The Scintigraphic Diagnosis of Stress Fractures in the Lower Extremity

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Stress fractures are usually found in athletes and military populations. They occur more commonly in the lower extremity. The most commonly involved bone is the tibia, and is frequently associated with running activities. Diagnosis is often difficult, and may be missed due to the limited sensitivity of plain radiographs. Magnetic resonance imaging (MRI) is the gold standard for the diagnosis of stress fractures. Three-phase radionuclide bone scintigraphy is another imaging modality: it is highly sensitive, simple and safe. Thus, it can be used solely, or complementary to MRI.

Keywords: *Stress fracture, fatigue fracture, bone scan, bone scintigraphy*

The Thai Journal of Orthopaedic Surgery: 36 No.1-2: P22-28
Full text. e journal: *http://www.rcost.or.th, http://thailand.digitaljournals.org/index.php/JRCOST*

Stress fractures are classified into two types. A ***fatigue fracture*** occurs in a normal bone when the bone is overused, while an ***insufficiency fracture*** occurs when a normal stress is applied to structurally abnormal bone, such as osteoporotic bone[1]. In general, the term "stress fracture" is more commonly used to mean a fatigue fracture resulting from repetitive, excessive stress to the bone, and is most frequently found in military and athletic populations. This often occurs within 6 to 8 weeks of a rapid increase in physical activity, leaving insufficient time for bone remodeling and adaptation to the stress. The pathogenesis of bony stress injury is multifactorial[2].

It was estimated that stress fractures account for 0.7% to 20% of all running injuries[3]. Females are more susceptible than males to the development of stress injuries to bones, especially in the military population[4-7].

Approximately 75% of stress fractures occur before the age of 40 years[8]. The trend of these fractures has been increasing among young adults, because of increased participation in sporting activities[9]. One study found that 9% of fractures occurred in children younger than 15 years, and 32% occurred in those between 16-19 years of age[10].

Most stress fractures, both in athletic and military groups, occur in the lower extremity [11-12], with running injury playing the most important role. Running more than 20 miles a week carries a high risk of developing lower-extremity injuries[13].

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The most common site of stress fractures in most reports is the tibia, which may be as high as 72%[14-17]. Other common locations of stress fractures are fibula, femur, metatarsal, and tarsal bones[12].

The diagnosis of stress fractures depends primarily on a high index of suspicion. It may be problematic because several musculoskeletal disorders can cause exercise-induced leg pain. Examples are soft tissue injuries, medial tibial stress syndrome (MTSS) or shin splints, artery or nerve entrapment, compartment syndrome, bone tumors, and bone infection[18-19].

The classic clinical feature of a stress fracture is insidious onset of activity-related local pain with weight bearing. The pain is relieved by rest and becomes worse when the activity is resumed. Local tenderness and swelling are often found at the fracture site[19]. Nevertheless, stress fractures should be considered in any patient who presents with local pain after a recent increase in activity, or repeated activity with limited rest[11, 20].

Since early detection is essential to prevent progression of lesions and to avoid further complications, a definitive diagnosis should be made. However, clinical diagnosis may be inconclusive and thus require one or more imaging tests to confirm a stress fracture. Each modality has different advantages and disadvantages. (see Table 1 below).

Plain radiography is usually the first imaging modality obtained because of its wide availability and low cost [19] The plain radiograph is often negative initially, but frequently becomes positive over time[21]; thus it has a very low sensitivity for stress fractures, varying from 10% to 30%[15-16, 21]. However, follow-up radiographic

Table 1 Advantages and disadvantages of imaging modalities for stress fractures (modified from Patel et al.[19])

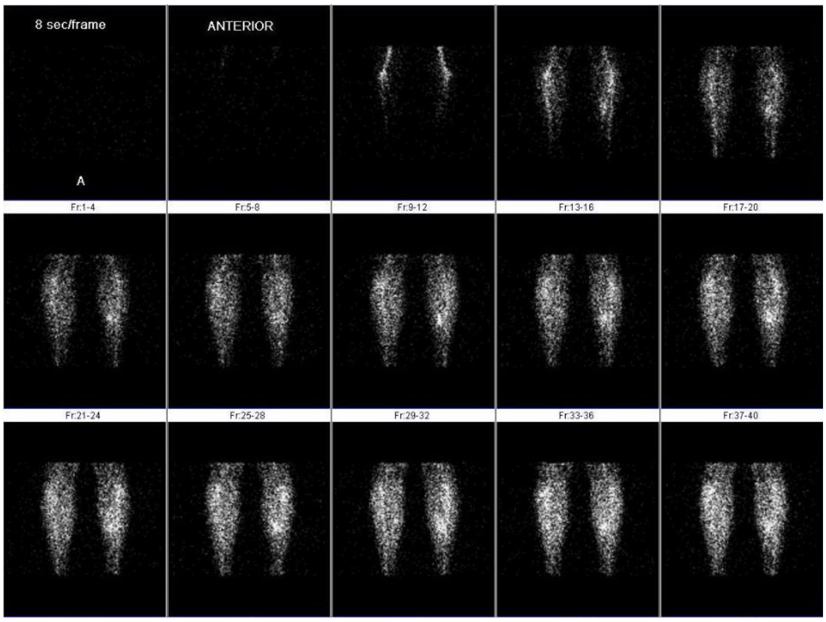
Imaging	Advantages	Disadvantages
Plain radiography	- Lowest cost - Widely available	- Poor initial sensitivity - Some radiation exposure - Limited differential details
Bone scinitigraphy	- Higher cost - High sensitivity	- Limited availability - Limited differential details - Some radiation exposure - Can be falsely positive in bony infection or tumor
Magnetic resonance imaging (MRI)	- Best differential details - No radiation exposure - Highest differential details - Highest specificity - Equal or slightly better sensitivity than scintigraphy	- Highest cost - Limited availability - Sometimes may be falsely positive in bony infection or tumor
Ultrasonography	- No radiation exposure - Low cost - Widely available	- Little differential details - Limited data on use in diagnosing stress fractures

examinations have a higher rate of detection, ranging between 40% to 54%[16,22]. Radiographic signs may include decreased cortical density, so called "*gray cortex*" sign, periosteal reaction, endosteal thickening, and a cortical fracture line[19,23].

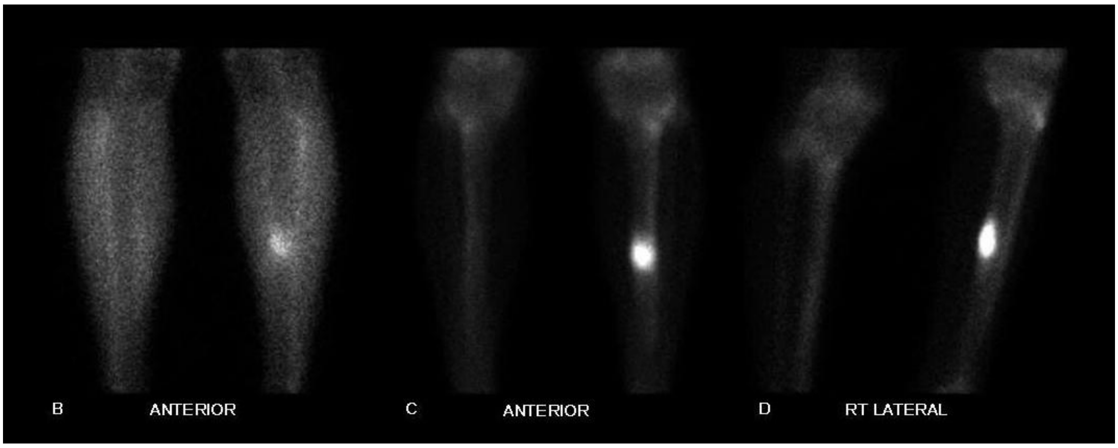
If the initial radiograph is negative, more advanced imaging modalities such as three-phase bone scintigraphy or magnetic resonance imaging (MRI) may be helpful for further evaluation. Both modalities have similarly high sensitivity for detection of stress fractures, but MRI has greater specificity[19]. Radionuclide bone imaging had traditionally been the standard tool to confirm stress fractures in most studies prior to the development of MRI, because of its high sensitivity[15,24-26]. However, nowadays, MRI is currently considered the method of choice for this purpose because of its high image resolution of bone, bone marrow, and surrounding soft tissue. This results in better anatomical evaluation and higher specificity when compared to bone scintigraphy[27-29].

While MRI costs about 10,000 Baht per examination, whole-body bone scintigraphy costs only 2,900 to 4,000 Baht. Since MRI is quite costly (more than twice that of radionuclide bone scanning) and usually has a much longer waiting time (especially in most tertiary public medical centers), prompt diagnosis using this modality is quite difficult. As a result, bone scintigraphy becomes a good, alternative choice.

Scinigraphic Images



(A)



(B) **(C)** **(D)**

Fig. 1 Three-phase bone scintigram of grade III stress fracture of the left tibia revealed mild hyperemia to the left leg (A), focal increased uptake at medial aspect of left leg in the anterior view of blood-pool phase (B) and also in the delayed 3-hour phase (C). Lateral delayed static image of the leg demonstrated fusiform-shaped increased uptake in the cortico-medullary region at posteromedial aspect at mid shaft of left tibia (D).

Bone scintigraphy is very sensitive, and may be positive as early as 48-72 hours after onset of injury[30]. Three-phase or triple-phase bone scanning is highly recommended for complete evaluation of skeletal lesions, especially in the extremities. This study is typically performed by intravenous injection of 20 millicuries of the radiopharmaceutical technetium-99m methylene diphosphonate (Tc-99m MDP) for adult patients, or 200 microcuries/Kg for children. While the radiotracer is administered, the dynamic imaging of the specific region is acquired in the first 1-2 minutes as a vascular or angiographic phase. Then static soft tissue or blood-pool images are obtained within the next 5 minutes. Delayed 3-4 hour imaging of a particular region or the whole body is used for skeletal evaluation.

In acute stress fractures, all three phases of the bone scan are positive (Figure 1). Zwas et al.[16] developed an important scintigraphic classification of stress fractures, which was divided into four grades according to lesion dimension, bone extension, and tracer accumulation in the lesions (Table 2). A higher grade of bone scan pattern suggests increased severity of the stress fracture.

Table 2 Zwas's classification of stress fractures of long bones[16]

Grading of stress fractures	Bone scan findings
Grade I	Small, ill-defined lesion with mildly increased activity in the cortical region.
Grade II	Larger than grade I, well-defined, elongated lesion with moderately increased activity in the cortical region.
Grade III	Wide fusiform lesion with highly increased activity in the cortico-medullary region.
Grade IV	Wide extensive lesion with intensely increased activity in the transcortico-medullary region.

Triple-phase bone scintigraphy is also helpful in the differentiation between soft tissue and bony lesions. In soft tissue inflammation-infection, only the first two phases are abnormal, while in MTSS, only the delayed third phase will be positive with a specific scintigraphic pattern different from the findings of stress fracture. The increased uptake in stress fractures tends to be more focal (with fusiform shape in advanced stages) than that seen in MTSS, which tends to be longitudinally-oriented along the posterior cortex of the tibia[31].

Arendt et al.[28] had also compared the MRI findings with the scintigraphic grading for tibial stress fractures as described by Zwas et al.[16] which could be also used to guide for the treatment duration as shown in Table 3.

Table 3 Radiologic grading of stress fractures (modified from Arendt et al.[28])

Grade	Plain Radiograph	Bone Scan	MRI	Treatment
Grade I	Normal	Poorly defined area of mildly increased activity	Positive STIR image	3 weeks rest
Grade II	Normal	Well defined area of moderately increased activity	Positive STIR and T2W images	3-6 weeks rest
Grade III	Discrete line; discrete periosteal reaction	Sharply marginated area of fusiform increased activity	Positive T1W and T2W images without definite cortical break	12-16 weeks rest
Grade IV	Fracture or periosteal reaction	More intense transcortical Localized uptake	Positive T1W and T2W Images with fracture line	16^{+} weeks rest

STIR : *S*hort *T*au *I*nversion *R*ecovery
T1W : T1-weighted
T2W : T2-weighted

Apart from planar bone imaging, SPECT (single photon emission tomography) acquisition is a 3-dimentional imaging technique providing better delineation of the bony lesions. When SPECT and computed tomography (CT) imaging are combined in the same instrument, so called SPECT/CT scanning, the study even adds more anatomical details over the SPECT images alone. Up to date, SPECT and SPECT/CT studies have been used in the field of Sports Medicine to evaluate several parts of the body, such as the spine, hips, knees, and feet[32-33]. SPECT/CT images of tibial stress fractures with bone remodeling are very well demonstrated in Figure 2.

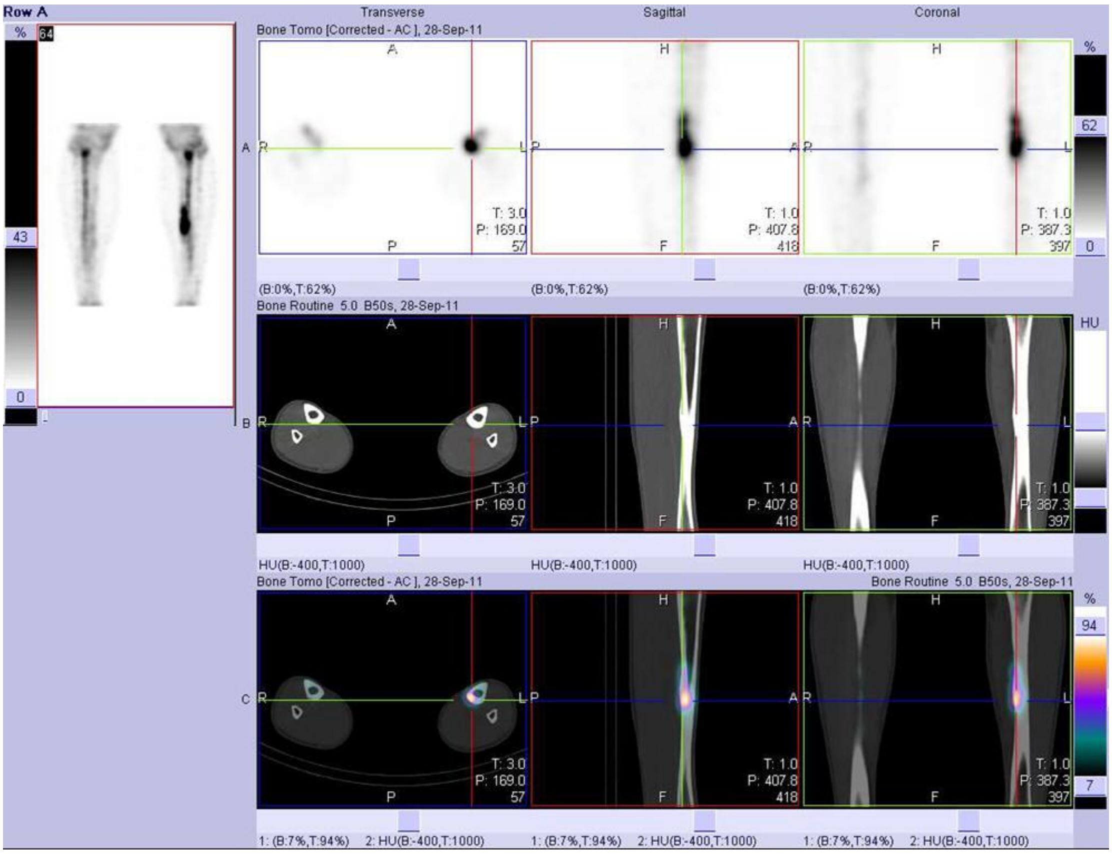


Fig. 2 Sequential SPECT/CT images in transverse, sagittal, and coronal planes of the previously diagnosed left tibial stress fracture revealed increased uptake along the posteromedial aspect of left tibia corresponding to sclerotic bone lesion demonstrated on CT images as a result of bone remodeling.

Although MRI is considered as an imaging of choice for evaluation of stress fractures, the common findings of periosteal or bone marrow edema are not specific and may resemble osteomyelitis or neoplastic process. Combined relevant clinical correlation will improve the accuracy of diagnostic interpretation.

Conclusion

Although MRI is currently accepted as the gold standard for evaluation of stress injuries of the bone, some limitations and pitfalls remain. Three-phase bone scintigraphy can provide prompt and sensitive diagnosis of stress fractures. Additional SPECT/CT imaging will enhance the diagnostic accuracy of planar bone scanning. In summary, radionuclide bone scanning can be used alone for the diagnosis of stress fractures, or used as an adjunct when the MRI findings are inconclusive, especially in cases presenting with a high clinical suspicion of stress fractures.

References

1. Flinn SD. Changes in stress fracture distribution and current treatment. Curr Sports Med Rep 2002; 1(5): 272-7.
2. Patel DR. Stress fractures: diagnosis and management in the primary care setting. Pediatr Clin North Am 2010; 57(3): 819-27.
3. Bergman AG, Fredericson M. MR imaging of stress reactions, muscle injuries, and other overuse injuries in runners. Magn Reson Imaging Clin N Am 1999; 7(1): 151-74.
4. Protzman RR. Physiologic performance of women compared to men. Observations of cadets at the United States Military Academy. Am J Sports Med 1979; 7(3): 191-4.
5. Pester S, Smith PC. Stress fractures in the lower extremities of soldiers in basic training. Orthop Rev 1992; 21(3): 297-303.
6. Bijur PE, Horodyski M, Egerton W, Kurzon M, Lifrak S, Friedman S. Comparison of injury during cadet basic training by gender. Arch Pediatr Adolesc Med 1997; 151(5): 456-61.
7. Gam A, Goldstein L, Karmon Y, Mintser I, Grotto I, Guri A, et al. Comparison of stress fractures of male and female recruits during basic training in the Israeli anti-aircraft forces. Mil Med 2005; 170(8): 710-2.
8. Courtenay BG, Bowers DM. Stress fractures: clinical features and investigation. Med J Aust 1990; 153(3): 155-6.
9. Dixon S, Newton J, Teh J. Stress fractures in the young athlete: a pictorial review. Curr Probl Diagn Radiol 2011; 40(1): 29-44.
10. Orava S, Jormakka E, Hulkko A. Stress fractures in young athletes. Arch Orthop Trauma Surg 1981; 98(4): 271-4.
11. Daffner RH, Pavlov H. Stress fractures: current concepts. Am J Roentgenol 1992; 159(2): 245-52.
12. Bennell KL, Brukner PD. Epidemiology and site specificity of stress fractures. Clin Sports Med 1997; 16(2): 179-96.
13. Hootman JM, Macera CA, Ainsworth BE, Martin M, Addy CL, Blair SN. Predictors of lower extremity injury among recreationally active adults. Clin J Sport Med 2002; 12(2): 99-106.
14. Orava S, Puranen J, Ala-Ketola L. Stress fractures caused by physical exercise. Acta Orthop Scand 1978; 49(1): 19-27.
15. Matheson GO, Clement DB, McKenzie DC, Taunton JE, Lloyd-Smith DR, MacIntyre JG. Stress fractures in athletes. A study of 320 cases. Am J Sports Med 1987; 15(1): 46-58.
16. Zwas ST, Elkanovitch R, Frank G. Interpretation and classification of bone scintigraphic findings in stress fractures. J Nucl Med 1987; 28(4): 452-7.
17. Jones BH, Harris JM, Vinh TN, Rubin C. Exercise-induced stress fractures and stress reactions of bone: epidemiology, etiology, and classification. Exerc Sport Sci Rev 1989; 17: 379-422.
18. Key VH. Leg pain in runners. Current Opinion in Orthopaedics 2007; 18(2): 161-5.
19. Patel DS, Roth M, Kapil N. Stress fractures: diagnosis, treatment, and prevention. Am Fam Physician 2011; 83(1): 39-46.
20. Wall J, Feller JF. Imaging of stress fractures in runners. Clin Sports Med 2006; 25(4): 781-802.
21. Prather JL, Nusynowitz ML, Snowdy HA, Hughes AD, McCartney WH, Bagg RJ. Scintigraphic findings in stress fractures. J Bone Joint Surg Am 1977; 59(7): 869-74.
22. Greaney RB, Gerber FH, Laughlin RL, Kmet JP, Metz CD, Kilcheski TS, et al. Distribution and natural history of stress fractures in U.S. Marine recruits. Radiology 1983; 146(2): 339-46.
23. Mulligan ME. The "gray cortex ": an early sign of stress fracture. Skeletal Radiol 1995; 24(3): 201-3.
24. Rupani HD, Holder LE, Espinola DA, Engin SI. Three-phase radionuclide bone imaging in sports medicine. Radiology 1985; 156(1): 187-96.
25. Brukner P, Bradshaw C, Khan KM, White S, Crossley K. Stress fractures: a review of 180 cases. Clin J Sport Med 1996; 6(2): 85-9.
26. Ohta-Fukushima M, Mutoh Y, Takasugi S, Iwata H, Ishii S. Characteristics of stress fractures in young athletes under 20 years. J Sports Med Phys Fitness 2002; 42(2): 198-206.
27. Fredericson M, Bergman AG, Hoffman KL, Dillingham MS. Tibial stress reaction in runners. Correlation of clinical symptoms and scintigraphy with a new magnetic resonance imaging grading system. Am J Sports Med 1995; 23(4): 472-81.

28. Arendt EA, Griffiths HJ. The use of MR imaging in the assessment and clinical management of stress reactions of bone in high performance athletes. Clin Sports Med 1997; 16(2): 291-306.
29. Gaeta M, Minutoli F, Scribano E, Ascenti G, Vinci S, Bruschetta D, et al. CT and MR imaging findings in athletes with early tibial stress injuries: comparison with bone scintigraphy findings and emphasis on cortical abnormalities. Radiology 2005; 235(2): 553-61.
30. Markey KL. Stress fractures. Clin Sports Med 1987; 6(2): 405-25.
31. Holder LE, Michael RH. The specific scintigraphic pattern of "shin splints in the lower leg": concise communication. J Nucl Med 1984; 25(8): 865-9.
32. Van der Wall H, Lee A, Magee M, Frater C, Wijesinghe H, Kannangara S. Radionuclide bone scintigraphy in sports injuries. Semin Nucl Med 2010; 40(1): 16-30.
33. Hirschmann MT, Davda K, Rasch H, Arnold MP, Friederich NF. Clinical value of combined single photon emission computerized tomography and conventional computer tomography (SPECT/CT) in sports medicine. Sports Med Arthrosc 2011; 19(2): 174-81.

การวินิจฉัยภาวะ stress fractures ของรยางค์ล่าง ด้วยเทคนิคทางเวชศาสตร์นิวเคลียร์

จิราพร ศรีประภาภรณ์, พบ

ภาวะ stress fractures ส่วนใหญ่พบในนักกีฬาหรือกลุ่มทหาร-ตำรวจ ที่มีการฝึกซ้อมอย่างหนัก ซึ่งมักเกิดกับรยางค์ล่างมากกว่ารยางค์บน โดยเฉพาะการฝึกซ้อมที่เกี่ยวกับการวิ่งระยะทางไกลๆ การวินิจฉัยภาวะ stress fractures นี้ทำได้ยาก เนื่องจากภาพถ่ายรังสีมักมีความไวไม่พอ ทำให้ต้องอาศัยการตรวจที่ซับซ้อนยิ่งขึ้น ซึ่งการตรวจด้วยเครื่องเอ็มอาร์ไอ (MRI, magnetic resonance imaging) ถือเป็นวิธีมาตรฐานในการวินิจฉัย แต่การตรวจสแกนกระดูกทางเวชศาสตร์นิวเคลียร์แบบ 3 ระยะ (3-phase bone scan) ซึ่งเป็นการตรวจที่มีความไวสูง ทำการตรวจง่าย ไม่มีข้อห้าม หรือผลแทรกซ้อนในการตรวจ จึงมีบทบาทในการวินิจฉัยภาวะ stress fractures และสามารถใช้เป็นการตรวจเสริมกับการตรวจด้วยเครื่องเอ็มอาร์ไอ เพื่อให้ได้ผลการตรวจที่แม่นยำยิ่งขึ้น