Bone stress injuries of the lower extremity

A review

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ABSTRACT – Bone stress injuries can cause long-lasting damage, especially in young athletes and military conscripts, if not diagnosed and treated properly.

Diagnosis has been traditionally based on clinical, radiographic and scintigraphic examinations, but MRI has become increasingly important. High resolution MRI is particularly valuable for the grading of bone stress injuries. The clinician should be aware of the wide range of bone stress injuries and available diagnostic methods. Early diagnosis is the prerequisite for avoiding long-lasting complications.

Most bone stress injuries heal with closed treatment, but surgery is necessary in some cases. They heal well if the diagnosis is not delayed and the treatment adequate.

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Bone stress injuries are mostly seen among long-distance runners, soldiers, dancers, athletes and other sportsmen. The patients are usually young or middle-aged (Table 1).

About 400–500 sportsmen are affected by a bone stress injury annually in Finland (population 5 million; Hulkko and Orava 1991). The global incidence of bone stress injuries in sports has been estimated to be 2–4%: 2% in men and 7% in women (Johnson et al. 1994). Female athletes run an up to four times higher risk of a bone stress injury (Brunet et al. 1990, Zernicke et al. 1993). Among athletes, one fifth of all musculoskeletal stress injuries are located in bones (Bennell et al. 1996). Bone stress injuries of the lower extremities are commonest in the shin of long-distance runners (Table 1).

The recurrence rate of bone stress injuries among athletes during a 4-year follow-up varied between 2% and 13% (Sullivan et al. 1984, Matheson et al. 1987), and 11–20% in military conscripts (Milgrom et al. 1985). Multiple stress injuries are seen in 10% of runners (Sullivan et al. 1984) and in over 20% of female athletes (Bennell et al. 1996).

Etiology

The main factor predisposing to bone stress injuries is repeated mechanical load. The amount of load seems to correlate directly to the extent of injury (Marti et al. 1988).

The ratio of exercise to rest seems to be important, according to the authors' own experience and some reports (Nordin and Frankel 1989). In sports, the quality of running shoes and road or track surfaces are important mechanical factors for bone stress injuries. If bone is given enough time to recover from strain, it will become stronger with exercise (Conroy et al. 1993). The quality and

Table 1. Location (%) of bone stress injuries according to various kinds of sports according to Bennell and Brukner 1997

Sports	Shin bone	Foot	Fibular bone	Navicular bone
Athletics	39	21	17	73
Long-distance running	42	12	27	4
Dance	3	43	23	0
Basket ball	0	2	0	4
Racket games	3	2	7	4
Aerobic	0	7	3	0
Other sports	14	12	23	16

amount of the bone's reaction depend on the type of stress (Haapasalo et al. 1994): strength exercises to improve strength increase bone mass more than running (Robinson et al. 1995).

The effect of load on bone changes when the type of training is modified. We have found that shock absorbers or different shoe models had no effect on the occurrence of bone stress injuries, which agrees with other reports (Jones et al. 1989). Height and weight do not seem to affect the risk of developing bone stress injuries, but the percentage of body fat in women shows a negative correlation (Jones et al. 1989, Bennell et al. 1996). Some controversy exists about the effect of age in that one report found no influence on the incidence of stress injuries (Shwayhat et al. 1994).

We have noted that when bone stress injuries recur often and are bilateral or multi-focal, some important risk factor probably exists. Anteversion of the femur, varus or valgus knees, tibia vara, varus- or valgus-rotated calcaneus, hyperpronation of the foot, plain or curved foot or a foot with an intermetatarsal neurinoma are regarded as anomalies that increase the risk of stress injuries (Matheson et al. 1987, Krivickas 1997). Flat foot (Sullivan et al. 1984) and leg-length discrepancy (Brunet et al. 1990) also seem to increase the risk for stress injuries. Currently there is hardly any scientific evidence to prove that certain anatomical features—e.g., the anatomical shape of the middle foot—really affects the development of stress injuries (Krivickas 1997).

A lower bone density increases the risk of stress injuries in women more than in men (Bennell et al. 1996). However, men with bone stress injuries do not usually have less bone density (Bennell et al. 1996). The relevance of bone density to stress injuries therefore remains controversial (Bennell et al. 1995).

Menstrual disturbances and delayed menarche seem to increase the risk of sustaining a bone stress injury 2–4-fold (Bennell et al. 1996). In some studies, contraceptives seemed to reduce the risk of stress injuries by 50% (Myburgh et al. 1990), but in others had no effect (Kadel et al. 1992). Estrogen replacement therapy may reduce the incidence of stress injuries (Bennell and Brukner 1997). Spontaneously normal menstrual periods seem to prevent bone stress injuries and enhance density of bone matrix more effectively than any substitutes (Jonnavithula et al. 1993).

No correlation has been found between the development of bone stress injuries and nutrition in men, but anorectic women run a higher risk of stress injuries (Bennell et al. 1996).

Pathogenesis

Bone is a dynamic tissue, which needs a constant load for normal remodeling (Sterling et al. 1992), according to Wolff's law (Chamay and Tschants 1972). Repeated traumatic strain induces remodeling, starting with osteoclastic activation and bone resorption (Chamay and Tschants 1972, Carter et al. 1981, Burr 1993). This process reaches its maximum in 3 weeks (Jones et al. 1989, Sallis and Jones 1991, Sterling et al. 1992). Thereafter, the new bone created fills resorption tunnels and pits. This usually takes about 3 months (Frost 1991, Sallis and Jones 1991). Macroscopically, apart from a periosteal reaction, stress-induced endosteal bone growth can often be seen even when no fractures are present (Uhthoff and Jaworski 1986). Later, the new bone matures and forms normal lamellar layers (Uhthoff and Jaworski 1986).

In optimally-directed loading, with enough time for the remodeling process, bone mass remains unchanged and no stress injury will result, but the bone becomes stronger (Uhthoff and Jaworski 1986, Frost 1991, Sallis and Jones 1991, Frost 1994). However, if the load is excessive, prolonged or recurrent, the resorption process dominates and formation of new bone does not proceed properly. This weakens the bone and a stress injury occurs (Burr et al. 1985, Jones et al. 1989, Frost 1994, Maitra and Johnson 1997). Repeated micro-trauma of a previously stress-injured bone may eventually result in a stress fracture, which can be seen on plain radiographs (Carter and Caler 1983, Frost 1994). We have measured high intraosseous hydrostatic pressures—i.e., 46–58 cm H_2O (normal 21–23 cm H_2O) in patients having symptoms related to bone stress injuries, but no detectable fracture (unpublished observations) and found that a stress-injured bone with an obviously increased uptake in scintigraphy may have focal necroses on histological examination. This is probably due to intraosseous compartment syndrome-like conditions which, because of poor local blood circulation, result in bone necrosis. Ischemia may also explain the local pain. Poor blood circulation and ischemia as well as a low pH contribute to enhanced resorption and reduce the formation of new bone.

Diagnoses

Load-related pain is typical of bone stress injuries. The onset of pain usually occurs during the first 2 weeks after the training becomes more strenuous, but it may be delayed by several months (Greaney et al. 1983, Jones et al. 1989, Maitra and Johnson 1997). The onset of symptoms is gradual. At first, pain is present only during stress and it depends partly on the amount of the load. As the process goes on, it starts to occur also at rest and even during the night. Surrounding soft tissues may become swollen. Early suspicion of a possible stress injury is essential for adequate treatment. Local tenderness can be detected by simply tapping the affected bone.

Conventional radiography remains the first routine examination for suspected stress injuries of bone (Daffner 1978). Radiographic changes become visible 2–12 weeks after the onset of symptoms, if ever (Sullivan et al. 1984, Matheson et al. 1987). The sensitivity of radiography is 15–35% in the early stage (Daffner 1978, Greaney et al. 1983). Findings indicating stress fracture are seen in 30–70% of cases only during the follow-up (Daffner 1978, Matheson et al. 1987). The first sign, on the surface of long bones, is the so-called "grey cortex". A grey-looking hypodensic area seen in compact bone is related to the resorption phase of remodeling (Daffner 1984, Mulligan 1995). After this phase, periosteal new bone forms and endosteal bone thickens (Daffner 1978, Martin and Burr 1982, Greaney et al. 1983). A fracture, if present, can be seen as a radiolucent line in compact cortical bone and as a sclerotic line in cancellous bone (Daffner 1978, Mulligan 1995).

In most cases CT is less sensitive than conventional radiography for the detection of stress injuries of bone. However, certain fracture lines, such as longitudinal and spiral ones, can be seen more clearly with CT (Daffner 1978, Torg et al. 1982, Matheson et al. 1987, Allen 1988).

Scintigraphy has long been considered to be the best diagnostic method for bone stress injuries (Daffner 1978) with a sensitivity close to 100% (Stafford et al. 1986, Matheson et al. 1987). However, false negative diagnoses have been reported (Sterling et al. 1993), possibly because necrotic bone tissue is not labeled (Kanstrup 1997). In these injuries, an increase in uptake can be detected as early as 6–72 hours after the onset of symptoms (Greaney et al. 1983, Matheson et al. 1987, Kanstrup 1997). An oval signal, the intensity of which correlates to the severity of the bone stress injury, can be seen with scintigraphy (Floyd et al. 1987). Asymptomatic mild stress injuries can also be seen with scintigraphy as clusters of increased uptake (Daffner 1978, Matheson et al. 1987). Follow-ups with scintigraphy, however, are not entirely satisfactory (Kanstrup 1997).

MRI provides important information in studies of bone stress injuries. It is as sensitive, but more specific than scintigraphy (Daffner 1978, Stafford et al. 1986, Lee and Yao 1988, Meyers and Weiner 1991). In addition to changes in bone, it gives information about the surrounding soft tissues in all three dimensions. T2- and STIR-techniques are useful for detecting edema of cancellous bone, periosteum and bone marrow (Daffner 1978, Stafford et al. 1986, Resnick 1995). Edema, however, is a nonspecific finding. A fracture can be seen as a lower signal intensity in the middle of the edema (Daffner 1978, Stafford et al. 1986, Resnick 1995), but it is better seen as a low-density signal line on T1-images. Edema disappears before the signal indicating new formation of bone appears. Therefore, MRI-analysis is most accurate during the first 3 weeks (Daffner 1978, Stafford et al. 1986, Martin et al. 1993). The diagnosis is clear if a fracture line can be seen. If only a swelling without signs of a fracture is visible, an accurate diagnosis cannot be made (Daffner 1978, Stafford et al. 1986, Martin et al. 1993). Although bone tissue is seen more efficiently on CT than on MRI, the latter is better for early detection and a differential diagnosis (Daffner 1978, Stafford et al. 1986, Martin et al. 1993, Uhmans and Pavlov 1994). If radiographs show normal bone structure despite pathological findings on scintigraphy, MRI usually gives additional information. In case of uncertainty one can repeat the radiographic and MRI examinations after 3–4 weeks.

Jones et al. (1989) suggested a practical classification of bone stress injuries (Table 2). The

Table 2. Classification of bone stress injuries according to Jones et al. 1989

Grade	Scintigraphy	Stress pain	Local tenderness	Radiography	Fracture
0	+	–	–	–	–
1	+	+	–	–	–
2	+	+	+	–	–
3	+	+	+	+	–
4	+	+	+	+	+

grade of a stress injury is known to have a positive correlation with the intensity of the scintigraphic signal (Zwas et al. 1987, Matin 1988). We mainly use both MRI- and scintigraphic-based classifications (Table 3; Fredricson et al. 1995) to get more accurate and useful information for diagnosis, classification and follow-up. In conclusion, the MRI-based classification gives more detailed information about the bone stress injury, but scintigraphy is good for screening and measuring the activity of the lesion.

Differential diagnosis. A negative scintigraphy finding rules out bone stress injuries with great certainty. In medial tibial stress syndrome, an increase in the uptake is seen in a large area on the surface of the shin bone. The signal is seen only in the collecting phase, but not with angiography or bone-pole phases in connection with bone stress injuries. MRI shows swelling only in the periosteal area (Daffner 1978, Matheson et al. 1987, Kanstrup 1997).

Chronic sclerotic osteomyelitis causes bone changes that usually extend throughout the bone circumference and affect a larger area than those associated with stress injuries. Variable cortical thickening, uneven sclerosis and swelling of the bone are seen. In chronic sclerotic osteomyelitis, radiographs do not change during a few weeks of follow-up (Daffner 1978, Daffner and Pavlov 1992).

Ewing's sarcoma, which usually occurs in young patients, may be the most important differential diagnostic problem. New bone growth is more even and lamellar-like in stress injuries (Uhmans and Pavlov 1994). Ewing's sarcoma causes more severe periosteal changes, such as uneven surfaces and spine-like spiculum, and a soft tissue component is always present. Osteolysis is usually severer in malignant diseases than in bone stress injuries (Daffner 1978, Martin and Burr 1982, Daffner and Pavlov 1992). A biopsy is sometimes necessary for the diagnosis.

Treatment

We consider an early diagnosis is necessary for optimal treatment. To diagnose and classify bone stress injuries correctly, one must combine the clinical, MRI, radiographic and scintigraphic findings. It is also important to understand the specific characteristics and natural healing ability of injuries in various bones.

Closed treatment is sufficient in most bone stress injuries of the lower extremities (Sallis and Jones 1991). The main principle is to treat the injury and prevent recurrences and complications. To achieve this goal, one has to understand the natural history of the injury (Reeder et al. 1996).

It is essential to reduce or eliminate the bone load from the beginning (Sallis and Jones 1991). The time the patient should avoid weight bearing varies according to which bone is injured and how severely it has been affected (McBryde 1982, Matin 1988, Fredricson et al. 1995). The treatment of the shin bone, based on the MRI classification, is shown in Table 4 (McBryde 1982).

Table 3. Classification of bone stress injuries by MRI according to Fredricson et al. 1995

Grade	T1	T2 and STIR
0	normal	normal
1	--------	mild periosteal and no bone marrow swelling
2	--------	evident periosteal and bone marrow swelling
3	bone marrow swelling	severe periosteal and bone marrow swelling
4	bone marrow swelling “low-signal“ -fracture	severe periosteal and bone marrow swelling severe bone marrow swelling

Table 4. Conservative treatment protocols for various grades of stress injuries of the shin bone, according to Fredricson et al. 1995 and present authors

Grade	Time without loading	Gradual increase in weight bearing
1	2–3 weeks	according to pain
2	4–6 weeks	according to pain
3	6–9 weeks	according to pain
4	cast for 6 weeks	
	without cast for 6 weeks	according to pain

Non-steroidal anti-inflammatory drugs (NSAID) have been recommended for treatment of the early phase of stress injury (Sallis and Jones 1991, Reeder et al. 1996), but no evidence shows that they affect healing. Theoretically, the NSAIDs may have an osteoblast-inhibiting effect. A variety of physiotherapeutic methods have been recommended, such as cold, phonophoresis, electric and electromagnetic treatments (Sallis and Jones 1991, Fredricson et al. 1995, Reeder et al. 1996). Several uncontrolled studies have been published concerning electric/electromagnetic methods in the treatment of delayed fracture healing (Brighton and Pollack 1985, Behari 1991). Such treatments may have a positive effect on healing of stress injuries (Matheson et al. 1987, Benazzo et al. 1995).

Pulsed low intensity ultrasound is a new promising non-operative treatment for bone stress injuries. The energy given is extremely low and the treatment protocol includes daily treatment sessions for several weeks (Brand et al. 1999). This method reduces pain and permits patients to return to their sports activities earlier (Brand et al. 1999).

The use of long air-casts has shortened the recovery time of fractures (Dale et al. 1993) and minor stress injuries (Whitelaw et al. 1991, Swenson et al. 1997).

The second phase of the treatment—i.e., a gradual increase in load which should be started 14 days after painless walking (Sallis and Jones 1991, Reeder et al. 1996) and done in an orderly fashion. Initially practice is started with a stationary bike and exercise in a pool, and only then continued with running and jumping exercises. Stress-related pain is a valuable way to assess the ability to exercise.

The incidence of stress injuries has been reduced from 5% to 2% by changing the training methods (Scully and Besterman 1982). Proper studies are still needed concerning the value of supporting soles in shoes (Reeder et al. 1996). The following rules are important in prophylaxis: avoid sudden major changes in running track surface and shoes, ensure adequate nutrition (anorexia is common in young female endurance athletes), avoid overtraining (natural steroid balance can be disturbed) and shorten workouts when first signs of overuse occur.

Surgical treatment is indicated if a fracture dislocates or does not heal with closed treatment (Sallis and Jones 1991). Many methods are available. Drilling the bone improves healing in our experience and that of others (Hulkko and Orava 1991). It lowers excessive hydrostatic pressure in the bone which, due to lowered perfusion resistance, improves the blood circulation in local bone. As the bone pressure falls, pain subsides. We have used drilling, especially in patients who suffer from a symptomatic bone stress injury with no detectable fracture. The value of drilling, however, remains controversial.

For fractures resection or autograft transplantation, alone or combined with osteosynthesis, has also been used (Monteleone 1995, Reeder et al. 1996, Egol et al. 1998). A bone transplantation improves healing of the fracture. Tension wires, screws, sliding screws, plates and intramedullary nails have been used for osteosynthesis.

Various bones in the lower extremities have very different mechanical and biological individual properties that affect their healing and treatment. The physician should know the principles mentioned below to be able to handle different kinds of stress fractures.

In most cases, sesamoid bone stress fractures of the big toe do not unite with closed treatment, especially if the fracture is dislocated (Hulkko and Orava 1991). Cases with persistent pain have been treated with bone transplantation (Bergfeld and Khoury 1994) and partial or total excision of the sesamoid bone (Bergfeld and Khoury 1994). In our experience, total excision of this bone does not give good results—e.g., in runners.

Metatarsal bone (MT) stress fractures, especially when located in the diaphyseal middle and proximal fifth areas are common in field and track athletes (Figure 1). Stress injuries of the diaphyseal

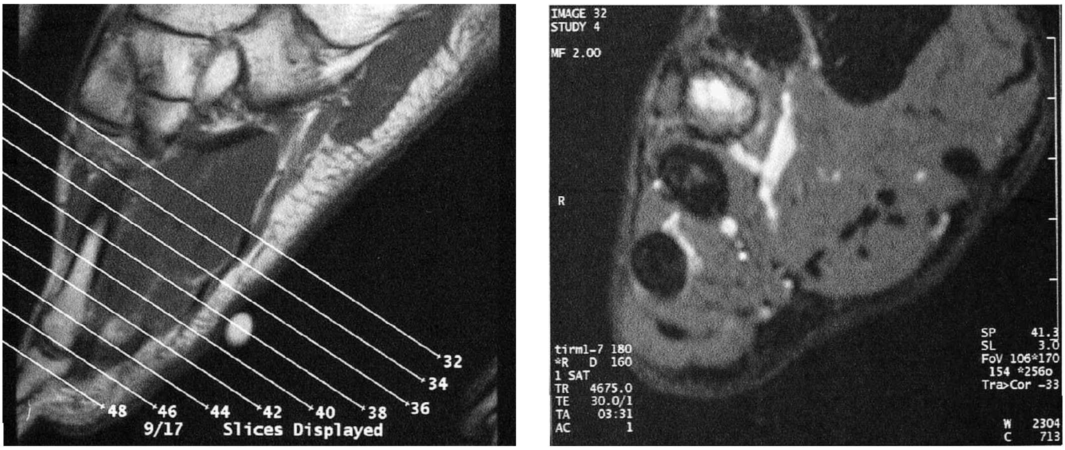


Figure 1. A 24-year-old male long distance runner who had persistent foot pain. MRI shows edema in the third metatarsal bone due to an overuse injury of bone without a fracture.

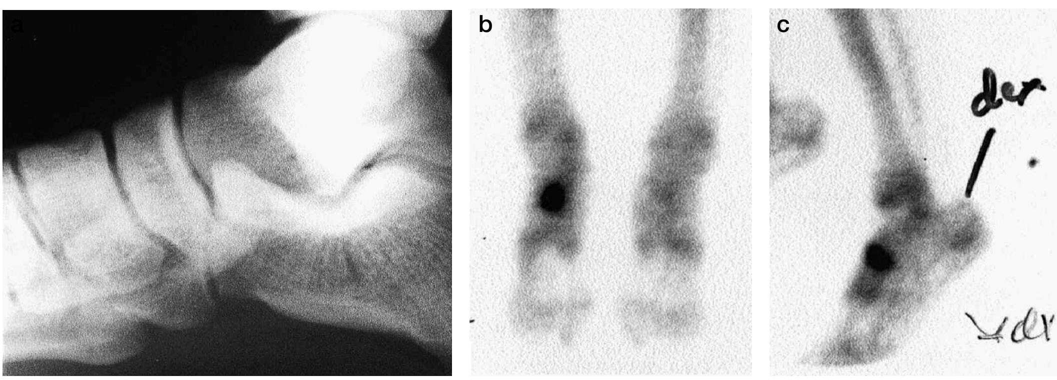


Figure 2. A 20-year-old male high-jumper who had to give up jumping because of ankle pain during exercise. The radiograph remained negative (a). Scintigraphy showed a bone stress injury in the navicular bone (b-c).

area of MT II in dancers heal almost always during 4–6 weeks after closed treatment, with the exception of the proximal injury of the MT V bone. In case of delayed healing, drilling seems to help in our experience. If a patient has a proximal fracture of the fifth MT with a wide lateral fracture line, sclerotic fracture edges and a high activity level, one should consider surgery with compression osteosynthesis by an intramedullary screw (Bergfeld and Khoury 1994, Quill 1995) or tension wire osteosynthesis (Hulkko and Orava 1991). We have had good results with the intramedullary screw.

The navicular bone is subject to a wide variety of stress injuries from stress osteopathy or an impending fracture to a dislocated one (Figure 2). By stress osteopathy, we mean bone stress injuries which have not been exactly defined diagnostically as yet, but they are painful enough to disturb an athlete's ability. Bone necrosis is a well-known complication of stress injuries of this bone (Torg et al. 1982, Reeder et al. 1996). We have detected osteonecrotic spots in stress osteopathy of the navicular bone on histological examination. This probably explains our finding that drilling and 6 weeks immobilization in the cast with full weight bearing during the last 2 weeks can restore the ability to exercise fully in 3–4 months (unpublished observation). Good results have been obtained with treatment of stress fractures of the navicular bone also by cast-immobilization for 6–8 weeks and restricted weight bearing (Torg et al. 1982, Khan et al. 1992). To estimate the optimal time for cast-immobilization one should use palpation rather than radiological examinations.

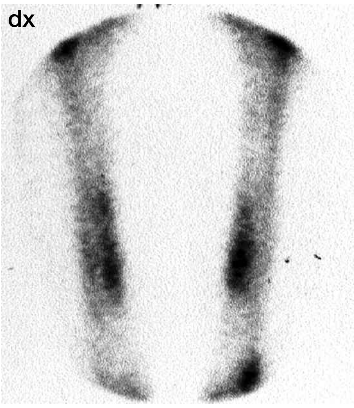
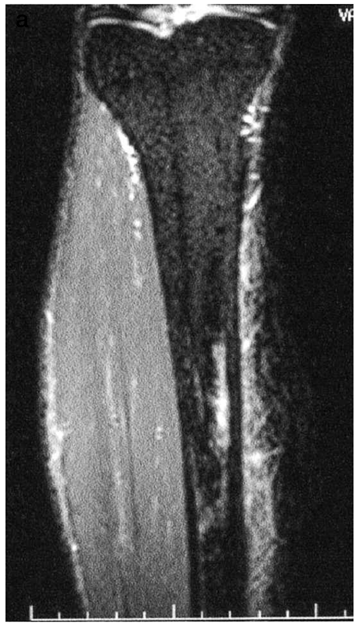


Figure 3. A 20-year-old male long distance runner who had mid tibial pain for several months. The radiographs were negative but scintigraphy shows bilateral bone stress injuries.



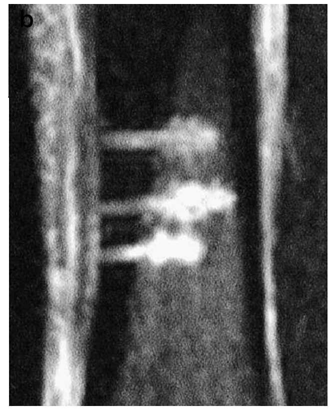


Figure 4. A 34-year-old female hurdle runner who complained of mid tibial pain which did not respond to several types of conservative treatment (a). The site of chronic bone edema was seen with MRI and then successfully treated by drilling (b).

It takes in average of 4–5 months for the patient to return to sports (Monteleone 1995). Combined bone transplantation and screw-fixation help although both methods have also been used alone with 6–8 weeks of immobilizationin a cast after surgery (Khan et al. 1992, Bergfeld and Khoury 1994). We advocate surgery for stress injuries of the navicular bone.

Stress fracture of the talus is rare and affects the collum or corpus areas (Greaney et al. 1983, Uhmans and Pavlov 1994, Brandshaw et al. 1996). The recommended treatment for stress osteopathies of the collum area is drilling followed by 6 weeks immobilization in a cast and restricted weight bearing. Stress fractures in the collum can be treated at first with immobilization for 6–8 weeks in a cast. However, screw-fixation is recommended if the fracture tends to dislocate and healing is delayed. The results are poor with closed treatment of bone stress injuries of the corpus area. The risk of bone necrosis has to be remembered and weight bearing should be delayed (Black and Ehlert 1994). Drilling may also be useful.

Dislocated stress fractures of the calcaneus are rare. According to a few reports and our clinical experience, stress injury of this bone heals in most cases after 6 weeks of reduced activity and even without immobilization in a cast (Reeder et al. 1996, Marcelli 1997).

Fibular stress injuries mostly affect the upper or lower third of the bone (Monteleone 1995). Most of them heal without surgery in 6 weeks (Monteleone 1995). If healing is delayed, drilling seems to be helpful in our experience. Closed treatment of fractures located in the upper part of the malleolus can cause complications. Dislocation leading to malunion easily follows total fractures (Guille et al. 1997).

Medial malleolar stress fractures usually have a relatively vertical course from the corner of the joint. Osteopathies or partial and total fractures occur in the medial malleolus. Total stress fractures tend to dislocate (Schils et al. 1992) and we prefer screw-fixation in these cases. We have treated some osteopathy cases, where healing was delayed for 2 years although the patient only walked during that time. Healing improved with drilling. In other cases with delayed healing for 8–12 months, drilling also enhanced recovery (Orava et al. 1995). Early surgery may be indicated for athletes who are very active.

Tibial fractures in the distal and proximal third of the diaphyseal area can be treated successfully with closed methods in most cases (Sallis and Jones 1991, Monteleone 1995, Reeder et al. 1996) (Figures 3 and 4). Surgery is recommended when the fracture dislocates or does not heal despite closed treatment (Hulkko and Orava 1991). The usual therapy for tibial fracture is used in such cases. Stress fractures on the tension side of the anterior aspect of the middle third of the tibia tend to heal poorly. Closed treatment has been recommended for the first 3–6 months (Taube and Wadsworth 1993). In many cases, early surgery can be better: drilling or bone transplantation alone or together with plate fixation (Reeder et al. 1996). Even immediate intramedullary nailing has been suggested for athletes (Plasschaert et al. 1995). Healing of ordinary stress injuries of the shin bone can take between 3 weeks and 18 months (Sullivan et al. 1984, Hulkko and Orava 1991).

Patellar stress fracture rarely occurs. It is usually a partial fracture in the anterior cortical area (Rockett and Freeman 1990) or a horizontal one in the lower pole (Rockett and Freeman 1990, Orava et al. 1996). Such fractures can heal in 3 months with closed treatment (Mata et al. 1996). A total stress fracture, however, may dislocate (Jerosch et al. 1989) and require reduction combined with osteosynthesis.

Femoral stress injury may affect any part of the bone, but the commonest sites are the shaft and femoral neck. Most fractures located in the shaft or condylar areas can be treated without surgery in two phases, as mentioned above, if the fracture is undetectable or partial. Healing usually takes 2–3 months (Clement et al. 1993). Total fractures are treated with IM-nailing. Compression side fractures of the femoral neck are mostly treated without surgery, but require long follow-ups; in most cases tension side stress fractures result in total fractures and run a risk of avascular necrosis. It is therefore advisable to operate on them by using several parallel screws or a dynamic hip screw (Egol et al. 1998). Avascular necrosis of the femoral caput is a serious complication after a stress injury of the femoral neck.

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