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Review Article

Simple guidelines for evaluating intraoperative alignment after the reduction of intertrochanteric fractures

Yong-Cheol Yoon [a, 1], Jinil Kim [b, 1], Jae-Woo Cho [b], Won-Tae Cho [c], Hyung-Jin Kim [d], Jong-Keon Oh [b, *]

[a] Orthopedic Trauma Division, Trauma Center, Gachon University College of Medicine, Incheon, Republic of Korea
[b] Department of Orthopedic Surgery, Korea University Guro Hospital, College of Medicine, Korea University, Seoul, Republic of Korea
[c] Department of Orthopaedic Surgery, Ajou University School of Medicine, Gyeonggi-do, Republic of Korea
[d] Department of Orthopaedic Surgery, Hallym University Dongtan Sacred Heart Hospital, Gyeonggi-do, Republic of Korea

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SUMMARY

The incidence of intertrochanteric femoral fractures has rapidly increased with the extended lifespan of the elderly population. Surgery enables early ambulation by achieving anatomic reduction and stable internal fixation. However, reduction usually involves postoperative evaluation. Here, we present reliable parameters obtained from analyses of three-dimensional computed tomography images from cadavers to serve as guidelines during the reduction of intertrochanteric fractures.

We included 184 three-dimensional modeling samples from cadavers placed in two standardized positions, similar to C-arm imaging. We recorded the level of the orthogonal line from the greater trochanter (GT) tip to the femoral head (GT orthogonal line [GTOL]) in the anteroposterior view and the line along the anterior femoral cortex passing through the femoral head (anterior cortical line) in the axial view. Correlations between these lines and angular alignments were statistically determined.

The GTOL passed above the femoral head center at mean 2.36 mm in all patients; 77.17% of such instances were in the upper second quadrant of the femoral head. The anterior cortical line passed under the femoral head center at mean 10.82 mm; 73.37% of such instances were in the inferior one-third of the femoral head. Consistent correlations were found between the GTOL and neck-shaft angle and between the anterior cortical line and anteversion.

The GTOL and anterior cortical line passed through a constant level of the femoral head in most samples and were correlated with angular alignments. The intraoperative use of these simple imaginary lines improves the intertrochanteric fracture reduction quality.

1. Introduction

Intertrochanteric fractures are fairly common injuries in the elderly.[1] The percentage of elderly individuals with osteoporosis has been increasing, which is likely to continue for many years. In 1997, Gullberg et al[2] estimated that the incidence of hip fractures worldwide would double to 2.6 million cases by 2025 and to 4.5 million cases by 2050. Hip fractures are the most frequently operated fractures because surgical treatment offers advantages including decreased mortality, improved function, preservation of hospital beds, and greater patient mobility.[3] Revision surgery after fixation failure leads to a dramatic increase in postoperative mortality and morbidity. Thus, the so-called single-shot surgery is imperative for successful treatment.[4,5]

The factors to consider for successful treatment are fracture pattern, bone quality, reduction quality, and optimal implant positioning,[6] among which fracture pattern and bone quality are beyond the surgeon's control. The surgeon's role for a successful, stable fixation is limited to achieving accurate reduction and ideal implant positioning to ensure maximum construct stability. Although optimal implant positioning has been investigated in detail, reduction quality has not been extensively studied.[7]

* Corresponding author. Department of Orthopedic Surgery, Korea University Guro Hospital, College of Medicine, Korea University, 148, Gurodong-ro, Guro-gu, 08308, Seoul, Republic of Korea.
E-mail address: jkoh@korea.ac.kr (J.-K. Oh).
[1] Yong-Cheol Yoon and Jinil Kim contributed equally to the present work.

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Currently, few published standards exist for evaluating reduction quality in intertrochanteric fractures. Kyle et al[8] suggested criteria for angular alignment and displacement of proximal fragments on the anteroposterior (AP) and lateral views. These guidelines involve measuring the angular alignment, which may be suitable for retrospective assessments. We usually evaluate reduction quality by noting the continuity of the medial and anterior cortices and fracture gap using C-arm fluoroscopy during surgery. Furthermore, we assess both the neck-shaft angle (NSA) (also called the angle of inclination) and anteversion (also called the femoral neck version) to restore normal alignment. In various studies, the average NSA and anteversion were 120–135° and 10–15°, respectively.[9–13] Intraoperative evaluations of cortical continuity and fracture site gap are relatively accurate. However, these parameters require measurement of the angles, which is complex and time-consuming during surgery. In practice, surgeons estimate these parameters through subjective assessment without attempting to obtain accurate measurements, resulting in unrecognized malreduction or misinterpreted reduction.

To prevent such problems, we suggest using two imaginary lines as simple and intuitive guidelines for evaluating the alignment of the proximal femur under intraoperative C-arm fluoroscopy. We hypothesized that a constant relationship would exist between these lines and the femoral head; therefore, we investigated their correlations with known angular parameters to ascertain their relevance in predicting proximal femur alignment. We suggest using these lines as criteria for assessing the accuracy of reduction alignment, serving as an easy-to-use intraoperative modality.

2. Methods

We collected 187 three-dimensional (3D) models of adult femurs (98 cadavers). Samples were obtained from cadavers using computed tomography (CT) scans with 1-mm-thick slices. Only fully mature individuals aged >18 years at the time of death were included. We excluded three samples that appeared anatomically abnormal on gross inspection (suspicious history of fracture and malunion [n = 2], malformed femoral head and neck [n = 1]). Thus, 184 total femurs (98 cadavers) were available for the study. Table 1 summarizes the demographic data. The study design and data collection were approved by our hospital's Human Experimental and Ethics Committee. Patients and/or their families were informed that data from their case would be submitted for publication, and each provided consent.

Using a 3D software (Mimics v16.0; Materialise, Belgium), each sample was placed in two standardized positions—AP and axial views—similar to intraoperative C-arm fluoroscopy. To achieve the AP position, we first placed the 3D model of the femur in the supine position on an imaginary flat plane, and then rested it on the convex surfaces of the medial and lateral condyles distally and on the greater trochanter (GT) proximally on the same plane. Posterior condyles were superimposed in the true lateral view. The same AP view as that seen on the C-arm image could be obtained by positioning the 3D model upright at 90° and rotating it 90° horizontally. To achieve the axial position, we again placed the 3D model of the femur in the supine position on an imaginary flat plane, as previously mentioned, and then rotated it. The degree of rotation was determined by considering the actual intraoperative C-arm fluoroscopy image. Braten et al[14] reported that construction of the traction table limited the approach angle during C-arm fluoroscopy in the range of rotation to the long axis of the femoral shaft. When the angle between the long axis of the femoral shaft and the horizontal beam of the C-arm was within 45–60°, the angle between the femoral shaft and the central neck head axis was not significantly different from the actual anteversion angle. We considered a 45° angle of rotation as a representative value for this study (Fig. 1).

In the AP view, we measured the relationship between the level of the tip of the GT and the femoral head.[15–17] An anatomical axis of the femur was placed along the long axis of the femoral shaft (mid-diaphyseal femoral axis). The GT orthogonal line (GTOL) was defined as the orthogonal line perpendicular to the anatomical axis of the femur and passing through the level of the tip of the GT (Fig. 2). The center of the femoral head was determined using templates of concentric circles. The vertical distance between the center of the femoral head and the GTOL was calculated. We recorded the vertical distance (lines above the center of the femoral head were arbitrarily positive, whereas those below it were negative) and the percentage as a standardization by considering the superior margin as 0% and the inferior margin as 100%. We then divided the femoral head into four zones and kept track of the included 3D models in each zone. We additionally measured the NSA to determine its correlation with the GTOL.

In the axial view, we measured the relationship between the anterior cortical line and the femoral head. First, we defined the anterior cortical line as a continuous imaginary line along the anterior cortex of the femoral shaft from the distal to proximal ends (Fig. 3). This line passed along the transitional point, transforming the geometric slope of the proximal femur from a downward to an upward slope in the neck–shaft junction and then extended to the femoral head. We recorded the levels of the lines passing in the femoral head, the vertical distance from the center of the femoral head (lines below the center of the femoral head were arbitrarily positive, whereas those above it were negative), and the percentage as a standardization from the superior (0%) to inferior (100%) ends. We divided the region of the femoral head into three zones and kept track of the included 3D models in each zone. Anteversion was achieved based on descriptions by Toogood et al[9] and measured from a true lateral view, with the femoral shafts abducted, which allowed the axis of the femoral neck to be parallel to the visual level. The angles above this plane were arbitrarily negative, whereas those below it were positive. The anteromedial cortical line is the most important and fundamental parameter for the intraoperative assessment of reduction adequacy; therefore, surgeons should ensure correct medial and anterior alignment of the fracture.

The average values and ranges were calculated for each measurement. We analyzed the distribution in each dividing zone. Student's paired t-test was used to establish the significance of any differences. Pearson's correlation coefficients were calculated to examine the correlation between variables (GTOL and NSA, anterior

Table 1
Demographic data of the cadavers.

		Original number of femurs	Number of abnormal femurs	Final number of femurs	Mean age (years)	Age range (years)
Males	Left	46	0	46	50.6	21–60
	Right	46	3	43		
Females	Left	49	0	49	53.8	27–60
	Right	46	0	46		
Entire population		187	3	184	52.3	21–60

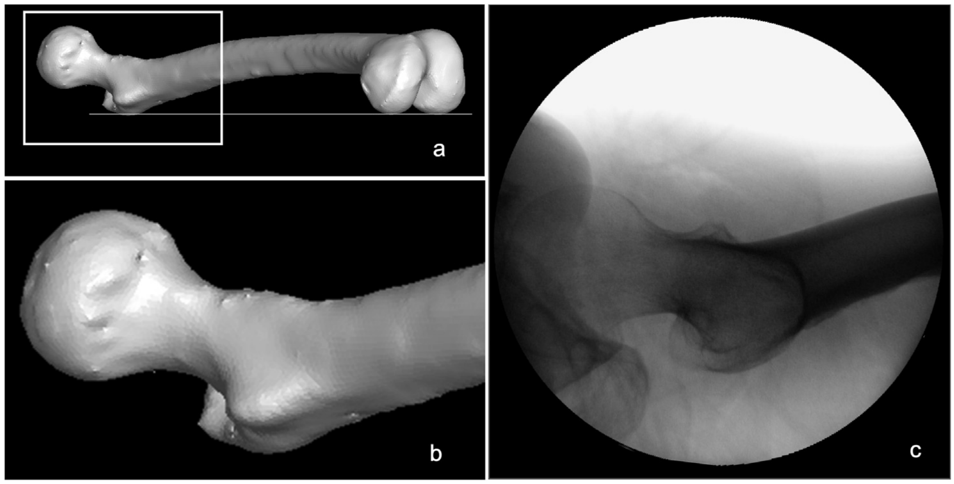

Fig. 1. a) A three-dimensional (3D) model placed in the standard axial view. Posterior condyles are superimposed in the lateral view. The proximal part of the femur (around the greater trochanter) rested on the imaginary table at the same level of the distal posterior condyle and is rotated 45° on a vertical axis to the ground. (b) Reconstructed image from the 3D model. (c) Actual image from the axial image of C-arm fluoroscopy taken intraoperatively. The images show great similarity to each other.

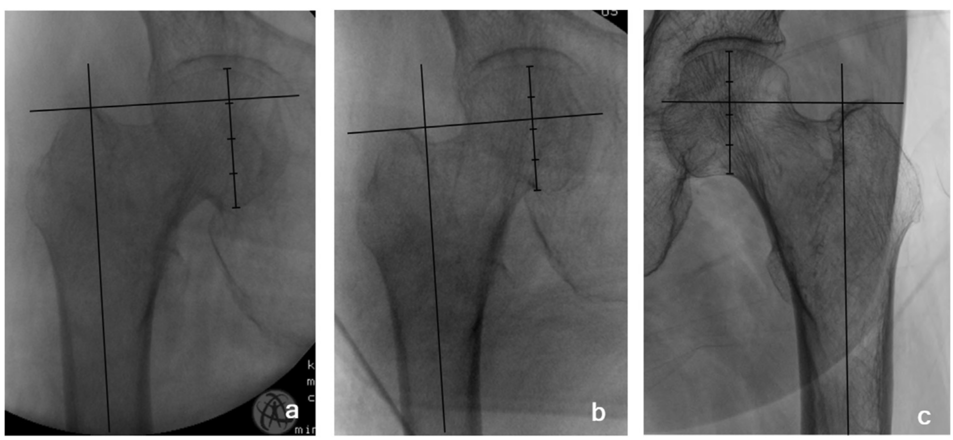

Fig. 2. (a) Initial anteroposterior image of a 78-year-old woman showing good contact and continuity of the medial cortex. The greater trochanter orthogonal line (GTOL) passed through the upper first quadrant of the femoral head. (b) We applied more longitudinal traction to adjust the level of the GTOL to pass through the upper second quadrant of the femoral head. (c) The operated and contralateral sides look similar.

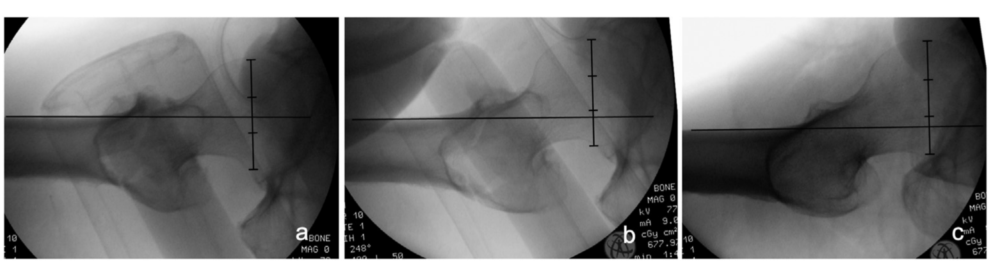

Fig. 3. (a) Initial axial image of an 86-year-old man showing good contact and continuity of the anterior cortex. The anterior cortical line passed through the middle one-third of the femoral head. (b) We pushed from the anterior side to adjust the level of the anterior cortical line to pass through the inferior one-third of the femoral head. (c) The operated and contralateral sides look similar.

cortical line and anteversion). A value of $p < 0.05$ was considered statistically significant, and SPSS software (version 20.0; SPSS Inc., Chicago, IL, USA) was used for all statistical analyses.

3. Results

The overall results are summarized in Table 2.

3.1. GTOL

The GTOL generally passed above the center of the femoral head at mean 2.36 (−9.99~11.31) mm in all samples. No significant difference was observed between sexes ($p = 0.089$). Furthermore, the GTOL passed through the femoral head at mean 44.65% (25.49~73.94%) in all samples. After dividing the femoral head into

Table 2
Summary of measurements of all samples.

	Males	Females	Total	Pearson's correlation coefficient	p-Value
Mean GTOL (mm) [min–max]	2.03 [-7.65-11.13]	2.67 [-9.99-9.93]	2.36 [-9.99-11.31]	0.78	<0.001
Mean GTOL (%) [min–max]	45.7 [25.49–66.36]	43.66 [26.07–73.94]	44.65 [25.49–73.94]		
Mean NSA (°) [min–max]	131.17 [122–137.44]	131.32 [124.66–141.93]	131.25 [122–141.93]		
Mean anterior cortical line (mm) [min–max]	8.81 [-4.64-20.82]	11.23 [-7.73-25.2]	10.82 [-7.73-25.2]	0.84	<0.001
Mean anterior cortical line (%) [min–max]	70.63 [46.57–102.4]	78.19 [32.57–107.03]	74.53 [32.57–107.03]		
Mean anteversion [min–max]	10.17 [-7.5-37.54]	15.07 [-12.49–34.96]	12.7 [-12.49-37.54]		

GTOL, greater trochanter orthogonal line; NSA, neck-shaft angle.

four zones, 77.17% of all samples had the GTOL crossing the upper second quadrant, whereas the other 22.83% had it crossing in the next lower zone. The GTOL crossings in the upper second quadrant represented 74.16% of all crossings in males and 80% of those in females. A significant difference was observed in the distribution among the four zones ($p < 0.001$).

3.2. NSA

The average NSA was 131.25° (122~141.93°), being 131.17° (122~137.44°) in males and 131.32° (124.66–141.93°) in females. No significant difference was observed between sexes ($p = 0.095$). Consistent correlations were found between the GTOL and NSA ($r = 0.78$, $p < 0.001$). In regression analysis between the level of the GTOL and the used NSA, normal NSA (defined as 125–130° according to general consensus in a normal population) was expected when the GTOL passed through the upper second quadrant (26.6~41.4%) of the femoral head (Table 3).

3.3. Anterior cortical line

The anterior cortical line crossed 10.82 (−7.73~25.2) mm below the center of the femoral head and passed through the femoral head at mean 74.53% (32.57~107.03%) of the height. Furthermore, the anterior cortical line passed through the head more inferiorly in females than in males at 2.37 mm and 7.56% of the height. In a zonal distribution, 73.37% of the total crossings were in the inferior one-third, 23.37% in the middle one-third, and 0.54% in the superior one-third. Furthermore, the inferior one-third comprised 85.26% of the total crossings in females and 60.67% of those in males. The difference between sexes was statistically significant ($p = 0.039$).

3.4. Anteversion

The mean anteversion measurements were 12.7° (−12.49~37.54°) in all samples, 10.17° (−7.5~37.54°) in males, and 15.07° (−12.49~34.96°) in females, with a significant difference between sexes. Males had less anteversion than females (mean 4.9°). Consistent correlations were found between the anterior cortical line and anteversion ($r = 0.84$, $p < 0.001$). In regression analysis, the normal range of anteversion (defined as 10–15° according to general consensus in the normal population) was expected when the anterior cortical line passed through the inferior one-third (68.9~77.98%) of the femoral head (Table 4).

Table 3
Regression analysis between GTOL level and expected NSA.

GTOL level (%)	Expected NSA (°)
25	124.62
26.6	125
35	128
41.4	130
45	131.38
55	134.76
65	138.14
75	141.52

GOTL, greater trochanter orthogonal line; NSA, neck-shaft angle.

4. Discussion

This study based on 3D images of cadavers revealed that the GTOL and anterior cortical line can be used as reliable guidelines during the reduction of intertrochanteric fractures. The reduction adequacy during surgery can be deemed acceptable when the GTOL passes through the upper second quadrant and when the anterior cortical line passes through the inferior one-third.

During surgery for intertrochanteric fractures, a decision should be made on whether the reduction quality is acceptable and whether implant fixation should proceed. Although some studies have reported on reduction of intertrochanteric fractures, no acceptable general consensus guidelines have been reported.[15,16] The anterior and medial cortical continuity, fracture gap, and proximal femur alignment are routinely evaluated intraoperatively. Cortical continuity disruption can be relatively clearly evaluated, whereas measurement of alignments, including the NSA and anteversion, is a complex and time-consuming process during surgery. Many authors recommend using contralateral images with C-arm fluoroscopy as a template.[5,6,8] However, this procedure is rarely performed because it includes manipulation of the injured unstable limb to obtain the image, prolonging the operation time. Moreover, in some cases, natural alignment of the contralateral limb cannot be ensured, such as in cases of dysplastic hip, history of previous arthroplasty, or deformed hip due to a previous procedure. In these situations, using a generalized guideline for reproducing the average limb alignment in a normal population may be beneficial. Developing simple and validated criteria for alignment in the normal population can solve this issue.

The GTOL has previously been described as the relationship between the tip of the GT and the center of the femoral head.[17–19] This line can be used during surgery by marking the anatomical axis and orthogonal line on the skin before draping. This can be represented by a guidewire with C-arm fluoroscopy during surgery. Antapur and Prakash[20] found that the center of the femoral head was 9.5 ± 6 mm below the tip of the GT in 82% of the cases. They recommended using the tip of the GT as a reference for restoring the center of the femoral head. Krishnan et al[17] found that the tip of the GT was at a higher level than the hip center in 95% of the hips,

Table 4
Regression analysis of anterior cortical line level and expected anteversion.

Anterior cortical line level (%)	Expected anteversion (°)
66.66	8.73
68.9	10
77.98	15
100	27.14

and Theivendran et al[18] reported that the tip was 3.4 mm proximal to the center of the femoral head. In our study, we found a similar relationship between the tip of the GT and the center of the femoral head; the tip was at a higher level in 77.17% of the total samples and proximal to the center of the femoral head at mean 2.36 mm. Previous studies demonstrated that the GTOL line passed above the center of the femoral head in most cases. Using the zonal distribution, the GTOL passed in the upper second quadrant in most of our samples. The level of the GTOL was significantly correlated with coronal alignment, such as the NSA (r = 0.78, $p < 0.001$). The GTOL passing through the upper second quadrant implied that the coronal alignment is in an acceptable range in the normal population.[21] Additionally, regression analysis showed that the expected NSA of the normal population (125–130°) was calculated using the level of the GTOL (26.6–41.4%) that passed through the upper second quadrant, which is consistent with our recommendation that the GTOL can be used to explain the reliability and reproducibility of such measurements.

We developed a method for evaluating the quality of anteversion correction. No consensus exists yet for evaluating the reduction quality in axial alignment. The anterior cortical line—a simple diagnostic tool using only one guidewire—had the strongest correlation with anteversion (r = 0.84, $p < 0.001$) and was correlated with the expected anteversion of the normal population when it passed through the inferior one-third of the femoral head. Laage et al[22] performed horizontal lateral radiography of the proximal femur and indicated that this method would be useful in the intraoperative determination of anteversion. Braten et al[14] reported a correlation between the autonomous angles on intraoperative fluoroscopy and the actual anteversion in anatomical studies. They concluded that fluoroscopic determination of anteversion had sufficient accuracy. Hawi et al[23] studied the use of a mobile image intensifier with CT to intraoperatively measure antetorsion. Many studies have used methods that could accurately assess anteversion; however, these methods were limited in that they required specialized instruments or several steps to measure the angles. In our study, the anterior cortical line was highly correlated with anteversion, which was comparable to the methods used in other studies and superior in terms of simplicity and rapidity during surgery. Furthermore, the anterior cortex is rarely associated with comminuted fractures in actual clinical circumstances and can be easily observed on image intensifier images; therefore, setting the anterior cortex as the reduction guideline is suitable.

It is essential to apply our proposed guideline to actual surgery.[24] Although the GT is involved, its tip is recognizable in most cases and the fracture line commonly originates between the GT tip and the vastus ridge and extends to the lesser trochanter.[25,26] Additionally, despite the age-related reduction in the NSA, using the GTOL is still feasible in actual practice owing to the correlation between the GTOL and NSA.[27] Interpreting the image intensifier images is paramount. For consistent (image intensifier) images, they should be taken while maintaining the same distance and angle between the image intensifier and the injured limb after measuring the distance, and surgery should be performed by setting the femoral neck as the center in the AP and axial views to minimize image distortion. Moreover, adopting a fluoroscopic navigation system using a computer will enable a more accurate assessment of the reduction status and fixation stability.[28]

Yoon et al[29] used an image intensifier for intraoperative evaluation of 106 patients with intertrochanteric fractures and classified

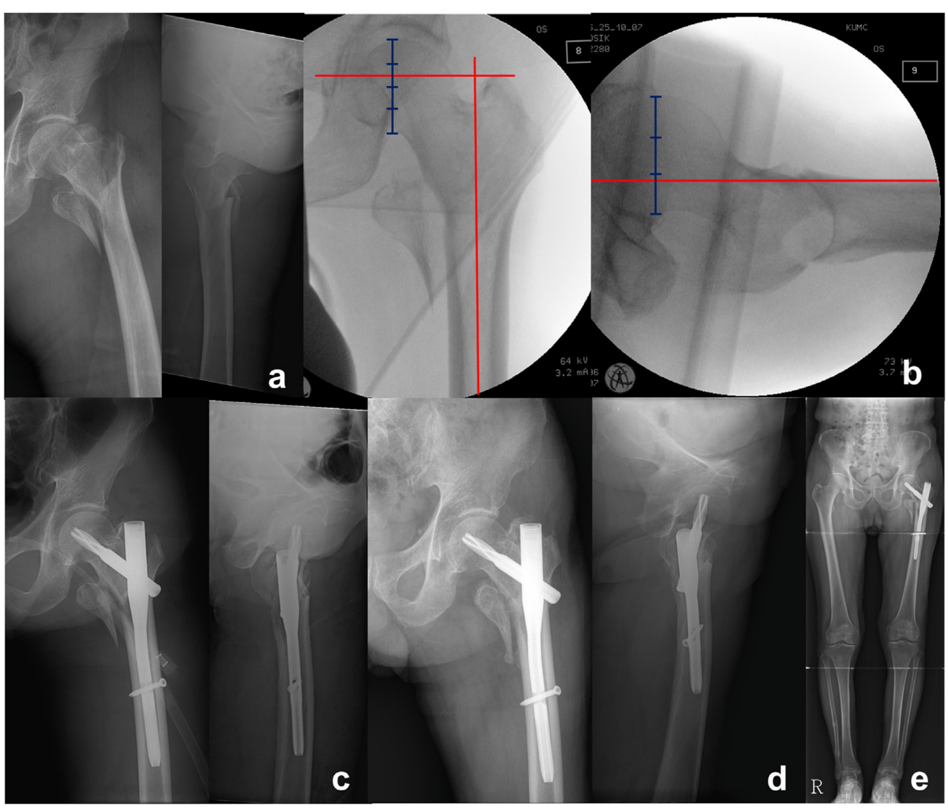

Fig. 4. (a)An AO-OTA A2 intertrochanteric fracture in a 75-year-old male patient who visited the hospital because of a slip down. (b) The closed reduction was determined to be acceptable, with restored anteromedial continuity, as the greater trochanter orthogonal line was in the upper second quadrant of the femoral head in the anteroposterior view and the anterior cortical line was in the inferior one-third of the femoral head in the axial view. (c) After the surgery, the reduction was stably maintained and firm fixation was achieved with intramedullary nailing (d, e) Bone union was achieved without any special complications up to 1 year after the surgery.

them into the optimal/acceptable/unacceptable groups based on the three guidelines: anteromedial continuity, GTOL with the NSA, and anteversion. They conducted a comparative analysis on clinical outcomes in each group and reported a $\geq$40% incidence of resurgery and two or more times more excessive sliding in the unacceptable group than in the optimal and acceptable groups. This validates the clinical significance of our experimental results and confirms that recovery of the GTOL and anteversion are key factors for successful surgery of intertrochanteric fractures (Fig. 4).

Our study had several limitations. First, contrary to the GTOL, the anterior cortical line differs between sexes; therefore, its practical use can be problematic. There was a greater proportion of the distribution in the middle one-third in males than in females (38.20% versus 9.47%), indicating that more samples from males had less anteversion than those from females, which corresponded to the general consensus of a sex-based difference in anteversion.[30] When applying the method of this study in male patients, it must be carefully monitored whether the anteversion is excessive. It was helpful to evaluate anteversion using the comprehensive methods employed in previous studies in which anteversion of the opposite leg was measured in advance. Second, 22.83% of the total GTOL crossings and 26.63% of the total anterior cortical line crossings had an eccentric distribution. In this group, the unexpected distribution meant that they had their own inherited alignment that was outside that of the normal population's average. If we adjusted their alignment into the normal population's average, they would have lost their own alignment. Nevertheless, we were able to achieve an acceptable range of reduction and alignment, as Kyle et al[8] previously described, and could expect good outcomes. This study included a relatively young population aged 21–60 years. Therefore, decreases in the NSA and anterolateral bowing of the femoral diaphysis due to age may exist; however, the GTOL sufficiently reflects age-related deformity, as a significant correlation was observed between the NSA and GTOL.[31] Future prospective studies with more cases based on diverse ethnic groups are required.

5. Conclusion

The GTOL and anterior cortical line correlated with angular alignment of the proximal femur in the coronal and axial planes. These lines can be easily represented using only a guidewire placed superficially on the skin. Accordingly, these lines can be used intraoperatively as a simplified and accurate tool for predicting alignment after the reduction of intertrochanteric fractures.

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Declaration of competing interest

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