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Supination External Rotational Ankle Fracture Injury Pattern Correlation With Regional Bone Density

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Abstract

Background: Rotational ankle fractures can present with an array of possible osseous and ligamentous injury combinations in reliable anatomic locations. What accounts for these different injury patterns and whether specific patient and injury factors underlie the different injury patterns is unclear. The purpose of this study was to determine whether causative factors exist that could account for the various injury patterns seen with rotational ankle fractures.

Methods: A registry of operatively treated supination external rotation stage IV (SER IV) ankle fractures was used to identify patients. Computed tomography imaging was used to calculate regional bone density by using average Hounsfield unit measurements on axial images from the distal tibia and fibula. Patients were grouped into those with no posterior or medial malleolar fracture (equivalent group), those with either a posterior or medial malleolus fracture (bimalleolar group), and those with both posterior and medial malleolar fractures (trimalleolar group). Sixty-seven patients met inclusion criteria.

Results: Regional bone density at the ankle, as measured with Hounsfield units, was significantly higher in the equivalent group (371) than in the bimalleolar group (271, $P < .0001$) and trimalleolar group (228, $P < .0001$). Logistic regression analyses identified regional bone density as a significant predictor of a medial malleolus fracture ($P = .002$) and of a posterior malleolus fracture ($P = .005$).

Conclusion: In our cohort of SER IV ankle fractures, regional bone density at the ankle significantly correlated with the presence and number of malleolar fractures compared with ligamentous ruptures. Treating surgeons can use this information to anticipate bone quality during operative fixation based on ankle fracture injury pattern. In addition, the presence of a trimalleolar

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ankle fracture was a significant indicator of poor bone quality and may represent the first clinical sign of abnormal bone metabolism in many patients.

Level of Evidence: Level III, prognostic retrospective cohort study.

Keywords

ankle fracture; bone density; SER; Hounsfield unit; CT

Ankle fractures are common injuries that often require treatment by orthopedic surgeons. Lauge-Hansen developed a comprehensive classification system for ankle fractures and defined rotational ankle fractures as either pronation external rotation or supination external rotation (SER) patterns.^{10,11,23} Rotational ankle fractures can present with an array of possible osseous and ligamentous injury combinations in reliable anatomic locations, with different stages of injury representing the progression of injury severity.^{10,11,15,24}

Stage IV rotational ankle fractures have injuries posteriorly with either a posterior inferior tibiofibular ligament (PITFL) rupture or posterior malleolus fracture, and medially with either a deltoid rupture or medial malleolus fracture.^{10,24} The different injury characteristics often define the surgical management for treating rotational ankle fractures.^{7,14} What accounts for these different injury patterns and whether specific patient and injury factors underlie the different injury patterns is unclear.

Patient bone density has significant effects on overall fracture risk and can alter surgical treatment algorithms.^{1,6,17,18,22} Assessment of regional bone quantity can be performed using Hounsfield unit (HU) measurements from computed tomography (CT) imaging and has been correlated with dual x-ray absorptiometry scores in several anatomic regions.^{12,16,19,21} Whether regional bone density contributes to specific injury patterns and predicts bone quality in an anatomic location is unknown. The purpose of this study was to determine whether differences in regional bone density could account for the various injury patterns seen with rotational ankle fractures.

Methods

Following institutional review board approval, a registry of operatively treated supination external rotation stage IV (SER IV) ankle fractures from 2014 through 2015 was used to identify patients. Patient demographics, medical comorbidities, and injury characteristics were recorded for each case. A low-energy mechanism of injury was considered a fall from standing height. All patients included in the study had preoperative radiographs and CT imaging of the injured ankle. Patients who were skeletally immature and had evidence of prior ankle fractures or retained ankle implants were excluded.

Sixty-seven patients were included in the study, with 11 patients in the equivalent group (those with no posterior or medial malleolar fracture), 18 patients in the bimalleolar group (those with either a posterior or medial malleolus fracture), and 38 patients in the trimalleolar group (those with both posterior and medial malleolar fractures). Patients in the equivalent, bimalleolar, and trimalleolar groups had no significant differences in age, body mass index, medical comorbidities, energy of injury, dislocation rate, or open fracture rate

(Table 1). Female sex was less common in patients in the equivalent group compared with the trimalleolar group (55% vs 87%, $P = .033$) but not the bimalleolar group (55% vs 72%, $P = .43$) (Table 1).

CT imaging was performed using a 64-slice scanner with 1.25-mm axial images without contrast. A Picture Archiving and Communication System was used to calculate regional bone density from CT scans by using average HU measurements on axial images from the cancellous bone in the regions of the distal tibia and fibula (Figure 1), as has been previously performed for other anatomic regions.^{3,19,20} For the distal tibia, HU measurements were taken from an elliptical region of interest placed in the metaphyseal area approximately 1 cm proximal to the tibial plafond, taking care to avoid the physeal scar. For the distal fibula, HU measurements were performed at the level of the tibial plafond. HU measurements were taken using the largest possible elliptical region of interest, excluding fracture areas and cortical margins to prevent aberrant values from volume averaging. HU values from 3 sequential axial slices were averaged to generate a mean HU value for each distal tibia and fibula, and these values were then averaged to calculate a mean HU value for each ankle.

Ankle injury patterns were determined using intraoperative direct observations during surgical fixation so that the precise osseous and ligamentous injuries for all patients included in the study were defined and recorded. Based on these data, patients were placed into 1 of 3 groups: those with no posterior or medial malleolar fracture (equivalent group), those with either a posterior or medial malleolus fracture (bimalleolar group), and those with both posterior and medial malleolar fractures (trimalleolar group) (Figure 2).

For statistical analyses, the Fisher's exact test was used to test for associations between the equivalent, bimalleolar, and trimalleolar patient groups with respect to sex, medical comorbidities, mechanism of injury, dislocation rate, or open fracture rate. Student *t* tests were used to compare associations between the equivalent, bimalleolar, and trimalleolar patient groups with respect to age, body mass index, and mean ankle HU measurements. Separate multiple logistic regressions were performed, one using posterior malleolus fracture (vs PITFL injury) as the outcome and one using medial malleolus fracture (vs deltoid ligament injury) as the outcome. Both regression models controlled for age and sex, both of which are known to affect bone density.^{2,18} These analyses produced β coefficients for individual parameters, including age, sex, and HU as measured at the tibia. All comparative analyses were 2-tailed, and $P = .05$ was used as the threshold statistical significance.

Results

Regional bone density at the ankle, as measured with HU, was significantly higher in the equivalent group (371) than in the bimalleolar group (271, $P < .0001$) or trimalleolar group (228, $P < .0001$) (Table 1). In addition, regional bone density was significantly higher in the bimalleolar group compared with the trimalleolar group ($P = .02$) (Figure 3).

Similarly, after controlling for age and sex, logistic regression analyses identified regional bone density as a significant independent predictor of a medial malleolus fracture over a

deltoid injury ($P = .002$) and of a posterior malleolus fracture over a PITFL injury ($P = .005$) (Table 2). Age was not a significant predictor of a medial malleolus fracture over a deltoid rupture ($P = .42$) or a posterior malleolus fracture over a PITFL injury ($P = .78$) after controlling for sex and mean HU. Female sex was an independent predictor of a posterior malleolus fracture over a PITFL injury ($P = .016$), but not a medial malleolus fracture over a deltoid injury ($P = .97$).

Discussion

Rotational ankle fractures occur with a variety of osseous and ligamentous injuries. Lauge-Hansen described the pathoanatomy of ankle fractures based on the mechanism of injury, including a descriptive analysis of the 4 stages of a SER pattern.¹⁰ Subsequent studies have questioned whether the exact mechanisms originally described by Lauge-Hansen can account for these injury patterns using online videos of the injury and cadaveric studies.^{8,9} These studies have suggested that the biomechanical explanation proposed by Lauge-Hansen may not account for all rotational ankle fracture patterns. However, the constellation and sequence of injury characteristics as originally described by Lauge-Hansen have shown to be reliable.²³

Although these stages and specific injury patterns have been well defined, the underlying factors for why some patients have ligamentous injuries and others have osseous injuries has not been characterized. We demonstrated that regional bone density at the ankle was significantly associated with whether a patient sustains an osseous or ligamentous injury. While these data do not prove causation, this study suggests that in patients with higher bone density at the ankle, the posterior and medial ligaments yield before the malleoli fracture. On the contrary, in patients with lower ankle bone density, the malleoli fracture before the ligaments rupture. While female sex was more common in the trimalleolar than in the equivalent group, surprisingly no other patient or injury characteristic analyzed was significantly correlated with the constellation of ankle injury patterns. This highlights the importance of bone density on fracture injury characteristics.

Other studies have examined potential correlations between bone density and fracture patterns. Lee et al demonstrated that decreased bone density of the humeral head is associated with increased fracture comminution.¹³ Similarly, Hey et al examined bone regional density of the proximal femur in patients with hip fractures and concluded that hip fracture pattern may be influenced by the bone density in different areas of the hip.⁵ Related findings were also reported in the radial head. Haverstock et al found that the anterolateral aspect of the radial head, which is the region involved in most partial articular radial head fractures, has significantly lower bone density compared with other regions of the radial head.⁴

With the increasing incidence of osteoporosis,¹⁸ bone density has become increasingly important for clinicians and surgeons to consider when treating patients with fractures. Bone quality can have important implications for surgical treatment options and implant selection.⁶ Cadaveric studies have demonstrated an important role of bone density with implant fixation strength in the tibial plateau as well as the proximal humerus.^{1,22} Identifying

radiographic features or injury patterns that correlate with bone density can improve surgical decision-making and optimize patient care. For example, knowing an operative ankle fracture has poor bone density may prompt alternative fibular fixation strategies, such as using fixed-angle implants or augmenting with a transsyndesmotic screw for the recruitment of tibial cortices, which could require separate surgical instrumentation. Even if the operative fixation technique is not altered by the bone quality surrounding the fracture, knowledge of the association of trimalleolar ankle fractures with poor bone quality can prompt aggressive medical optimization of bone metabolism, similar to other osteoporotic fractures.

Despite the significance of our results, this study has limitations. The retrospective nature of the study leads to inherent limitations with retrospective analyses, although we attempted to minimize these by using a consecutive series of patients. Also, this cohort of patients may not be representative of patient populations in other trauma centers or different geographic areas, which may limit the generalizability of the results. In addition, although we attempted to control for confounding variables using regression models, other confounding variables may exist that were not identified.

Conclusion

In conclusion, our cohort of SER IV ankle fractures had a significant correlation between regional bone density at the ankle and the presence and number of malleolar fractures compared with ligamentous ruptures. Treating surgeons can use this information to anticipate bone quality during operative fixation based on ankle fracture injury pattern. In addition, the presence of a trimalleolar ankle fracture was a significant indicator of poor bone quality and may represent the first clinical sign of abnormal bone metabolism in many patients. While all patients with fractures should be evaluated for abnormal bone metabolism, clinicians should strive to aggressively optimize bone metabolism in patients with trimalleolar ankle fractures postoperatively.

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Figure 1.

(A and C) Coronal computed tomography images were used to localize (B) the metaphyseal distal tibia 1 cm proximal to the plafond and (D) the metaphyseal distal fibula at the level of the plafond. Elliptical regions of interest were then placed in the corresponding axial images from the distal tibia and fibula to calculate Hounsfield units.

Figure 2.

Anteroposterior and lateral radiographic views demonstrating examples of the different ankle fracture groups based on the presence of (A) no posterior or medial malleolus fracture (equivalent group), (B and C) either a posterior or medial malleolus fracture (bimalleolar group), or (D) both posterior and medial malleolar fractures.

Figure 3.
Comparison of local bone density between the 3 different ankle injury groups.

Table 1.

Comparisons of Patient Characteristics, Injury Features, and Ankle Hounsfield Units Between Equivalent, Bimalleolar, and Trimalleolar Ankle Injury Groups.

	Injury Pattern			P Value	
	Equivalent (n = 11)	Bimalleolar (n = 18)	Trimalleolar (n = 38)	Equivalent vs Bimalleolar	Equivalent vs Trimalleolar
Mean age, y ^a	48.4	45.3	50.1	.62	.75
Female gender ^b	54.6%	72.2%	86.8%	.43	.033 ^c
Mean BMI ^a	28.1	27.0	29.5	.69	.64
Comorbidities ^b					
Diabetes	9.1%	11.1%	7.9%	1.0	1.0
CAD	9.1%	16.7%	13.2%	1.0	1.0
HTN	27.3%	16.7%	26.3%	.65	1.0
Smoking	18.2%	11.1%	10.5%	.62	.61
PVD	9.1%	11.1%	7.9%	1.0	1.0
Low-energy mechanism of injury ^b	63.6%	72.2%	78.9%	.69	.43
Dislocation ^b	54.5%	44.4%	39.5%	.71	.49
Open injury ^b	9.1%	5.6%	5.3%	1.0	.54
Mean ankle Hounsfield units ^a	371	271	228	<.001 ^c	<.000001 ^c

Abbreviations: BMI, body mass index; CAD, coronary artery disease; HTN, hypertension; PVD, peripheral vascular disease.

^a Analyzed with Student *t* test.

^b Analyzed with Fisher's exact test.

^c *P* < .05.

Table 2.

Linear Regression Analysis of Hounsfield Unit Values and Ankle Injury Pattern After Adjusting for Age and Gender.^a

Comparison	Odds Ratio	Standard Error	P Value ^b
Equivalent vs bimalleolar	0.965	0.0148	.019
Equivalent vs trimalleolar	0.948	0.0186	.007

^aThe β coefficients listed represent the coefficient for the mean Hounsfield unit variable in each model.

^b $P < .05$.