The influence of sagittal angle of posterior malleolus fracture on ankle joint stability—a retrospective study of 87 cases

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Research Article

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Abstract

Background

Previous studies have studied more factors on the ankle stability of the posterior ankle fracture, which is related to a stereostructure of the fracture fragment. Previous studies have shown that the ankle stability may be affected by the sagittal surface of the fracture block, with less research in this field. The aim of this study was to explore the influence of the sagittal angle(SA) on ankle joint stability by scanning and reconstructing three types of posterior malleolus fractures(PMFs) with different sagittal angle (SA).

Methods

The CT data of 87 patients with PMFs were collected retrospectively and reconstructed. PMFs were divided into three types: posterolateral-oblique type (type I), medial-extension type (type II) and small-shell type (type III).The collected sagittal angle data were statistically analyzed with the posterior fragment area, fragment area ratio (FAR), fragment transverse diameter ratio (FWR), fragment length ratio (FLR), fragment height (FH), and contact area (CA).

Results

(1)SA was positively correlated with posterior fragment area($r = 0.804, P < 0.01$),with regression equation $s = 0.085 \times SA + 0.34$;(2)SA was positively correlated with FAR($r = 0.392, P < 0.01$),with regression equation $FAR = 0.004 \times SA + 0.092$;(3)SA was positively correlated with FWR($r = 0.261, P < 0.05$), with regression equation $FWR = 0.03 \times SA + 0.4624$;(4)SA was positively correlated with FLR($r = 0.481, P < 0.01$), with regression equation $FLR = 0.05 \times SA + 0.209$;(5) SA was positively correlated with CA ($r = 0.474, P < 0.01$),with regression equation $CA = 7.942 \times SA + 160.866$;(6)SA was positively correlated with FH($r = 0.474, P < 0.01$), with regression equation $FH = 0.046 \times SA + 1.406$.

Conclusion

The sagittal angle was positively correlated with posterolateral-oblique type (type I) of Posterior malleolus fractures, and SA could be considered to reflect the ankle joint stability of PMFs.

Level of evidence: Level III, retrospective comparative study.

Background

In the past decade, more and more attention has been paid to the ankle injury with Posterior malleolus fracture (PMF) [1, 2]. PMF is a fracture extending from the infrafibular notch to the posterior edge of the distal tibia. The important premise of maintaining ankle stability is the complete structure of posterior ankle. At present, many biomechanical studies have evaluated the effect of PMF in stabilizing ankle. Studies have shown that the stability of the ankle joint is affected by bones and ligaments. When the posterior ankle fracture, if the fracture block is too large, it can cause the displacement of the distance

and then cause serious ankle instability[3]. Thus, the size of posterior fragment may be the most important determinant of ankle joint stability and some clinical and biomechanical features of PMF are important for ankle joint stability such as contact area and posterior fragment area [4, 5]. At present, it is found that [6] SA is positively correlated with the contact area, and negatively correlated with the maximum contact stress and relative displacement. However, as a three-dimensional structure, the posterior fragment may have different effects on the sagittal plane due to the influence of fragment area, height and length. In addition, Wang et al. [7] found that as the fragment height increased on the sagittal plane, the posterior fragment area and posterior fragment area ratio on the cross section also increased, thus affecting the stability of the ankle joint. The sagittal angle is an important factor to reactive the posterior fragment on the sagittal plane. Therefore, it is necessary to explore the correlation between SA and posterior fragment area, fragment area ratio (FAR), fragment transverse diameter ratio (FWR), fragment length ratio (FLR), fragment height (FH) and contact area (CA). Because the ankle joint is a very flexible joint of the whole body, its position will change with the change of different posture. Different fracture types have different effects on the contact pressure displacement of the ankle joint, resulting in different effects on the stability of the ankle joint. The anatomical morphology of the fracture line of the posterior malleolus was studied based on CT data, Haraguch et al.[8]divided the fracture types involving the posterior malleolus into posterolateral-oblique type (type I), medial-extension type (type II) and small-shell type (type III) (Fig. 1. a, b and c). Therefore, this study analyzed the correlation between SA of three types of PMFs and the posterior fragment area, fragment area ratio, fragment transverse diameter ratio, fragment length ratio, fragment height and contact area to explore whether SA could influence the ankle joint stability of PMFs.

Figure 1 Based on the orientation of the fracture line of the posterior malleolus shown by the CT image at the level of the articular surface of the distal tibia, PMFs were divided into three types: type I was posterolateral-oblique type, and fracture fragment was wedge-shaped, involving the posterior outer angle (a); Type II was medial-extension type. The fracture line extended from the fibular notch to the medial malleolus, the posterior malleolus was divided into posterior outer and posterior inner parts (b); Type III was a small-shell type, which was characterized by a small-shell type bone fragment at or above the posterior edge of the distal tibia (c)

Materials And Method

Materials

The complete CT data provided by the radiology department of The Affiliated Traditional Chinese Medicine Hospital of Southwest Medical University from January 2010 to January 2020 were collected (No. KY2018043). All data were measured by two clinicians, and the final results were averaged. There were 87 patients with PMFs including 53 male patients (60.9%) and 34 female patients (39.1%). All patients were aged 18-82 years and the average age was 45 years. All cases of ankle joint were scanned by Spiral CT scanner (Siemens AG, Munich, Free State of Bavaria) for plain cross-sectional scanning, and

reconstructed CT sagittal plane and cross section based on three-dimensional imaging. The scanning layer was 2mm thick.

Inclusion criteria: (1) the patients were older than 20 years old and less than 60 years old; (2) the patients suffered from posterior malleolus fracture, and pathological fracture was excluded; (3) the CT data of the patient were clear. Exclusion criteria: (1) the patients with poor quality of CT imaging data; (2) the patients with old ankle injury.

Imaging data measurement

Measurement of Sagittal angle (SA) (Fig.2.a) and fragment height (FH) (Fig.2.c)

Based on the reconstructed images of CT, a neutral axis (NA) was selected according to bisection of the midshaft of the tibia. And the major fracture line of posterior fragment was drawn at the highest point(A) and lowest point(B) of posterior fragment on the sagittal plane. SA was measured relative to NA and major fracture line. Making a parallel line with NA at point A, the height between point A and the point that was a cross of the posterior fragment and the NA' was FH.

Measurement of posterior fragment area (s) and fragment area ratio (FAR) (Fig.2.b)

According to the definition of the posterior malleolus fragment (PMF) involving posterolateral fragment at the distal tibia and fibula in the cross section and the overall posterior malleolus fragment split from outside to inside [6,9], the posterior fragment area (s) and remaining area of the tibial plafond(S) were measured by the PACS system. The fragment area ratio (FAR) was the ratio of the fragment area(s) to the total cross-sectional area of the tibial plafond (s +S).

Measurement of fragment length ratio (FLR) (l / L) (Fig.2.d) and fragment transverse diameter ratio (FWR) (w / W) (Fig.2.e)

The distance from the center of fibula to the distal tibia was bimalleolar axis on the cross section. Making parallel lines with bimalleolar axis on the anterior lip (BA') and posterior lip (BA'') of the tibia, the distance between BA' and BA'' was L, and the distance between BA and BA'' was l. FLR was the length of the fragment(l) to the capital diameter of the tibial plafond(L) ratio. Making vertical lines of the bimalleolar axis at the lateral end and the medial end of the tibia, the distance between the vertical line at the medial end and the vertical line at the lateral end was W, and the distance between the vertical line at the lateral end and the innermost point D was w. FWR was the horizontal distance of fragment(w) to the horizontal distance of tibia(W) ratio on the coronal plane of tibia.

Measurement of contact area (CA) of fracture fragment (Fig.2.f)

Based on CT three-dimensional reconstruction images, the reconstructed posterior fragment was intercepted and CA was measured.

Figure 2 The sagittal angle (θ) was measured (a) and fragment height(FH) was the largest distance between A and B (c)on the sagittal plane; the posterior fragment area (s) was measured by the PACS system and the fragment area ratio (FAR) was determined by calculating the percent of area(s)/area(s+S)(b);The fragment length ratio (FLR) was determined by calculating the percent of length (l)/ length (L)(d);The fragment transverse diameter ratio(FWR)(w/W) was determined by calculating the percent of diameter (w)/diameter(W)(e);the contact area (CA) was measured(f)

Statistical analysis

All data were collected and sorted by EXCEL software, and all data were input into SPSS 20.0 software for analysis. The correlations between sagittal angle and posterior fragment area, posterior fragment area, fragment length, fragment length ratio, fragment transverse diameter ratio, contact area were analyzed by pearson correlation analysis. The P value of $P < 0.05$ meant the difference was significant statistically. If there was a linear correlation between them and the correlation equation was obtained by simple regression analysis.

Results

Clinical results

Using the classification in the study of Haraguch, there were 58 cases of type I (66.67%), 12 cases of type II (13.79%) and 17 cases of type III (19.54%). Through the correlation analysis of the sagittal angle of the three types of posterior malleolus fractures with the posterior fragment area, FAR, FLR, FWR, FH and CA, it was found that only type I fractures had correlation and the rest had no correlation. In the analysis of imaging parameters of 58 type I patients, SA was from 0.6° to 69.3° and FH was from 0.92cm to 4.74 cm; CA was from 33.5 mm^2 to 501 mm^2 ; the posterior fragment area was from 0.81 cm^2 to 6.59 cm^2 ; FAR was from 4.7–52.7% and its average was 16%; FLR was from 7.6–61.8% and its average was 29.8%; FWR was from 24.7–77.8% and its average was 51%.

Data analysis

The sagittal angle data of 58 patients with type I and posterior fragment area were put into SPSS 20.0. Taking sagittal angle as X axis and the posterior fragment area, posterior fragment area ratio, fragment height, fragment length ratio, fragment transverse diameter ratio, contact area as Y axis, the scatter plots were created. And pearson linear correlation analysis was used to verify the correlation and obtain the correlation equation. It could be seen that type I had highly correlation, and SA was positively correlated with the posterior fragment area ($r = 0.804$, $P < 0.01$)(Fig. 3.a),the linear regression equation was obtained through simple regression analysis: $s = 0.085 \cdot \text{SA} + 0.34$. Besides, SA was positively correlated with FAR($r = 0.392$, $P < 0.01$)(Fig. 3.b), the linear regression equation was obtained through simple regression analysis: $\text{FAR} = 0.004 \cdot \text{SA} + 0.092$. SA was positively correlated with FH($r = 0.474$, $P < 0.01$)(Fig. 4.a), the linear regression equation was obtained through simple regression analysis: $\text{FH} = 0.046 \cdot \text{SA} + 1.406$. SA was positively correlated with FLR ($r = 0.481$, $P < 0.01$) (Fig. 4.b), the linear regression equation was

obtained through simple regression analysis: $FLR = 0.05 \cdot SA + 0.209$. SA was positively correlated with FWR ($r = 0.261$, $P < 0.05$) (Fig. 5.a), the linear regression equation was obtained through simple regression analysis: $FWR = 0.03 \cdot SA + 0.462$. SA was positively correlated with CA ($r = 0.474$, $P < 0.01$) (Fig. 5.b), the linear regression equation was obtained through simple regression analysis: $CA = 7.942 \cdot SA + 160.866$.

Discussion

The current studies confirmed that ankle joint was a joint composed of tibia, fibula, talus and shin bone [9]. With an incidence of about 10%, ankle fracture was a common injury in all fractures. PMF accounted for 10% – 44% of the total number of ankle fractures [5, 7, 10, 11], and osteoarthritis caused by posterior ankle fracture could lead to cartilage injury and ankle instability caused by improper fragment reduction and trauma. Clinically, there were many types of ankle fractures, and anatomical structures were complex. There were also many ankle methods, X-ray was a common method in the diagnosis of fracture types and the measurement of posterior malleolus fragment. Its remarkable feature was cheap, simple and fast [12]. However, due to the complex anatomical structure of the ankle, the detection rate of ankle fracture by X-ray was reduced and it could cause 34% of PMFs underestimated [13]. Many studies had shown that [12, 14–18], for the measurement of posterior fragments, lateral X-ray was inferior to CT scanning in repeatability, reliability and accuracy. CT scanning enabled to better understand the anatomical structure of posterior fragments and the images of CT scanning were used as the basis for classification and surgery [19]. Therefore, the sagittal angle and posterior fragment area, fragment area ratio, fragment transverse diameter ratio, length ratio, fragment height and of PMFs were measured by CT scanning and contact area was measured based on CT three-dimensional reconstruction.

At present, many studies [20, 21] focused on the influence of posterior malleolus fragment size on cross-sectional ankle joint stability. The study showed that when the posterior fragment was less than 10% of the articular surface, there would not be joint unevenness, and the effects of surgery and conservative treatment were good; When the posterior fragment was greater than or equal to 10%, the size and fixation of the fragment were prognostic factors [21]. Especially when the minimum displacement fracture of the posterior ankle involves 50% of the articular surface, the patient may further develop towards internal fixation [9, 22, 23]. Therefore, for patients whose posterior fragment was greater than or equal to 10%, the joint flatness could be restored by surgical treatment. Traditionally, the posterior fragment involved more than 25% of the articular surface and displaced more than 2 mm, it could be used as an indication for surgery [2, 24, 25]. According to the research of Hartford [9], it was found that the area of posterior fragment with the size of 25%, 33% or 55% accounts for 4%, 13% and 22% respectively, which affected the stability of ankle joint.

But in fact, the posterior fragment was a three-dimensional structure, which had different effect on the sagittal plane due to the influence of area, height and length. Through the retrospective analysis of CT data of 650 patients with PMFs, Luo et al. proposed the definition of SA of posterior fragment on the sagittal plane. Sagittal angle (SA) of PMF is the included angle measured on the sagittal plane of posterior fragment relative to the posterior fracture line and the neutral axis and proposed that SA can be

used as an ideal factor in evaluating the three-dimensional size of posterior fragment. At present, it was found that SA could not only be related to the height, length and height of the posterior fragment, but also highly related to the contact area of the joint surface [20, 26–28]. However, there was a lack of research on the sagittal angle on the sagittal plane and the morphological characteristics on the cross section. Since PMFs were clinically divided into posterolateral-oblique type (type I), medial-extension type (type II) and small shell type (type III), this study discussed the correlation between SA on the sagittal plane and the posterior fragment area, FAR, FLR, FWR on the cross section, and this study discussed whether there was correlation between SA and FH on sagittal plane. The results showed that sagittal angle was positively correlated with posterior fragment area, posterior fragment area ratio, fragment length ratio, fragment transverse diameter ratio, fragment length ratio height and contact area. With the increase of sagittal angle, the contact area gradually increased to close to the normal contact area, which was 483.55mm^2 . Therefore, it can be seen that posterior fragment fracture involving type I is a three-dimensional anatomical structure, and the sagittal angle on the sagittal plane is highly correlated with the morphological characteristics on the cross section. SA could be considered to reflect the ankle joint stability of PMFs.

However, there are still several limitations in this study. The sample size of type II and type III in this study is small, which may also affect the measurement results, resulting in no correlation. In addition, some studies showed that the sagittal angle also had a correlation with the maximum stress of the ankle joint. This study did not study the relationship between sagittal angle and cross angle, relative displacement and maximum stress, they should be considered in further research.

Conclusion

The sagittal angle was positively correlated with posterolateral-oblique type (type I) of Posterior malleolus fractures, With the increase of sagittal angle, the posterior fragment area, fragment area ratio, fragment transverse diameter ratio, fragment length ratio, fragment height, and contact area gradually increased. Thus, SA could be considered to reflect the ankle joint stability of PMFs. In the clinical study of the influence of posterior ankle fracture on ankle stability, it should be considered that the posterior is a three-dimensional structure. Not only the influencing factors should be considered on the cross section, but also the influence of sagittal angle should be paid more attention on ankle stability.

Abbreviations

SA: sagittal angle; FAR: fragment area ratio; FWR: fragment transverse diameter ratio; FLR: fragment length ratio; FH: fragment height; PMFs: posterior malleolus fractures; CT: computed tomography; NA: neutral axis.

Declarations

Author contribution All the authors mentioned above participated in the experiment of this study and the completion of the article.

Ethics and consent to participate

Since our study is a retrospective study, we only need to obtain the patient's informed verbal consent without informed written consent, and we can access the patient's relevant data with the consent of the Ethical Committee of The Affiliated Traditional Chinese Medicine Hospital of Southwest Medical University. The ethics committee that approved our study did not waive informed consent, but rather we only required verbal informed consent from the patient. Approval was granted by the Ethical Committee of The Affiliated Traditional Chinese Medicine Hospital of Southwest Medical University (No. KY2018043). All methods were performed in accordance with the relevant guidelines and regulations.

Consent for publication:

Not applicable

Availability of data and materials

The datasets used and analyzed during the current study are available from the corresponding author on reasonable request, and we are willing to share the research data after the article is published.

Competing interests

The author(s) received no financial support for the research, authorship, and/or publication of this article.

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Authors' contributions

Conceptualization LZ and YY; Methodology YY; Validation FS; Investigation XP; Resources JX; Writing-Original Draft preparation LZ, YY and FS; Formal analysis JX and XS; Project administration RZ and DW; Writing-Reviewing HC; Editing BX. All authors read and approved the final manuscript.

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Figures

Figure 1

Classification of PMFs

Figure 2

CT scanning and 3D reconstruction of PMFs

Figure 3

The scatter plot of posterior fragment area and sagittal angle (a),the scatter plot of posterior fragment area ratio and sagittal angle (b)

Figure 4

The scatter plot of fragment height and sagittal angle (a),the scatter plot of fragment length ratio and sagittal angle (b)

Figure 5

The scatter plot of fragment transverse diameter ratio and sagittal angle (a),the scatter plot of contact area and sagittal angle (b)