RESEARCH ARTICLE

Patterns of Ankle Fractures Based on Radiographs and CT Images of 1000 Consecutive Patients

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Abstract

Objectives: The knowledge of different types of ankle fractures based on plain radiographs and computed tomography (CT) images can help improve patients' management.

Methods: This cross-sectional study assessed the plain radiographs and CT images of 1,000 consecutive patients observed in an emergency department between March 2015 and March 2020. Fractures were labeled as uni-, bi-, or trimalleolar. Malleolar fractures were classified into medial, lateral, and posterior ones based on Herscovici, Danis-Weber, and Mason and Molloy classifications, respectively. Bi- and trimalleolar fractures, on the other hand, were categorized according to the Lauge-Hansen classification.

Results: This study included 1,000 patients with 1,003 ankle fractures. Of them, 901 were adults (mean±SD age: 41.6±16.7, male: 567 [62.9%]) with 904 fractures. In total, 53% of adult patients were 18 to 39 years old. Considering unilateral ankle fractures, the medial malleolar fracture was the most common unimalleolar fracture (62.6%), with Herscovici C being the most frequent subtype (65.3%). On the other hand, the most common type of lateral malleolar fracture was Danis-Weber type B (65.5%). There were also 209 (23.3%) bimalleolar and 114 (12.7%) trimalleolar fractures, 5.8% (16 fractures) of which could not be classified based on the Lauge-Hansen classification. Unimalleolar fractures were also observed in 87 (87.9%) children, with the medial malleolar fracture being the most common type (89.7%).

Conclusion: Medial malleolar fractures were the most frequent malleoli in patients observed in the emergency department under study. Among bi- and trimalleolar ankle fractures, supination-external rotation and pronation-external rotation injuries were the most common patterns. The Lauge-Hansen classification was not applicable in 5.8% of bi- and trimalleolar fractures.

Level of evidence: IV

Keywords: Ankle, Ankle fracture, Bimalleolar ankle fracture, CT, Radiograph, Trimalleolar ankle fracture, Unimalleolar ankle fracture

Introduction

Ankle fractures are among the most common fractures treated by orthopedic surgeons.[1] The annual incidence of ankle fractures is about 168 to 179 per 100,000 persons, which is rising in the aging population.[2-4] If left untreated, they could rapidly result in significant morbidities, such as pain, post-traumatic arthritis, ankle instability, and deformity.[5] Moreover, inappropriate treatment may lead to the loss of range of motion, deformity, chronic pain, and restrictions in daily activities.[6,7] Therefore, describing different patterns of ankle fractures observed in an emergency department of a university teaching hospital can help develop various

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treatment plans.[8]

The Lauge-Hansen, Herscovici, and Danis-Weber classification systems have been introduced to characterize ankle fractures with their specific reproducibility.[9] Different types of ankle fractures have been frequently described in the literature; however, no survey has assessed these fractures based on both plain radiographs and computed tomography (CT) images, while the accuracy of diagnosis would increase by adding CT images to plain radiographs.[10,11]

The current knowledge regarding the epidemiology, demographic features, and clinical characteristics of ankle fractures is significantly heterogeneous. The epidemiology of ankle fractures is changing worldwide, and it is unclear whether gender, advanced age, and associated osteoporosis increase the risk of ankle fractures. Considering such heterogeneity and changing epidemiological features, all regions must be aware of their own epidemiological features of ankle fractures.[2,5]

This study aimed to retrospectively study the epidemiological distribution of ankle fractures and the related classifications based on plain radiographs and CT images. The secondary aim of this study was to determine the exact frequency of ankle fractures that could not be categorized according to the Lauge-Hansen classification (unspecified injuries).

Materials and Methods
Study Design
After receiving approval from the Ethics Committee and the Institutional Review Board of Shiraz University of Medical Sciences, Shiraz, Iran, following the declaration of Helsinki (Ethic number: IR.SUMS.REC.1398.780), this retrospective cross-sectional study was conducted at a major orthopedic university teaching hospital in Shiraz, Iran. Local electronic charts from March 21, 2015, to March 20, 2020 were reviewed to find 1,000 consecutive patients with ankle fractures observed in the emergency department of the hospital under study. Patients with ankle fractures were detected based on the International Classification of Diseases (9th revision)-Clinical Modification (ICD-9-CM) diagnosis codes. The radiological images of the recruited patients were queried to identify those for whom both plain radiographs and CT images were used. On the other hand, patients with associated pilon fractures were excluded from the analysis. If there were any doubts regarding the exact type of injury, the exact type of ankle fracture would be reported according to the operation note. Based on the hospital's policy, proper ankle images, including anteroposterior, lateral, and mortise views, were primarily taken to assess the injuries. If there was evidence favoring the widening of the distal tibiofibular syndesmosis or medial ankle joint space (deltoid ligament injuries or medial malleolus fractures), high tibia-fibular images would be taken to rule out associated Maisonneuve fractures. The decision to take CT images for pediatric patients was based on case-by-case conditions, since taking CT images routinely is not recommended for these patients.

The demographic data of the patients was extracted from their medical records. A comprehensive and stepwise review of the patients' plain radiographs and CT images was performed retrospectively to describe different patterns of ankle fractures. At first, ankle injuries were labeled as uni-, bi-, or trimalleolar fractures. Malleolar fractures were classified into medial, lateral, and posterior ones based on Herscovici, Danis-Weber, and Mason and Molloy classifications, respectively. Medial malleolar fractures were classified based on the Herscovici classification[12] as below the level of the plafond, including avulsion fractures of the tip medial malleolus (types A and B), at the level of the tibial plafond (type C), or extending vertically above the tibial plafond (type D). Since concomitant deltoid ligament injury and fracture of the lateral and/or posterior malleolus are considered bi- or trimalleolar equivalent ankle fractures, they were added to the bi- or trimalleolar ankle fracture category.[13]

Based on the Danis-Weber classification, lateral malleolus injuries were categorized into type A (below the syndesmosis), type B (at the level of the syndesmosis), or type C (above the syndesmosis).[9,14] Posterior malleolar fractures were classified based on the Mason and Molloy classifications. Type 1 fracture was an extra-articular avulsion fracture, and type 2A comprised the primary Volkman area extending into the incisura, which mainly occurred following talar rotation in the mortise. Constant talar rotation results in a secondary fragment, usually at a 45° angle to the primary one. Type 3 was a coronal plane fracture involving the whole posterior plafond.[15] Finally, the Lauge-Hansen classification was used to describe bi- and trimalleolar fractures of the ankle.

Statistical Analysis
The data were compiled in an Excel spreadsheet (Microsoft Corporation, Redmond, WA). Mean and standard deviation (SD) were used to describe quantitative variables, while frequency and percentage were used for qualitative variables.

Results
A total of 1,000 patients (mean±SD age: 38.9±17.8 years, male: 64.3%) with 1,003 ankle fractures were identified. There were 99 (9.9%) pediatric cases with unilateral ankle fractures and three adult patients with bilateral ankle fractures.

Adults
In total, 898 patients (mean±SD age: 41.6±16.7 years) with unilateral ankle fractures were detected. Unilateral ankle fractures were seen more in males than in females (565, 62.9%). The mean age of ankle fractures was less in males than in females (38.1±16.0 vs. 47.6±16.0 years), and 85 cases (9.5%) were older than 65 [Figure 1]. Furthermore, right ankle fractures (483 feet, 53.8%) were more common than left ones (415 feet, 46.2%). Bilateral and open ankle injuries were also observed in 3 and 51 cases (5.7%), respectively. Among all adults (n=901), young men between 18 and 39 years of age were the predominantly affected group (480 cases, 53.3%).

Unimalleolar Ankle Fractures
Unimalleolar ankle fractures, the most common type, were observed in 575 fracture cases (64.0%), as shown in [Table 1].
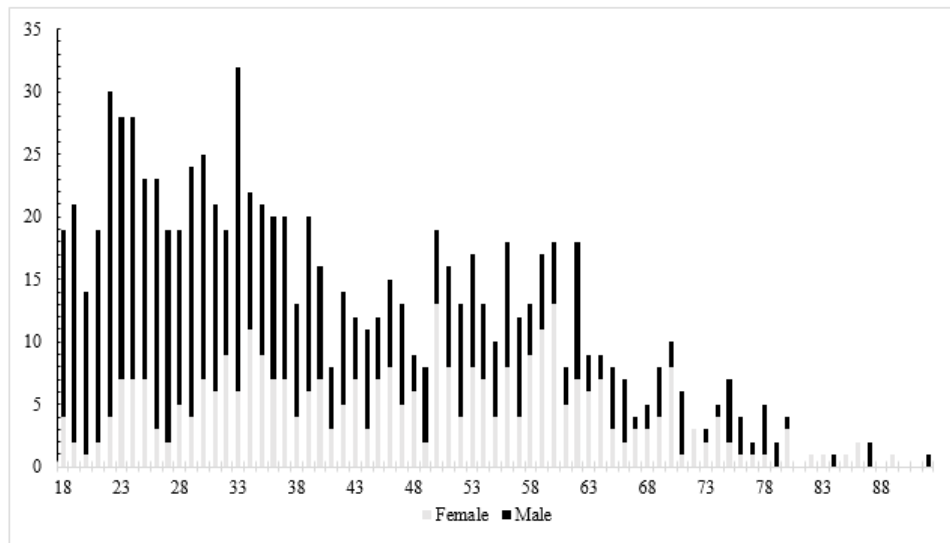
Figure 1. Distribution of ankle fractures among adult patients by age and gender

Table 1. Demographic features of adults with unilateral ankle fracture based on Lauge-Hansen Classification System (n=898 fractures)			
Type	**Frequency (%)**	**♂/♀ (ratio)**	**Age, Mean (SD)**
Unimalleolar	575 (64.0)	384/191 (2.0)	41.2 (16.7)
Medial Malleolus	360 (62.6)	278/82 (3.4)	38.75 (16.73)
Herscovici A & B	76 (21.1)	57/19 (3.0)	41.4 (20.2)
Herscovici C	235 (65.3)	185/50 (3.7)	37.9 (15.5)
Herscovici D	49 (13.6)	36/13 (2.8)	35.75 (16.4)
Lateral Malleolus	206 (35.8)	100/106 (0.9)	46.0 (15.8)
Danis-Weber A	59 (28.7)	35/24 (1.5)	44 (17.0)
Danis-Weber B	135 (65.5)	57/78 (0.7)	47.7 (15.2)
Danis-Weber C	12 (5.8)	8/4 (2.0)	37.2 (11.2)
Posterior Malleolus	9 (1.6)	6/3 (2.0)	34.8 (14.9)
Mason & Molloy 1	1 (11.1)	0/1 (0.0)	24.0 (N/A)
Mason & Molloy 2A	6 (66.7)	5/1 (5.0)	38.7 (17.1)
Mason & Molloy 2B	2 (22.2)	1/1 (1.0)	28.5 (3.5)

Table 1. Continued			
Mason & Molloy C	0	0	0
Bimalleolar	209 (23.3)	128/81 (1.6)	41.6 (16.9)
Medial & Lateral Malleoli	174 (83.3)	109/65 (1.7)	42.2 (17.4)
Supination-adduction	36 (20.7)	21/15 (1.4)	44.8 (22.1)
Supination-external rotation	68 (39.1)	36/32 (1.1)	41.4 (15.5)
Pronation-external rotation	39 (22.4)	27/12 (2.3)	41.6 (15.8)
Pronation-abduction	21 (12.1)	16/5 (3.2)	39.2 (16.3)
Unspecified	10 (5.7)	9/1(9.0)	47.0 (19.9)
Medial & Posterior Malleoli	9 (4.3)	5/4 (1.2)	31.2 (11.4)
Pronation-external rotation	5 (55.5)	3/2 (1.5)	29.2 (12.0)
Unspecified	4 (44.4)	2/2 (1.0)	33.7 (11.9)
Lateral & Posterior Malleoli	26 (12.4)	15/12 (1.2)	41.1 (14.2)
Supination-external rotation	26 (100)	14/12 (1.2)	41.1 (14.2)
Trimalleolar	114 (12.7)	53/61 (0.9)	43.3 (16.0)
Supination-external rotation	76 (66.7)	27/49 (0.6)	44.6 (16.0)
Pronation-external rotation	35 (30.7)	23/12 (1.9)	40.0 (15.9)
Pronation-abduction	1 (0.8)	1/0	59.0 (N/A)
Unspecified	2 (1.8)	2/0	45.0 (19.8)

SD, Standard Deviation; ♂, male; ♀, male

1) Medial malleolar fractures

There were 360 (62.6% of unimalleolar injuries, right: 197) isolated medial malleolar fractures, with Herscovici C being the most common type (65.3%). There were also 22 cases (6.1%) of open fractures, and isolated medial malleolar fractures affected males about 3.4 times more than females.

2) Lateral malleolar fractures

There were 206 cases (35.8%, right: 104) of isolated displaced lateral malleolar fractures, with Danis-Weber B (65.5%) being the most common type. There were also 12 cases (5.8%) of open fractures, and females were affected as much as males.

3) Posterior malleolar fractures

There were nine cases (1.6%, right: 8) of isolated closed posterior malleolar fractures. Figure 2 details the radiological and CT features of a patient with such a fracture. The medial and lateral malleoli were intact on the mortise view [Figure 2a]. The lateral ankle X-ray revealed a tiny fracture line of the posterior malleolus [Figure 2b], which was also confirmed in axial [Figure 2c] and sagittal CT images

[Figure 2d]. Figure 2e shows that such injuries were not associated with Maisonneuve fractures. Males were affected

twice as much as females by this type of fracture.

Figure 2. An isolated closed posterior malleolar fracture without an associated Maisonneuve fracture

Bimalleolar Ankle Fractures

There were 209 (23.3%) bimalleolar ankle fractures in adult patients. The frequency and distribution based on age and gender are demonstrated in [Table 1].

1)   Combined medial and lateral malleolar fractures

There were 174 (83.3%) combined medial and lateral malleolar fractures (right: 99), representing the most common type of bimalleolar ankle fractures. The most frequent pattern of injuries based on the Lauge-Hansen classification was supination-external rotation (68 fractures, 39.1%). There were also 13 cases of open fractures, and males were affected about 1.7 times more than females.

2)   Combined medial and posterior malleolar fractures

There were nine cases of combined medial and posterior malleolar fractures, including six on the right and three on the left side. Males were affected about 1.2 times more than females.

3)   Combined lateral and posterior malleolar fractures

There were 26 (12.4%) cases of combined lateral and posterior malleolar fractures, including 14 on the left and 12 on the right side. There was also one open fracture, and males were affected 1.2 times more than females.

Trimalleolar Ankle Fractures

There were 114 (12.7%) trimalleolar fractures, three of which were open injuries. The right side was affected in 58 cases, and females were affected 1.17 times more than males.

Bilateral Fractures

Three patients presented with bilateral ankle fractures. Their mean±SD age was 31.7±1.5 years. The first one was a 31-year-old woman with a right Danis-Weber type A lateral malleolar fracture and a left trimalleolar equivalent ankle fracture (supination-external rotation injury). The second was a 52-year-old man with a right trimalleolar ankle fracture following a pronation-external rotation injury and a left medial malleolar vertical fracture with intact lateral and posterior malleoli. The last one was a 25-year-old man with a right combined lateral and posterior bimalleolar fracture (unspecified Lauge-Hansen type) and a left lateral malleolar Danis-Weber type A fracture with intact medial and posterior malleoli.

Unspecified Fractures

Sixteen bimalleolar and trimalleolar fractures could not be categorized into any Lauge-Hansen types. Figure 3 details the radiological and CT images of a patient with vertical and Denis-Weber type B fractures of the medial and lateral malleoli, respectively, as shown on the AP X-ray, as well as coronal and axial CT images [Figures 3a, 6c, and 6d]. Ankle's lateral X-ray demonstrated an intact posterior malleolus [Figure 3b]. Another unspecified fracture occurred in a 65-year-old man with Herscovici type C medial and lateral malleoli fractures [Figure 4a]. However, two distinct fracture lines (Denis-Weber type C) were detected in the lateral malleolus [Figures 4a and 4b].

Figure 3. Fracture of the lateral malleolus above the plafond articular surface in association with a vertical fracture of the medial malleolus

Figure 4. Fracture of the lateral malleolus from two parts (Danis-Weber B and C) associated with medial malleolar fractures (A and B)

Pediatric Patients

There were 99 (male: 76) ankle fractures in patients below 18 [Table 2]. The mean±SD age was 14.32±2.55 years. Figure 5 shows the age and gender distribution of ankle fractures in the pediatric population. In this group of patients, right ankle fractures were more common than left ankle fractures (53 vs. 46) [Figure 5].

Table 2. Frequency of different types of ankle fractures among 99 pediatric patients	
Type	**Frequency (%)**
Unimalleolar	87 (87.9)
Medial Malleolus	78 (89.7)
Lateral Malleolus	9 (10.3)
Bimalleolar	12 (12.1)
Medial + Lateral Malleoli	12 (100.0)

Unimalleolar ankle fractures were seen in 87 (87.9%) children, with medial malleolar fractures (78 cases, 89.7%)

being the most common type (right: 53). There was one Tillaux fracture and 9 (10.3%) isolated lateral malleolar fractures, including five on the left and four on the right ankle. Males were affected about 3.5 times more than females.

In total, 12 (12.1%) bimalleolar ankle fractures were discovered in the pediatric population in this study. All were combined fractures of the medial and lateral malleoli [Table 2]. There were two cases of open fractures, and males were affected about 11 times more than females.
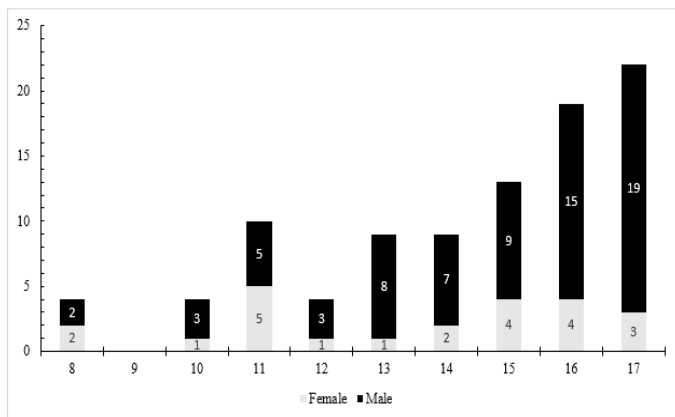

Figure 5. Distribution of pediatric patients by age and gender

Discussion

Determining different fracture patterns can help surgeons diagnose the injuries accurately and treat them properly. Multiple studies have assessed different features of calcaneal and talar fractures[16,17] and ankle fractures based on X-ray images;[2,3,5,18] however, plain radiographs have shown low diagnostic accuracy in detecting posterior malleolar and Tillaux fractures.[1] By reviewing 78 cases of acute ankle injuries, Boszczyk et al. concluded that X-ray images failed to predict the mechanisms of fractures correctly.[19] Therefore, this study retrospectively reviewed both plain radiographs and CT images of 1,000 patients to characterize the patterns of injury.

Patients aged 18 to 39 were the most frequent age group with ankle fractures. Notably, this group of adults is the most physically active population and is prone to all kinds of trauma, especially ankle fractures. In this study, ankle fractures were more frequent in males than in females in all age groups, which differed from the findings of previous population-based surveys. Juto et al. showed that the annual incidence of ankle fractures steadily increased from 83 to 319 per 100,000 patients as the age of females increased from 30-39 to 60-69 years; however, males had a more even distribution pattern.[18] It is assumed that the main reason for this difference is that males, even older ones, are more physically active than females in the geographic location of this study. In this study, males were affected more frequently than females by almost all ankle fracture types except for isolated lateral malleolar fractures (M/F= 0.9) and trimalleolar fractures (M/F= 0.8). The other important issue is that the epidemiology of ankle fractures was not checked in a normal population, and thus possible biases should be considered.

The present study discovered medial malleolar fractures to be the most frequent type of ankle fracture among patients in the emergency department of a major orthopedic center. The university teaching hospital under study is a major orthopedic referral center in Shiraz, Iran, meaning that patients with low-energy trauma may present to other hospitals or clinics. Therefore, the results might be completely different if all ankle fractures in the area could be evaluated. The goal was to understand the fracture patterns detected in the emergency department. Among patients with lateral malleolar fractures, the most common types were Dennis Weber types B, A, and C, in descending order, which is consistent with previous findings.

Medial malleolar fractures with a fracture line at the level of the tibial plafond were the most frequent type of isolated medial malleolar fracture. This was similar to the previous studies analyzing X-ray images.[12,20] Aitken et al. detected Herscovici type C medial malleolar fractures in 61 out of 130 patients.[12] According to their findings, the Herscovici classification had moderate interobserver reliability and substantial reproducibility. CT images were used to increase the diagnostic accuracy and, unlike the aforementioned studies, also include associated lateral and/or posterior malleolar fractures in the analysis.

An isolated posterior malleolar fracture is a rare injury, representing 0.5-4% of all ankle fractures.[15,21] Some scholars believe posterior malleolar fractures are almost always associated with other osteoligamentous injuries.[22,23] Interestingly, in this study, nine patients had isolated posterior malleolar fractures without associated overt bony or ligamentous injuries in other parts of the ankle or proximal fibula. Mason and Molloy 2A posterior malleolar fractures comprised about two-thirds of the cases in this study.

Among bimalleolar and trimalleolar ankle fractures, the supination-external rotation type was the most common pattern (171/326), which was similar to previous reports.[24] The Lauge-Hansen classification provides a framework to help orthopedic surgeons predict the details of each ankle fracture and aid in deformity reduction. Even though the CT images of all 1,000 cases were reviewed to determine the exact ankle fracture pattern, 19 (5.8%) ankle fractures (16 bimalleolar and three trimalleolar fractures) could not be classified according to the Lauge-Hansen classification (unspecified injuries). Therefore, a new classification system may be required to include all types of bimalleolar and trimalleolar ankle fractures.

Several limitations were encountered in this study. Firstly, this study only included ankle fractures for which both plain radiographs and CT images were available. In addition, only patients seen in the emergency department of a major orthopedic center were studied, ignoring ankle fractures managed by other centers or cases treated in an outpatient setting. Therefore, if this study included patients with isolated plain radiographs or cases managed in other centers, fracture patterns would probably be different. Despite these limitations, this study included all age groups and reported fracture patterns according to both X-rays and CT findings of 1,000 patients.

Conclusion

In conclusion, the findings revealed that medial malleolar fractures served as the most frequently injured malleolus in patients with ankle fractures observed in an emergency department. Among bi- and trimalleolar ankle fractures, supination-external rotation and pronation-external rotation injuries were the most frequent patterns. About 5.8% of bi- and trimalleolar ankle fractures could not be classified according to the Lauge-Hansen classification. The findings of such epidemiological studies should be used by policymakers to improve healthcare services.

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