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To evaluate the sensitivity and specificity of digital radiography and ultrasound in correlation with MRI for early diagnosis of stress injuries in lower extremity

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Abstract

Apoptosis is triggered by disruption of healthy skeletal structure, leading to BSI. Stress fractures that make training and competitive performance difficult can result from BSI, which are commonly underestimated and mistakenly classified as muscle or tendon injuries. The best way to reduce the chance that microfractures may develop into larger ones is to identify them early. Imaging methods like radiography, CT, and MRI can help with management decision-making, training return, and injury recurrence prediction. 106 patients who had been undergoing intense training for the previous two weeks at the tertiary care hospital and complained of lower limb pain were the subjects of a hospital-based prospective case-control study. Radiography, US, and specialized MRI were performed on every patient. In contrast to the controls, which included patients who complained of lower limb discomfort but did not exhibit bone stress injuries on MRI, the cases included patients who had bone stress injuries verified by MRI. Following the proper data filtering, Medcalc (vs. 20.0) was used to transmit and evaluate the data sheet. In the study, majority were male (98.1%), age distribution varied, with 43.4% of participants aged 21-30 years, 35.8% under 20 years, and 20.8% over 30 years. Tibial involvement was predominant among cases (92.2%), with the right side being more commonly affected for both tibial and fibular injuries. The most frequent injury grade was Grade 4b (37.2%), followed by Grade 1. Radiography showed a sensitivity of 41.18% and an accuracy of 71.70%, whereas ultrasound (USG) demonstrated higher accuracy (89.62%), with better sensitivity and specificity. Radiography is accessible but has low sensitivity (41.18%) for early bone stress injury (BSI) detection. Ultrasound, with higher sensitivity (78.43%) and perfect specificity (100.00%), is a valuable adjunct, offering insights into soft tissue involvement and early bone stress reactions, and guiding therapeutic interventions effectively.

Keywords: Bone health, MRI grading, bone stress injury, stress fracture

Introduction

Bone stress injuries (BSI), such as stress fractures, arise from the application of severe repeated loads on a typically healthy skeletal structure. Physical activity-related overuse injuries accounts for major cause of morbidity. BSI presents itself across a range of pathological states, commencing with a stress reaction, progressing to a stress fracture, and finally resulting in a complete bone fracture. The occurrence of musculoskeletal injuries in aesthetic sports is around 10% which may potentially surpass that of endurance sports (e.g., running; 8%) (Nose-Ogura *et al.*, 2019) ^[13]. Lower extremity stress fractures constitute 80%-90% of all stress fractures, accounting for around 0.7% to 20% of all injuries in sports medicine (Chen *et al.*, 2013) ^[2]. Up to 22% of injuries are recurring, necessitate extended recovery (>3 weeks), and frequently result in injuries that end a season or career. Pathogenesis of BSI is complex. The occurrence of micro damage can be attributed to abrupt or progressive escalations in physical activity, which can disrupt the intricate network of osteocyte 'master cells' that are embedded within the bone matrix. This disruption triggers apoptosis, a process that regulates bone resorption and formation, facilitating the removal and replacement of damaged bone in a manner that is reliant on both time and space. Consequently, incremental fragments of damage accumulate and ultimately amalgamate, resulting in the formation of little fractures (Kardouni *et al.*, 2021) ^[9]. Although not exclusively, these injuries commonly occur in individuals with narrower bones. This is because they have lower cross-sectional moments of inertia and bone stiffness, which leads to increased local strain when subjected to loading (O'Leary *et al.*, 2021) ^[16].

The most common stress fractures occur in the tibia but also develop in the tarsal navicular, metatarsals, femur, and pelvis (Kahanov *et al.*, 2015) [8]. Individuals who engage in more intense exercise and have lower bone mineral density are more susceptible to developing bone-specific injuries compared to those who engage in more intense training but have normal BMD. BSIs can be caused by a number of lifestyle factors, such as hormone levels, food, stress, and sleep patterns. Sex and age are inherent, unchangeable risk factors for bone stress injuries.

The formation of BSIs is influenced by the training load and recuperation. BSIs cause acute pain, decreased athletic activity, and disability (Hamstra-Wright *et al.*, 2021) [5]. If they continue their physical activity and training program, people with bone stress injuries may eventually experience muscle fatigue and weakening, decreased shock absorption, and bone remodelling (Nusselt *et al.*, 2010) [15]. Osteoclastic activity is a process in which bone is broken down and resorbed, which may occur when bone is cyclically stressed more often than the skeleton can repair itself, leading to bone weakening. This can happen with or without a significant bone stress fracture or biomechanical disruption (Miller *et al.*, 2011) [11]. Stress fractures and impaired limb function can result from BSI, especially in elite athletes who refuse to interrupt their practice. Therefore, in this scenario, the most advantageous objective is to promptly identify and address micro fractures in order to reduce the likelihood of them progressing into macro fractures.

Clinical examination continues to be a fundamental component of patient assessment. Utilizing imaging techniques can aid in making informed management decisions, facilitating the return to training, and predicting the likelihood of injury recurrence. Over the course of history, radiography and radionuclide bone scans have served as the prevailing diagnostic modalities employed for the evaluation and identification of bone stress injuries. In the majority of clinical scenarios, simple radiographs remain the primary imaging modality for BSIs owing to their cost-effectiveness, minimal radiation exposure, and widespread accessibility. While routine radiographs may detect skeletal alterations linked to stress injuries, they frequently remain within the normal range. The skeletal location of the bone stress injury and the timing of symptom onset both affect radiographic abnormalities (Deutsch *et al.*, 1997) [3]. Even though radiographs are frequently used as the first diagnostic test, their sensitivity is only thought to be 10% in the early stages of an injury (Kiuru *et al.*, 2004) [10]. Computed tomography (CT) is a valuable and precise imaging technique that is particularly effective in detecting fracture lines, particularly in the advanced stages of bone stress injuries (Papalada *et al.*, 2012) [17]. The constraints of these methods have facilitated the dependence on alternative diagnostic methods. Magnetic resonance imaging (MRI) and other imaging modalities provide the most realistic depiction of periosteal and endosteal marrow edema, which are further markers of stress-induced damage.

Clinicians utilize the MRI grading system to efficiently strategize and oversee patients with bone stress injury (Beck and Drysdale, 2021) [1]. Despite MRI being the prevailing diagnostic method, therapeutic ultrasonography (TUS) was employed in the early 1980s as an alternative to plain radiography for the early detection of BSI. The utilization of ultrasonography, a method that is gaining popularity in the assessment of the musculoskeletal system, has lately demonstrated promise in diagnosing stress fractures. Although TUS is mostly used for therapeutic purposes, soft tissue sports injuries are also managed with its help. Furthermore, it functions as an accurate and economical diagnostic substitute for imaging methods in the

preliminary assessment of bone stress injuries. This is because applying TUS directly to the injured site may cause pain, which would validate the diagnosis [16]. In this particular setting, therapeutic ultrasonography can serve as an initial assessment tool due to its cost-effectiveness, safety, and non-invasive nature. Hence, the present study was designed to evaluate the radiographic, US and MRI findings in bone stress injuries in Indian population, correlate the radiographic finding with US and MRI and the correlation of radiographic, US and MRI findings.

Materials and Methods

Study design

Demographic details of the patient age, sex, BMI, height, weight, comorbidities were recorded. Information on mechanism of injury, and onset of symptoms were also collected. Neurovascular status was also assessed. Radiography assessment was done by using Digital Radiography. All patients underwent US and dedicated MRI. A hospital based prospective case-control study was conducted at Department of Radiodiagnosis and Imaging, Command Hospital Air Force, Bengaluru, during June 2022 to Dec 2023. The study populations were selected based on the following criteria: (i) inclusion criteria: (a) patient involved in vigorous training or exercise activity from last 2wks (minimum), (b) patients presented with complaint of pain in lower limb, (ii) exclusion criteria: (a) asymptomatic individuals, (b) patients with fractures due to trauma, disease or pharmacologic intervention. The sample size was calculated on the basis of following formula:

$$SS = (Z\text{-score})^2 * p * (1-p) / (e)^2$$

SS = Sample Size

Z-score = Critical value and a standard value for the corresponding level of confidence. (1.96 for confidence level 95%)

e = Margin of error (margin of error of 10% is taken).

P= Expected prevalence. (The prevalence of BSI reported in studies from different parts of the world varies from less than 10% to nearly 90%. Assuming a crude prevalence of 50% as there are no definitive data from large scale community based studies from India).

$$SS = (1.96)^2 * 0.5 (1-0.5) / (0.10)^2$$

$$SS = 96.04$$

Considering the dropout rate of 10%; adjusted sample size would be 96 + 10% dropout rate = 106 subjects.

Imaging Studies for Suspected Bone Stress Injuries

Ultrasound

All participants underwent examination in accordance with the standard protocol following written informed consent. An ultrasound coupling gel at room temperature was applied to the symptomatic limb. Continuous ultrasound at a maximum intensity of 2.00 W/cm² was utilized to evaluate the targeted area, with the most symptomatic point being assessed for 30 seconds. If pain was reported, the intensity was reduced by 0.10 W/cm². The probe was moved at a standardized rate of 1 cm/s. The contralateral asymptomatic leg served as the control.

Magnetic Resonance Imaging

MRI was conducted using a dedicated 1.5 Tesla Siemens Magnetom Avanto unit. An appropriate imaging coil was employed. Routine coronal T1-weighted images were acquired

with a TR of 35 ms, TE of 16 ms, a single signal averaged, and a matrix size of 192 × 136 × 400 mm. This was followed by a coronal STIR sequence with parameters of TR 1460 ms, TE 26 ms, TI 85 ms, two signals averaged, and a matrix size of 192 × 122 mm. The field of view was 190 × 190 × 50 mm for the T1-weighted images and 200 × 190 mm for the STIR images, with slice thicknesses of 0.8 mm and 4 mm, respectively, and intersection gaps of 0.08 mm and 0.4 mm. Additionally, routine axial T1-weighted 3-D sequence images were obtained with a TR of 50 ms, TE of 16 ms, a single signal averaged, and a matrix size of 192 × 182 × 40 mm. This was followed by an axial STIR sequence with parameters of TR 980 ms, TE 26 ms, TI 85 ms, two signals averaged, and a matrix size of 192 × 144 mm. The field of view for these sequences was 180 × 180 × 90 mm and 200 × 200 mm, respectively, with slice thicknesses of 1.4 mm and 4 mm, and intersection gaps of 0.01 mm and 0.4 mm. The total duration of the MRI examination ranged from 30 to 45 minutes.

MRI Grading of Injuries

A 5-stage MRI grading system was used to classify bone stress injuries. A normal appearance was graded 0; periosteal and bone marrow edema were graded 1. Periosteal edema and increased marrow signal on fat-suppressed T2-weighted images were graded 2; more extensive periosteal edema and marrow signal abnormalities, readily seen on T1-and T2-weighted sequences, were graded 3; stress fractures, with a discrete fracture line visible on MRI, were graded 4.

Statistical analysis

The data was collected using pre-designed proforma and subsequently entered into an Excel spreadsheet. Categorical variables were described as frequencies, while continuous variables were described using means and standard deviations. Following appropriate data filtration, the dataset was transferred and analyzed using Medcalc (version 20.0). The Chi-square test was applied to see the association between outcome and demographic characteristics. The analysis was done to estimate the sensitivity and specificity of the obtained cutoff values. Results were considered to be statistically significant when $p<0.05$.

Results and Discussion

In this study, 106 patients were enrolled and divided into two groups: cases (n=51) and controls (n=55). The cases comprised patients who had bone stress injuries confirmed by MRI, whereas the controls included patients presented with complaint of pain in lower limb but did not show bone stress injuries on MRI (Fig.1). Bone stress injuries arise from chronic, repetitive physical activity and can vary in severity from stress reactions to cortical fractures. These are common among athletes often presenting subtle symptoms that challenge initial diagnosis. In clinical practice, early diagnosis of bone stress injuries is crucial to facilitate the timely application of suitable rest and treatment strategies, thereby preventing prolonged healing periods associated with more severe injuries. Consequently, the availability of an accessible, point-of-care imaging modality that can serve as an effective diagnostic tool for healthcare providers

in the evaluation of bone stress injuries is essential. Radiographic imaging, such as X-rays, is typically used first but may not always reveal early stress fractures. While magnetic resonance imaging (MRI) is considered the gold standard for diagnosing BSIs, its accessibility and cost limitations have prompted exploration of alternative imaging modalities. Ultrasound (US) is a readily available, cost-effective, and non-invasive technique that has shown promise in detecting early-stage bone stress injuries. Hence the present study was designed to evaluate the sensitivity of ultrasound and MRI in early diagnosis of stress injuries of lower extremity



Fig 1: 40 year old male presented with pain at the anteromedial aspect of right upper leg since 03 days. History of physical exertion present for last 01 month. Radiograph right leg AP (a) and Lateral (b) views reveals no significant bony or soft tissue changes.

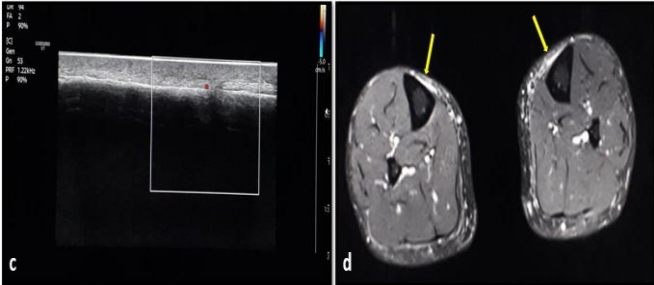


Fig 1: (c) Ultrasound right leg reveals focal hyperemia with periosteal edema at the anteromedial aspect of right leg (site of pain). (d) STIR Axial MRI images reveals presence of periosteal hyperintensities at anteromedial aspect of bilateral proximal tibia (arrow).

Out of total 106 patients, 98.1% (n=104) were males and 1.9% (n=2) were females. Among the 51 cases, 98.0% (n=50) were males and only 2.0% were females. While among the 55 controls, 98.2% (n=54) were males and only 1.8% were females (Table 1, Fig. 2). There was no significance difference was observed between cases and control with respect to gender ($P=0.9572$). Similarly, among the 55 controls, 98.2% (n=54) were males and 1.8% (n=1) were females. This significant male predominance can be attributed to the nature of our study site, which is a hospital dedicated to individuals serving in the Air Force. Given the demographic composition of military personnel, where males predominantly serve, it is expected that the majority of patients in our study would be male. Contrary to our findings, Syrop *et al.*, (2022) ^[18] reported that BSI was observed in 84% of females and 16% of males. Nattiv *et al.*, (2013) ^[12] reported that 64.7% were females and 35.3% were females.

Table 1: Distribution of gender of the patients in cases and controls

Gender	Cases (N=51)		Control (N=55)	
	N	%	N	%
Male	50	98.0	54	98.2
Female	1	2.0	1	1.8
Significance: $\chi^2=0.0029$; $P=0.9572$.				

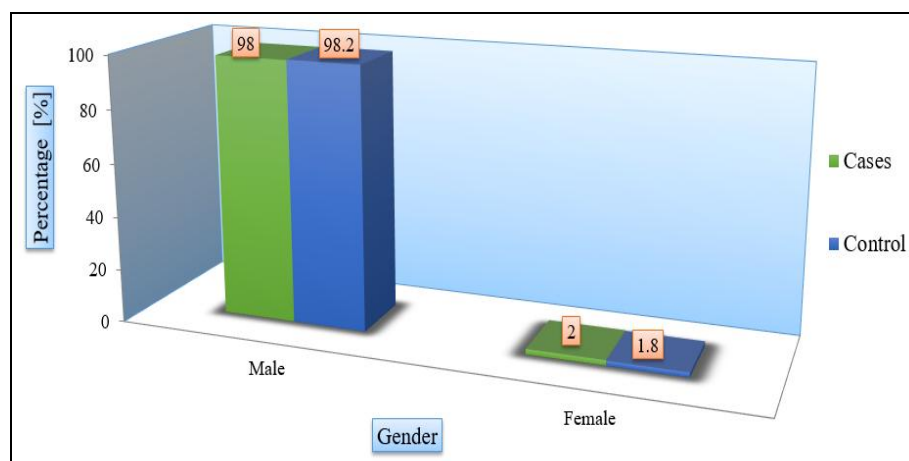


Fig 2: Distribution graph of gender in cases vs. controls

Table 2: Distribution of age of the patients in cases and controls.

Age group	Cases (N=51)		Control (N=55)	
	N	%	N	%
<20years	25	49.0	13	23.6
21-30years	19	37.3	27	49.1
>30years	7	13.7	15	27.3

Significance: $\chi^2=7.9502$; $P=0.0188$.

43.4% (n=46) of subjects fall in the age range of 21-30 years, 35.8% (n=38) were below the age of 20 years and 20.8% (n=22) were above the age of 30 years. However, among the 51 cases, 49% (n=25) patients were below the age of 20 years, 37.3% (n=19) patients were between the age of 21-30 years and only 13.7% (n=7) patients were above the age of 30 years.

Conversely, among the 55 controls, 49.1% (n=27) patients were between the age of 21-30 years, and 23.6% (n=13) were below the age of 20 years. There was significance difference was observed between cases and control with respect to age ($P=0.0188$) (Table 2, Fig. 3).

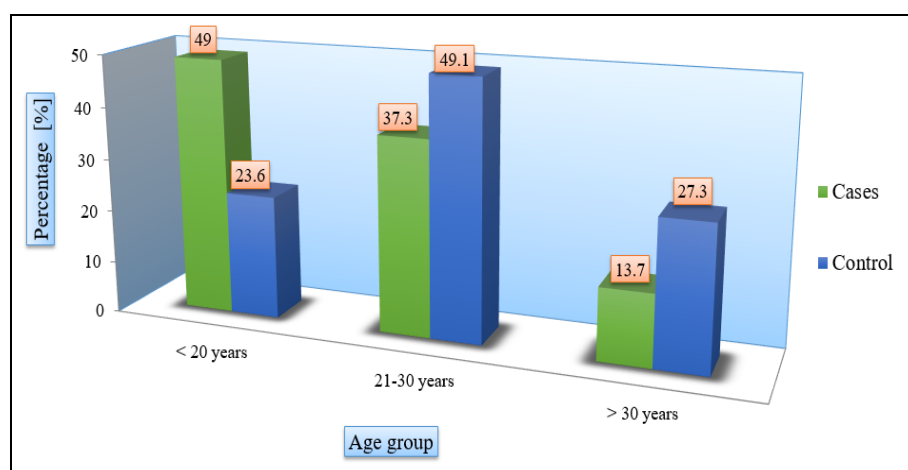


Fig. 3: Distribution graph of age in cases vs. controls.

The data compares the duration of injury to presentation between cases (N=51) and controls (N=55). For cases, 29.4% presented in less than 5 days, 51.0% between 5 to 7 days, and 19.6% after more than 7 days. For controls, 34.6% presented in less than 5 days, 43.6% between 5 to 7 days, and 21.8% after

more than 7 days. The distribution suggests that the majority in both groups presented within the 5 to 7-day period. Although there are slight differences in the percentages for each duration category but there was no significance difference ($P=0.7474$) (Table 3, Fig. 4).

Table 3: Distribution of duration of injury to presentation of the patients in cases and controls.

Duration of Injury	Cases (N=51)		Control (N=55)	
	N	%	N	%
< 5days	15	29.4	19	34.6
5days-7 days	26	51.0	24	43.6
>7 days	10	19.6	12	21.8

Significance: $\chi^2=0.5823$; $P=0.7474$.

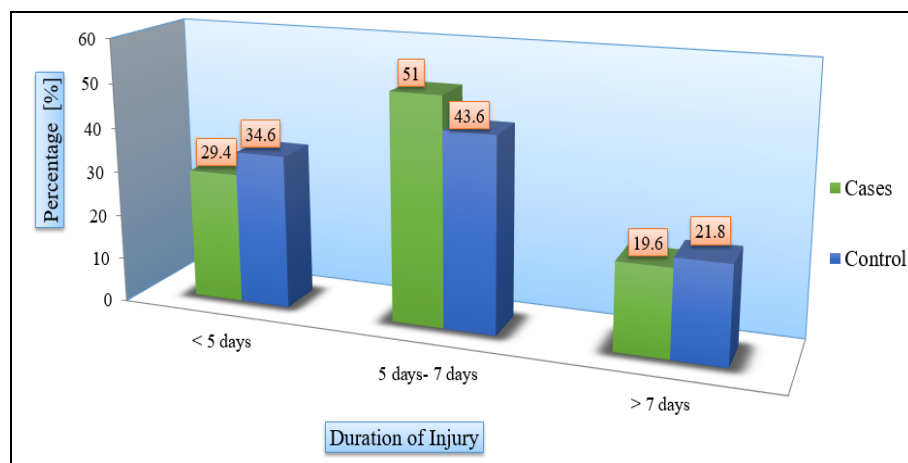


Fig 4: Distribution graph of duration of injury in cases vs. controls.

Table 4: Distribution of physical examination of the patients in cases and controls.

Physical Examination	Cases (N=51)		Control (N=55)	
	N	%	N	%
Swelling and tenderness	23	45.1	1	1.8
No swelling and tenderness	28	54.9	54	98.2

Significance: $\chi^2=28.0329$; $P<0.001$.

Swelling and tenderness was observed in 22.6% (n=24) patients, while no swelling and tenderness was observed in 77.4% (n=82) patients. Among cases, swelling and tenderness was observed in 45.1% (n=23) of subjects (Table 4, Fig. 5). While among controls swelling and tenderness was observed in only 1.8% patients. This significant disparity underscores the need for clinicians to pay close attention to these physical signs when evaluating patients for potential bone stress injuries. The marked difference in symptom prevalence between the two groups

further supports the role of inflammation and localized tissue response in the pathophysiology of bone stress injuries. Ishibashi Y *et al.*, (2002) [6] reported that spontaneous pain was observed in 7 lesions (19.4%), tenderness in 36 lesions (100%) and swelling in 16 lesions (44.4%). Dobrindt O *et al.*, (2012) [4] reported that increase of pain during exercise (n=14); swelling (n=11), local pressure tenderness (n=11) and articular dysfunction (n=10) was observed among subjects with stress injuries.

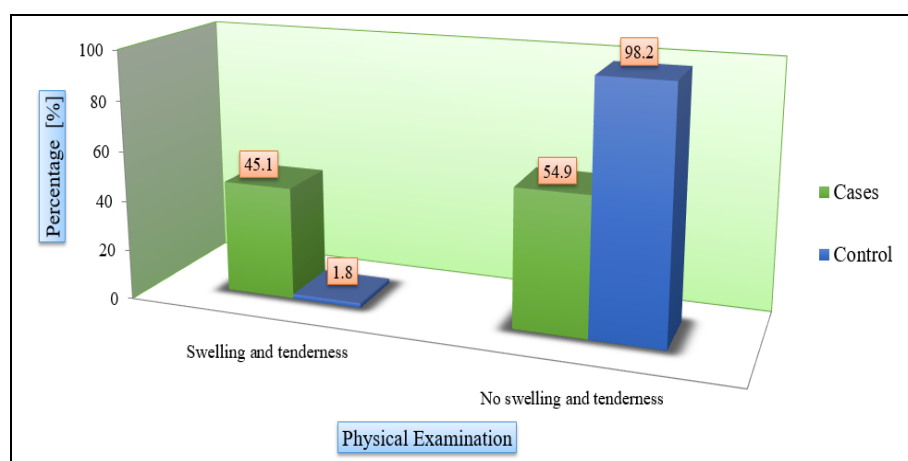


Fig 5: Distribution graph of physical examination in cases vs. controls.

Table 5: Distribution of patients with bone stress injuries on the basis of their bone involvement.

Bone Involved	Right side involved		Left side involved		Bilateral	
	N	%	N	%	N	%
Tibia (n=47)	21	44.7	15	31.9	11	23.9
Fibula (n=3)	2	66.7	1	33.3	0	0
Tibia & Fibula (n=1)	0	0	1	100	0	0

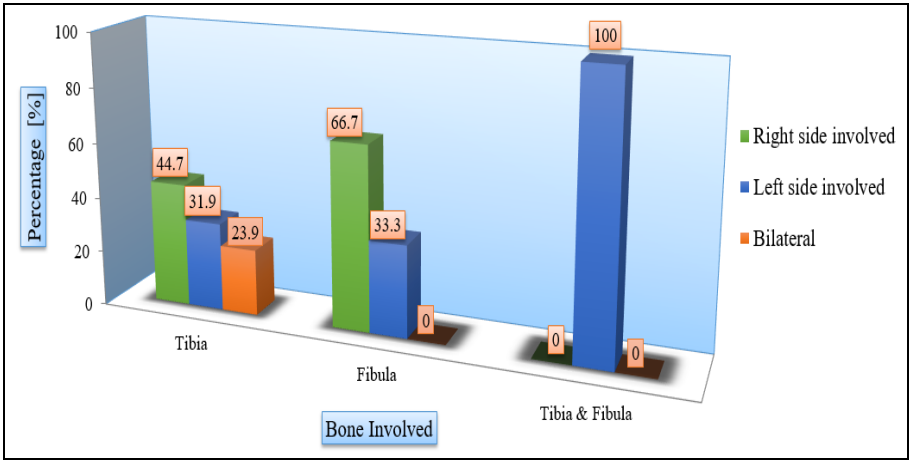


Fig 6: Distribution graph of patients with bone stress injuries on the basis of their bone involvement.

Out of 51 cases, tibial involvement was involved in 92.2% (n=47) of patients, fibular involvement was observed in only 5.9% (n=3) of patients. Both Tibial and Fibular were involved in only one patient, with left side being affected. Among the tibial cases right side was involved in 44.7% (n=21), left side was involved in 31.9% (n=15) and bilateral involvement was observed in 23.9% (n=11) of subjects. Among the fibular cases right side was involved in 66.7% (n=2) of subjects and left side involvement was observed in 33.3% (n=1) of subjects (Table 5, Fig. 6). This suggests that the right tibia may be more susceptible to stress injuries, possibly due to dominance or specific physical activities that place more strain on the right leg. In contrast, fibula injuries were relatively rare, with 66.7% occurring on the right side and 33.3% on the left side, and no bilateral cases reported. The limited number of fibula injuries makes it difficult to draw definitive conclusions, but the data suggests a possible preference for right-side involvement similar to the tibia. For combined tibia and fibula injuries, only one case was reported, and it involved the left side exclusively (100%). This singular occurrence highlights the rarity of simultaneous stress injuries to both bones and underscores the need for further

investigation into the specific conditions or activities that might lead to such injuries. Overall, these findings point to a higher prevalence of right-side bone stress injuries, particularly in the tibia, which could be linked to biomechanical factors, dominant leg use, or specific athletic activities. Dobrindt *et al.* (2012) [4] reported that the most common locations of stress injury were the metatarsal-and tarsal bones. Iwamoto *et al.*, (2011) [7] reported that tibia was most commonly affected. Nattiv *et al.*, (2013) [12] reported that tibia (51%) and metatarsal (21%) were commonly affected.

Table 6: Distribution of patients with bone stress injuries on the basis of their MRI grading.

MRI Findings	N	%
Grade 1	15	29.4
Grade 2	6	11.8
Grade 3	10	19.6
Grade 4a	1	2.0
Grade 4b	19	37.2
Total	51	100.0

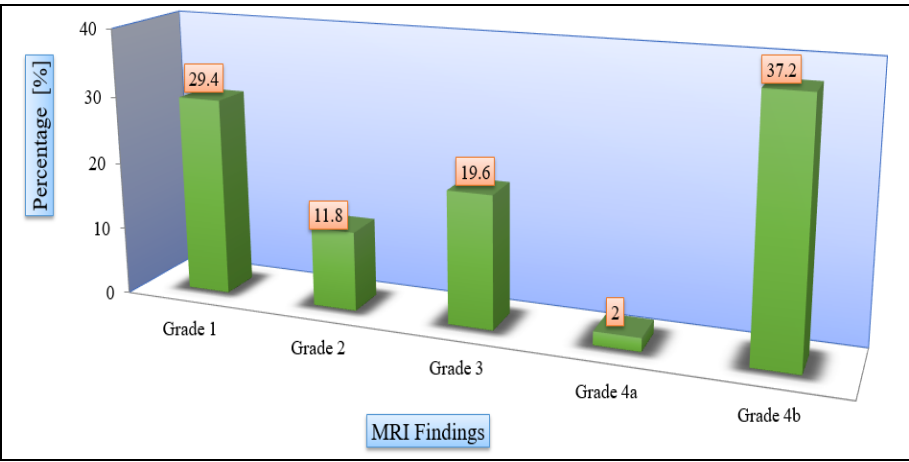


Fig 7: Distribution graph of patients with bone stress injuries on the basis of their MRI grading.

As depicted above, the most common finding was Grade 4b injury, accounting for 37.2% of cases. Conversely, 29.4% of cases exhibited Grade 1 injuries, intermediate severity was observed in 11.8% of cases with Grade 2 injuries and 19.6% with Grade 3 injuries. A small percentage (2.0%) were Grade 4a injuries (Table 6, Fig. 7). The higher prevalence of Grade 4b injuries indicates a significant proportion of individuals are

experiencing severe bone stress injuries that require extensive treatment and rehabilitation. Overall, the distribution of MRI grades highlights a wide range of injury severities, with a notable concentration of more severe cases. Nattiv *et al.*, (2013) [12] reported that 9% of injuries were grade I, 49% of injuries were grade II, 28% of injuries were grade III and 14% of injuries were grade IV. Kiuru *et al.*, (2004) [10] reported that 27.8%

(n=10) of cases were Grade IV similarly, 27.8% (n=10) were Grade II and 22.2% (n=8) were Grade I. However, Nussbaum *et*

al., (2019) ^[14] reported 60.6% (n=80) of the cases as Grade II, 21.2% (n=28) as Grade III and five cases as Grade IV.

Table 7: Diagnostic accuracy of Radiography.

Radiography	Value	95% CI
Sensitivity	41.18%	27.58% to 55.83%
Specificity	100.00%	93.51% to 100.00%
Positive Predictive Value	100.00%	83.89% to 100.00%
Negative Predictive Value	64.71%	59.30% to 69.76%
Accuracy	71.70%	62.12% to 80.02%

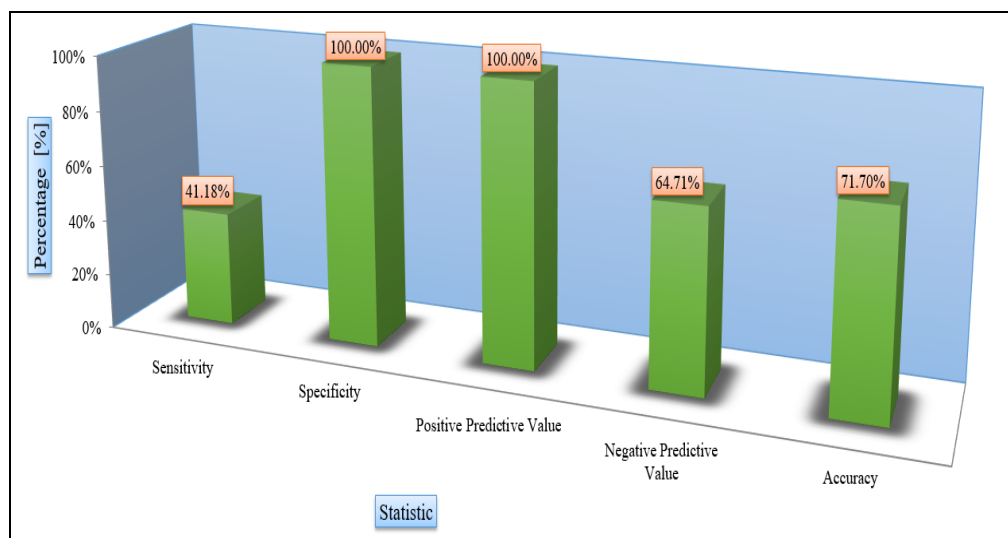


Fig 8: Distribution graph of Subjects based on Diagnostic accuracy of Radiography.

Conventional radiography plays a vital role in the initial evaluation of bone stress injuries by providing a preliminary assessment to rule out other conditions and detect obvious fractures. It has been the primary imaging tool in the assessment of a bone stress-related injury, because it is widely available and relatively cheap. Radiographic findings can help guide the need for further imaging studies. If radiographs are negative but clinical suspicion remains high, more sensitive imaging techniques like MRI can be employed. The performance of radiography in the evaluation of bone stress injuries shows a nuanced profile of diagnostic capabilities. Radiography exhibited a sensitivity of 41.18% (95%CI: 27.58% to 55.83%)

and specificity of 100.00% (95%CI: 93.51% to 100.00%) with the positive predictive value of 100.0% (95%CI: 83.89% to 100.00%), negative predictive value of 64.71% (95%CI: 59.30% to 69.76%) and accuracy of 71.70% (95%CI: 62.12% to 80.02%) (Table 7, Fig. 8). These statistics underscore the utility of radiography in confirming bone stress injuries but also highlight its limitations in early detection, where more sensitive imaging modalities like MRI or CT scans are often required for a comprehensive assessment (Fig. 9). Similar findings supported by Nussbaum *et al.*, (2023) ^[14] except sensitivity and NPV were reported 27% and 17%, respectively.

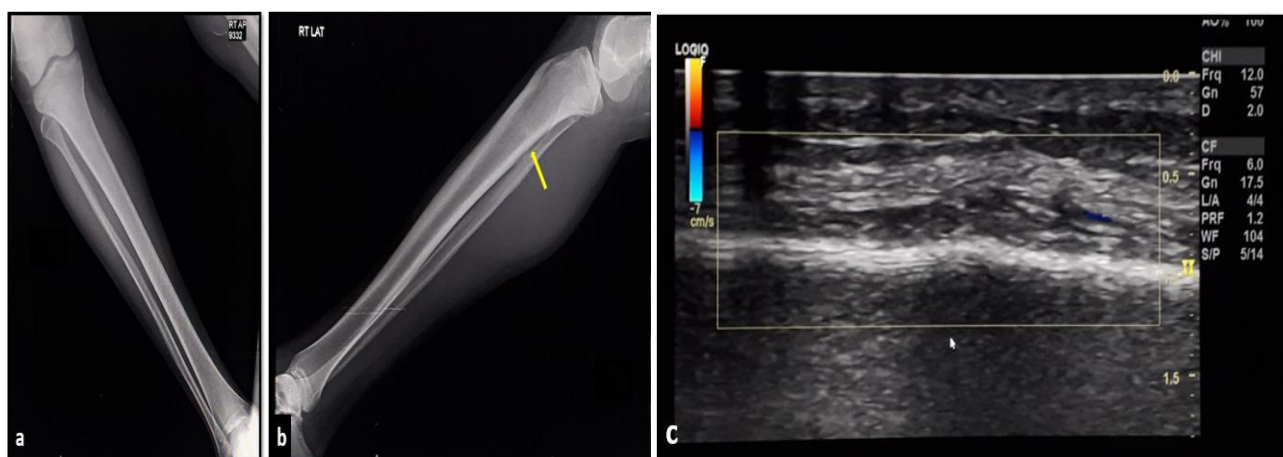
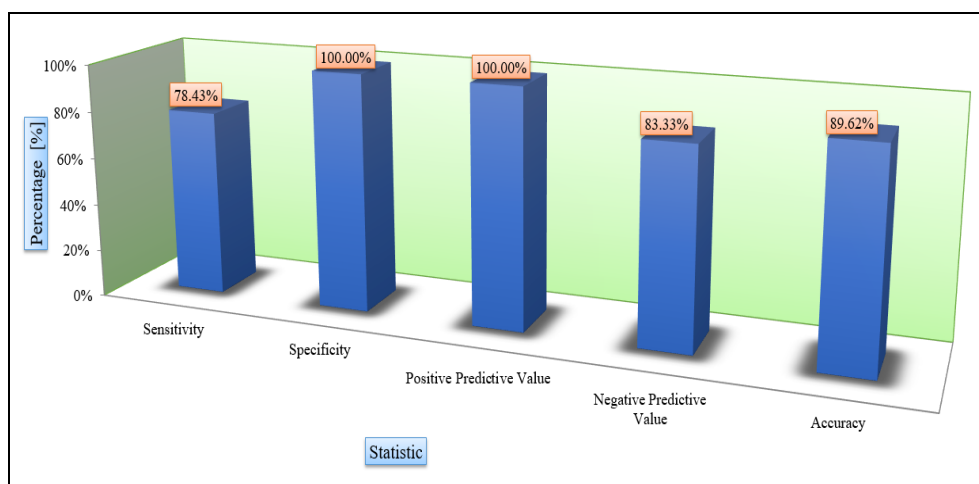


Fig 9: 19 year old male presented with pain at the anteromedial aspect of right upper leg since 05 days. History of physical exertion present for last 3 month. Radiograph right leg AP (a) and Lateral (b) views reveals focal sclerosis involving upper third of tibia without any obvious fracture line (arrow). (c) Ultrasound right leg reveals focal hyperemia with periosteal edema at the anteromedial aspect of right leg (site of pain)

Table 8: Diagnostic accuracy of Ultrasound.

Ultrasound	Value	95% CI
Sensitivity	78.43%	64.68% to 88.71%
Specificity	100.00%	93.51% to 100.00%
Positive Predictive Value	100.00%	91.19% to 100.00%
Negative Predictive Value	83.33%	74.76% to 89.41%
Accuracy	89.62%	82.19% to 94.70%

**Fig 10:** Distribution graph of Subjects based on Diagnostic accuracy of Ultrasound.

USG demonstrated an accuracy of 89.62% (95%CI: 82.19% to 94.70%), sensitivity of 78.43% (95%CI: 64.68% to 88.71%) and specificity of 100% (95%CI: 93.51% to 100.00%). While PPV and NPV of USG was found to be 100% (95%CI: 91.19% to 100.00%) and 83.33% (95%CI: 74.76% to 89.41%) respectively (Table 8, Fig. 10). While ultrasound excels in detecting soft tissue changes and guiding interventions, its high accuracy and specific strengths make it a complementary tool to X-rays and MRI in the comprehensive assessment and management of bone stress injuries. Syrop *et al.* 68 (2022) ^[18] reported sensitivity of 80.00% and specificity of 71.00%, while PPV and NPV of USG was found to be 92.00% and 45.00% respectively. Rao *et al.*, (2022) showed sensitivity of 86.00% and specificity of 77.27%, while PPV and NPV of USG were found to be 88.10% and 73.91% respectively.

Conclusion

In conclusion, this study highlights the significant role of imaging modalities in the diagnosis and management of bone stress injuries with a particular focus on radiography, ultrasound, and MRI. The findings demonstrate that while radiography remains a widely accessible and cost-effective initial screening tool, its relatively low sensitivity (41.18%) and moderate overall accuracy (71.70%) limit its effectiveness in early detection of BSIs. Ultrasound emerges as a highly promising adjunctive tool with a sensitivity of 78.43% and an impressive specificity of 100.00%, offering valuable insights into soft tissue involvement and early-stage bone stress reactions. The high positive predictive value of ultrasound (100.00%) and its ability to guide therapeutic interventions further underscore its utility in a comprehensive diagnostic approach. Moreover, the study reveals that younger individuals (under 20 years) are at a higher risk for bone stress injuries compared to older age groups, emphasizing the need for targeted prevention and intervention strategies. MRI grading highlights a range of injury severities, from early-stage stress reactions to severe fractures, guiding treatment decisions. Overall, integrating radiography, ultrasound, and MRI into a multi-modal diagnostic approach enhances the accuracy and

effectiveness of bone stress injury management, providing a more comprehensive evaluation and tailored treatment for affected individuals.

Conflict of Interest

Not available

Financial Support

Not available

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