Original Article

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Correlation of Magnetic Resonance Imaging and Bone Scintigraphy in Stress Injuries of Lower Extremities Bones

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Abstract

Introduction: Stress fracture of foot and long bones of leg is a common disability. The problem of "stress fracture" is clinically significant amongst armed forces and athletes due to the high standard of training imparted in the various military regimental training centers and academies. This study was undertaken to compare findings of scintigraphy and magnetic resonance imaging (MRI) in early detection of stress injuries of the bone when radiography findings were normal or inconclusive.

Purpose: We undertook a prospective study of symptomatic patients who were referred to Department of Radiology, Command Hospital Air Force, Bengaluru, Karnataka, India, from various military units with history of prolonged exertion and clinical suspicion of stress injury.

Methodology: In this prospective study, 50 consecutive patients with suspicion of stress injuries of bone and with negative radiographs were selected for the study from May 2006 to June 2009. Scintigraphy and MRI were performed on the same day or within 4 days and the findings were compared for correlation accuracy of MRI and scintigraphy.

Results: In all patients, both scintigraphy and MRI indicated stress injury of bone. On Evaluation of MRI for grades of bone stress injury in relation to bone scintigraphy findings. There is good agreement between MRI and bone scintigraphy and with a strong *P* value ($P < 0.001$). Compared with scintigraphy, MRI showed more diagnostic information, such as fracture line, periosteal and soft tissue edema.

Conclusion: From these observations, we conclude that MRI provides more diagnostic information than scintigraphy and is recommended as the diagnostic and assessment tool in early stages of stress injury of bone.

Key words: Bone scintigraphy, Magnetic resonance imaging, Radiography, Stress fracture

INTRODUCTION

Stress fracture is a common disability amongst Armed forces personnel especially in military recruits due to high standard of training imparted in the various military regimental training centers and academies.[1]

It is a frequent cause of discontinuity in training. It results in loss of training time to the recruit, loss of man-hours, trained manpower and financial loss to the organization. It also affects the morale of the recruit and trained manpower which is unquantifiable.[2]

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Stress fractures or fatigue fractures were originally reported by Breithaupt, Military Surgeon in Prussian army recruits in 1855. He described a syndrome of painful swollen feet amongst soldiers after long marches as "March fracture" the stress fractures in the metatarsals.[2] Using conventional radiography, these signs and symptoms were first reported as stress fractures in 1897. Stress fractures are most common noted in the lower extremities, these injuries also occur in the upper extremities, ribs, spine, and pelvis.[3] Clinical evaluation of stress fractures includes a thorough history, a physical examination, and imaging studies. The recent advancement of musculoskeletal imaging techniques has aided the evaluation and diagnosis of stress-related

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injuries. Standard management of stress fractures consists of pain-free crutch ambulation for lower extremity stress fractures followed by a gradual return to weight-bearing activity culminating in running.[4]

Pathophysiology

The stress fractures are caused by continuous and repetitive muscular pulling on the normal bone, resulting in a disruption of the periostium and the underlying bone, at the origin or insertion of a given muscle.[5] Stress fractures are in a very real sense a microfracture secondary to intense muscle contraction.[6] Unaccustomed prolonged and excessive physical activity that causes resorption of bone in excess of repair and bone formation in certain regions can also result in stress fractures.

Overuse or fatigue stress fractures

It is clinically described in military recruits and runners in whom normal bone is exposed to repeated abnormal stress.[6]

Types of overuse stress fracture are compression type and distraction type. This is subdivided as transverse, longitudinal and oblique. The transverse fracture is more dangerous and this type is known to cause a complete fracture if not diagnosed at an early stage and properly treated. The common locations of stress fractures are the tibia, fibula, metatarsals, calcaneum, and navicular bones. It can also occur at rare sites such as pubic-ramus, pubic symphysis, spine, femoral neck, femoral diaphysis, distal shaft of humerus and proximal ulna.[7,8]

The main modality for investigating of stress fractures at the initial stage is the plain X-ray which is easily available at all primary health care centers. Sometimes, the plain radiographic findings of stress fracture are difficult to interpret and may even be normal in early stages. Hence, there is a high possibility of missing early stress fractures which can further lead to complete bone fracture if the part is not rested, and the patient continues his rigorous training activity. In recent years, newer techniques such as scintigraphy and magnetic resonance imaging (MRI) enable for timely and accurate diagnosis and treatment of stress fractures, thus preventing significant morbidity.[9]

This study was undertaken to compare the efficacy of bone scintigraphy and MRI in the diagnosis of stress injuries of lower limb bones in those symptomatic patients whose initial plain radiographs were negative for stress injuries and recommend the best imaging modality for early detection of stress injuries of bone.

METHODOLOGY

The study was conducted on 50 patients of suspected stress injuries of lower limb bones, in the age group of 18-32 years who were referred to Radiology Department, Command Hospital (Air force), Bengaluru and whose initial plain radiographs were negative for stress injuries. The study was conducted from November 2006 to June 2009.

Inclusion criteria included apparently healthy individuals belonging to the armed forces presenting with history of prolonged repetitive exertion and reporting with pain. Exclusion criteria included acute direct trauma to the bones and metabolic bone diseases. Patients with negative X-rays were subjected to MRI and bone scan according to the following protocols:

MRI equipment used for study was Siemens Magnetom Avanto 1.5 tesla. The following imaging protocol was followed fast spin-echo (SE) short-tau inversion-recovery (STIR) (TR, 2400-3600; TE, 20-40; inversion time, 80-100 m) T1- weighted (T1W) SE imaging (repetition time [TR], 500 m; echo time [TE], 25 m) and T2-weighted (T2W) SE imaging (TR, 3000; TE, 100) using the above sequences coronal images of the effected region were obtain after application of surface coil.

MRI

Study was evaluated for: (a) Marrow changes of edema/contusion, (b) cortical/periosteal changes (Table 1).[10]

Scintigraphy

The patient was injected with 20 mCi of 99^{m}Tc-methyl diphosphonate intravenously. Anterior and posterior whole body images were acquired using dual head Siemens E-cam Gamma Camera 3 h after injection. If abnormalities seen in whole body image require detailed evaluation, further spot views of particular areas were taken.

Scintigraphy study was evaluated for: Increase uptake of tracer at the involved bone (Table 2).[11]

Comparison of scintigraphy and MRI findings and gradings were done with Chi-square test and Fisher Exact Test.

Statistical Methods

Descriptive statistical analysis has been carried out in the present study. Chi-square/Fisher exact test has been used to find the significance of correlation of examination and results. Kappa Statistic has been used to find the significance of agreement between the bone MRI and scintigraphy findings. Diagnostic statistics *viz.* sensitivity, specificity, positive predictive value, negative predictive values, accuracy was used to correlate the findings of MRI with bone scintigraphy.

Kappa statistic for agreement

Inter-rater agreement statistic (Kappa) to evaluate the agreement between two classifications on ordinal or nominal scales (Cohen, 1960). Agreement is quantified by the Kappa (K) or weighted Kappa (Kw) statistic: K is 1 when there is perfect agreement between the classification system; K is 0 when there is no agreement better than chance; K is negative when agreement is worse than chance.

Value of K/strength of agreement: $P < 0.20$ - Poor, $P = 0.21$-0.40 - Fair, $P = 0.41$-0.60 - moderate, $P = 0.61$-0.80 - Good, and $P = 0.81$-1.00 - Very good.

RESULTS

In this prospective study of 50 patients, the age distribution of patients studied (Table 3). The age range varied from 18 to 32 years, the mean age was 21.68 years. The maximum number of patients was in the age group of 21-25 years constituting 52%. The least number of patients who developed stress injuries were more than 25 years old.

Duration of exertion in days of patients studied (Table 4). The average duration for stress injuries to develop during the training period was 28.1 days. The maximum number of patients to develop stress injuries was seen from 11 to 20 days who were subjected to un acclimatized training. The least number of patients who developed stress injuries had undergone more number of gradual acclimatized training days.

Table 1: Grading of stress fracture of bone on MRI

Grade 0	Normal
Grade 1	Positive on STIR
Grade 2	Positive on STIR plus positive on T2WI
Grade 3	Positive on T1WI and T2WI, but without cortical break
Grade 4	Positive on T1WI and T2WI fracture line

STIR: Short-tau inversion recovery, T1W: T1-weighted, T2W:T2-weighted

Table 2: Grading of stress fracture of bone on scintigraphy

Grade 0	Normal
Grade 1	Irregular uptake and/or a poorly defined area of increased activity
Grade 2	Similar to Grade 1, but more intense yet still poorly defined
Grade 3	Sharply marginated area of increased activity, usually focal or uniform in shape
Grade 4	Similar grade 3, but more intense uptake

Table 3: Age distribution of patients studied

Age in years	*n* (%)
18-20	20 (40.0)
21-25	26 (52.0)
>25	4 (8.0)
Total	50 (100.0)
Mean±SD	21.68±3.96

SD: Standard deviation

Studying the bones involved in patients (Table 5). The common bone involved was tibia. The right tibia was involved in 33 patients, followed by left tibia in 11 patients, femur in one patient (2%) and metatarsal in one patient (2%). The most common part of the tibia to be involved was proximal thirds of shaft.

On studying the region of fracture involved in bones (Table 6). The most common part of the tibia to be involved was proximal thirds of shaft. This pattern of injuries was observed more in recruits who underwent running and cross county pattern of training.

Scinigraphic results total patients - 50, Positive - 46, Negative - 04.

Additional findings - tracer up take was seen at asymptomatic sites in nine cases.

MRI results total patients - 50, Positive - 48, Negative - 02.

Additional findings - fracture line was seen in two cases

On correlating the findings of bone scintigraphy and MRI (Table 7). There is good agreement between bone

Table 4: Duration of exertion in days of patients studied

Duration of exertion in days	*n* (%)
Up to 10	10 (20.0)
11-20	22 (44.0)
21-30	7 (14.0)
31-50	4 (8.0)
51-80	5 (10.0)
>80	2 (4.0)
Total	50 (100.0)
Mean±SD	28.16±28.87

SD: Standard deviation

Table 5: Bone involvement of patients studied

Bone involvement	*n* (%)
Left femur	1 (2.0)
Left tibia	15 (30.0)
Right tibia	33 (66.0)
Metatarsal foot	1 (2.0)
Total	50 (100.0)

Table 6: Region of fracture of patients studied

Region	*n* (%)
Upper third tibia	22 (44.0)
Middle third tibia	18 (36.0)
Lower third tibia	8 (16.0)
Neck of femur	1 (2.0)
Meta tarsal	1 (2.0)
Total	50 (100.0)

Table 7: Correlation of findings of bone scintigraphy and MRI

Bone scintigraphy↓	MRI (%)					Total (%)
	Grade 0	Grade 1	Grade 2	Grade 3	Grade 4	
Grade 0	0	4 (8.0)	-	-	-	4 (8.0)
Grade 1	1 (2.0)	15 (30.0)	-	-	-	16 (32.0)
Grade 2	1 (2.0)	1 (2.0)	13 (26.0)	-	-	15 (30.0)
Grade 3	-	2 (4.0)	1 (2.0)	9 (18.0)	1 (2.0)	13 (26.0)
Grade 4	-	-	-	-	2 (4.0)	2 (4.0)
Total	2 (4.0)	22 (44.0)	14 (28.0)	9 (18.0)	3 (6.0)	50 (100)

Strongly significant kappa co-efficient of 0.699 ($P<0.001$)

scintigraphy and MRI with kappa coefficient of 0.699 ($P < 0.001$).

On evaluation of MRI for grades of bone stress injury in relation to Bone scintigraphy findings. (Table 8) There is good agreement between MRI and bone scintigraphy and with a strong *P* value ($P < 0.001$).

Table 8: Evaluation of MRI in relation to bone scintigraphy findings

MRI grade	Sensitivity	Specificity	PPV	NPV	Accuracy	*P* value
Grade I	93.8	79.4	68.2	96.4	84.0	<0.001**
Grade II	86.7	97.1	92.9	94.4	94.0	<0.001**
Grade III	69.2	100.0	100.0	90.2	92.0	<0.001**
Grade IV	100.0	97.9	66.7	100.0	98.0	<0.001**

**Strongly significant $P \leq 0.01$, MRI: Magnetic resonance imaging, PPV: Positive predictive value, NPV: Negative predictive values

DISCUSSION

The stress fractures can be diagnosed by following imaging modalities. Plain radiography, computed tomography (CT), ultrasound, skeletal scintigraphy, and MRI.

Radiography

Stress fracture of the bone can be effectively diagnosed on plain radiographs by taking two orthogonal views of the involved part to demonstrate the bony injury. In cortical bone, stress fractures are diagnosed based on the presence of endosteal reaction, periosteal callus without a fracture line or circumferential periosteal reaction with a fracture line through one cortex, sometimes frank fracture may be present. Generally for the periosteal reaction to develop it takes more than 3 weeks preceding the injury. In cancellous bone, stress fractures are poorly visible but sometimes may be appreciated as flake like patches of new bone formation 2-3 weeks after the onset of pain. The mineralized fracture site appears as a focal linear area of sclerosis oriented perpendicular to the trabeculae While the location and nature of a fracture are usually readily demonstrated on radiographs, the status of the adjacent soft tissue is usually very difficult to assess. The conventional radiographs have a sensitivity of 15-35% in early fractures, which increases to 30-70% during later exams because of overt bone reaction.[12] Even though sensitivity of the conventional radiographs is very low, plain X-ray examination is mandatory as a first imaging study to detect an overt fracture or rule out differentials such as infection or malignancy. In the present study, plain X-rays were used as screening modality to exclude patients with in stress injury of bone.

CT

With the advent of multislice CT scanners, helical data acquisition is five times faster than sequential CT imaging. Using thin collimation with multiplanar reformats, bony and soft tissue injury can be easily demonstrated. In bone stress injuries, CT findings show cortical breach with surrounding endosteal and periosteal sclerosis however early marrow changes can be missed Hence, the role of CT is mainly limited to differential diagnosis. CT plays an important role in diagnosing longitudinal stress fracture of the tibia, which is difficult to diagnose on plain radiographs. Fractures involving regions of complex anatomy such as spine and pelvis can be conveniently demonstrated on CT. The disadvantage of CT is that and it involves excessive radiation exposure, In view of its limitations this modality was not included in our study.

Ultrasound (USG)

Evaluation of musculoskeletal injuries can be done using, higher resolution linear transducers of (7-12 MHz). Detail evaluation of the superficial structures such as Tendon, ligaments muscles and fractures can be made. Although USG is unable to penetrate cortical bone, the high reflective and very large acoustic impedance make it possible to assess the bone contour and cortical fracture.[13] USG by its ability to visualize developing callus before radiographic changes are evident and can also be useful in assessing fractures after initial radiographs. USG avoids excessive radiation exposure is relatively inexpensive and give accurate measurements about the process of calcification.[14]

Skeletal Scintigraphy

Bone scintigraphy is an imaging technique used in the detection of stress injury of bones since 1970's as described by Geslien *et al.*, and Wilcox *et al.*, as it can demonstrate subtle changes in bone metabolism even before seen on plain radiography. In this technique, the imaging is based on the detection of radiation emitted from a 99mTc - diphosphonate a radioactive radiopharmaceutical inside the patient as the phosphate compound gets incorporated into the new bone at the site of injury. Hod *et al*.: In a study conducted on female recruits of Israeli defense force has reported a sensitivity of 100% for stress fractures and bone scans of shin splint lesions occasionally show linear longitudinal uptake.[15] However, bone scintigraphic findings of stress reaction are nonspecific. Some authors reported that 20-40% of the lesions seen on scintigraphs were asymptomatic.[16] Although bone scintigraphy was considered to be the gold standard, false-negative bone scintigraphs have been reported by Milgrom *et al*.: Keene and Lash and Sterling *et al*.[16-18] In our study, we a observed four patients to be positive on MRI, which were not picked by scintigraphic imaging. The limitation of bone scans is that a positive scan may not be seen for 24 h following injury despite its high sensitivity, the specificity of bone scintigraphy is inferior to that of MRI because it cannot quantify the finer details of the lesion sometimes pathological conditions such as a tumors, infections, bone infarctions, or periostitis can also produce a positive finding. The scintigraphy, has a radiation risk were the radiation dose is equal to a dose of 2 years of background radiation.

MRI

The MRI on the human body was first performed in 1977 by Raymond Damadian. This landmark discovery has revolutionized the field of imaging. This breakthrough discovery in imaging has made an extraordinary difference in demonstrating the contrast between MR signals from normal and abnormal tissues. It can also demonstrate the nature and extent of injuries. Without moving the patient image acquisition with a variety of pulse sequences can be used for characterizing tissues. MRI is sensitive in detecting changes in bone marrow at all fractures sites even <24 h. Fracture on MRI is described on the basis of SE images emphasizing on T1 and T2 contrast. As compared to SE images STIR images provide superior contrast between normal and abnormal marrow. The MRI features on T1W SE images consisted of irregular intramedullary zones of hypointensity described as a band-like area of low signal intensity. On STIR images a corresponding zone of hyperintensity extending to the outer cortical margin can be seen. MRI using T2W SE and STIR sequences can consistently demonstrate prominent signal abnormalities at fracture sites including those in which radiographic signs are subtle. MRI is as sensitive, as but more specific than scintigraphy.[19] In addition to changes in bone, it gives information about the surrounding soft tissues in all three dimensions. T2W and STIR- sequences are useful for detecting edema of cancellous bone, periosteum, and bone marrow edema; however is this is a nonspecific finding and should be interpreted in correlation with clinical history. A fracture can be seen as lower signal intensity in the middle of the edema, but it is better seen as a low-density signal line involving the cortex on T1-images.

Ishibashi *et al*.: In a study conducted on 31 patients comparing scintigraphy and MRI for stress injuries of bone have reported a good correlation of Grades of scintigraphy and MRI as compared to scintigraphy MRI showed more diagnostic information.[20] In the present study, we also observed similar results in the patients studied. An illustration of few such representative cases, images for Case 1 are given as (Figure 1a-d) wherein bone scan revealed intense well defined areas of increase tracer uptake in middle thirds shaft of right femur, hypointense on T1W and T2W suggesting good correlation between bone scan and bone scintigraphy for Grade I stress fracture and the corresponding area appeared as hyper intense signal on STIR. In Case 2 images are given as (Figures 2a-d) wherein bone scan revealed sharply marginated area of increased signal intensity in upper third shaft of right femur and in middle third shaft of left femur. On MRI, STIR and T2W images, the corresponding areas appeared as hyperintense signal intensities, on T1W coronal revealed a hypointense band with cortical break on right side suggesting grade IV stress on right side and Grade II fracture on left side. Though there is a good correlation between bone scan and bone scintigraphy where the tracer uptake was clearly seen, MRI provides detailed information regarding marrow edema, cortical break and surrounding soft tissues.

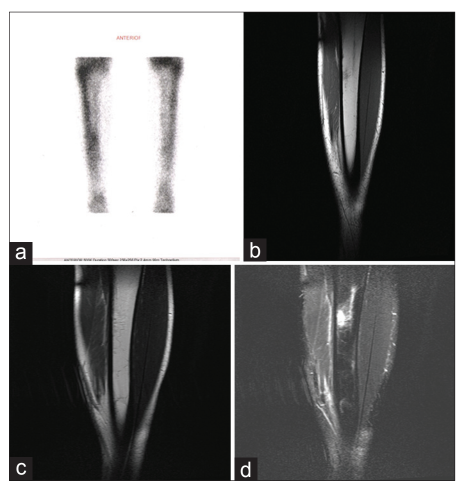

Figure 1: (a) Bone scan revealed intense well defined area of increase tracer up take in middle thirds shaftof right femur, (b) T1-weighted coronal magnetic resonance imaging (MRI) figure reveled normal signal intensities, (c) T2-weighted coronal MRI figure revealed normal signal intensities, and (d) short-tau inversion-recovery coronal MRI figures revealed focal area of hyper intense intensity in middle third shaft of right femur. Diagnosed as case of Grade I stress fracture

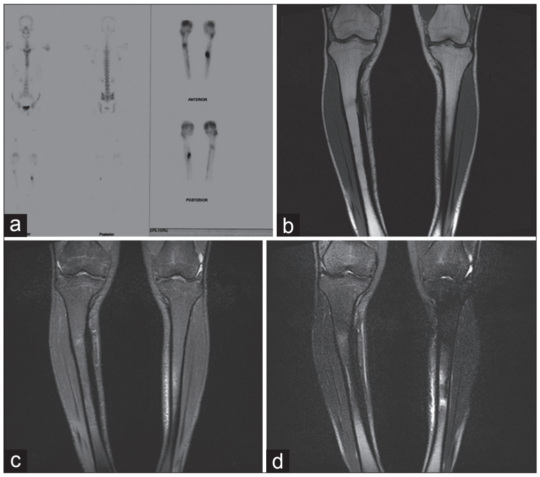

Figure 2: (a) Bone scan revealed sharply marginated area of increased signal intensity in upper thirds shaft of right femur and also in middle thirds shaft of left femur, (b) T2-weighted coronal magnetic resonance imaging (MRI) figures revealed a hypo intense band with cortical break in right femur, (c) T2-weighted coronal MRI revealed hyper intense signal intensities in upper thirds shaft of femur on right side and middle thirds shaft of femur on left side, and (d) short-tau inversion-recovery coronal MRI figures revealed hyper intense signal intensities in the corresponding anatomical locations shaft of tibias. Diagnosed as Grade IV stress on right side and Grade II on left side

CONCLUSION

In our study, we observed a good correlation of findings between MRI and skeletal scintigraphy for stress injuries of bone with Kappa value of 0.699 ($P < 0.001$). On evaluation of MRI in relation to bone scintigraphy findings for grading of stress injuries, MRI has comparable sensitivity to scintigraphy for detection of stress fractures and MRI has additional advantage of depicting the surrounding tissue inflammatory process, as well as providing greater anatomical details. Hence, we recommend MRI as the initial imaging modality in early detection of stress injuries of bone.

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