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ORIGINAL ARTICLE

Radiographic acetabulotrochanteric distance measurement as a novel method for determining leg length discrepancy in patients with hemiarthroplasty

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Hemiarthroplasty (HA) is the mainstay for many years in treating femoral neck fractures, particularly in elderly patients.[1,2] However, leg length discrepancy (LLD) during and after surgery is a challenging complication, even for experienced surgeons. Leg length discrepancy due to both HA and total hip arthroplasty (THA) is one of the most common causes of postoperative dissatisfaction in patients.[3,4] It is associated with an abnormal gait, low back pain, and dislocation.[5,6]

Band measurements between two bone segments and block measurements to clinically flatten the pelvis are examples of well-known simple

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ABSTRACT

Objectives: This study aims to evaluate the interobserver reliability and interobserver reproducibility of radiographic acetabulotrochanteric distance (ATD) measurement and to investigate its accuracy by comparing it with conventional radiographic methods used in leg length discrepancy (LLD) measurement.

Patients and methods: Between January 2017 and January 2022, a total of 97 patients (39 males, 58 females; mean age: 77.8±7.1 years; range, 61 to 91 years) who underwent pelvic radiographic evaluation and hemiarthroplasty (HA) due to femoral neck fracture were retrospectively analyzed. For ATD measurement, the distance between the line connecting the upper cartilage of the acetabulum (AC) and the extreme point of the greater trochanter (GT) was used. The AC-GT measurement on both sides was compared with bottom of the ischial tuberosities-lesser trochanter (BI-LT), center of the femoral head-BI (CH-BI), inferior acetabular teardrops-LT (IT-LT) measurements. The agreement between the methods was examined with the intraclass correlation coefficient (CCI).

Results: According to the AC-GT & BI-LT, AC-GT & BI-CH methods, there were very strong (ICC: 0.75), moderate (ICC: 0.69) and acceptable (ICC: 0.33) agreements, respectively. Significant agreement was found between all measurements ($p<0.001$). A positive correlation was detected in the correlation analysis of all measurements ($p<0.001$). Intra- and interobserver agreement for ATD measurement (AC-GT) was excellent (ICC: >0.8).

Conclusion: The ATD measurement correlates well with known measurement techniques on pelvic radiography and can be used as an alternative to this method. It has excellent intra- and interobserver agreements. This method can predict LLD after HA, but does not consider other length differences in the lower limbs.

Keywords: Acetabulotrochanteric distance, hemiarthroplasty, hip joint, leg length discrepancy, pelvic radiography.

clinical techniques. However, it has been shown that radiographic images are more accurate than clinical measurements in determining LLD, but this also involves radiation exposure.[7] Long-leg radiographs can be performed in various ways (orthoroentgenograms, teleroentgenograms), depending on the equipment available, but may miss angular deformities and fixed flexion deformities of the femur or tibia.[8] Computed tomography scans with radiopaque rulers provide more accurate LLD measurements, but higher radiation exposure and cost are the main disadvantages.[9] Plain pelvic radiographs, which are simple, reproducible, have low radiation exposure and allow comparative measurement, are frequently used to determine LLD differences originating only from the hip joint.[10,11]

Leg length discrepancy is defined as the difference in the distance between the femoral and pelvic points on both sides. Pelvic radiographs are known to help assess LLD, but may also be subject to variations due to changes in the position of the pelvis and limbs.[10,12,13] In particular, pelvic or femoral rotation may make it difficult to determine the teardrops or lesser trochanter (LT) used for measurement in some cases.[8,14] In the present study, we hypothesized that radiographic acetabulotrochanteric distance (ATD) measurement was an alternative method which could be used to determine LLD. We, therefore, aimed to define an alternative, novel measurement method including the upper part of the acetabulum as the pelvic reference point and the upper part of the greater trochanter (GT) as the femoral reference point. We also aimed to measure the interobserver reliability and interobserver reproducibility of radiographic ATD measurement and to evaluate its accuracy by comparing it with conventional radiographic methods used in LLD measurement.

PATIENTS AND METHODS

This single-center, retrospective study was conducted at Afyonkarahisar Health Science University Hospital, Department of Orthopedics and Traumatology between January 2017 and January 2022. Medical records of patients who underwent hip HA in our center were analyzed. Patients with appropriate postoperative anteroposterior (AP) pelvic radiographs in neutral plane were included in the study. Exclusion criteria were as follows: severe lower limb deformity, history of hip, knee or ankle surgery, deformity due to advanced knee and/or hip arthritis, flexion contracture of the hip and/or knee, acetabular dysplasia or related surgery, trochanter major fractures and inappropriate X-rays. Standing AP radiographs, in which the acetabular cartilage (AC), femoral head, inferior acetabular teardrops (IT), bottom of the ischial tuberosities (BI), LT, and GT were visualized, and there was no rotation in the transverse axis with the coccyx-centered on the pubic symphysis, were considered appropriate. Finally, a total of 97 patients (39 males, 58 females; mean age: 77.8±7.1 years; range, 61 to 91 years) who met inclusion criteria were recruited. Written informed consent was obtained from each patient. The study protocol was approved by the Afyonkarahisar Health Sciences University Clinical Research Ethics Committee (Date: 01.04.2022, No: 217). The study was conducted in accordance with the principles of the Declaration of Helsinki.

For pelvic LLD, the center of the femoral head (CH), a line drawn along the IT, a line drawn along the BI, and the most medial part of the LT as described by Meermans et al.[10] on AP pelvic radiography were measured. Acetabulotrochanteric distance was

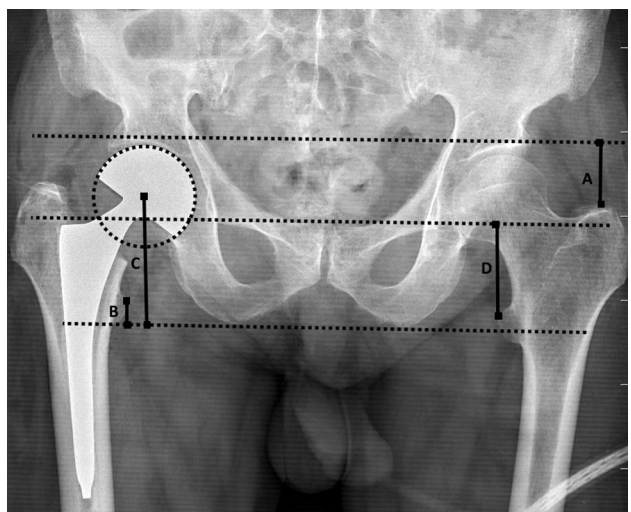

FIGURE 1. Pelvic measurements are performed to determine limb length discrepancy. The upper horizontal line connects the acetabular teardrops. The middle horizontal line connects the acetabular upper. The lower horizontal line connects the ischial tuberosities. The perpendicular distance from those lines to the greater trochanter, the center of the femoral head, and the lesser trochanter was measured on each side and compared. The measurements are A: AC-GT (acetabulotrochanteric distance), B: BI-LT, C: BI-CH, and D: IT-LT. A circle was drawn along the femoral head to ensure the center is located. (AC: upper part of acetabulum cartilage; GT, the most superior point of the greater trochanter; BI, bi-ischial line; CH, center of the femoral head; IT, inter-teardrop line; LT, most medial location of the lesser trochanter).

AC: Acetabulum; GT: Greater trochanter; BI: Bottom of the ischial tuberosities; LT: Lesser trochanter; CH: Center of the femoral head; IT: Inferior acetabular teardrops.

TABLE I
Patient demographics (n=97)

	n	%	Mean±SD	Median	Min-Max
Age (year)			77.8±7.1	78	61-91
Sex					
Male	39	40.2			
Female	58	59.8			
Height (m)			1.68±0.085	1.65	1.55-1.85
Weight (kg)			78.74±5.20	78	68-92
Body mass index (kg/m²)			27.75±2.39	27.8	21.9-35.4

SD: Standard deviation.

measured using a line drawn along the top of the AC and the upper end point of the GT. A line was drawn from AC-GT, BI-CH, IT-LT, and BI-LT on both sides and the difference between the two sides was defined as pelvic LLD. An example of measurements is shown in Figure 1. All measurements were made by two orthopedic surgeons, one month apart, twice, using Picture Archiving and Communication System (PACS) software (Nucleus MBS, MONAD Yazılım ve Danışmanlık A.Ş., Ankara, Türkiye). Longer measurements on the operated side were recorded as positive values and shorter measurements as negative values. In cases where the roundness of the femoral head is impaired, such as severe arthritis of the hip joint, the CH can be difficult to determine. Therefore, patients with hip arthritis causing femoral head deformity were excluded.

Statistical analysis

Study power analysis and sample size calculation were performed using the G*Power version 3.1.9.2 software (Heinrich-Heine-Universität Düsseldorf, Düsseldorf, Germany). Power analysis was performed as described by Tipton et al.[11] With the assumption that a difference of 0.50 mm between the means of the differences two measurements would be considered significant and using a "difference from constant" (one-sample) test with an effect size of d = 0.30, a power of 80%, and a significance level of 0.05, it was calculated that at least 90 patients would be required for the study.

Statistical analysis was performed using the IBM SPSS version 20.0 software (IBM Corp., Armonk, NY, USA). Continuous data were expressed in mean ± standard deviation (SD) or median (min-max), while categorical data were expressed in number and frequency. The Kolmogorov-Smirnov test was used to examine the suitability of the data for normal distribution. The Mann-Whitney U test was used for comparisons of continuous data between sexes. The relationships between age, height, weight, body mass index, and measurement values were examined with Spearman correlation coefficient. The agreement between the methods was examined with the intraclass correlation coefficient (ICC) and Bland-Altman methods. The ICC method examined intra- and interobserver agreement. The interpretation was as follows: >0.8 represents an almost perfect agreement, 0.7-0.8 is strong, 0.5-0.6 is moderate, 0.3-0.4 is fair, and 0-0.2 is poor. A p value of <0.05 was considered statistically significant.

RESULTS

Demographic data of the patients are given in Table I. Pelvic LLD measurements are shown in Figure 2.

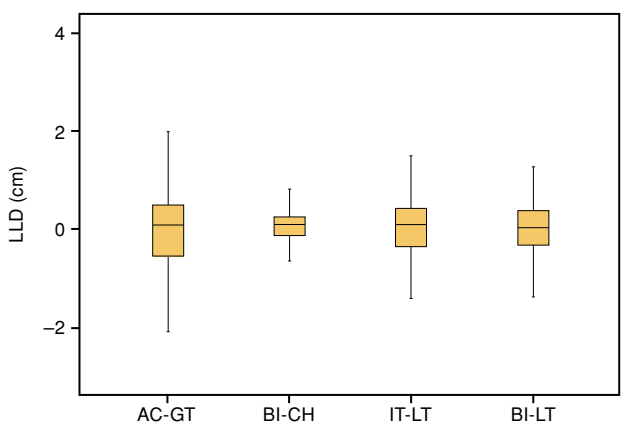

FIGURE 2. This boxplot figure shows the average pelvic LLD determined using each measuring technique. Error bars indicate the standard deviation. Measurement values are given in centimeters.

LLD: Leg length discrepancy; AC: Acetabulum; GT: Greater trochanter; BI: Bottom of the ischial tuberosities; CH: Center of the femoral head; IT: Inferior acetabular teardrops; LT: Lesser trochanter.

TABLE II
Correlations between patients' age, height, weight, and BMI values and measurements

	Age	Height	Weight	BMI
AC-GT				
r*	0.139	0.071	0.066	0.020
p	0.175	0.489	0.520	0.844
BI-CH				
r*	−0.079	**0.206**	0.050	−0.199
p	0.441	**0.043**	0.624	0.051
IT-LT				
r*	0.136	0.050	0.008	0.004
p	0.184	0.625	0.941	0.971
BI-LT				
r*	0.047	0.076	0.064	0.059
p	0.651	0.457	0.535	0.564

BMI: Body mass index; AC: Acetabulum; GT: Greater trochanter; BI: Bottom of the ischial tuberosities; CH: Center of the femoral head; IT: Inferior acetabular teardrop; LT: Lesser trochanter; * Spearman's correlation coefficient.

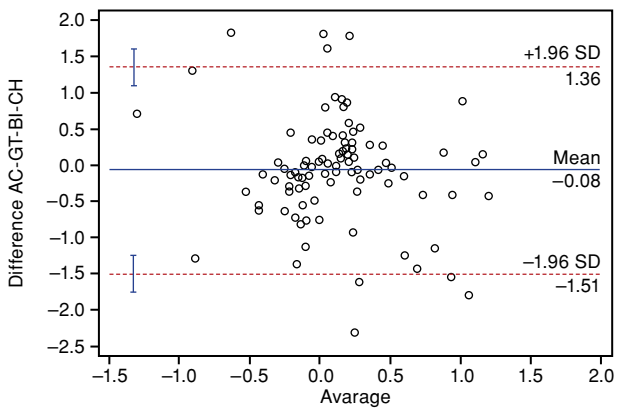

FIGURE 3. Bland Altman plot of AC-GT & BI-CH measurements.
AC: Acetabulum; GT: Greater trochanter; BI: Bottom of the ischial tuberosities; CH: Center of the femoral head; SD: Standard deviation.

According to the correlation analysis, there was a positive correlation between the heights and BI-CH values (r=0.206, p<0.05). However, there was no correlation between the age, height, weight, and BMI and AC-GT, BI-CH, IT-LT, or BI-LT values (p>0.05) (Table II).

The agreement between the methods was examined and the results are presented in Table III, Figure 3, Figure 4, and Figure 5.

The ICC agreement results were strong (>0.7), moderate (>0.6), and acceptable (>0.3) for AC-GT & IT-LT, AC-GT & BI-LT, and AC-GT & BI-CH, respectively (Table IV). Significant concordance was found between all measurements (p<0.001). A positive correlation was detected in the correlation analysis of all measurements (p<0.001) (Table V).

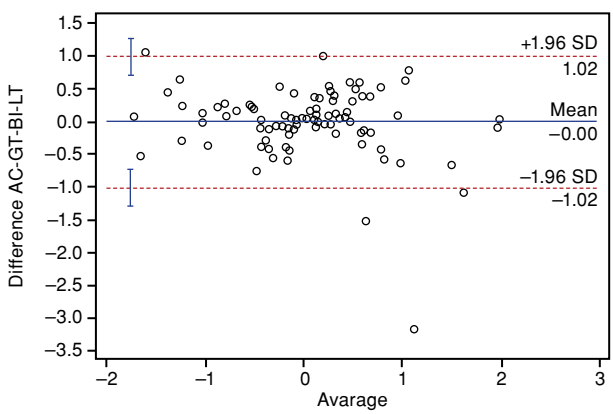

FIGURE 4. Bland-Altman plot of AC-GT & IT-LT measurements.
AC: The upper part of acetabulum cartilage; GT: Greater trochanter; BI: Bottom of the ischial tuberosities; LT: Most medial location of the lesser trochanter; SD: Standard deviation.

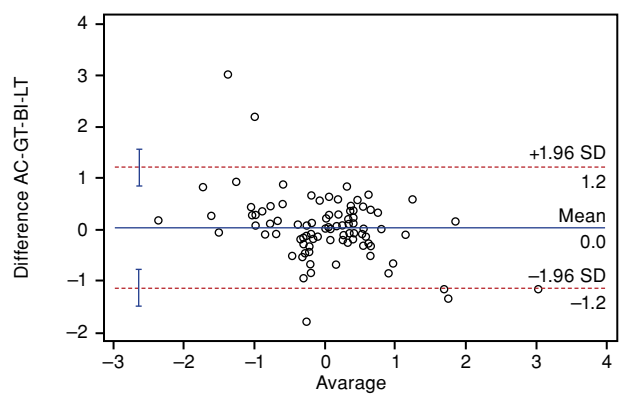

FIGURE 5. Bland-Altman plot of AC-GT & BI-LT measurements.
AC: The upper part of acetabulum cartilage; GT: Greater trochanter; BI: Bottom of the ischial tuberosities; LT: Most medial location of the lesser trochanter; SD: Standard deviation.

TABLE III
Blant Altman fit results between AC-GT measurements and BI-CH, IT-LT, and BI-LT measurements

	Difference		Limits of agreement (95%)	
	Mean	95% CI	Lower	Upper
AC-GT & BI-CH	–0.075	–0.223-0.072	–1.506	1.356
AC-GT & IT-LT	–0.0017	–0.106-0.103	–1.020	1.016
AC-GT & BI-LT	–0.040	–0.081-0.163	–1.152	1.243

AC: Acetabulum; GT: Greater trochanter; BI: Bottom of the ischial tuberosities; IT: Inferior acetabular teardrop; LT: Lesser trochanter; CH: Center of the femoral head; CI: Confidence interval.

TABLE IV
ICC correlation results between AC-GT measurements and BI-CH, IT-LT, BI-LT measurements

	ICC	95% CI	*p*
AC-GT & BI-CH	0.333	0.144-0.499	<0.001
AC-GT & IT-LT	0.752	0.651-0.827	<0.001
AC-GT & BI-LT	0.697	0.579-0.787	<0.001

AC: Acetabulum; GT: Greater trochanter; BI: Bottom of the ischial tuberosities; CH: Center of the femoral head; IT: Inferior acetabular teardrop; LT: Lesser trochanter; CI: Confidence interval.

Intraobserver agreement was excellent (>0.8) for evaluating AC-GT, IT-LT, and BI-LT. Intraobserver agreement for the BI-CH measurement was also strong (0.74). Interobserver agreement was excellent (>0.8) for AC-GT and IT-LT and strong for BI-CH and BI-LT measurements (0.78 and 0.72, respectively). Intra- and interobserver agreement values were statistically significant for all measurements (p<0.001) (Table VI).

DISCUSSION

In the present study, we compared the intra- and interobserver reliability of ATD measurement, a novel method on pelvic radiography, with commonly used pelvic measurement techniques. The main finding of this study is that our proposed ATD measure can be used to assess LLD from pelvic radiography. Each radiographic measurement from pelvic radiography showed a statistically significant correlation with the assessed ATD. The primary

TABLE V
Correlations between AC-GT measurements and BI-CH, IT-LT, BI-LT measurements

	AC-GT & BI-CH	AC-GT & IT-LT	AC-GT & BI-LT
r *	0.462	0.817	0.744
p	<0.001	<0.001	<0.001

AC: Acetabulum; GT: Greater trochanter; BI: Bottom of the ischial tuberosities; CH: Center of the femoral head; IT: Inferior acetabular teardrop; LT: Lesser trochanter; * Spearman's correlation coefficient.

TABLE VI
Intraobserver and interobserver agreement

	AC-GT	BI-CH	IT-LT	BI-LT
Intraobserver				
ICC	0.979	0.781	0.908	0.892
95% CI	0.968-0.986	0.689-0.848	0.866-0.938	0.842-0.926
p	<0.001	<0.001	<0.001	<0.001
Interobserver				
ICC	0.923	0.784	0.929	0.724
95% CI	0.887-0.948	0.694-0.850	0.896-0.952	0.613-0.806
p	<0.001	<0.001	<0.001	<0.001

AC: Acetabulum; GT: Greater trochanter; BI: Bottom of the ischial tuberosities; CH: Center of the femoral head; IT: Inferior acetabular teardrop; LT: Lesser trochanter; ICC: Intraclass correlation coefficient; CI: Confidence interval.

goal of hip arthroplasty for femoral neck fractures in the elderly is to reduce pain, correct anatomy, and provide good gait and function.[15,16] Leg length discrepancy is a relatively common postoperative complication which leads to patient dissatisfaction and potential legal problems.[15] Therefore, surgeons should evaluate LLD before, during and after arthroplasty.

In AP plain radiography, IT, the lower border of the BI, and the medial prominence of the LT are commonly used for measurements.[10,12,17,18] However, there are various inconsistencies regarding the accuracy and reproducibility of different methods for assessing LLD. Heaver et al.[8] made measurements using the reference lines on the non-optimal AP pelvic radiograph of the Sawbones model. The authors reported that the most repeatable method was the measurement method from the inferior aspect of the BI to the most prominent medial point on the LT. Konyves and Bannister[19] used IT and the medial protrusion of the LT in LLD measurements after THA and reported that this method could accurately evaluate the pre-and postoperative status. Meermans et al.[10] suggested that the BI should not be used, that the teardrop was the correct landmark and that the CH was a more reliable femoral point than the LT. In cases where the roundness of the femoral head is distorted, it may be difficult to determine the CH. On the other hand, Tsang et al.,[20] considering that osteoarthritis cases would not typically produce an LLD between the CH and the LT, did not recommend the clinical use of this reference point. The same study showed that the obturator foramen line and the LT were more reliable on the Sawbones model and could be used to predict real LLD. At the same time, the teardrop was the least reliable landmark. The ease of determination is the most crucial advantage of the AC line and the GT tip point used in our recommended measurement method. Rotation at the hip joint makes it difficult to identify the LT, but the rotation does not affect the GT tip point. Likewise, IT are challenging to locate interpersonally, but the AC line can be revealed more clearly.

The literature is conflicting on pelvic LLD measurements and reports inconsistent results. As Pettit et al.[21] concluded in their systematic review on LLD variability for THA, there has yet to be a commonly accepted reference point standard in radiographs. In a recent deep-learning analysis study, Jang et al.[22] suggested using the superior point of the GT instead of the LT as the femoral landmark in determining LLD for THA. They emphasized that the main reason for this preference was the difficulty in determining the reference point due to rotational pelvic radiographs. The same study did not recommend using the ischial tuberculum and obturator foramen to measure LLD due to low compliance.

In their meta-analysis, Pettit et al.[21] reported that the intra- and interobserver agreement in assessing LLD from AP pelvis radiographs ranged from poor to excellent. Kjellberg et al.[23] found that the interobserver reliability and interobserver reproducibility of LLD measurements on plain radiographs were excellent. Similarly, intra- and interobserver agreements were excellent in our study. Our study had an excellent intraobserver agreement for AC-GT, IT-LT, and BI-LT and a strong agreement for BI-CH measurement. Interobserver agreement was excellent for AC-GT and IT-LT, and there was also strong agreement for BI-CH and BI-LT measurement.

Measuring true LLD requires an assessment of the full-length limb. Current publications question the validity of using AP pelvic radiography alone to detect LLD and do not recommend it.[11,23] Methods which provide complete imaging of the limb, such as teleoroentgenogram and orthoroentgenogram, can provide a more complete understanding of all existing sources of LLD.[24] Pelvic radiography is a brief imaging of orthoroentgenograms used for LLD detection. It is utilized much more frequently than orthoroentgenograms due to its affordable cost, low radiation exposure, simplicity in comparison, and effectiveness.[25] Since the only change in limb length before and after surgery originates from the hip joint, assessing pelvic LLD from a preoperative pelvic radiograph and comparing these measurements with a postoperative film would likely provide an accurate change in LLD.[11] In the light of all these reports, AP pelvic radiography would continue to be used in evaluating LLD in HA due to femoral neck fracture and in THA due to osteoarthritis. The ATD method has also shown strong compatibility with commonly employed methods and can be an alternative to these methods.

Nonetheless, this study has several limitations. First, we used only AP pelvis LLD measurement methods to compare our proposed method. Second, since this was a retrospective study, we did not use the tape measure or standing full-length radiographs, which are direct clinical measurement methods; instead, we indirectly validated our method. This may present a slight discrepancy

between the LLD measurement and our proposed method. Third, since the acetabular cup in THA may be located differently depending on the reaming depth, we only included HA patients in our study. We minimized the margin of error by validating the ATD measurement method on X-rays with no acetabular dysplasia, intact GT, and appropriate leg abduction-adduction. However, the main strengths of this study are that it is the first study in the literature, the number of patients is relatively high, and the intra- and interobserver evaluations are made.

In conclusion, ATD measurement on plain pelvic radiographs correlates well with known methods and can be used instead of these methods. It has excellent intra- and interobserver agreements. Of note, this method does not account for other length differences in the lower limbs, but provides a possibly accurate assessment of pre- and postoperative conditions. However, further comparative studies with larger patient series using different methods are needed to confirm these findings.

Data Sharing Statement: The data that support the findings of this study are available from the corresponding author upon reasonable request.

Author Contributions: Author Contributions: All authors have made substantial contributions to the conception and design, or acquisition of data, or analysis and interpretation of data, drafting the article or revising it critically for important intellectual content, final approval of the version to be published, and agree to be accountable for all aspects of the work if questions arise related to its accuracy or integrity.

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