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Original Article

The CT morphological characteristics and the clinical management strategy of posterior malleolar fractures with talar subluxation

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Abstract: Background: The optimal clinical treatment and the computed tomography (CT) morphological characteristics of posterior malleolar fractures (PMF) with talar subluxation remain inconclusive. Clinically, both plate screws and lag screws are widely used to fix posterior malleolar fragments using a direct or indirect approach. We sought to summarize the morphological characteristics and modified classification on the basis of CT and the intraoperative strategy for posterior talar subluxation in PMF. Methods: Retrospectively, 46 adult PMF patients with subluxations of the talus were recruited as the study cohort. According to its morphological features, PMF with subluxation of the talus can be divided mainly into two types using this modified classification: a complete fracture (the single-fragment type) and PMF with two-angled fracture fragments (the double-fragment type). The cohort's demographic information, classifications, fracture morphology, fixation methods, pain levels, and functional scores were recorded for both fracture types. Results: The average values of the depths and heights of the posterior malleolar fragments were (29.1±7.3) mm for the single-fragment type and (17.9±4.2) mm for the double-fragment type. There was a significant difference in the mean values between the two types ($P < 0.05$). Posterior plate fixation was suitable for the single-fragment type, while antero-posterior and postero-anterior (AP-PA) lag screws fixations were made available for the double-fragment type. Both methods achieved good results. No significant differences were found in terms of sex, age, body mass index (BMI), side, Haraguchi classification, Bartoníček and Rammelt classification, Visual Analog Scale (VAS) scores, or American Orthopedic Foot & Ankle Society scores (AOFAS) when comparing the single-/double-fragment type groups after the mid-term follow-up ($P > 0.05$). Conclusion: According to the injury mechanism and the morphological characteristics of the fractures, the proposed improved classification system for PMF with subluxation of the talus based on the injury mechanism and the fracture morphology can provide guidance for surgical management strategies and achieve optimal outcomes.

Keywords: Ankle fractures, posterior malleolus, talus subluxation, classification, treatment

Introduction

Ankle fractures (AFs) are a major lower limb fracture, second only to hip fractures, accounting for 10% of all fractures [1]. Posterior malleolar fractures (PMFs) account for about 7%-44% of AFs [2-4]. The incidence of PMF is on the rise, especially among women over 65 years of age. [5]. An AF associated with a posterior malleolus (PM) fragment is generally considered to have a poorer prognosis than other AFs [6]. Major factors for the prognosis of AFs include the location of the AFs and the impact of the lower tibiofibular joint, in addition to the size of the PM bone [3, 7, 8]. According to the clinical and biomechanical studies assessed by Odak et al. [2], the fragment morphology, the fracture displacement, the subluxation of the talus, and the articular incongruence are considered to be the major factors for determining the final endpoint of PMF.

PMFs have been classified according to their morphological characteristics and their fracture mechanisms. Ideally, with a fracture classification system, physicians are not only informed of the mechanism and severity of the fracture, but they are also given guidelines for treating the fracture and determining the prognosis. The Lauge-Hansen fracture classification, the Weber classification, and the Haraguchi classification are widely used in clinical practice. Recently, it has been reported that foot and ankle surgeons prefer to use a fracture morphological classification based on computed tomography (CT) images to guide the clinical treatment. For example, the Haraguchi classification [9] and the Bartoníček classification [10] describe the basic characteristics of the PM fragments from the fracture morphology based on CT plain scans and three-dimensional (3D) reconstructions. Historically, PMF fixation could not be performed unless a fragment larger than one quarter of the articular surface was viewed on the lateral radiograph [11]. The preferred treatment recommendation was to fix the fracture fragments with percutaneous antero-posterior (AP) lag screws. Also, a posterolateral approach could be used to directly reduce the fracture, where postero-anterior (PA) lag screws or posterior plating maintained the internal fixation. Good clinical results were achieved through the follow-up. In recent years, a great quantity of biomechanical work has shown that the size of the PM fragment alone is not the only criterion for determining the surgical indications and prognosis [2]. Depressed intercalary fragments in the articular surface [12], posterior medial tibial talus instability, inferior tibiofibular instability, and the morphology of the fragments are identified as other major factors for the final endpoint of PMF.

The fixation of PM fragments has attracted more attention. Large numbers of surgical approach studies have indicated that direct reduction and plate-screw fixation via the posterolateral approach have good results after surgical treatment in the long and medium terms [13-15]. However, these treatments are more general, and there is no individualized treatment. We found that the occurrences of PMF with subluxation of the talus, the morphological characteristics of CT, and the detailed treatment have rarely been reported. The purpose of this study was to review the relevant cases, review the surgical options, and evaluate the treatment efficacy.

Materials and methods

Following a review and the approval of the Institutional Review Board (IRB) of Funing People's Hospital, we performed a retrospective-chart and radiological review of adult patients with PMF who received treatment in the institution from January 2014 to December 2016. All study participants provided a written informed consent prior to participating in the study. All procedures were performed by two of orthopedic trauma surgeons who received specialized training (XQP & ZGF). The subjects were distinguished using Current Procedural Terminology (CPT) codes such as 27769, 27822, 27823, and 27814, as the codes could label the trimalleolar or equivalent fractures.

Inclusion criteria: (1) Age: 18-75 years old, (2) An AF related to the PM, (3) A complete preoperative CT scan, and (4) A follow-up for no less than one year. Exclusion criteria: (1) Pathological or old fractures, (2) Gustilo type II/III open fractures or conservatively-treated fractures, (3) Infection of the local soft tissue or a clinical syndrome characterized by systemic inflammation, (4) A fracture of multiple segments or of bones in the same limb, or an associated injury of a vital organ, (5) History of injury or disease of the ipsilateral ankle joint, and (6) Psychiatric or neurologic disorders. Demographic data (i.e. the age, gender, BMI, and side), the Haraguchi classification, the Bartoníček and Rammelt classifications, the fracture morphology (depth and height of the posterior malleolar fragment), the fixation strategy [posterior plate, antero-posterior, and postero-anterior (AP-PA) lag screws], the Visual Analog Scale (VAS) pain scores, and the American Orthopedic Foot & Ankle Society (AOFAS) scores [16] were recorded for each fracture.

Before each operation, a CT plain scan and a 3D reconstruction were routinely performed to evaluate the course of the fracture line and the dislocation. The PMF with subluxation of the talus group was split into three groups according to the shape and number of the PMF fragments in the transverse section of the 3D CT. Type I, a single complete fracture fragment with or without a depressed intercalary fragment in the articular surface was called the single-fragment type group. Type II, PMF with two angled fracture fragments, was called the double-fragment type group. Type III, a rare type with severe comminuted fracture fragments, was called the comminuted-fragment type group. The features of most of the PMF fragments were single and with or without a depressed

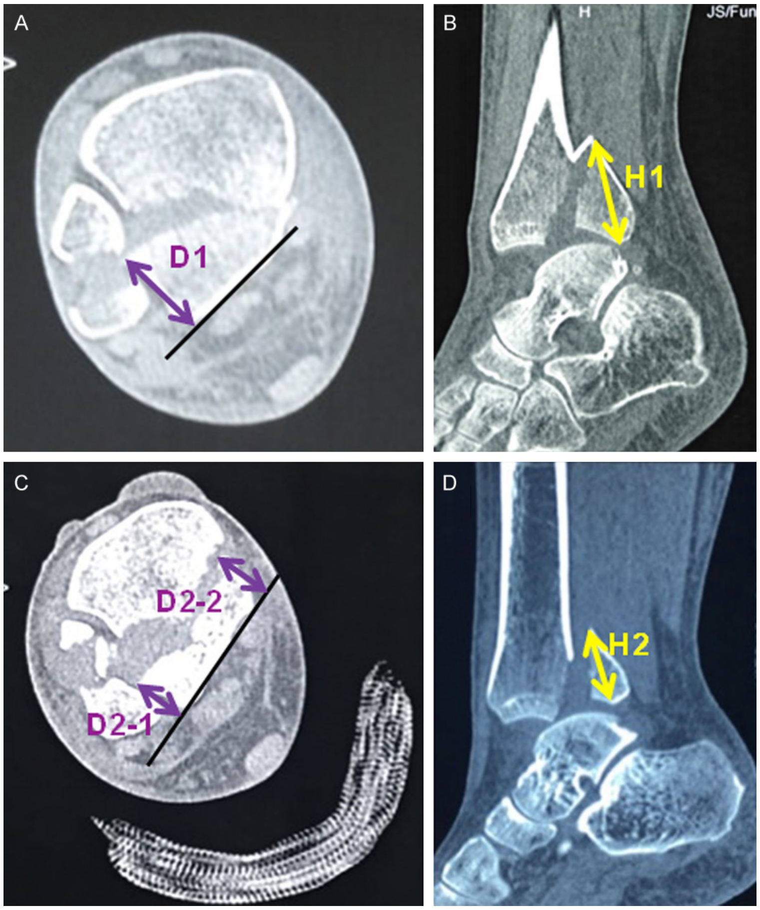

Figure 1. Dimensions of the fracture fragments. A. D1 measured on the transverse plane of the CT scan. B. H1 on the sagittal plane. C. D2-1 and D2-2 on the transverse plane for the posterolateral and posteromedial fragments. D. H2 on the sagittal plane.

intercalary fragment and angled between the two fragments. Few of the others were comminuted, and their geometric parameters could not be measured in detail. A sagittal split-off was one of the basic features in all the groups mentioned above. The maximum depths and heights of the PMF were measured on the CT transverse sections and sagittal sections, and the average value of the sum of the bone depths and heights was calculated. The average value of the single-fragment type was represented by (D1+H1)/2, and the double-fragment type was represented by [(D2-1+D2-2)/2+H2]/2 (see **Figure 1**). The surgical treatment strategy for the single-fragment type was posterior plate fixation, which was achieved using a posterolateral approach in a prone position (see **Figure 2**), while the double-fragment type used AP lag screws to fix the posterolateral fragment and PA lag screws to fix the posteromedial fragment in a supine position (see **Figures 3**, **4**). The demographic data, classification, CT morphological characteristics, fracture geometric parameters, surgical treatment strategies, and follow-up results of type I and type II were analyzed.

All the assessments were completed independently by two senior surgeons (CL & QJZ). The quantitative data from the two observers were averaged for the subsequent statistical procedure. IBM SPSS V. 20.0 helped complete the analysis where a *P*-value less than 0.05 was considered statistically significant. Q-Q plots were used to test the normal distribution of the parametric data. The demographic analyses, classifications, fragment geometry, and the fracture fixations of type I and type II were compared using independent t tests or *Chi*-square tests. The VAS and AOFAS scores were discussed using Mann-Whitney U tests for grouped comparisons.

Results

Epidemiology

A retrospective analysis was made in the 308 AF patients who met the inclusion criteria from January 2014 to December 2016 at the hospital. The follow-up lasted from 1 to 3 years. All the patients had unipedal injuries. Among them, 123 patients suffered PMF and 47 patients were involved in PMF with a subluxation of the talus. One patient was excluded because of a severe comminution of the fracture fragments in the PM. 85% of patients underwent emergency surgery on the first day after their injury. In our investigation, we found that 39.9% of the AF patients (123/308) developed PMF, and PMF with a subluxation of the talus accounted for 15.3% of the AF (47/308). Since the comminuted-fragment type only

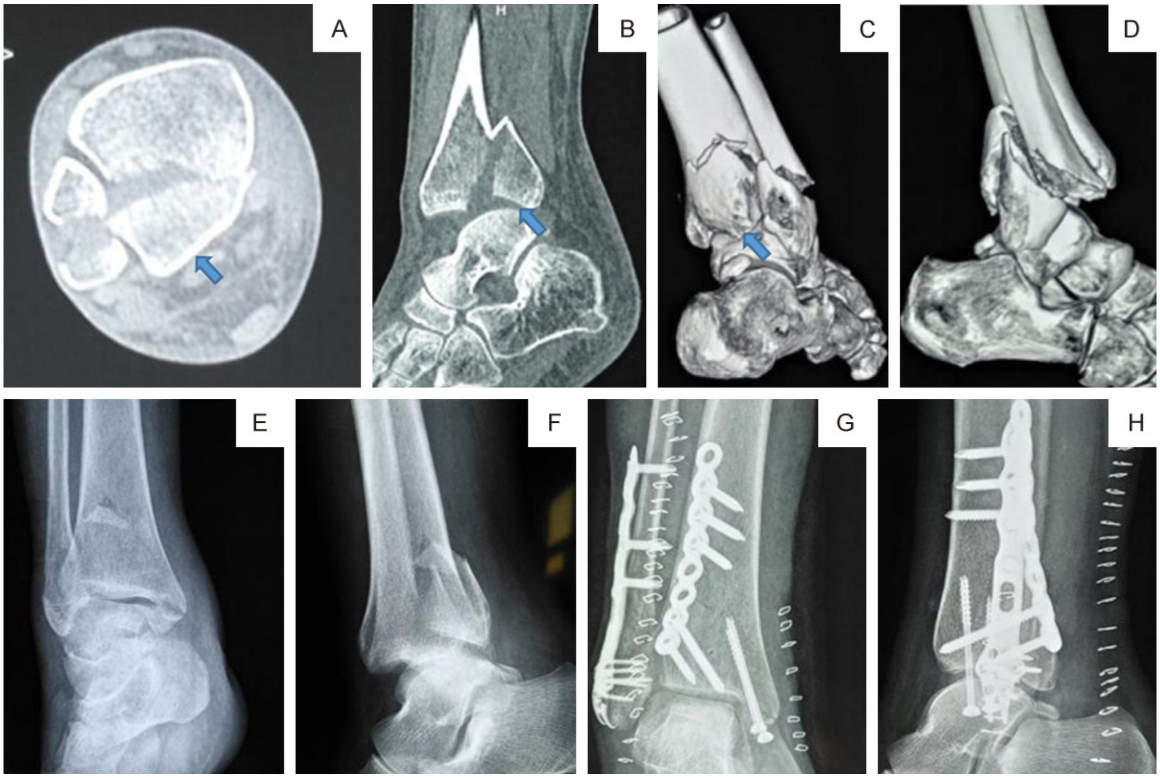

Figure 2. A 49-year-old female had a PMF with a subluxation of the talus due to a fall injury. This was a single-fragment fracture. A, B. Transverse & sagittal CT showed the PMF. The posterolateral fracture line did not involve the medial malleolus. C, D. A CT 3D reconstruction showed the PMF. E, F. The preoperative anteroposterior and lateral radiograph images showed the PMF. G, H. A posterolateral approach was deployed for reduction and buttress plating. Reduction of the PMF with a smooth articular surface was shown on the postoperative/anteroposterior and lateral radiographic images.

occurred in one patient, we ignored the patients with this type in our study.

PMF modified classification and the CT parameters

According to our CT classification criteria, the enrollment rate was 97.9% (46/47). There were 12 patients with the single-fragment type, accounting for 9.8% of the PMF (12/123), and there were 34 patients with the double-fragment type, accounting for 27.6% of the PMF (34/123). The average values of the depths and heights of the posterior malleolar fragments were (29.1±7.3) mm for the single-fragment type and (17.9±4.2) mm for the double-fragment type. There was a significant difference in the mean values between the two types ($P < 0.05$).

Surgical methods and radiological evaluation

For the single-fragment type, the posterior malleolus fracture fragment involved more than 25% of the articular surface (**Figure 2A**, **2B**). The biomechanical stability of the large fracture fragments using screw fixation alone was inadequate, but anatomic reduction and satisfactory initial stability could be achieved with a posterior lateral approach under direct reduction with support and reconstruction plate fixation, and the anteroposterior and lateral film of the ankle joint showed a flat surface of the distal tibia and a symmetrical ankle space (**Figure 2G**, **2H**).

For the double-fragment type, the fractures were usually scattered both internally and externally posterior to the posterior malleolus (**Figure 3C-E**, **3G**), and even a single T-shaped plate could not completely fix the double fracture fragments. If two plates were used, the enlargement of the implant increased the irritation of the soft tissue. In addition, due to the small involvement of the double bone blocks on the articular surface (**Figure 3F**) and the small influence on the stability of the posterior mal-

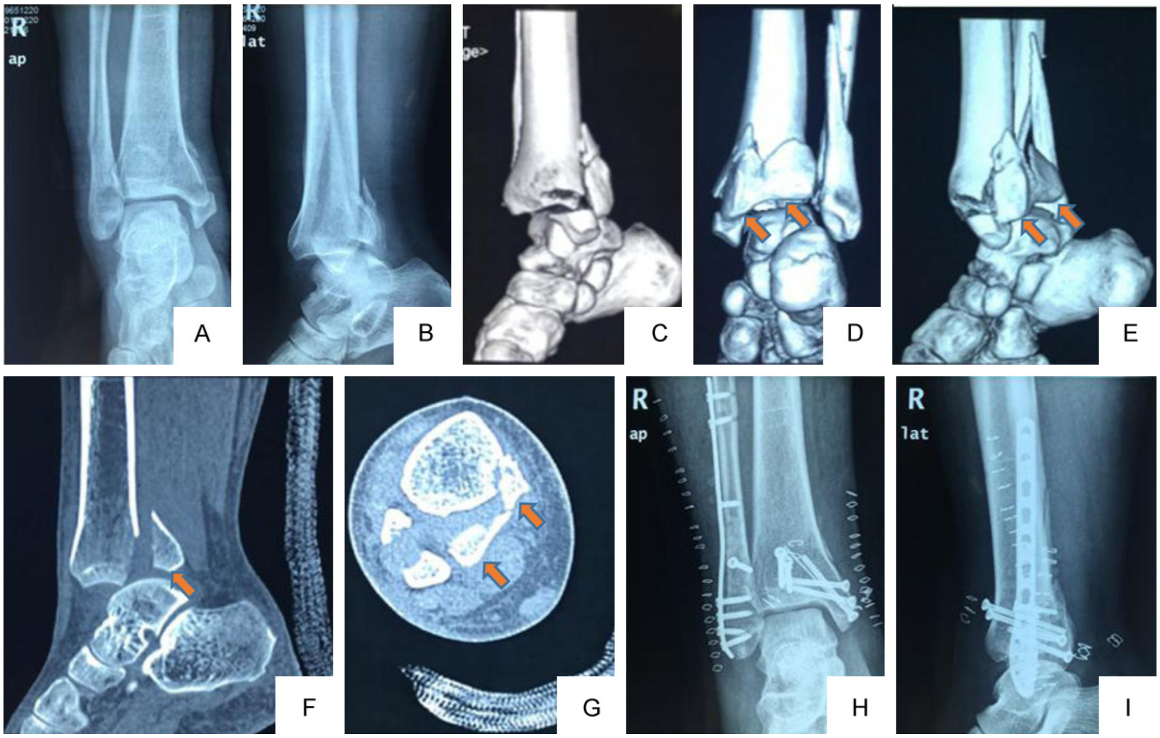

Figure 3. A female aged 53 suffered a PMF with a subluxation of the talus after an electric moped accident. The PMF was the double-fragment type. A, B. The preoperative anteroposterior and lateral radiograph images showed the PMF. C-E. A CT 3D reconstruction displayed the PMF. The posterolateral fracture line did not involve the medial malleolus. F, G. Sagittal and transverse CT showed the PMF. H, I. Reduction and fixation with AP-PA lag screws was performed using the percutaneous and posteromedial approach. A reduction of the PMF with a smooth articular surface was shown on the postoperative/anteroposterior and lateral radiographic images.

leolus, the anatomical reduction could be achieved through anterior, posterior and posterior multidirectional cannulated screw fixation (**Figure 4C-E**). The postoperative X-ray examinations showed smooth articular ankle joint surfaces, symmetrical ankle points, but no signs of the dislocation of the talus (**Figure 3H**, **3I**).

Functional evaluation

There were no nonunions. The median VAS score was 10 of 100 (0-70), and the median AOFAS score was 87 (range: 62-98) with an excellent/good rate in the single-fragment type group. In the double-fragment type group, the scores were 12.8 of 100 (range: 0-85), and 83 (range: 53-95), respectively. The data indicated insignificant differences in terms of sex, age, BMI, side, classification, pain scores, and joint function score when comparing the single- and double-fragment type groups after the mid-term follow-up ($P > 0.05$) in **Table 1**.

Discussion

PMF with a subluxation of the talus is a serious injury with a poor prognosis [3, 11, 17]. The recent recognition that the size of the PM fragment is not the only factor determining the fracture outcome has changed the clinical practice. We should not only pay attention to the size of the posterior malleolus fracture but also to its height [18]. Other factors, including articular incongruency, talar subluxation, fracture displacement, the morphology of the fragments, compression of anterior tibial soft tissue, tension blisters and skin necrosis are also important determiners [2]. The front lip of the tibia was pushed forward, and the soft tissue in front of the ankle joint was pressed continuously. The local appearances of swelling, ecchymosis, and vesicles were called "potential open fractures" [19]. Unlike tibial or fibular shaft fractures, calcaneal skeletal traction is less effective for PMF with a subluxation of the talus, and there is an increased risk of postoperative adja-

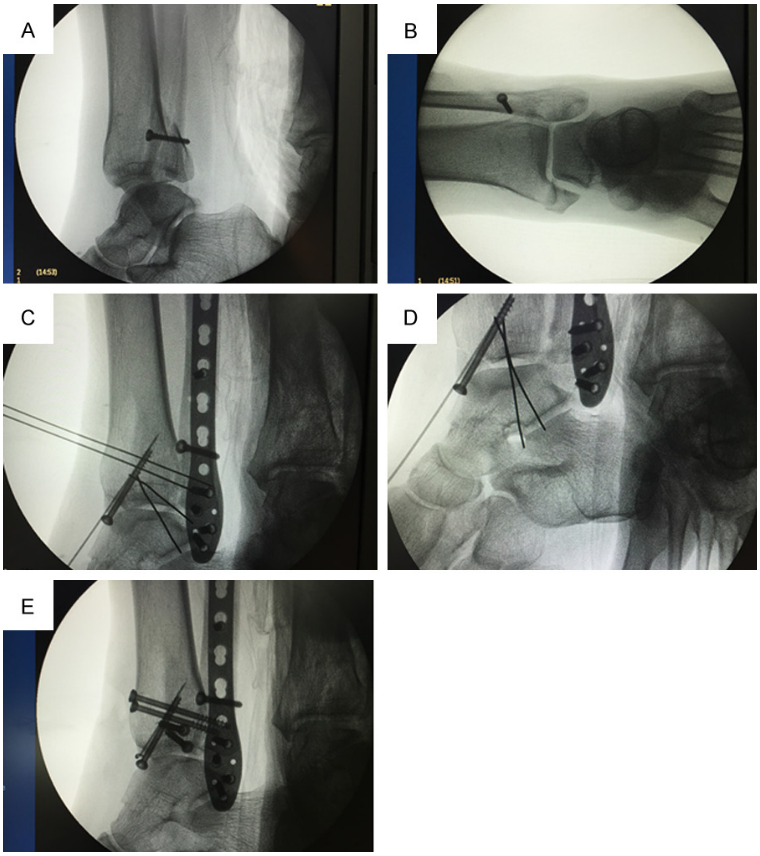

Figure 4. The procedure for the AP-PA lag screw fixation for the double-fragment type PMF with a subluxation of the talus. A, B. First, the fibula was reduced and fixed, and the fibula length was restored. The posterior tibiofibular ligament was used to reduce the posterior malleolus. C, D. Evaluation of the posterior malleolar reduction using C-arm fluoroscopy with ankle external rotation of 50 degrees. The PA lag screw fixation was carried out using the posteromedial approach, and the AP lag screw fixation was carried out using the percutaneous anterior approach. E. An ankle external rotation of 50 degrees revealed a PMF reduction with a smooth articular surface.

cent joint infections. Emergency surgery is often performed to alleviate these complications. Most of the patients in this study underwent quasi-emergency surgery within one day after their injuries, even though some patients had relatively significant swelling. The swelling of the injured limb decreased, and the soft tissue recovered rapidly after the surgery, and no incision complications occurred.

It is an extremely tough task to attain accurate evaluation results of the morphology and size of a PM fragment on the basis of plain radiographs, especially when the medial malleolus or the fibular notch is involved. The preoperative CT examination is considered the gold standard for the evaluation of the PMF and other intra-articular fractures [20]. CT plain scans and 3D reconstruction can show the morphological characteristics of the PMF fragments in the coronal, sagittal and transverse 3D planes, respectively, and they can also demonstrate the changes in the distal tibiofibular space, the tibial-talus space, and the internal/external malleolus space. In our study, all the patients underwent a preoperative radiograph and a CT scan. It was easy to find that there were about 16% of all the AF involved in PMF with a subluxation of the talus from the lateral radiographs and the sagittal CT scans.

Ideally, with a fracture classification system, investigators can not only understand the mechanism and severity of the fracture, but they can also provide guidelines for treating the fractures and determining the prognosis. The Haraguchi classification is widely used in the early stage of CT classification. For AF, it was Haraguchi et al. [9] who first proposed a classification system by which PMF were categorized by fragment pathoanatomy rather than size into the posterolateral-oblique, transverse medial-extension, and small-shell fracture types. Among these three types, Type II (involving 29.8% of the tibial plafonds) meets the current indications for PM fixation. Recently, Bartoníček et al. [10] in Europe proposed a new classification in accordance with the location, shape, and number of fractures, providing a basis for the selection of the clinical surgical treatment. In 2015, they observed the CT imaging data of 141 patients with Weber B or C AF or a fracture dislocation on the PM. Transverse, sagittal, and coronal analyses of the fragments were carried out, and 91 patients were subjected to a 3D CT reconstruction. PMFs are divided into five fundamental sub-types: extraincisural fragments, posterolateral fragments, posteromedial, two-part fragments, large, posterolateral triangular fragments, and irregular osteoporotic fractures.

Table 1. Comparison of the demographics, fracture morphology, fixation strategies and results

Characteristic	Single-fragment type (n=12)	Double-fragment type (n=34)	*p* value
Sex, % male	38.5	44.4	0.237
Age, years	51.3±12.5	53.5±14.7	0.726
BMI, kg/m^2	25.6±5.3	28.3±7.2	0.935
Side, % left	30.8	33.3	0.633
Haraguchi			
Posterolateral oblique fracture	11 (84.6)	0 (0)	0.0007
Medial extension fracture	2 (15.4)	36 (100)	0.0084
Small-shell fracture	0 (0)	0 (0)	
Bartoníček and Rammelt			
Extraincisural	0 (0)	0 (0)	
Posterolateral	1 (7.7)	0 (0)	0,0039
Two-part	0 (0)	36 (100)	0.0006
Large triangular	12 (92.3)	0 (0)	0.0051
Irregular osteoporotic	0 (0)	0 (0)	
Depth of posterior malleolar fracture, mm	19.5±4.4	15.8±3.5	0.02
Height of posterior malleolar fracture, mm	36.7±8.1	28.2±3.8	0.014
Mean value of depth and height, mm	29.1±7.3	17.9±4.2	0.002
AP-PA lag screws for fixation (yes)	2 (15.4)	32 (88.9)	0.0026
Posterior plate for fixation (yes)	11 (84.6)	4 (11.1)	0.0378
Follow-up duration, months	18.8±3.3	17.2±4.6	0.1635
VAS pain (median)	10 (0 to 70)	12.8 (0 to 85)	0.063
AOFAS (median)	87 (62 to 98)	83 (53 to 95)	0.1785

BMI: body mass index, AP: antero-posterior, PA: postero-anterior, VAS: visual analog scale scores, AOFAS: American Orthopedic Foot & Ankle Society score. The data were expressed as a percentage (%) or as the mean ± SD.

They are characterized by constant pathoanatomical manifestations, especially the fibula notch. It reflects the injury mechanism of PMF, that is, the intensity and degree of the injury gradually increased from rotational violence to vertical violence.

We selected patients with trimalleolar fractures accompanied by subluxation. For these patients, the following characteristics were found. (1) The deformity of the ankle joint was significant, and the anterior margin of the ankle acupoint could touch the distinct bony protrusion. Local skin and soft tissue tension was high in front of the ankle joint, presenting as a banding sensation. (2) Manual traction reductions were partly recoverable, while others were difficult to restore, and preoperative reduction was difficult to maintain. A novel radiographic sign or the so-called "tongues of flame" sign is viewed with bony spikes from the distal fibular fragment posterior to the PM fragment, on the lateral radiograph [21]. The posterior/lateral displacement of the distal fibular fragment may result in the compression of the peroneal tendons, hence the non-reductibility of the trimalleolar dislocation/fracture. The sagittal reconstruction images revealed a posterior talus shift. A remarkable posterior displacement of the low Weber B distal fibular fractures occurred, and its soft tissue density fell in between those of the proximal/distal fibular fragments and the posterior malleolar fragments. The distal fibular fractures showed a coronal fracture line and a soft tissue density. Imaging and physical examinations revealed a posterior subluxation of the talus and an extreme instability of the ankle joint. A retrospective analysis of CT in our study showed that the single and double fragments were the main morphological characteristics of PM. A single fracture line involved the posterior colliculus and fibular notch of the medial malleolus in the single fragment of the posterior malleolar fracture. The fracture fragment was larger and involved 1/3 of the distal tibial articular surface. The average maximum depth and height of the PM was usually greater than 20 mm in the single fragment type. The double fracture lines included both lateral and medial ones. The lateral fracture lines involved the fibular notch, the medial fracture line involved the posterior colliculus of the medial malleolus, and a Y-shaped angle was formed by the intersection of the two fracture lines, involving about 1/5 of the distal tibial articular surface. Based on the morphological characteristics of the PMF fragments accompanied by the subluxation of the talus described above, we proposed a modified PMF classification method with a subluxation of the talus. A type I fracture involved the entire posterior plafond and is called a single-fragment type. Pathologically, it is a representative postpilon fracture with axial loads on the plantarflexed talus. A type II fracture is characterized as the double-fragment type. In a 72-year-old woman, it was impossible to classify the PMF with a subluxation of the talus using the previously mentioned two criteria, which we call type III. This was due to a large amount of fragments, possibly as a consequence of osteoporosis. The modified classification was basically the same as Bartoníček types III and IV. The single-fragment type was similar to Bartoníček type IV or to a posterior Pilon fracture, and the double-fragment type resembled Bartoníček type III. The injury mechanisms of type I and type II have changed from rotational violence to vertical violence. Our results clearly indicate that PMFs present variable natures and thus should not be analyzed together.

Early PMFs are mostly treated conservatively. On the lateral radiograph, only the ankle fragments involving more than 1/3 of the distal tibial articular surfaces were treated surgically. Indirect reduction was performed with a percutaneous screw fixation vertical to the fracture line from anterior to posterior [22]. The mid-term follow-up results of the AP lag screw fixation were satisfactory. At present, a large number of domestic and foreign studies [13-15, 23, 24] have reported the surgical techniques and clinical effects of the posterolateral approach for PMF. Most studies have demonstrated that the posterolateral approach can expose posterolateral malleolar fractures under direct vision, anatomically reducing the fracture fragments, fixing them with a buttress plate or a 1/3 tubular plate, and the stability of the ankle joint recovered well after operation. It may be related to the anatomical reconstruction of the posterior ankle and the restoration of the tension of the lower tibiofibular ligament. Studies have shown that PM fixation is at least as effective as lower tibiofibular syndesmosis screw fixation in restoring lower tibiofibular stability [8, 25]. For patients who had a fragment size of < 15%, both PA and AP screws provide good fixation, cause less surgical trauma, and promote postoperative functional recovery [26]. For PMF with subluxation of the talus, the double-fragment type treatment option was combined with AP, PA lag screws. A posteromedial approach would keep the posteromedial fragment from anatomical reduction, meanwhile the medial malleolar fractures would be fixed in the same incision. Posterior plate fixation is recommended because lag screws could not resist the shear of the posterior malleolar fragments, and more weight-bearing articular surfaces accumulated in the single-fragment type.

Our trial was not our routine practice and was restricted by a relatively small cohort, short follow-up periods, and the absence of postoperative CT scans to confirm the reduction. However, according to the clinical and plain radiographic data, it is a repeatable and safe technique with minimal segment-specific fixation trauma. Meanwhile, in order to determine whether anatomic reduction has been achieved and whether it has brought better outcomes, subsequent postoperative CT imaging and extended follow-ups are be needed. A control group was not included here, as we aimed to depict different clinical management strategies for different classifications based on the CT morphological characteristics rather than comparing them with patients who didn't undergo an operation.

Conclusions

Compared with plain radiographs, PMF with a subluxation of the talus was found to have better anatomical results as well as fracture fragments which influenced the fixation modality, surgical method, or incision, as indicated on the CT scans. Management plans were formulated for all the patients who underwent quantitative CT assessments, which reemphasized the function of the CT scans on the morphological classification and management of PMFs. CT scans can describe joint coordination, fracture displacement, and fracture geometry well, especially the characteristics of the PM fragments. We recommend that the appropriate surgical treatment strategy for the single-fragment type is posterior plate fixation with a posterolateral approach, while the double-fragment type can use AP lag screws to fix the posterolateral fragment and PA lag screws to fix the posteromedial fragment.

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Disclosure of conflict of interest

None.

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