Localisation of the ilioischial line on axial computed tomography images for pre-operative planning of total hip arthroplasty

Michitaka Kato (katomic29@gmail.com)
Nagoya Joint Replacement Orthopaedic Clinic https://orcid.org/0000-0003-4800-4396
Hideki Warashina
Nagoya Joint Replacement Orthopaedic Clinic
Akito Kataoka
Nagoya Joint Replacement Orthopaedic Clinic
Takanori Ando
Nagoya Joint Replacement Orthopaedic Clinic
Shingo Mitamura
Nagoya Joint Replacement Orthopaedic Clinic

Research Article

Keywords: ilioischial line, pelvic radiograph, axial computed tomography, total hip arthroplasty, cup offset

Posted Date: March 16th, 2022

DOI: https://doi.org/10.21203/rs.3.rs-1100304/v1

Abstract

Background: The ilioischial line can be an important landmark in determining cup offset in two-dimensional preoperative planning for total hip arthroplasty by identifying the bony region showing the ilioischial line on axial computed tomography (CT). This study aimed to validate the hypothesis that the ilioischial line is located in the bony region where the X-ray beamline to the ilioischial line (line α) is tangent to the medial acetabular cortical bone with a maximum overlap in axial CT images.

Methods: Equidistance of the following two measures would prove the validity of our hypothesis: (A) distance between the ilioischial line and the metal cup, measured at the level of the hip center on pelvic radiographs, multiplied by 0.9 to correct for the magnification of the radiograph and (B) distance between the metal cup and line α, which is tangent to the medial acetabular wall with maximum overlap, in the axial CT image at the level of the hip joint center. These two distances were measured for 51 hip joints.

Results: The average distance A was 4.5±2 mm, and the average distance B was 4.7±2.1 mm. The difference between distances A and B was 0.2±0.2 (range, 0–2.6) mm. In >90% of the cases, the cortical bone area of the inner acetabular wall, indicating the location of the ilioischial line, was located posteriorly.

Conclusions: The ilioischial line is located in the bony region where line α intersects with the acetabular medial wall with maximum overlap on axial CT images.

Background

The ilioischial line is very conspicuous on pelvic radiographs and is often used as a landmark. It has been used as a reference line for characteristic hip morphology in coxa profunda [1–3] and proturusio acetabli [4–6]. Preoperative planning of total hip arthroplasty (THA) with pelvic radiographs is a standard procedure, and the ilioischial line has been suggested as a reference for cup placement [7], probably because it is recognized as representing a part of the acetabular medial wall [8, 9]. However, no report has shown in detail where the bony region indicated by the ilioischial line is located on axial computed tomography (CT) images.

Previous studies created a two-dimensional (2D) template on radiographs before THA and used preoperative pelvic CT images to confirm cup size and combined anteversion [10, 11]. The cup size is determined by the anteroposterior (AP) width of the acetabulum, measured at the level of the femoral head center within the anatomical hip center on CT images (Fig. 1). When a cup with an appropriate size is placed on the anterior and posterior walls on the axial CT in preoperative simulation, the distance between the cup and ilioischial line can be measured if the bony area showing the ilioischial line in the CT is known (Fig. 1), and the distance from the ilioischial line to the cup can be reflected as the offset position of the cup in the 2D template, as shown in Figure 2.

In this study, we searched the bony region of the ilioischial line on axial CT imaging using postoperative pelvic radiographs and CT images. The distance from the metal cup to the ilioischial line was measured in a supine pelvic radiograph, and the actual distance from the ilioischial line to the metal cup was calculated by considering the magnification rate in the radiograph. If this actual distance and the distance between the metal cup and acetabular medial wall showing the hypothetical ilioischial line on axial CT is equal, we consider that its acetabular medial wall would be the bone region that shows the ilioischial line on CT.

This study aimed to validate the hypothesis that the ilioischial line is located in the bony region where the X-ray beamline to the ilioischial line (line α) is tangent to the medial acetabular cortical bone with a maximum overlap in axial CT images.

Methods

Study design

This retrospective evaluation of the location of the ilioischial line on plain radiographs and axial CT images was approved by our Institutional Review Board of Nagoya Orthopedic Joint Replacement Clinic (Approval No. 201905002) and written informed consent was obtained from all patients for THA and publication of results.

Location of the ilioischial line

During radiography, the angle between the X-ray beam from the X-ray tube to the ilioischial line and the line perpendicular to the floor was calculated using a trigonometric function. We assumed that, on CT axial images, the ilioischial line would be located at the intersection of the medial acetabular wall with the X-ray beam (line α) that most overlaps the cortical bone of the medial acetabular wall on axial CT images. We considered that this hypothesis would be proven if the following two distances were equivalent, measured with the patient in the supine position: distance A, between the iliac line and metal cup measured at the level of the hip joint center on pelvic radiographs (Fig. 3), corrected for the magnification of the radiograph, and distance B, between line α and metal cup at the point of greatest overlap with the acetabular medial wall on axial CT images (Fig. 4).

Study sample

Our study included 67 patients (76 hip joints) who underwent primary THA by one of the authors between November 2018 and September 2019. The exclusion criteria were as follows: absence of postoperative CT images or supine radiographs of the pelvis; Crowe classification III and IV; radiographs in which the distance between the cup and ilioischial line could not be measured due to contact or overlap; cementless cup fixation in which screw fixation interfered with measurement; use of a cemented cup; pelvic osteotomy; and pelvic fracture. After exclusion, 44 patients (51 hip joints) were included (12 males), with a mean age (±standard deviation) of 63.2±8.4 years and a body mass index of 24.6±4 kg/m^2.

Imaging

Plain pelvic radiographs and CT axial images were obtained routinely on postoperative day 5. Radiographs were obtained with patients in the supine position. The X-ray tube was positioned vertical to the floor and centered on the pubic symphysis, with a film focal length of 100 cm. Three examiners measured the distance between the pelvis and the film on the CT axial images for 51 cases with good reliability (inter-class correlation coefficient [ICC], 0.85). The average distance was 10.7 cm, yielding a magnification of approximately 110% on the radiographs.

Routine CT was performed to assess for an anteversion position of the cup and stem and for occult fractures. A 16-row multi-CT model ECLOS (HITACHI, Tokyo) was used for all patients in this study. The coronal plane was set through the center of both hips from the volume axial image and the axial plane along a line connecting the tear drops, bilaterally, from the volume coronal image. Multiplanar reformation (MPR) axial images with 3-mm spacing were created. The slice with the largest anterior-posterior diameter of the metal femoral head was selected to determine the location of the ilioischial line.

Angle of the line of radiation

The angle of the X-ray beam around the ilioischial line was calculated as follows (Fig. 5): tan θ= -1× (distance C from the source to the film /distance D between the ilioischial lines/2). The distance from the radiation source to the film was set to 100 cm. Distance D, between the right and left ilioischial lines, was measured twice by four observers on frontal radiographs for each hip as a reference. The inter- and intra-examiner reliability were excellent (ICC, 0.99). The mean distance between the two ilioischial lines was 133.5 mm, with the distance divided by 2 (6.7 cm), used as distance D in the calculation of tan θ. The X-ray beam angle offset to the ilioischial line was calculated to be approximately 3.8°. Therefore, for simplification, the angle was set to 4° from vertical.

Distance from the pelvic center to the ilioischial line

The distance from the pelvic center to the ilioischial line was measured on the CT axial image slice nearest to the femoral head center. The line of radiation, set at an angle of 4° from vertical, was drawn, and distance B was measured between line α and a line parallel to line α and tangent to the metal cup (Fig. 4). The distance from the ilioischial line to the metal cup at a level parallel to the interosseous line and through the femoral head center on the pelvic radiograph was measured to one decimal place using a digital viewer. Since the radiographic magnification was approximately 110%, the measured value was multiplied by 0.9 to obtain distance A, which was the actual size. Distance E, i.e., the distance between the overlapping area of the cortical bone on the medial acetabular wall and line α, was also measured on CT axial images (Fig. 4).

To determine if the ilioischial line was located anteriorly or posteriorly in the pelvis, we drew line β from the most anterior to the most posterior point on the pelvic medial wall. This line was then divided into four equal parts, designated as zones 1–4, from the anterior to the posterior points (Fig. 6). If the cortical bone was located between two zones, the two adjacent zones were identified, including the ilioischial line.

Statistical analysis

For the 51 hips, distances A, B, D, and E, and zone classification of the location of the ilioischial line were recorded by four blinded observers (1 orthopedic surgeon, 2 physical therapists, and 1 radiological technician), twice, with an interval of at least 2 weeks between measurements. The images were enlarged sufficiently using a digital viewer to measure up to one decimal point. The ICC was calculated for intra- and inter-observer reliability. ICC values were interpreted as follows [12]: <0.5, poor reliability; 0.5–0.75, moderate reliability; 0.75–0.9, good reliability, and >0.90, excellent reliability. Data were expressed as the mean (±standard deviation), with 408 measures (4 observers, measured twice, for 51 hips) included. For each hip, the difference between distances A and B was calculated. The percentage of hips in which this difference was >1 and >2 mm was calculated. The correlation coefficient between distances A and B was calculated. A Bland–Altman analysis was used to determine the level of agreement between the measured distances. The distribution of localization of the ilioischial line within the four zones of the medial acetabular wall was calculated.

Results

The inter- and intra-observer reliability in measurement were excellent for distances A, B, and D; however, for distance E, while the intra-observer reliability was good, the inter-observer reliability was only fair for the first measurement and moderate for the second (Table 1).

Table 1
Inter- and intra-observer agreement [ICC (2, 1) and ICC (1, 1), respectively] for the measurement of distances A, B, D, and E

		First measurement	**Second measurement**		**Observer 1**	**Observer 2**	**Observer 3**	**Observer 4**
Distance A	ICC (2,1)	0.96	0.99	ICC (1,1)	0.98	0.93	0.99	0.98
	Lower bound	0.94	0.98	Lower bound	0.97	0.88	0.98	0.97
	Upper bound	0.98	0.99	Upper bound	0.99	0.96	0.99	0.98
Distance B	ICC (2,1)	0.96	0.96	ICC (1,1)	0.98	0.96	0.99	0.98
	Lower bound	0.93	0.92	Lower bound	0.96	0.93	0.97	0.97
	Upper bound	0.97	0.98	Upper bound	0.99	0.98	0.99	0.99
Distance D	ICC (2,1)	0.98	0.91	ICC (1,1)	0.99	0.97	1	0.84
	Lower bound	0.96	0.87	Lower bound	0.99	0.95	0.99	0.73
	Upper bound	0.99	0.94	Upper bound	1	0.98	1	0.90
Distance E	ICC (2,1)	0.44	0.57	ICC (1,1)	0.72	0.80	0.77	0.74
	Lower bound	0.21	0.34	Lower bound	0.56	0.68	0.63	0.59
	Upper bound	0.64	0.73	Upper bound	0.83	0.88	0.86	0.84

ICC, intraclass correlation coefficient

The mean distance A for the 51 joints was 4.5±2 mm and 4.7±2.1 mm for distance B. The difference between distances A and B was 0.2±0.2 (range, 0–2.6) mm. The scatter plot of distance A versus distance B for each case is shown in Figure 7. The correlation between the two measured distances was strong (R2=0.86). A difference of ≥1 mm between the two distances was observed in 11 cases (21.6%) and of ≥2 mm in 1 case (2%). The Bland–Altman plot shows that 94.1% of the difference in measures was within ±1.96 SD, with only three outliers (Fig. 8).

The mean distance E for the 51 joints was 22.1±5.1 (range, 13.7–35.8) mm. The distribution of the 408 localizations of the ilioischial line within the four zones of the medial wall of the acetabulum was as follows (Fig. 9): 0 (0%) in zone 1; 14 (3.4%) in zone 2; 19 (4.7%) between zones 2 and 3; 268 (65.7%) in zone 3; 30 (7.4%) between zones 3 and 4; and 77 (18.4%) in zone 4. Overall, the position of the ilioischial line was located in the posterior half of the medial acetabular wall in 92% of cases (Fig. 9).

Discussion

In recent years, three-dimensional templating has been used for preoperative THA planning [13, 14]; however, this method requires specialized software and is time-consuming. Contrary, 2D preoperative templating using plain radiographs and axial CT images is simple, inexpensive, and can be completed in a few minutes. Knowing the ilioischial line on CT can provide information on the offset for cup placement, which may be helpful for creating more accurate 2D radiographic templates. The offset position of the cementless cup is critical to avoid iliopsoas impingement [15–19], ensure adequate acetabular coverage [7, 20], and for THA stability [21–23]. When placing the cup, the anterior edge of the cup should not overhang the anterior acetabular wall, and there should be adequate coverage of the host bone above the cup to prevent cup loosening. For patients with acetabular dysplasia, where the cup center-to-edge angle is <0º, the surgeon should consider placing the cementless cup more medially or with the hip center slightly higher to stabilize the cup [23]. It is also possible to use a cemented cup and graft the bulk bone of the acetabulum if necessary [24, 25]. The cup size can be predicted by CT at the level of the acetabulum, and the distance from the ilioischial line on CT to the cup can be measured and incorporated into the radiographic template to adjust the simulation, especially for patients with acetabular dysplasia. Global offset is also vital for hip function [26]; however, the need for cup medialization may require the selection of a high offset stem.

The iliac crest line is also an important landmark for identifying hip joint morphologies, including coxa profunda and protrusio acetabuli. In their CT-based imaging study, O'Sullivan et al. [8] identified the location of the ilioischial line in 10 cadaveric pelvises to be posterior to the acetabulum and at the radiographic interface of the cortical bone of the posterior column. However, a 5° rotation of the pelvis yielded a change in the radiographic location of the tear drop used as a reference for the ilioischial line. In their investigation of the morphology of the acetabulum in coxa profunda, Fujii et al. [9] reported the ilioischial line to be located at the outermost point of the sciatic acetabular medial wall. We hypothesized that the ilioischial line would be located in the bony region where the radiographic beam overlaps to the greatest extent with the cortical bone of the acetabular medial wall on axial CT imaging. This required considering the angle of the radiographic beam relative to the ilioischial line. On a related note, the X-ray beam offset has previously been described to measure acetabular cup anteversion after THA [26–30]. Goergen and Resnick proposed a correction factor of 5° for the radiographic angle for AP pelvis radiographs centered on the symphysis pubis; this correction factor was, however, variable for different relative cup positions [29]. Using trigonometry, Widmer calculated a radiographic beam offset of 5.46° to measure the cup anteversion angle [27]. Measuring the distance from the pelvic center to the ilioischial line on AP radiographs obtained with patients in the supine position, we calculated a radiographic angle of 4°. Our hypothesis regarding the relationship between line α and ilioischial line is theoretical but consistent with previous opinions [8, 9]. Our study aimed to prove that line α is the bony region representing the ilioischial line on axial CT images by confirming that distances A and B were nearly equivalent. We showed that these two distances are strongly correlated ($R2=0.87$), with an average difference of 0.2 mm (calculated from the regression line $y=x+0.2$). The ilioischial line was located in the cortical bone area of the acetabular medial wall, which overlapped to the greatest extent with line α. The average width of the cortical bone defining the ilioischial line was about 2 cm in width, but the measurement reliability was only fair-to-moderate. The zone classification showed that the ilioischial line concentrated in zone 3 and was located posteriorly in almost 90% of cases. The more posterior the zone containing the ilioischial line, the shorter the cup distance. We did exclude cases where the cup and ilioischial line either touched or overlapped; therefore, there is a possibility for localization of the ilioischial line in zone 4 in some cases.

Measurement errors of distances A and B can be caused by the magnification rate of the X-ray beam, differences in pelvic rotation in the supine position during imaging, and metal artifacts in the cup. O'Sullivan et al. [8] reported that the relationship between the ilioischial line and tear drop could be altered with as little as 5° of pelvic rotation. The Bland–Altman plot identified only 3 outliers among the 51 hips included in our study. Therefore, we can assume that our correction of 0.9 for radiographic magnification was appropriate. Errors are also possible on the CT image, although the software does correct for these greatly [31]. A specific issue is the limit of 3 mm between slices; thus, the image used for measurement may not be exactly through the femoral head center. Additionally, the X-ray beam offset of 4° was calculated only in Japanese patients, with the possibility of differences based on race. However, we did note the high correlation between distances A and B. Therefore, it is reasonable to consider line α as representing the point of the ilioischial line at the CT slice level. The error using this method was within 2 mm, with this level of accuracy being sufficient for clinical applications, such as preoperative planning of THA cup placement.

On the pelvic CT axial image, the cortical bone region at the contact point of the acetabular medial wall, which overlaps the line tilted at 4° from the floor to the hypotenuse, is the bony component representing the ilioischial line. As such, the offset distance based on the ilioischial line of the cup can be measured on the CT axial slice. This would provide accurate preoperative templating from radiographs and CT images without the need for specialized software, which could improve THA outcomes.

Limitations

The limitations of our study are as follows. First, the number of cases was small. Second, we did not evaluate the pelvic tilt on radiographs and CT images. Third, although it is desirable to calculate and measure the radiographic offset beam based on the size of each pelvis, it is complicated in actual clinical practice; therefore, we simplified it to 4º. However, in individual cases, the radiation angle ranges from 3.3° to 4.3°, and this difference has little effect on distance B. Finally, the use of our methods for preoperative planning needs to be evaluated.

Conclusion

In conclusion, the ilioischial line is located where line α intersects with the acetabular medial wall. This may provide information on the three-dimensional characteristics of the acetabular structure from radiographs and CT images. As the ilioischial line is important to guide appropriate positioning of the acetabular cup, our method provides an easy-to-use approach that may improve THA outcomes.

Abbreviations

CT Computed tomography

THA Total hip arthroplasty

2D Two-dimensional

AP Anteroposterior

BMI Body mass index

ICC Inter-class correlation coefficient

MPR Multiplanar reformation

Declarations

Ethics approval and consent to participate: This study has been approved by Nagoya Orthopedic Joint Replacement Clinic Ethics Committee (Approval No. 201905002). Written informed consent was obtained from the patients before study participation.

Consent for publication: Consent to publish was obtained from all participants.

Availability of data and materials: The data that support the findings of this study are available from the corresponding author, MK, upon reasonable request.

Competing interests: The authors declare that they have no competing interests.

Funding: No funding was received for conducting this study.

Authors' contribution: All authors contributed to the study's conception and design. Material preparation, data collection, and analysis were performed by MK, AK, TA,and SM. MK wrote the first draft of the manuscript and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Acknowledgments: MK would like to express his gratitude to Professor Hirokazu Iida, Kansai Medical University Medical Center, for his guidance in the preoperative planning of total hip arthroplasty.

The authors thank Editage (www.editage.jp) for English language editing.

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Figures

Fig. 1

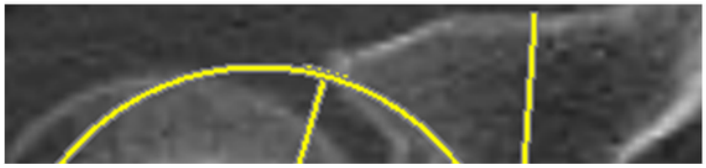

Figure 1

Preoperative planning based on computed tomography (CT) images.

The slice with the largest anterior-posterior diameter of the femoral head on CT axial images is selected as the hip center, with the cup diameter estimated by the distance between the edge of the anterior wall and the edge of the posterior wall of the acetabulum. The depth at which the cup is to be placed is predicted from the radius of the acetabulum. If we know the position of the ilioischial line on CT, we can get information about the offset of the cup. The ↔ is the expected distance from the ilioischial line to the cup

Fig. 2

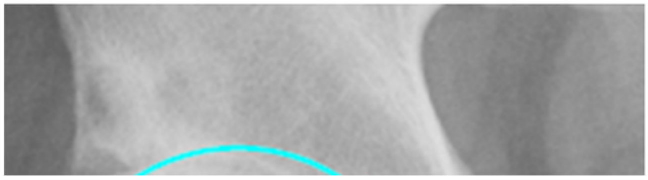

Figure 2

Two-dimensional templating.

Images show the use of the ilioischial line to determine the target offset position of the acetabular cup. However, the exact distance from the ilioischial line to the acetabular cup is undermined, even on computed tomography axial images.

Fig. 3

Figure 3

The distance from the acetabular cup to the iliac line was measured along a line parallel to the interosseous line and through the center of the femoral head.

Fig. 4

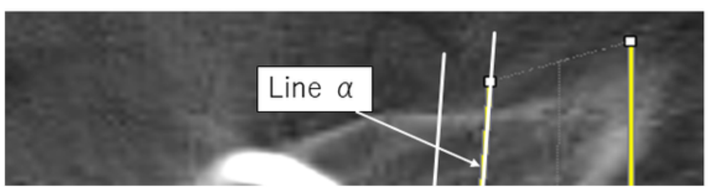

Figure 4

Measurement of distance B.

In the axial CT image at the level of the hip joint center, the distance between the metal cup and the line α tangent to the medial acetabular wall with maximum overlap was measured as shown in the figure.

Fig.5

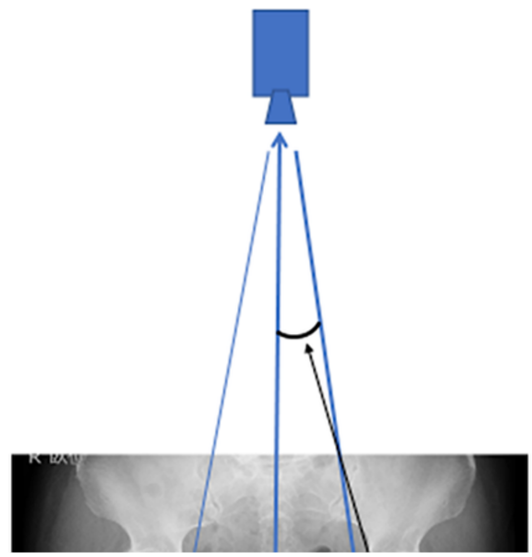

Figure 5

The offset of the X-ray beam measured on an anteroposterior radiograph of both hips.

The X-ray beam focused on the pubic symphysis. In this figure, the X-ray beam offset angle in the ilioischial line can be calculated by a trigonometric function using the distance from the center of the pelvis to the ilioischial line and the distance from the X-ray source to the film. With this method, an approximately 4° X-ray beam offset angle is located around the ilioischial line.

Fig 6

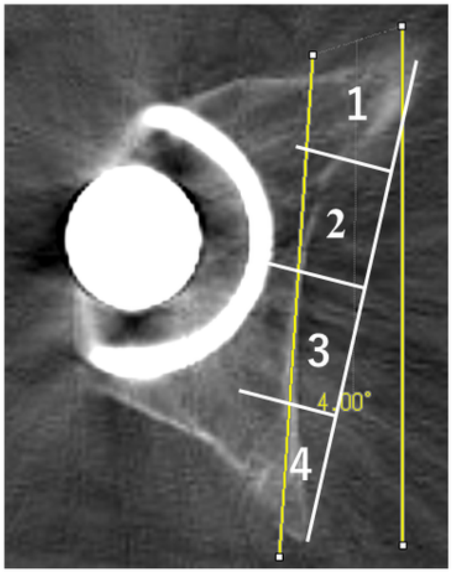

Figure 6

Location of the ilioischial line on the medial acetabular wall.

The line connecting the anterior and posterior margins of the medial acetabular wall is divided into four equal parts, i.e., zones 1–4, from the anterior to posterior points. A perpendicular line is drawn through all zones and the medial acetabular wall. The center of the medial acetabular wall that overlaps with line α is located in zone 3 in this example.

Fig. 7

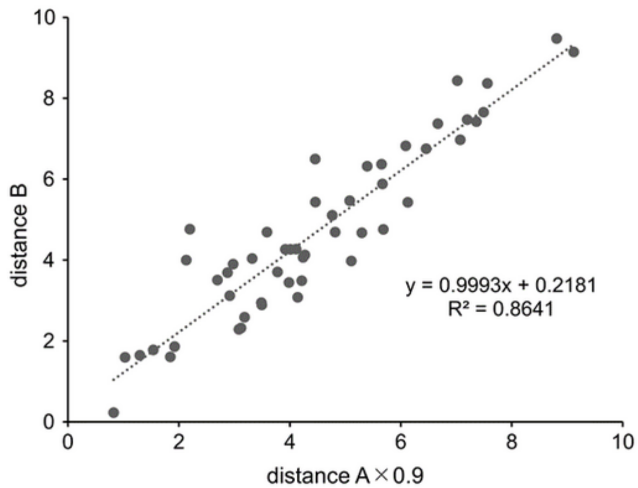

Figure 7

Scatter plot of measured distances A and B for each joint.

The correlation between distances A and B was high (R2=0.86); the regression line is shown (y=x + 0.2).

Fig. 8

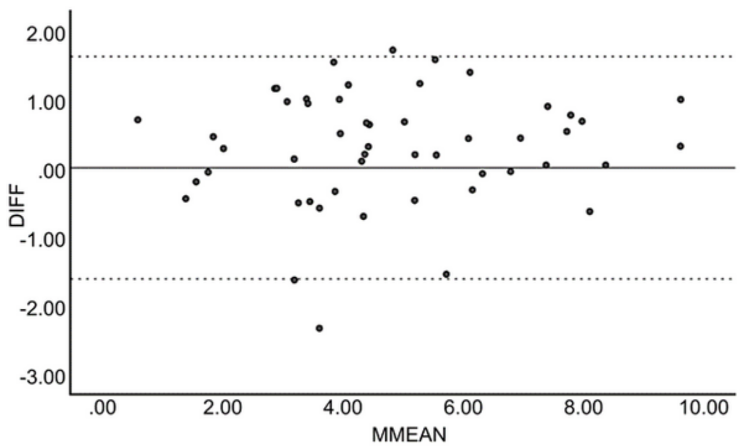

Figure 8

Bland–Altman plot of the measurement error.

The measurement error exceeded the allowable range in only three cases.

Fig. 9

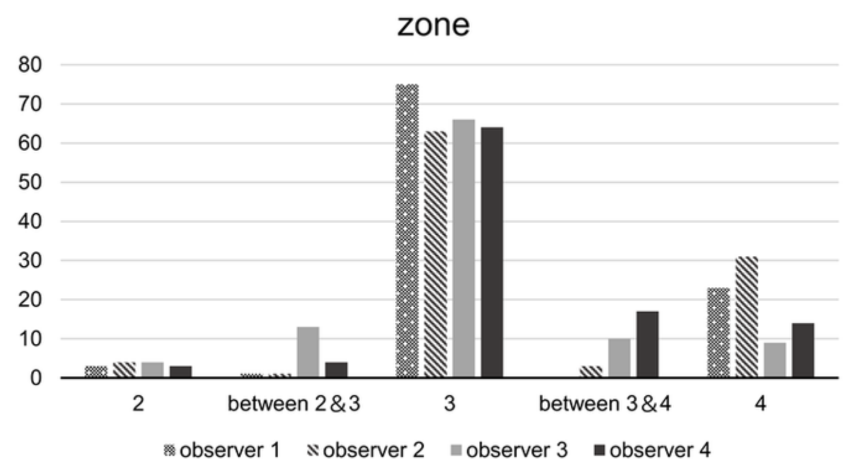

Figure 9

Location of the cortical bone of the medial acetabular wall.

The ilioischial line is located in zone 3 of the medial acetabular wall in 65.7% of cases and posterior to the medial acetabular wall in 91.9% of cases.