-limb imaging, such as CT scanograms,[10] and more recently long leg EOS scans (EOS Imaging, France). CT scanograms are taken while the patient is supine and can only be used to determine sources of tLLD, not aLLD. EOS produce

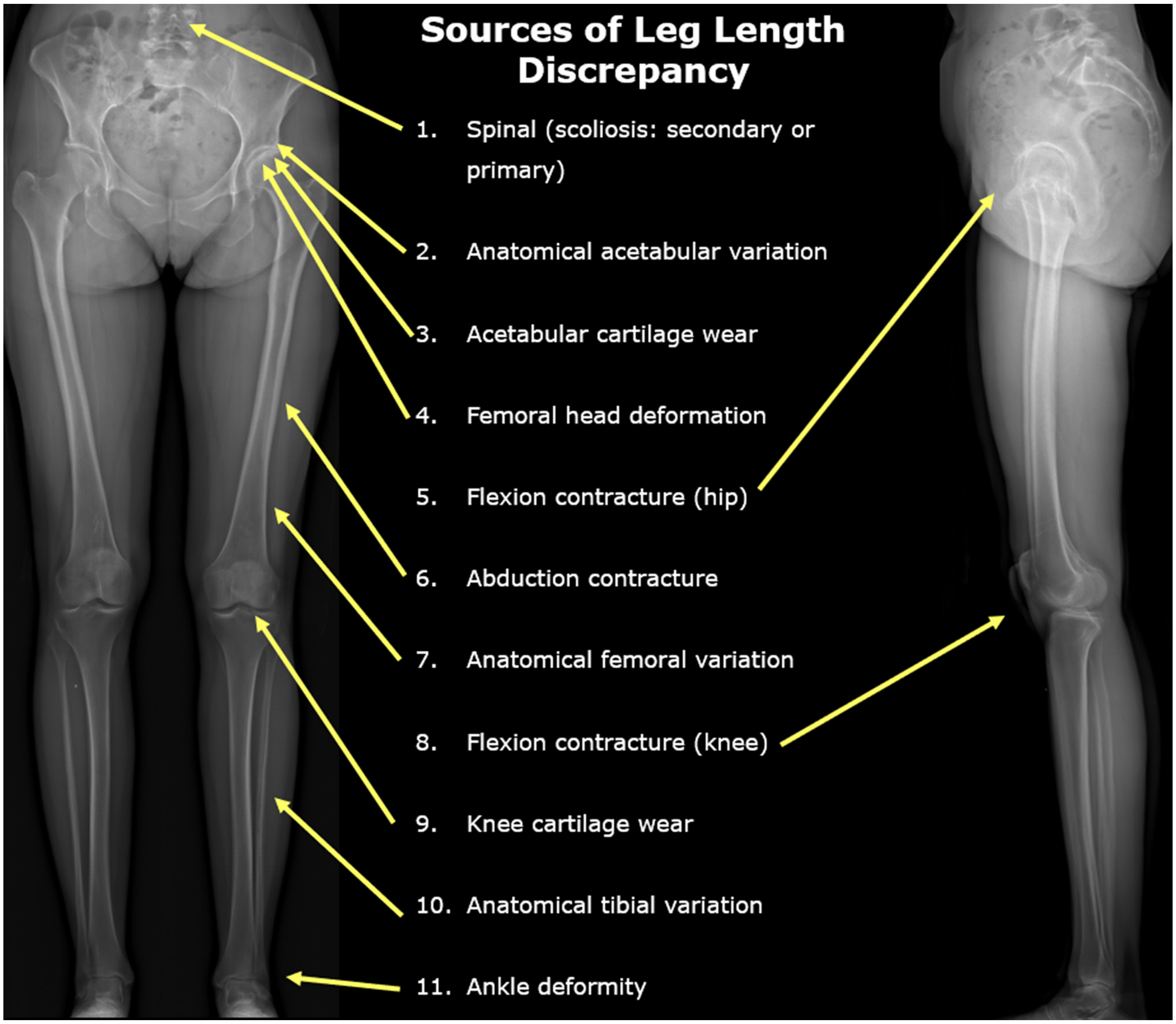

Fig. 1

Example long-limb EOS imaging to highlight the many different potential sources of leg length discrepancy.

simultaneous biplanar images of the subject with very low dose radiation,[26] no magnification error,[24] and allow 3D reconstruction.[26] This shows the full-leg functional stance of the patient in the coronal and sagittal planes and captures all potential sources of LLD (both tLLD and aLLD).

As far as the authors are aware, the only previous study to compare LLD measurements from a pelvic radiograph, such as the inter-teardrop to LT measurement, to long-limb measurements was an investigation by Tipton et al.[15] In this study, the authors concluded that LLD measurements on pelvic radiographs were significantly different to a long-limb measurement, and they did not support the use of pelvic radiographs for estimating true LLD. However, this study only investigated one measurement on the long-limb radiography, did not use EOS imaging, which has advantages over plain radiography,[24,26] and captured the pelvic radiograph measurements by simply zooming in on the long-limb radiograph, which may limit the applicability of its results due to magnification error.

Therefore, the aims of this study were two-fold. First, to assess the relationship between LLD measurements captured on EOS with the inter-teardrop measurement captured from a WB AP radiograph to determine if the WB AP measurement is reflective of the long-limb LLD. Second, to assess the repeatability and reproducibility of all measurements to understand which long-limb measurement may present as the most precise if this imaging modality was adopted. Our hypothesis was that long-leg EOS measurements would correlate well with each other, but not with the inter-teardrop measurement on WB AP radiograph.

Methods

In all, 93 consecutive patients (100 hips) underwent THA surgery from two experienced surgeons (PJY,

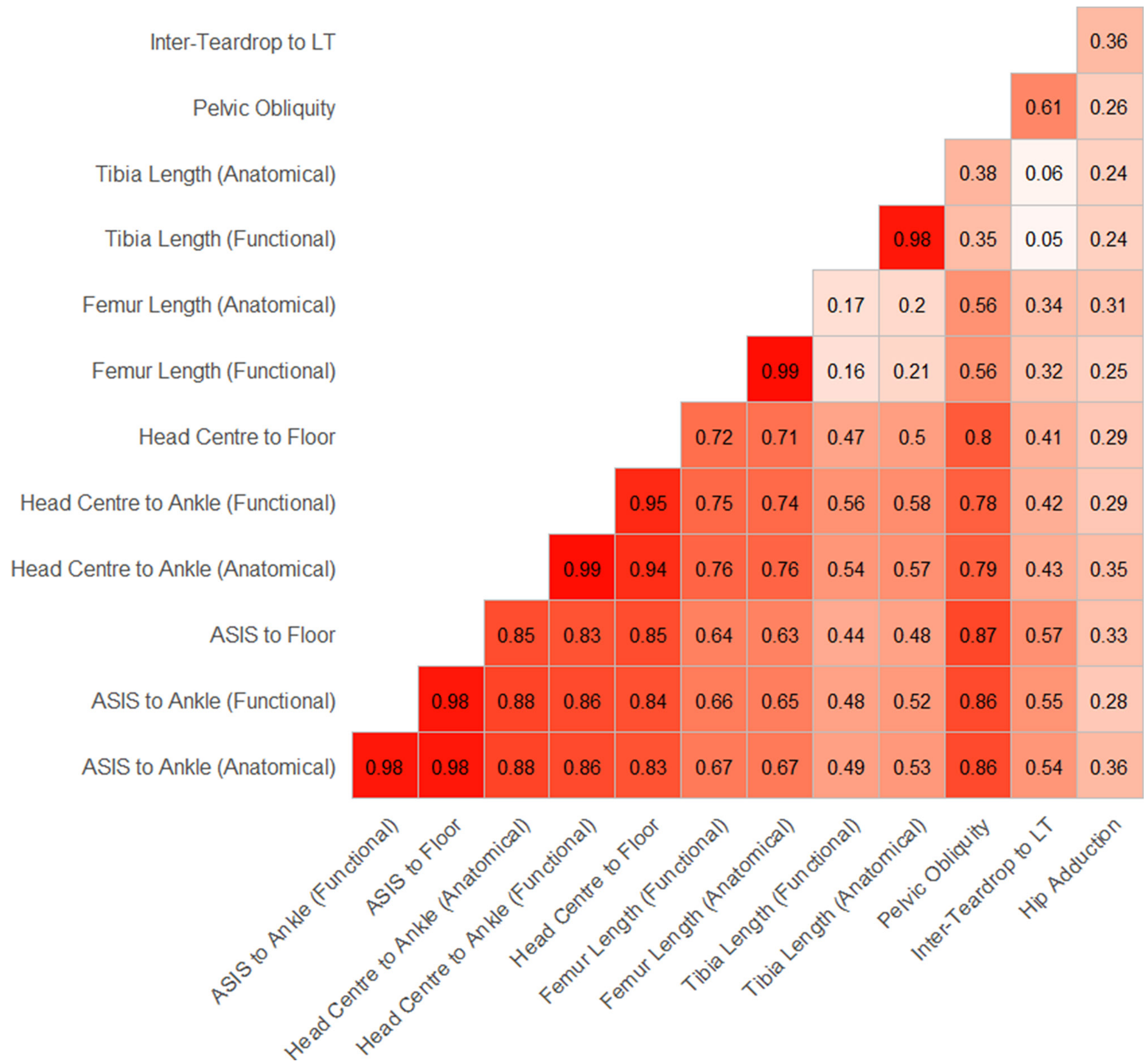

Fig. 2

Correlogram showing the linear correlation between all measurements.

CWJ) between July 2020 and August 2021. All patients underwent preoperative surgical planning by 360 Med Care, which included a standardized preoperative EOS scan and WB AP radiograph. Mean age of the patients was 69.6 years (standard deviation (SD) 9.4) and 50 patients (53%) were female. All patients received a Pinnacle (Depuy Synthes, USA) acetabular component and an S-ROM, Corail, or C-Stem (Depuy Synthes) femoral component.

A total of 13 measurements were taken, including the inter-teardrop to LT on WB AP radiograph as a reference standard, pelvic obliquity, femoral and tibial lengths, head centre-to-ankle, head centre-to-floor, anterior superior iliac spine (ASIS)-to-ankle, and ASIS-to-floor. A summary of these measurements can be found in Table I and Table II. Measurements were taken along both anatomical (limb aligned) and functional (gravity aligned) axes and on both the operative and contralateral side. Each measurement was measured twice by an orthopaedic fellow and twice by a qualified surgical planning engineer in RadiAnt DICOM Viewer v2.2.5.10715 (Medixant, Poland), with repeat measurements taken at least two weeks apart to calculate the correlations between measurements and the repeatability of measurements.

Statistical analysis. Statistical analysis was performed in R Studio v1.3.1903 (R Studio, USA). An α value of 0.05 was used to determine clinical significance. Shapiro-Wilk normality tests confirmed that not all test parameters were normally districted. Therefore, Spearman's correlations were used to assess the relationship between

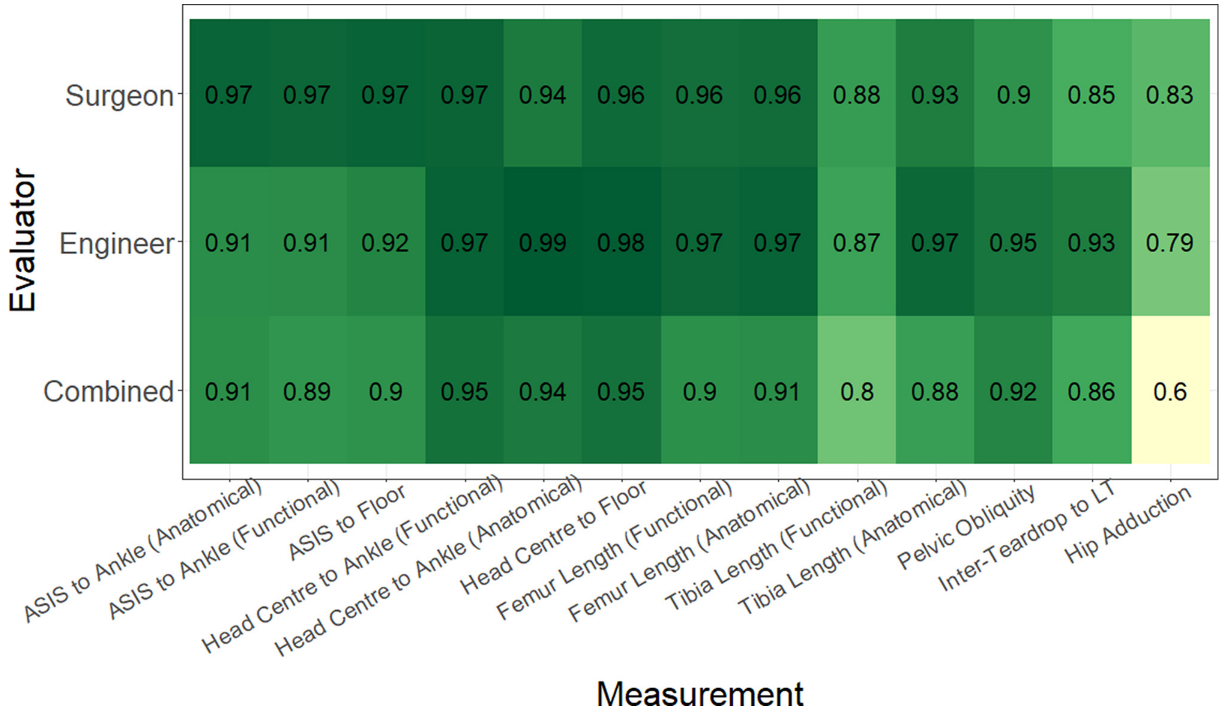

Fig. 3

Intra- and interclass correlation coefficients of all measurements.

measurements. Intraclass correlation coefficient (ICC) was used to assess the repeatability of measurements.

Ethics. This retrospective study was approved by the Bellberry Human Research Ethics Committee (study number 201203710).

Results

Spearman's correlations between all measurements can be found in the correlogram in Figure 2. ASIS and head centre referencing EOS measurements demonstrated the highest correlations with each other ($r_s > 0.9$) and other linear measurements ($r_s > 0.8$). The inter-teardrop measurement had a moderate correlation with ASIS referencing measurements ($r_s \sim 0.55$) and low correlations with other measurements ($r_s < 0.45$). Pelvic obliquity correlated well with ASIS and head centre referencing measurements ($r_s > 0.8$). Femur and tibia lengths had moderate correlations with other, but low correlations with other EOS measurements ($0.4 < r_s < 0.6$).

The most repeatable measurement was head centre-to-floor, followed by ASIS-to-ankle. However, most measurements had an ICC of > 0.9 and all non-angular measurements had an ICC > 0.8. ICC values for all measurements can be seen in Figure 3.

Mean LLD measured on the WB AP radiograph was 1.7 mm (SD 5.6), and 4.2% patients had an absolute LLD of greater than 10 mm. Mean LLD measured using head centre-to-ankle (anatomical axis) was 0.6 (SD 8.0), and 17.9% of patients had an absolute LLD of greater than 10 mm. Mean LLD measured using ASIS-to-ankle (anatomical axis) was 3.1 (SD 12.2) and 32.6% of patients had an absolute LLD of greater than 10 mm. The percentage of patients with greater than 10 mm LLD measured using these long leg measurements was statistically different from the AP inter-teardrop LLD measurement ($p < 0.005$). A spread of LLDs using different measurements along both anatomical and functional axes can be seen in Figure 4.

Discussion

LLD is a critical consideration in THA as large LLDs may lead to adverse outcomes for the patient.[2-8] Lack of clarity over the best technique of measuring and addressing LLD has led to this being one of the most widely litigated issues in orthopaedic practice.[9] Conventionally, clinicians may assess LLD radiologically on a WB AP pelvic radiograph;[19-23] however, this only captures anatomical sources of LLD at the level of the hip joint.[19] Other methods of measuring LLD include CT scanograms,[15] tape measure,[10] and block measurements,[10] but these are subject to various limitations regarding their accuracy, precision, and granularity.[10,14,20,27] Therefore, using a consecutive series of patients undergoing THA, we sought to investigate whether functional EOS imaging might provide a more complete understanding of LLD by addressing the four qualities that a LLD measurement should have accuracy, precision, affordability and availability, and granularity.

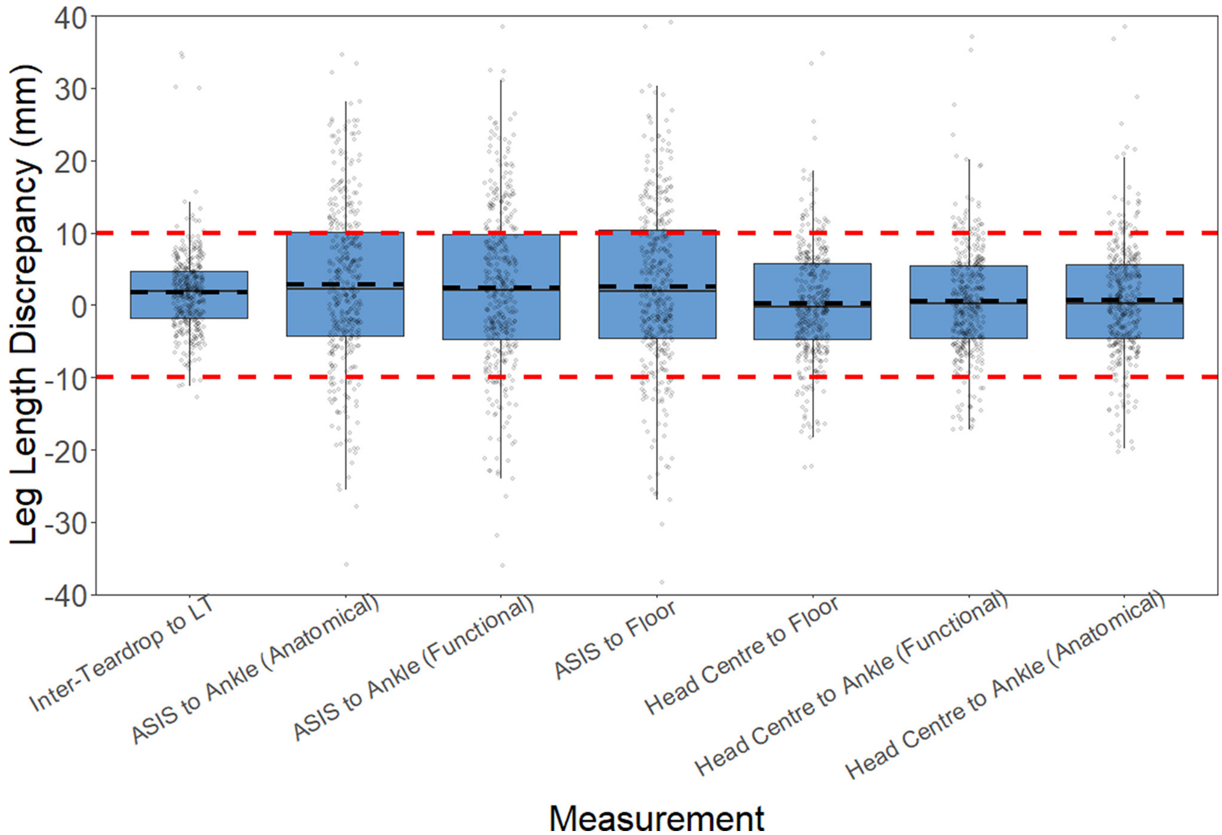

Fig. 4

Box and whisker plots to demonstrate the variability of leg length discrepancy measurements when using different landmarks and axes.

With no correlation coefficient higher than 0.57, we found that the conventional inter-teardrop to LT measurement of LLD does not correlate well with other long-limb measurements. We also found reduced inter- and intraobserver agreement for this measurement, indicating limitations in its repeatability and reproducibility. Therefore, similar to Tipton et al,[15] Kjellberg et al,[20] and Sabharwal et al,[10] our results call into question the validity of using the WB AP radiograph to measure LLD as they indicate that it does not provide a complete understanding of LLD.

The ASIS-to-ankle measurement in both the functional and anatomical axes was observed to have a high repeatability (ICC > 0.9) and strong correlations with pelvic obliquity and other EOS measurements. This measurement may provide greater detection of clinical LLD than other measurements and, where available, there is a strong case for use of this measurement to determine pre- and postoperative LLD. This is enhanced by the fact that EOS imaging has been shown to not be subject to magnification error, regardless of subject BMI, whereas plan radiography is,[24] and is also becoming more widely available. However, it should be noted that there is a potential oversensitivity of the ASIS-to-ankle measurement to sources of LLD that naturally correct postoperatively. For example, intraoperative lengthening in response to a hip contracture that corrects after surgery may lead to excessive lengthening. For this reason, the ASIS-to-ankle measurement may have limitations regarding its granularity and the surgeon may need to determine whether to correct these types of postural sources of preoperative LLD or utilize additional methods.

To further explore the notion of the WB AP radiograph not capturing all sources of LLD, example EOS imaging can be found in Figure 5. This imaging is of a 49-year-old female requiring THA on her left hip due to secondary osteoarthritis from developmental dysplasia of the hip. As seen on the left in Figure 5(a), the inter-teardrop line on WB AP radiograph shows a 7.2 mm LLD. Conventional planning here would be to correct this LLD by lengthening the operative hip by 7 to 8 mm intraoperatively to yield equal leg lengths. However, with the use of the long-leg functional alignment from EOS imaging (Figure 5(b), it is apparent that the patient has different femoral and tibial lengths. These sources of LLD manifest as the left leg being 3 to 4 mm longer. Therefore, attempting to restore the leg lengths by using the WB AP radiograph alone could lead to an operative leg that is over a centimetre longer postoperatively, which has been associated with poor patient outcomes.[2-8]

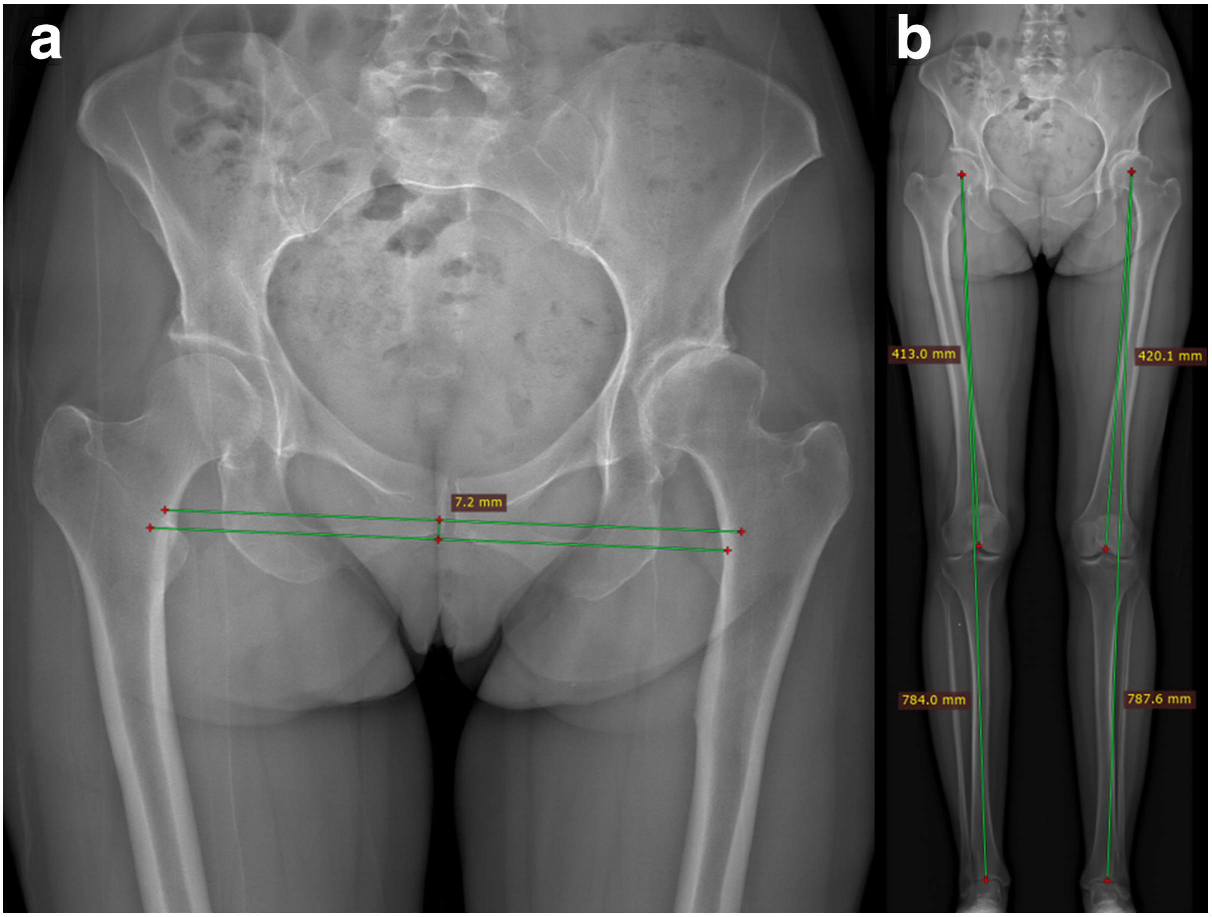

Fig. 5

EOS imaging from a patient 49-year-old female who underwent total hip arthroplasty. On the left is a zoomed-in recreation of a standing anteroposterior radiograph from the EOS. On the right is the full EOS image of the long leg alignment.

The results of our study should be interpreted within the context of its limitations. First, although EOS has utility in its ability to capture the long-leg functional stance in simultaneous biplanar images, it requires that the subject stand with one-foot forwards and one-foot backwards to ensure the knee joints are not overlapping. This may create an aLLD where one does not exist due to the functional stance of the subject. Second, this study did not include postoperative data, patient-reported outcome measures (PROMs), or measurements of the patient's perceived LLD, which would provide insight into the mechanisms of functional correction from pre- to postoperative states and how patients subjectively experience any LLDs that are present. For example, pre- and postoperative data will be required to understand how much a hip contracture corrects postoperatively, and how this subsequently affects any aLLD. Further to this point, although the ASIS-to-ankle measurement has been shown to be precise, our study has not linked this measurement to the patients' experience of LLD as we did not include clinical measurements. Therefore, we have not yet demonstrated its accuracy. Third, we did not include offset measurements, which also impact the patient's perception of LLD. Fourth, although EOS imaging machines are becoming more widely available, they are not a standard service at radiology centres. Therefore, the results of this study may not be implementable by all clinicians due to a lack of availability. Future work may investigate maquet view imaging, which is more widely available, to understand if this better fulfills the four qualities required of LLD measurements. Finally, despite EOS presenting an improvement to previously used methods of radiologically measuring LLD, EOS remains somewhat limited in its granularity for determining which sources of LLD should and should not be corrected from surgery.

In conclusion, the inter-teardrop to LT measurement taken on an AP WB pelvic radiograph, which is widely considered the industry standard for measuring LLD, does not correlate well with measurements taken on EOS imaging. Therefore, there may be a need to reassess the ongoing use of this measurement of LLD. As a arthroplasty, long-limb functional imaging methods may provide a more complete understanding of all sources of LLD that exist and could become the new 'gold standard' to create postoperatively equal aLLD, which has been proposed as the better target.[16] Specifically, we propose that the ASIS-to-ankle (anatomical) measurement, which exhibited a high correlation to other linear measurements and the highest ICC, may be the best measurement of LLD. Further work should involve the collection of pre- and postoperative EOS imaging, with the addition of patient perceptions of LLD, to understand how contractures correct postoperatively, and to build predictive algorithms that can be integrated into preoperative planning.

Take home message

- The conventional method of measuring leg length discrepancy (LLD) on an anteroposterior pelvic radiograph does not correlate well with long leg measurements, and may not provide a true appreciation of LLD. As such, there may be a need to reassess the ongoing use of this measurement of LLD.

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- M. Hardwick-Morris: Validation, Formal analysis, Investigation, Visualization, Project administration, Writing – original draft.
- E. Wigmore: Validation, Investigation, Writing – review & editing.
- J. Twiggs: Conceptualization, Metholodolgy, Formal analysis, Investigation, Visualization, Writing – review & editing.
- B. Miles: Conceptualization, Resources, Supervision, Writing – review & editing.
- C. W. Jones: Conceptualization, Metholodolgy, Data curation, Supervision, Writing – review & editing.
- P. J. Yates: Conceptualization, Metholodolgy, Data curation, Supervision, Writing – review & editing.

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