.ower Extremity Stress 'ractures in Athletes

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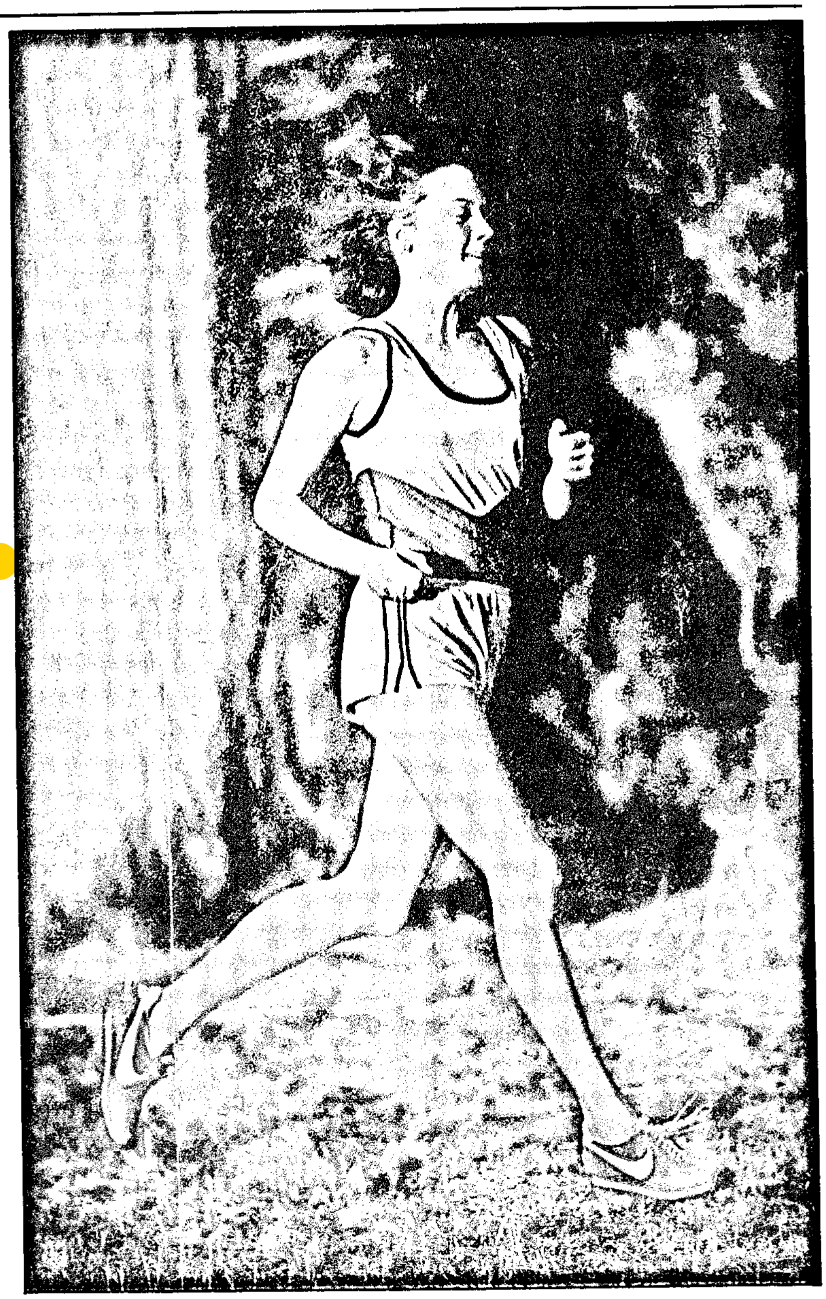

brief: A review of the records of 62 ınners treated for stress fractures ıowed that initial x-rays were positive 47.2% of the cases, while bone scans ere positive in 95.8%. A combination f errors in training and changes in ›otwear accounted for 44% of the actures, and all the patients had ignment problems. The runners had 'aited until their performance was eriously impaired to seek treatment. he authors concluded that if point enderness and soft-tissue swelling are ecognized early, stress fractures can ›e prevented with rest, muscle ehabilitation, and orthotic control of ›xcessive pronation.

The current emphasis on cardiovascular fitness and the longer distances run by endurance athletes have increased overuse injuries, includng stress fractures, to the lower extremities. Until now the diagnosis and treatment of stress fractures were based on clinical findings that were later confirmed by radiological examination when possible. However, bone scanning, using the radionuclide technetium 99m complexed with a diphosphonate derivative, has recently been used to accurately

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Table 1. Activity of Athletes with Stress Fractures

Activity	No.
Distance running more than 50 km/week	24
Recreational running less than 30 km/week	19
Sprinting	7
Volleyball	4
High jumping	2
Skiing	1
Miscellaneous	5
Total	62

Table 2. Sites of Stress Fractures

Site	No.	Total
Tibia		
Midshaft	14	
Distal third	14	
Proximal	3	
Bilateral	3	34
Fibula		
Distal third	7	7
Metatarsals		
First base	1	
Second shaft	2	
Third shaft	4	
Fourth shaft	1	
Nonspecific*	2	10
Tarsals		
Cuneiform	1	
Navicular	2	
Calcaneus	3	
Nonspecific*	1	7
Femur		
Neck	2	
Distal shaft	1	
Midshaft	1	4
Total		62

*Anatomical site not clear by bone scan

detect sites of stress in the bone long before radiological evidence appears.[1-3]

We believe that in many cases an increased radionuclide uptake is the prodromal state to an overt fracture. By starting treatment early in the evolution of the lesion, stress fractures can be prevented. Garrick,[1] Geslien et al,[2] and Stanitski et al[4] have shown the importance of bone scans in patients who have a history and physical findings of focal swelling and tenderness, but who show no stress fracture roentgenographically. The earlier diagnosis possible with bone scans allows earlier treatment and hence decreased morbidity.

The purpose of this article is to describe the presenting history and the signs and symptoms of both a stress fracture and the period preceding it. Etiological factors and treatment plans will also be discussed.

Histological and Physiological Factors. Stechow[5] was the first to document stress or fatigue fractures in metatarsals of army recruits. A number of explanations for this phenomenon have been presented. Johnson et al[6] had the largest biopsy series of stress fractures and concluded that they are a result of accelerated remodeling of circumferential lamellar bone. The initiation of remodeling is a multifactorial process. Tensional or compressive forces cause microscopic deformities in the bone, and increased blood flow occurs secondary to increased muscle activity. Both events produce characteristic piezoelectric potentials, which are also contributed to by the nervous activity of surrounding muscle. This overall bioelectric potential initiates remodeling.

The first result of the signal to remodel is that osteoclasts begin to actively remove bone matrix. At this time the symptoms begin to develop. The development of a stronger new matrix lags behind, and because of this discrepancy between bone removal and new development, the area is weakened and susceptible to fracture. However, if physical stress is stopped by rest, the remodeling can complete. The immature lamellar bones of the midtibia in young adults are particularly vulnerable to remodeling.

Etiological Factors. Recently, Frankel[7] presented a theory including four causes of stress fractures. One is simple overload brought about by muscle contraction. This theory was also developed by Stanitski et al.[4] Devas[8] believes that the powerful contractions of the leg muscles during running bow the fibula toward the tibia, resulting in fibular stress fractures. A similar theory has been proposed as the cause of calcaneal vertical stress fractures: The increased pull of the plantar fascia is working against the gastrocnemius-soleus pull.

The second mechanism presented by Frankel[7] and supported by earlier work by

Table 3. Comparison of Radiographic and Bone Scan Results in Stress Fractures

		X-ray		Bone Scan	
Site	No. of Stress Fractures	No. Tested	No. Positive Results	No. Tested	No. Positive Results
Tibia	34	19	8	27	25
Fibula	7	6	4	2	2
Metatarsals	10	6	2	10	10
Tarsals	7	2	0	7	7
Femur	4	3	3	2	2
Total	62	36	17 (47.2%)	48	46 (95.8%)

Clement[9] is that stress distribution in the bone is altered by continued activity in the presence of muscle fatigue. The third cause is a change in the running surface, and the fourth is high repetition of stress, even when the stresses are relatively low. The bone loading occurs at the plastic region of the bone.[10] Frankel[7] points out that a fatigue fracture on the tension side of the bone can result in a crack and go on to complete fracture. However, fatigue fractures on the compression side of the bone develop more slowly and repair early.

Biomechanics. As the leg swings through before contact with the ground, it rotates internally and the foot is supinated. Supination is a complex motion involving not only inversion of the subtalar joint, but also ankle plantar flexion and forefoot adduction. In a supinated foot the midtarsal joint is locked, which stabilizes the forefoot. The continuation of internal rotation of the leg after foot contact, given a fixed foot, makes it mandatory that the foot pronate. Pronation includes eversion of the subtalar joint with ankle dorsiflexion and forefoot abduction. The midtarsal joint is unlocked and the forefoot is unstable, but this instability enables the forefoot to adapt to the surface. As the body moves over the fixed foot into midstance of the gait, the foot begins to resupinate, stabilizing the forefoot, and thus the gastrocnemius-soleus unit has a rigid lever arm on which to work for propulsion.

Difficulties arise when pronation continues past midstance and into the propulsive phase of gait. This occurs with the malalignment conditions of forefoot varus, subtalar varus, and tibial varum.

The varus configuration requires more pronation before all points of the foot contact the ground. These and other problem alignments of the foot and leg are discussed in detail by James and Brubaker[11] and Subotnick.[12] The technique of physical examination to determine the degree of malalignment is concisely outlined by James et al.[13]

Prolonged pronation is related to stress fracture because it flattens the medial longitudinal arch. The arch system consists of a tie beam (primarily the plantar fascia) and a bow (the tarsals and metatarsals). A flattened arch puts increased stress on the bow and the beam, which can initiate bone remodeling and perhaps a stress fracture.

In walking and running the plantar fascia is tightened up to support the arch via a windlass effect during the toe-off when the toes are passively extended. With a rigid sole that prevents bending at the metatarsophalangeal joints, the windlass cannot work, and a stressed bow results. We suspect military trainees have more metatarsal stress fractures because of their rigid-soled boots. Most running shoes are flexible.

Methods

Files of 62 athletes who sustained stress fractures and were seen at a sportsmedicine clinic between October 1977 and June 1978 were used in this study. All patients were questioned to determine specific training methods, including intensity, duration, surfaces, terrain, and running shoes. Each athlete was examined with specific emphasis on lower leg alignment, muscle strength, flexibility, and foot configuration. The shoe was also inspected.

An x-ray or bone scan was obtained in all cases, and all x-rays were reviewed by a group

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of radiologists. In 25 cases only a bone scan was used because the athlete presented after only a short period of having symptoms.

Results

There were 25 men and 37 women, averaging 26.4 years of age and ranging from 14 to 51 years. The largest group consisted of distance and recreational runners (table 1). Table 2 shows the sites of the stress fractures. The tibia is involved in over 50% of the cases.

The comparison of radiographic and bone scan results in table 3 shows that the bone scan was the primary method of confirmation. The initial radiograph was positive in only 47.2% of the cases, but 95.8% of the bone scans indicated positive results. Seven follow-up radiographs on initially negative cases confirmed three more stress fractures.

Table 4 shows the time of presentation to the physician and recovery after treatment. The average time from symptom onset to presentation was 7.4 weeks, and after treatment was started, an average of 4.8 weeks elapsed before the athlete could return to his former level of training. Fibula fractures required the shortest recovery time, and tarsal fractures usually had a more lengthy period of disability.

The intensity of the training program was a major cause of stress fractures: 27% of the cases developed after a rapid commencement of training, 6% after sudden exposure to hill running, and 10% after a particularly severe single session. A rapid increase in mileage accounted for 8%. Faulty footwear was involved in only 5% of cases. A combination of errors in training and changes in footwear accounted for 44% of the cases.

Lower leg alignment and degree of subtalar varus and forefoot varus are shown in table 5. Virtually all athletes who had stress fractures had some varus alignment of the foot. This type of foot, which is often described as a flat foot when weight bearing, leads to excessive pronation, increased internal tibial torque and extra biomechanical stress.

Figure 1 summarizes the developmental history, signs, and treatment of stress fractures. At first pain is present only after exercise, and it is relieved by a short rest. If the athlete continues to train, however, the exertional pain becomes more severe and eventually becomes constant and is not relieved by rest. The original signs are point tenderness and soft-tissue swelling. If the athlete continues to train, an alteration of the gait will occur with secondary muscle disuse atrophy.

Discussion

This study illustrates, as others have, the importance of the bone scan in the early diagnosis of stress fractures. The delay in seeking medical help in this study was thought to represent the athletes' attitude to train through pain. It was only when performance

Table 4. Delay in Presentation and Length of Recovery After Treatment in Athletes With Stress Fractures (Weeks)

Site	Symptom Onset to Presentation	Treatment Onset to Full Recovery
Tibia	7.0	4.5
Fibula	3.6	2.4
Metatarsals	5.0	3.5
Tarsals	16.0	10.0
Femur	5.5	3.5
Mean	7.4	4.8

Table 5. Lower Extremity Alignment

Site	Forefoot Varus No.	Forefoot Varus Angle ($\bar{x}$)	Rearfoot Varus No.	Rearfoot Varus Angle ($\bar{x}$)	Tibial Varus (≥10°)	Genu Varus	No Deformity or Other	No Data
Tibia (n=34)	17	7.0°	7	5.0°	5	—	2	3
Fibula (n=7)	4	4.8°	2	6.0°	—	—	1	—
Metatarsals (n=10)	5	5.5°	4	5.2°	—	—	1, cavus	1
Tarsals (n=7)	1	3.8°	—	—	—	—	2, cavus	1
Femur (n=4)	1	10.0°	—	—	—	2, 4.5 cm	—	—

was seriously impaired that they sought help.

The prolonged disability caused by tarsal stress fractures is associated with the poor vascular supply of the navicular bone, much as in the scaphoid fracture of the wrist. Reports of navicular stress fractures going on to frank fractures and nonunion in distance runners have recently been made (unpublished communication from the Australian Olympic medical staff).

Today most running shoes have good heel stability and shock absorption without sacrificing flexibility. It is not surprising, therefore, that shoes were rarely indicated as a cause of stress fractures.

The fact that no specific cause was identified in a large number of cases is surprising. James et al,[13] in their survey of lower extremity injuries in runners, state that training errors are the primary cause of injury. We believe that the alignment of the foot and leg is of crucial importance in transferring stress to the musculoskeletal structures of the leg. When malalignment is coupled with the repetitive stress of distance running, the scene is set for a stress fracture.

The ideal foot has no forefoot or subtalar varus, and the ideal leg has no tibial varum or genu angulation. However, the ideal is not the norm. Our clinical impression is that the norm is subtalar varus of 3° and forefoot varus of 2°, which is less than the varus alignments shown in table 5. Table 5 shows that all sites of bone stress are associated with alignments that deviate from the ideal, and in general, from the norm. Prolonged pronation occurs with excessive varus alignment of the lower leg and foot. The results suggest that forefoot varus particularly predisposes the leg to internal tibial rotation and stress fractures of the tibia. As long as pronation occurs, so does internal rotation of the tibia. It is hypothesized that this excessive and repeated internal rotation of the tibia stresses the mid and distal tibia, as described by Chamay.[10]

Prolonged pronation is not the only cause of stress fractures. For example, a rigid cavus foot, which often has a forefoot valgus, absorbs shock poorly. Three of the patients with femoral stress fractures had either a significant genu varus or valgus. In those conditions the neck and shaft of the femur are not optimally positioned to bear weight.

The predominance of stress fractures in women in this study is consistent with lower extremity injuries in general. This is the result of what has been called the "terrible triad": a wide pelvis, coxa vara, and genu valgum.[13] This triad causes the following problem, among others: Because of the genu valgum, the foot is chronically inverted and less able to absorb shock. Force is less readily transmitted directly up the leg, and stress of the lower

continued

Figure 1. *Developmental history, signs, and treatment of stress fractures. Clip and copy for future reference.*

memory jogger

How Stress Fractures Develop

1. Causal event
2. Pain after exercise only and relieved by short rest
3. Pain tolerable during exercise but more marked after exertion and relieved by longer rest
4. Pain intolerable during and after exercise and partially relieved by long rest
5. Constant pain not relieved by rest

Signs of Stress Fractures

1. Point tenderness of bone (except well-shielded femur)
2. Soft-tissue swelling
3. Palpation of callus (with time)
4. Alteration of gait
5. Muscular atrophy, especially anterior tibial and gastrocnemius-soleus groups
6. Full and painless range of motion of adjacent joints
7. Painless resisted active movement of joint
8. Increased technetium 99m-diphenylmethane diisocyanate uptake indicating focal lesion
9. Hairline radiolucency, periosteal callus, or endosteal callus by x-ray; associated soft-tissue swelling

Treatment of Stress Fractures

1. Rest from running
2. Relieve symptomatic inflammation with ice and anti-inflammatory agent
3. Maintain strength (especially foot dorsum and plantar flexors)
4. Maintain cardiovascular fitness with swimming and/or biking
5. Orthotics tailored to need
6. When asymptomatic, gradually reintroduce running
7. Counsel patient about training errors

extremity during running is more likely.

Excessive repetitive loading of the legs, even if they are perfectly aligned, may fatigue the muscles and ligaments so that more stress is absorbed by bone than normal, resulting in the initiation of remodeling. Figure 2 summarizes this theory of etiology as proposed by Clement.[9] We believe that if the legs are not perfectly aligned, muscle fatiguing can only be more pronounced.

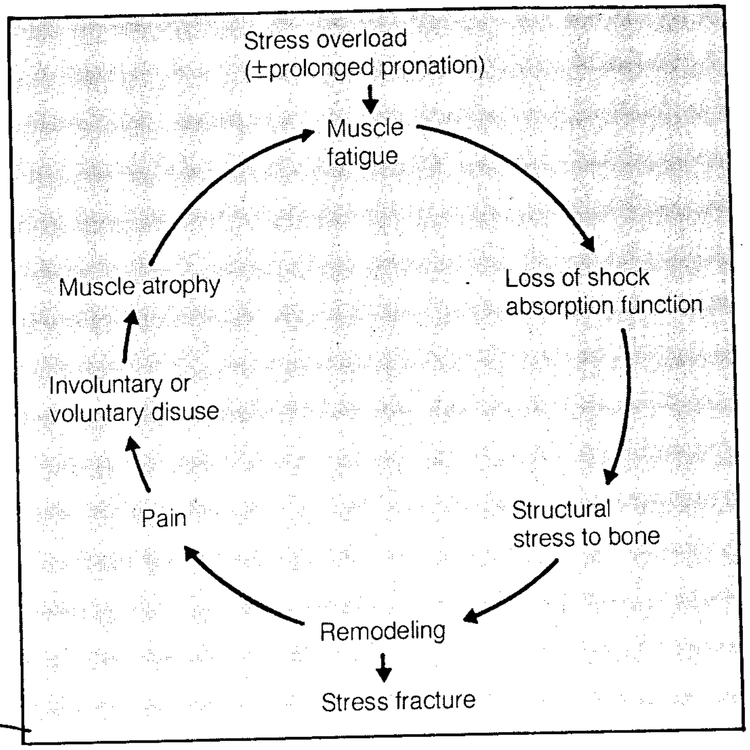

Figure 2. Theoretical etiology of stress fractures

Treatment

Treatment is aimed at minimizing the time the athlete is unable to train and compete. The treatment plan was not instituted promptly in most cases (the average time from symptom onset to beginning treatment was seven weeks), because the athletes tended to self-prescribe rest or to continue training while trying to block out the pain.

After the diagnosis patients were treated with a combination of modified rest, ice massage, anti-inflammatory medication, and physiotherapy for muscle retraining and flexibility. Naproxen was generally selected as the anti-inflammatory medication to reduce pain and swelling, which allows earlier adoption of the normal gait and recovery from muscle atrophy. Appropriate soft orthotics, and in some cases more rigid but flexible orthotics, were created to balance foot abnormalities.

To prevent prolonged pronation, the medial side of the foot must be supported with an orthotic to maintain a neutral position in midstance. In forefoot varus, it is only necessary to shim up the forefoot. The simplest orthotic is a wedge of felt tapered gradually for comfort and attached to the underside of the insole. More hardy and less bulky orthotics can be manufactured from plastics using a cast of the patient's foot taken in a neutral position with the midtarsal joint locked. The degree of wedging can be determined accurately from such a cast. It must be emphasized that orthotics should never overcorrect a prolonged pronation problem, because pronation enables the forefoot to adapt to rough surfaces and provides shock absorption.

It is our experience that orthotics decrease injuries. However, the initial breaking-in period is not well tolerated by some people. Blisters and discomfort can be avoided by gradual introduction of the orthotic.

Rest tends to rapidly weaken trained muscles. Training through the pain usually causes conscious or unconscious guarding of the painful area, and muscle weakening also occurs. A weakened musculature is less able to absorb shock and prevent transference of shock to the bone (figure 2).

Exercises to develop or maintain the strength and endurance of the ankle dorsiflexors and plantar flexors are begun almost immediately. These muscles as well as the quadriceps and hamstring groups may be atrophied. Bicycling and/or swimming are recommended to maintain cardiovascular fitness. Nonweight-bearing running in a pool with a life vest for buoyancy has been successful. These dynamic exercises do not impose the high momentary tensions on the leg that running does.

Running should be introduced gradually. The athlete should understand the dangers of training errors as outlined by Clement and Taunton[14] and James et al.[13] Finally, because stress fractures in the femoral neck may dislocate, rest should be rigidly enforced until radiological signs indicate the lesion has healed.

Summary

Stress fractures must be considered in the differential diagnosis of lower extremity pain in athletes. Confusion with other benign and malignant lesions can be avoided when the

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typical history, signs, and symptoms are recognized. The prodromal state of bone stress without fracture can be recognized and treatment started early to prevent stress fractures. It appears that a contributing cause of stress fractures is excessive foot pronation in the running gait combined with training too much and too soon. Bone scans appear to be more sensitive than radiographic techniques to the early changes of a stress fracture. Treatment must provide modified rest, muscle rehabilitation, and orthotic control of excessive biomechanical stress. PSM

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self-test

Select the best answer for each of the following. Answers are given on page 150.

1. Pronation continues past midstance and into the propulsive phase of gait with the malalignment conditions of:

- **a.** Forefoot varus
- **b.** Subtalar varus
- **c.** Tibial varum
- **d.** All of the above
- **e.** None of the above

2. The tibia was the site of more than ________% of stress fractures in this series.

- **a.** 10
- **b.** 20
- **c.** 50
- **d.** 90

3. Bone scans are more sensitive to bone stress than traditional x-rays.

- **a.** True
- **b.** False

4. ________fractures required the shortest recovery time.

- **a.** Tarsal
- **b.** Fibular
- **c.** Tibial

5. The intensity of the training program was a major cause of stress fractures.

- **a.** True
- **b.** False

6. All sites of bone stress are associated with alignments that deviate from the ideal.

- **a.** True
- **b.** False

7. Treatment for stress fractures includes:

- **a.** Modified rest
- **b.** Ice massage
- **c.** Anti-inflammatory medication
- **d.** Physiotherapy
- **e.** All of the above
- **f.** None of the above

8. Orthotics should be introduced gradually.

- **a.** True
- **b.** False

9. Frequent contributing causes of stress fractures include:

1. Excessive foot pronation
2. Training too much
3. Bad shoes

- **a.** 1.
- **b.** 1, 2
- **c.** 1, 2, 3