

Comparative Evaluation of MRI and CT in the Diagnosis of Ankle Fractures: A Prospective Diagnostic Accuracy Study

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Abstract

Background

To compare the diagnostic accuracy and clinical value of magnetic resonance imaging (MRI) and computed tomography (CT) in the evaluation of ankle fractures and associated ligamentous injuries.

Methods

This prospective diagnostic accuracy study enrolled 94 patients with suspected ankle fractures. Each patient underwent both CT and MRI examinations. A composite reference standard was used for the final diagnosis, which integrated clinical findings, intraoperative observations, and the consensus of experienced orthopedic surgeons and radiologists. Diagnostic performance parameters—sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and Cohen's kappa(κ)—were calculated for both imaging modalities. Interobserver agreement and McNemar's test were applied to compare performance between junior and senior orthopedic surgeons.

Results

CT and MRI showed similar effectiveness in diagnosing fractures among senior surgeons, with sensitivity rates of 100% for CT compared to 98.41% for MRI ($\kappa = 1.000$ vs 0.976 respectively). However, MRI was significantly superior to CT in identifying ligamentous injuries, with both junior and senior surgeons achieving 100% sensitivity and $\kappa > 0.98$. CT showed low sensitivity for detecting ligament injuries, especially among junior surgeons (3.33%, $\kappa = 0.045$). McNemar's test indicated statistically significant differences favoring MRI for ligament assessment ($p < 0.01$), but not for fracture detection. MRI also showed substantial agreement in Lauge-Hansen fracture classification.

Conclusions

While CT remains effective for fracture identification, MRI offers superior diagnostic performance in detecting ligamentous injuries and provides a more comprehensive evaluation of ankle trauma. MRI is particularly advantageous in cases requiring detailed soft tissue analysis or where radiation exposure must be minimized. Physician experience plays a critical role in the interpretation of MRI results, highlighting the need for comprehensive training and a thorough clinical assessment.

Introduction

Ankle fractures are among the most common lower limb fractures, with an incidence ranging from 157 to 187 per 100,000 individuals, as reported in the literature[1, 2]. In the United States, ankle fractures account for approximately 19.2% of all fracture-related emergency department visits [3, 4]. According to a study by Song et al., ankle fractures account for 7.6% of all fractures within the Chinese population [5]. The study identifies several independent risk factors, including alcohol consumption, living alone, and an average sleep duration of less than 7 hours per day[5]. Common complications following ankle fractures include post-traumatic arthritis, joint stiffness, infection, malunion, nonunion, syndesmotic fusion, deep vein thrombosis, and phlebitis [6, 7].

In the clinical assessment of ankle trauma, it is often difficult to confirm the diagnosis of ankle fracture without the use of radiography, so clinicians typically rely on the Ottawa Ankle Rules to determine whether radiographic imaging is necessary[8]. However, conventional X-rays may fail to detect subtle injuries, such as posterior malleolar fractures and ligamentous damage. Computed tomography (CT) has been shown to enhance diagnostic accuracy and improve the quality of information available to surgeons, playing a critical role in guiding treatment decisions [9].

However, diagnosing ankle fractures in pregnant patients is challenging because ionizing radiation may harm the fetus. Potential risks include fetal death, growth restriction, brain and organ abnormalities, developmental delays, and increased risk of childhood cancer. The fetus is especially sensitive to radiation during early pregnancy, making this period particularly vulnerable.[10][11]. At the same time, the foot and ankle region contains the most complex anatomical structure in the body, comprising 28 bones, 33 joints, and 112 ligaments, which work together to enable motion and provide stability[12]. Ankle fractures are frequently accompanied by ligament injuries, which can significantly affect joint stability and long-term outcomes [13]. The anterior talofibular ligament is the most commonly injured ligament, whereas syndesmotic injuries that involve the distal tibiofibular joint are linked to greater ankle instability [14][15]. Day et al. reported long-term follow-up results after open reduction and internal fixation of ankle fractures, concluding that over one-third of patients developed moderate to severe post-traumatic arthritis, and 76% had radiographic evidence of joint degeneration[16]. One key reason was the failure to recognize, reduce, and stabilize syndesmotic injuries. Moreover, some studies have shown no correlation between radiographic measurements of syndesmotic injuries and magnetic resonance imaging (MRI) findings, suggesting that in current clinical practice, X-ray and CT imaging are often insufficient for evaluating the extent of ligamentous damage[17].

Given the limitations of conventional radiographic modalities in the diagnosis of ankle fractures, Majid et al. [18] explored the use of ultrasonography and found it to be a potentially accurate and noninvasive diagnostic tool for ankle fractures. However, its accuracy was highly dependent on the skill of the radiologist. In contrast, MRI offers several advantages, including the absence of radiation exposure and superior visualization of soft tissue structures such as ligaments, tendons, and cartilage[19], making it a valuable modality in the assessment of fractures. MRI has proven particularly useful in detecting occult fractures that are not visible on plain radiographs. For instance, early MRI has been shown to reliably and accurately detect radiographically occult injuries in patients with suspected scaphoid fractures [20]. A comparative study between MRI and bone scintigraphy (BS) in the diagnosis of occult scaphoid fractures demonstrated that MRI had a sensitivity and specificity of 100%, outperforming BS, which had values of 83% and 95%, respectively [21]. Furthermore, MRI plays an important role in the classification of complex fractures. Lumbar spine MRI is considered crucial in identifying and classifying sacral insufficiency fractures[22]. Xu et al. found that MRI outperformed Multidetector Computed Tomography (MDCT) in evaluating the extent of tibial plateau fractures and associated soft tissue injuries, thereby aiding clinical decision-making[23]. In cases of stress fractures of long bones, MRI has been shown to reveal a wider spectrum of changes compared to radiographs, facilitating treatment planning[24]. Nevertheless, due to MRI's limited ability to depict cortical bone and complex osseous anatomy [19], its diagnostic accuracy in ankle fractures remains controversial. Therefore, the present study aims to evaluate the clinical value of MRI in diagnosing ankle fractures.

Methods

Study design

We conducted a diagnostic accuracy study comparing the clinical diagnostic value of MRI and computed tomography (CT) in detecting ankle fractures. According to the study protocol, a total of 94 patients with suspected ankle fractures meeting the inclusion criteria were prospectively enrolled. Both CT and MRI imaging data were collected for each patient. The diagnostic reference standard was a composite gold standard, established by a consensus of three orthopedic surgeons and one musculoskeletal-trained radiologist, based on a comprehensive assessment of clinical presentation, intraoperative findings, and both CT and MRI results.

Participants

The inclusion criteria for this study were as follows:(1) A history of relevant trauma such as ankle sprain or fall;(2) Positive findings on physical examination consistent with the Ottawa Ankle Rules;(3) Stable clinical condition and ability to complete both CT and MRI examinations;(4) Provision of written informed consent and voluntary participation in the study. The exclusion criteria were as follows:(1) Contraindications to MRI, including metallic implants or cardiac pacemakers;(2) Presence of open fractures;(3) Congenital or acquired deformities of the foot and ankle.

Intervention

The diagnostic accuracy of CT and MRI for ankle injuries was evaluated using a composite gold standard, which was established based on clinical symptoms, intraoperative findings, and imaging data from both CT and MRI. Final diagnoses were determined by consensus among four experienced specialists. The primary diagnostic outcomes collected included:(1) Presence or absence of an ankle fracture;(2) Lauge-Hansen classification and unclassifiable ankle fractures;(3) Presence of associated ligament rupture. All enrolled patients underwent both CT and MRI of the ankle. The imaging data were independently reviewed by two orthopedic surgeons with different levels of clinical experience: a senior surgeon with 12 years of orthopedic practice and a junior surgeon with 2 years of clinical experience. Both reviewers were blinded to the patients' clinical information. Diagnostic results from each imaging modality were compared with the gold standard to calculate sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and overall accuracy. Interobserver agreement between the two physicians was assessed using the Kappa statistic. This study aimed to comprehensively evaluate the diagnostic value of MRI and CT in the diagnosis of ankle injuries.

Statistical Analysis

Statistical analysis was performed using SPSS version 21.0 (SPSS Inc., Chicago, IL, USA). Qualitative data were reported as frequencies and percentages, while quantitative data were summarized as mean $\pm$ standard deviation (SD). Sensitivity, specificity, PPV, NPV, positive likelihood ratio (PLR), negative likelihood ratio (NLR), and Cohen's Kappa coefficient were calculated to evaluate diagnostic performance. A p-value ≤ 0.05 was

considered statistically significant. Paired proportion testing (McNemar’s test) was used to compare diagnostic parameters between CT and MRI.

Results

This study enrolled a total of 94 patients with ankle sprains who met the inclusion criteria. Based on the composite reference standard, 63 patients were diagnosed with ankle fractures, and 30 patients were confirmed to have an ankle ligament tear or rupture. According to the CT images interpreted by senior orthopedic surgeons, 63 patients were diagnosed with ankle fractures, and 5 patients were identified with ligament injuries. Using MRI, the same senior surgeons diagnosed 62 patients with fractures and 30 with ligament tears or ruptures. For junior orthopedic surgeons, CT-based interpretation resulted in 60 patients being diagnosed with fractures and only 1 case identified as a ligament injury. When interpreting MRI, junior surgeons diagnosed 55 patients with fractures and 32 with ligament tears or ruptures. The corresponding data are summarized in Table 1

Table 1
Patient Characteristics and Preliminary Imaging Diagnoses

	Gold Standard	Senior orthopedic surgeon		Junior orthopedic surgeon	
		CT	MRI	CT	MRI
Fracture	63	63	62	60	55
Non-Fracture	31	31	32	34	39
Ligament tear/rupture	30	5	30	1	32
Non-Ligament tear/rupture	64	89	64	93	62

Table 2 summarizes the diagnostic performance of CT and MRI in detecting ankle fractures and ligament injuries, stratified by surgeon seniority. For fracture diagnosis, senior orthopedic surgeons achieved near-perfect performance using both CT and MRI, with sensitivities of 100% and 98.41%, respectively, and kappa values of 1.000 and 0.976. Junior surgeons also demonstrated high sensitivity and agreement when using CT (sensitivity = 95.24%, κ = 0.930), though slightly lower when using MRI (sensitivity = 87.30%, κ = 0.819). In contrast, for ligament tear/rupture diagnosis, diagnostic performance varied substantially. Junior surgeon showed very poor sensitivity with CT (3.33%, κ = 0.0456), while MRI significantly improved both sensitivity (100%) and agreement (κ = 0.982). Similarly, senior surgeon using CT showed low sensitivity (16.67%, κ = 0.214), whereas MRI yielded perfect diagnostic agreement (κ = 1.000) and sensitivity (100%).

Table 2
Diagnostic Performance of CT and MRI in the Evaluation of Ankle Fractures and Ligament Injuries by
Orthopedic Surgeons with Different Levels of Experience

Diagnostic Category	Surgeon Seniority	Imaging Modality	Sensitivity(%)	Specificity(%)	PPV(%)	NPV(%)	Kappa
Fracture	Junior orthopedic surgeons	CT	95.24	100	100	100	0.930**
		MRI	87.3	100	100	100	0.819**
	Senior orthopedic surgeons	CT	100	100	100	100.01	1.000**
		MRI	98.41	100	100	96.88	0.976**
Ligament tear/rupture	Junior orthopedic surgeons	CT	3.33	100	100	68.82	0.045
		MRI	100	96.88	93.76	100	0.982**
	Senior orthopedic surgeons	CT	16.67	100	100	71.91	0.214**
		MRI	100	100	100	100	1.000**

Sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and Cohen's kappa were calculated based on agreement with the reference standard.

*** indicates statistical significance at $p < 0.01$.*

McNemar's test was conducted to compare the classification accuracy between CT and MRI for fracture diagnosis (Table 3). For junior surgeons, the difference between CT and MRI approached but did not reach statistical significance ($p = 0.063$). However, for senior surgeons, MRI showed a statistically significant difference in fracture classification accuracy compared to CT ($p = 0.008$), suggesting improved diagnostic consistency with MRI in this group.

Table 3
McNemar Test Comparing Diagnostic Consistency between MRI and CT in the Assessment of Fractures

Asymptotic Significance (p Value)	CT(Junior orthopedic surgeon)	CT (Senior orthopedic surgeon)
MRI (Junior orthopedic surgeon)	0.063	0.008
MRI (Senior orthopedic surgeon)	0.5	1

McNemar's test was used to compare the difference in fracture classification (correct vs incorrect) between imaging modalities (MRI vs CT) and surgeon experience levels.

$p < 0.05$ was considered statistically significant.

For ligament injury diagnosis (Table 4), McNemar's test revealed statistically significant differences in diagnostic accuracy between MRI and CT across both junior and senior surgeons. For junior surgeons, MRI significantly outperformed CT in identifying ligament tears ($p < 0.01$), and the same trend was observed

among senior surgeons ($p < 0.01$). These results underscore the superior diagnostic value of MRI over CT for detecting ligamentous injuries, regardless of surgeon experience level.

Table 4
McNemar Test Comparing Diagnostic Consistency between MRI and CT in the Assessment of Ligament Injuries

Asymptotic Significance (p Value)	CT(Junior orthopedic surgeon)	CT (Senior orthopedic surgeon)
MRI (Junior orthopedic surgeon)	< 0.01	< 0.01
MRI (Senior orthopedic surgeon)	< 0.01	< 0.01

McNemar's test was applied to determine whether MRI offered significantly different diagnostic accuracy compared to CT in ligament tear/rupture identification. All comparisons were stratified by surgeon seniority.

$p < 0.05$ indicates significant difference.

Based on the reference standard, 63 patients with ankle fractures were categorized using the Lauge-Hansen classification, and 12 of them were deemed unclassifiable. The most common fracture mechanism was supination-external rotation ($n = 28$, 56.0%), followed by pronation-external rotation ($n = 17$, 34.0%), supination-adduction ($n = 11$, 22.0%), and pronation-abduction ($n = 4$, 8.0%). In terms of injury stage, Stage IV injuries were the most frequent, observed in 41 out of 50 patients (82.0%). Interobserver agreement between junior and senior orthopedic surgeons and the reference standard was evaluated using kappa statistics. As shown in Table 6, both surgeons demonstrated high agreement in fracture classification. For CT-based diagnosis, the kappa values were 0.932 for the junior surgeon and 1.000 for the senior surgeon. For MRI-based diagnosis, the kappa values were slightly lower at 0.844 and 0.933, respectively. All kappa values were statistically significant ($P < 0.01$), indicating excellent diagnostic consistency across raters and modalities.

Table 5
Distribution of Lauge-Hansen Fracture Types Based on the Reference Standard

Lauge-Hansen Stage	Supination-External Rotation	Pronation-External Rotation	Supination-Adduction	Pronation-Abduction	Total
Stage I	1	2	0	0	3
Stage II	5	1	3	0	9
Stage III	3	6	5	1	15
Stage IV	19	1	0	3	23
Total	28	10	8	4	50

Table 6
Agreement (Kappa Values) Between Junior and Senior Orthopedic Surgeons and the Reference Standard in Lauge-Hansen Classification

	CT		MRI	
	Junior orthopedic surgeon	Senior orthopedic surgeons	Junior orthopedic surgeon	Senior orthopedic surgeons
Kappa	0.932**	1.000**	0.844**	0.933**

Discussion

The results of this study suggest that MRI demonstrates sensitivity and specificity comparable to CT in the diagnosis of ankle fractures, especially among senior orthopedic surgeons, who achieved a sensitivity of 98.41%, specificity of 100%, and a kappa value of 0.976. MRI not only enables precise identification of fracture cases but also shows an extremely low rate of false positives. In clinical practice, this combination of high sensitivity and specificity makes MRI a particularly valuable tool for both screening and definitive diagnosis of fractures, especially in patient populations for whom radiation exposure should be avoided, such as pregnant women and children.

Our findings also show that MRI is significantly superior to CT in diagnosing ligamentous injuries of the ankle. Regardless of the physician's level of experience, MRI exhibited extremely high sensitivity and diagnostic consistency, with kappa values of 0.982 and 1.000 for junior and senior surgeons, respectively. In contrast, CT performed poorly in this domain—most notably among junior physicians, who achieved a sensitivity of only 3.33% and a kappa value of 0.045—indicating its limited clinical utility for evaluating ligament damage. These findings are consistent with previous literature [25], which noted that while CT can identify secondary osseous changes, such as avulsion fractures, and thus indirectly infer ligament injuries, MRI provides greater sensitivity and accuracy through direct visualization.

McNemar's test was applied to compare the diagnostic consistency of MRI and CT for both fractures and ligament injuries. For ankle fracture diagnosis, no significant difference was observed between MRI and CT when interpreted by physicians with similar levels of experience, suggesting good agreement between the two modalities. However, a significant difference was found between the CT diagnoses by senior surgeons and the MRI diagnoses by junior surgeons ($p = 0.008$), indicating that effective MRI interpretation in fracture diagnosis may still rely, to some extent, on clinical expertise. In contrast, McNemar's analysis for ligament injury diagnosis revealed highly significant differences across all experience levels ($p < 0.01$), underscoring the superior diagnostic capacity of MRI for ligamentous injuries. This is particularly relevant in cases with atypical clinical signs or concurrent soft tissue and bony trauma, where MRI provides essential information for both diagnosis and treatment planning.

We also analyzed the performance of MRI and CT in the Lauge-Hansen classification of ankle fractures. Both modalities demonstrated high agreement with the reference standard, although MRI showed slightly lower kappa values (0.933 for senior physicians and 0.844 for junior physicians), which still fall within the range of substantial to excellent agreement ($\kappa > 0.8$). These results suggest that MRI remains a reliable modality for fracture classification, especially when interpreted by experienced clinicians. Accurate fracture classification

is crucial for determining surgical strategies and predicting prognosis. Given that the Lauge-Hansen system is based on injury mechanisms and progressive stages, certain subtypes—such as supination-adduction and supination-external rotation—can present overlapping imaging features, particularly in early stages of the injury. While CT offers superior visualization of cortical bone disruption and fracture lines, MRI provides additional insight into bone contusion, articular cartilage integrity, and ligament involvement, thereby supporting a more comprehensive classification in selected cases.

In summary, MRI's superior visualization of soft tissues and bone marrow enables better identification of fracture-associated features, contributing significantly to accurate classification and optimal treatment planning. For radiation-sensitive populations such as pregnant women and children, MRI also serves as a preferred imaging modality. However, image interpretation using MRI depends to some degree on the physician's experience, necessitating integration with clinical findings during early-stage assessments. Despite MRI's excellent sensitivity and specificity in ankle injury diagnosis, X-ray and CT remain the primary diagnostic tools in many institutions. This may be due to MRI's lower availability, higher cost, and longer examination times. Furthermore, MRI requires patients to remain still in a confined space for an extended period, which may not be well tolerated. Nevertheless, X-ray and CT offer excellent depiction of fracture lines, which remains essential for preoperative planning.

Several limitations existed in present study. This study focused solely on imaging examinations and structural abnormalities, without further exploring the functional changes that occur following ankle fractures. This limitation may reduce the clinical applicability of our findings. In addition, the relatively small sample size may have introduced sampling bias. Furthermore, as most participating physicians were from the same institution, the generalizability of the results to other clinical settings may be limited.

Conclusions

The results of this study indicate that MRI demonstrates acceptable diagnostic accuracy in the evaluation of ankle fractures. Furthermore, MRI offers superior sensitivity in detecting ligamentous injuries, thereby providing more precise guidance for clinical decision-making, particularly in special populations such as pregnant women and children who require radiation-free imaging. However, the diagnostic accuracy of MRI interpretation appears to be influenced by the physician's level of experience.

Abbreviations

Abbreviation	Full Term
MRI	Magnetic Resonance Imaging
CT	Computed Tomography
PPV	Positive Predictive Value
NPV	Negative Predictive Value
PLR	Positive Likelihood Ratio
NLR	Negative Likelihood Ratio
SD	Standard Deviation
SPSS	Statistical Package for the Social Sciences
MDCT	Multidetector Computed Tomography

Declarations

Ethics approval and consent to participate

The study was conducted in the Department of Orthopedics at Peking University Third Hospital and was approved by the institutional ethics committee. Clinical trial number: not applicable.

Consent for publication

Not applicable

Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

LYB and JXF contributed equally to the study design and data collection. XZL and PV performed data analysis. YC, ZZC, and YLF participated in patient recruitment and imaging interpretation. XNP supervised the study. YL conceptualized the study, interpreted the results, and was responsible for the manuscript revision. All authors read and approved the final manuscript.

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