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Tibial Stress Injuries

An Aetiological Review for the Purposes of Guiding Management

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Abstract

In the last 30 years, few advances have been made in the management of tibial stress injuries such as tibial stress fracture and medial tibial stress syndrome (MTSS). Tibial overuse injuries are a recognised complication of the chronic, intensive, weight-bearing training commonly practised by athletic and military populations. Generally, the most effective treatment is considered to be rest, often for prolonged periods. This is a course of action that will significantly disrupt an active lifestyle, and sometimes end activity-related careers entirely.

There is now considerable knowledge of the nature of tibial stress injuries, such that presently accepted management practices can be critically evaluated and supplemented. Most recent investigations suggest that tibial stress injuries are a consequence of the repetitive tibial strain imposed by loading during chronic weight-bearing activity. Evidence is presented in this article for an association between repeated tibial bending and stress injury as a function of: (i) strain-related modelling (in the case of MTSS), and (ii) a strain-related positive feedback mechanism of remodelling (in the case of stress fracture). Factors that influence the bending response of the tibia to loading are reviewed. Finally, a guide for injury prevention and management based on research observations is presented.

The most frustrating thing an elite athlete, military recruit or fitness fanatic can hear from their physician upon presenting with symptoms of tibial stress injury is 'I recommend an extended period of rest until your bone heals'. Considering the volume of information available in the literature that could ultimately assist in the prevention and/or more expedient treatment of such injuries, bone scientists may also feel some of the patient's frustration.

The time lag between scientific understanding and practical application appears to be particularly pronounced in the area of tibial stress injuries. While this may reflect the non–life-threatening nature of the injury, such belated dissemination of more progressive management techniques implies that rest from weight-bearing activity is an acceptable recommendation from a general health standpoint. However, not only can tibial stress injuries be highly disruptive to a regular fitness regimen, they can end the careers of competitive athletes or military recruits unable to complete basic training. Furthermore, in a world that is becoming increasingly focused on 'sport as business', in which readiness to participate is an economic consideration, prolonged periods of recovery from injury have additional negative repercussions for athletes.

1. Definitions of Tibial Stress Injuries

Part of the problem of slow information dissemination lies in past use of injury terminology. 'Shin splints' has long been utilised as a nonspecific term to describe conditions of pain in the leg resulting from activities involving repeated foot-to-ground impact. Even today, it is not uncommon to hear such varied leg injuries as tibial and fibular stress fracture, tibial periostitis, anterior and deep posterior compartment syndrome, popliteal artery entrapment, tibialis posterior and anterior muscle strain or tendinitis be referred to as 'shin splints'. Given the fundamental differences between the pathology of these conditions, continued use of the term 'shin splints' for diagnostic or research purposes is highly inappropriate.

Medial tibial stress syndrome (MTSS) is a condition comprising periostitis or symptomatic periosteal modelling occurring in the vicinity of the junction of the middle and distal thirds of the medial border of the tibia.[1-5] Stress fractures are focal structural weaknesses in bone occurring in response to the repeated application of sub–frank fracture threshold stresses.[6-9] In the athletic population, and in runners in particular, the most common site of tibial stress fracture coincides with that of MTSS. As such, this article predominantly pertains to injury at the junction of the middle and distal tibial thirds. Other less commonly affected sites are the proximal third of the tibia (prepubescent athletes[10]) and the mid–anterior cortex (predominantly in jumping athletes and dancers[11-13]). Injuries to the latter site are a rare and problematic form of stress fracture that have a propensity for non-union because of an underlying mechanism of tensile stress. They can be visualised on x-rays as a distinct radiolucent fissure in the anterior cortex of the tibia and are normally 'cold' on bone scans. Usually, these injuries require aggressive forms of treatment such as bone grafting for ultimate resolution. As a consequence, they are known in the clinical community as 'the dreaded black line.'

Although medial, distal tibial stress fracture and MTSS constitute different pathologies, they may, for management purposes, be considered as conditions on a 'bone stress–failure continuum,' on which MTSS is a relatively mild expression and stress fracture is a severe extreme. These conditions do not necessarily occur concurrently, nor in temporal sequence; however, it is likely that stress fracture and MTSS are invoked by similar mechanisms. The coincidence of the most common site of tibial stress fracture at or near the junction of the middle and distal thirds[14,15] with the site of incidence of MTSS, bolsters this suspicion.

2. Past Perspectives of Tibial Stress Injuries

To date, much of the inquiry into the mechanism of bone-related 'shin splints' has been directed toward investigation of the anatomical structures arising from the site of injury that have the potential to impart a traction force on the tibia and its periosteum.[5,16,17] There are limitations to a periosteal traction-based theory, however, not the least of which is the fact that the injury site coincides with only very small portions of the origins of implicated muscles (soleus and flexor digitorum longus) and fascia (deep crural).[16]

An alternative theory – often summarily referred to in the sports medicine literature but until recently attributed minimal consideration – deserves greater attention. The theory suggests that chronic, repetitive loads that induce tibial bending will precipitate stress injury at the site about which maximum bending occurs. Considerable clinical and experimental evidence exists to support this theory.[11,12,14,18,19]

It is the purpose of this article to review the literature pertaining to tibial stress injuries and the mechanistic theory of chronic tibial bending in order to identify scientifically sound, aetiology-based management guidelines.

3. Present Management of Tibial Stress Injuries

Conservative management (rest from weight-bearing activities) is generally considered to be the most satisfactory approach for treating tibial overuse injury.[9] A recent survey of 41 orthopaedic surgeons in Oregon in the US revealed that 58.5 and 61% of clinicians recommended rest as the primary treatment for MTSS and tibial stress fractures, respectively (unpublished data, Beck 1996). The recommended rest period ranged from 1 to 16 weeks for patients with MTSS (average of 6.6 ± 3.5 weeks) and 3 to 16 weeks for those with tibial stress fracture (average of 8.3 ± 2.8 weeks). Another 31.7% of clinicians elected casting the limb as a first option treatment for tibial stress fractures with a recommended immobilisation time ranging from 3 to 12 weeks (average of 6.4 ± 2.1 weeks). These management choices support reports in the literature that recommend between 2 and 24 weeks' rest (average of 12.5 ± 7 weeks) for the resolution of tibial stress fractures.[9,14,18,20-23] Considering the negative repercussions of reduced weight-bearing activity and immobilisation on bone, joint and muscle tissues, and the disruption to daily life caused by casting the limb, these treatment prospects are clearly not ideal.

Perhaps even more significantly, 48.8% of the clinicians surveyed recommended a daily regimen of exercises for triceps surae flexibility and strengthening as a primary or secondary treatment option in symptomatic MTSS patients (unpublished data, Beck 1996). Almost 30% of clinicians recommended this approach as a first or second treatment option for tibial stress fractures (unpublished data, Beck 1996). Traditionally, the literature has also supported this approach.[2,20,23,24] In light of the aetiological analysis given in sections 4.2, 4.3 and 5.5, however, such recommendations are of dubious merit and may, in fact, compound the problem.

4. Bone Geometry and Response to Loading

Bone appears to be a strong and rigid substance, hence the concept of significant bone bending during daily activities is, for some, difficult to conceive. Normal physiological loading provokes a range of deformation reactions (strains) in bone, including compression, tension, shear, torsion and vibration. When a force is applied to a solid object, it is deformed from its original dimensions. As bones are curved, compressive loads applied at the joint surfaces rarely act through the centre of the bone and, thus, bending occurs.[25] Long bones with narrow diaphyseal widths will bend to a greater extent when loaded than those with wider diaphyses.[26,27]

4.1 Bone Adaptation

The basic form of bone is intrinsically programmed within the cells of the cartilaginous primordium.[28] Bone morphometry across many species appears to have evolved to the extent that strains produced during normal, functional patterns of loading remain within the ranges of magnitude that are unlikely to produce gross tissue damage.[29-31] It is, however, well-documented that bone exhibits an intrinsic ability to adapt to alterations in chronic loading patterns by modifying geometric and/or material properties to best withstand future loads of the same nature – a phenomenon commonly (and somewhat loosely) referred to as Wolff's law.[32-44] In the case of long bones, such as the tibia, an increase in loading can precipitate increases in cortical thickness and density and widening of the diaphyseal diameter.[45-47] Frost[48] suggested that the objective of adaptations in bone geometry that reduce bending is to reduce the potential for strain-related tissue damage.

That widening of a diaphysis significantly affects the ability of a bone to resist bending-induced injury has been illustrated in the clinical setting. Milgrom et al.[19,49] observed that Israeli army recruits with wider tibiae exhibited a lower incidence of stress fracture than recruits with narrow tibiae. They measured the tibial diaphyseal area moment of inertia (a value indicating the distribution of cross-sectional bone mass in relation to an axis of bending) and found that the further the cortical bone mass is distributed away from the axis of bending, the greater the ability of the bone to resist bending forces. Beck et al.,[18] using dual energy x-ray absorptiometry, also found that US Marine Corps recruits who sustained tibial stress fractures in basic training had significantly ($p < 0.03$) smaller tibial cross-sectional areas and widths compared with recruits without tibial fracture. Others have reported similar findings.[50]

4.2 Aetiology of Medial Tibial Stress Syndrome (MTSS)

The 'pathology' of MTSS is likely to be merely a symptomatic expression of normal (albeit hyperstimulated) periosteal modelling at the site of maximal tibial strain when under load.[51] That is, when the tibia experiences chronic and repetitive strain in a pattern that invokes exaggerated or abnormal bending, it is stimulated to deposit new bone on its periosteal surface at the level of the narrowest diaphyseal cross-section (junction of the mid and distal thirds) to reduce potentially injurious strains at this site in the future.

4.3 Aetiology of Stress Fracture

Some controversy exists regarding the aetiology of stress fractures. Burr et al.[7] found that the location of stress fractures in chronically overloaded rabbit tibiae corresponded closely with the sites of maximum shear strains. This observation suggested that chronic loading alone creates microcracks in bone that accumulate and, ultimately, coalesce to form stress fractures. It is unlikely, however, that normal healthy bone tissue will accumulate the requisite degree of microcracking for a macro cortical crack (stress fracture) to ensue, even under substantially increased physiological loading. Rather, microcracking is likely to occur as a consequence of reduced tissue resistance to strain following the development of remodelling-related bone porosity.[52-55] Indeed, Burr et al.[56] observed that many more microcracks occurred in association with bone resorption spaces than would be expected by chance alone.

A bone remodelling sequence commences approximately 5 days after stimulation (the initiation of altered patterns of strain) with a 30- to 45-day period of osteoclastic tunnelling. At about 30 days after stimulation, osteoblasts begin to fill the resorbed space with new bone matrix. The bone replacement phase lasts approximately 180 days,[57,58] during which time there is a transient increase in the remodelling space. This represents a substantial period during which bone is relatively porous.

It is known that bone stiffness and strength are exponentially reduced with increasing porosity.[59-61] This property renders bone more susceptible to fracture during the period of adaptation, a problem that is compounded by a strain-remodelling positive feedback mechanism. With reduced bone mass, loads of equivalent nature and magnitude will incur greater strain on the remaining bone which, in keeping with the principle of Wolff's law, will re-stimulate the adaptive response. Periosteal modelling (such as MTSS), sometimes observed concurrently with tibial stress fracture, may be an example of compensatory geometric adaptation to enhance strain resistance in a region weakened by remodelling-induced porosity. Whether the remodelling process is stimulated by the accumulation of bone matrix microcracks or by the transduction of mechanical load signals remains controversial.[7,62-68]

Convincing evidence exists in support of these strain-related modelling and remodelling aetiological theories. The cellular progression of bone modelling and remodelling has been well documented,[57,58] thus comparisons of tissue activity between conditions of overuse-induced bone injury and everyday bone tissue turnover can be made. Biopsy samples indicate that the upregulated bone metabolism that occurs at the cellular level during bone remodelling or modelling is also observed in the vicinity of tibial periostitis and stress fracture.[2,69] Triple-phase bone scans of tibiae that are symptomatic for stress injury provide images of diffuse (MTSS) and focal (stress fracture) tracer uptake (^{99}technetium polyphosphonate) in the region of pain, again indicating increased metabolic activity.[2,5,9]

While some individuals progress from mild symptoms of tibial stress injury to radiologically evident stress fractures with continued repetitive loading, others recover without incident.[70] It is likely that periosteal modelling or intracortical remodelling in some individuals occurs sufficiently rapidly to adequately accommodate ongoing loading of the same nature. Alternatively, other soft tissues (such as muscle) may provide adequate interim support during the period of reduced bone integrity in these individuals.

Bone stress injury in the leg is not confined to the tibia. While the fibula supports substantially less bodyweight than the tibia, studies of tibial strain after fibular grafts demonstrate the load-shielding function of the fibula on the tibia.[71] It is therefore not surprising that the fibula is also susceptible to stress fracture following chronic, weight-bearing exercise.[72,73] The most common location of fibular stress fracture is the distal third of the bone,[72] at a site roughly corresponding to the level of maximum tibial bending under normal normal weight-bearing loads. As the fibula is closely bound to the tibia, proximally and distally, via amphiarthrotic joints, it is a reasonable assumption that fibular stress fractures are a consequence of chronic bending or vibration in synchrony with the tibia. Muscle contraction may compound fibular bending, as the usual stress fracture site coincides with the most inferior border of the origin of the peroneus brevis muscle. Consequent to a fixed distal fibular end, peroneus brevis contraction would augment fibular bending around this point.

5. Factors Affecting Tibial Loads

5.1 Changes in Training

Many authors have noted an increase in the incidence of bone stress injury after a change in training.[2,9,73-77] The change may be in the form of a change in footwear, terrain, activity or training intensity.[15] The important factor, however, appears to be altered loading, rather than increased loading. Theoretically, even subtle alterations in tibial loading may lead to bone pathology if skeletal adaptation fails to keep pace with the loading demands.

The most striking example of altered loading is that experienced by relatively sedentary individuals who begin training. Correspondingly, tibial stress injuries appear to affect 'out-of-condition' athletes more commonly than trained individuals.[78-84] Most stress fractures occur within 3 to 7 weeks of the initiation of increased levels of activity.[74,75,77] Montgomery et al.[83] observed that most stress fractures in military recruits occur during the first month of training. It is unlikely to be coincidental that the highest incidence of such injury usually corresponds to the timing of the most porous phase of the bone remodelling cycle.

Others have reported that preconditioning provides no protection from the risk of tibial stress injury.[50,85-87] These conclusions, however, have often been based on the self-reporting of preparticipation activity levels rather than standardised measures of training experience, such as maximal oxygen consumption ($\dot{V}O_{2max}$). Swissa et al.[50] reported that the results of $\dot{V}O_{2max}$ testing indicated that individuals with high to very high aerobic fitness experienced a lower incidence of stress fractures than individuals with low and moderately low fitness. Despite this observation, the authors concluded that no protective pretraining effect existed, presumably owing to the large proportion of other recruits who had self-reported some form of preparticipation activity. Low intensity, sporadic pretraining activities are unlikely to provide adequate protection from the development of bone stress injury following sudden implementation of much higher intensity training.

5.2 Activity Type and Volume

Certain activities are more commonly associated with the incidence of tibial stress injury than others, with running being the most frequently cited.[88] It is not surprising that running produces far greater impact loads on the skeleton than walking, possibly causing up to 6-fold greater tibial strain.[6] Few training-specific activities have been associated with the incidence of stress fracture, although runners with ‘shin injuries’ have been reported to spend a greater proportion of their training time performing interval training than those without shin injuries (13.8 *vs* 7.1%, respectively; $p < 0.04$).[89]

Many studies of overuse injuries observed that the distance run per week is the most reliable predictor of injury.[90-94] This led to the common recommendation that running distance should be restricted to <32km per week to prevent any and all overuse injuries.[92,94] It is difficult to support such a broad recommendation that does not take into account the range of injuries that can be referred to as ‘overuse.’ Recommendations for training volume, such as this, can only be constructive when formulated on a injury-specific basis, taking into account tissue involvement and its specific response to loading.

Jumping increases the load at impact 8-fold compared with walking values.[95] Activities that include a large component of jumping (basketball, volleyball, hurdling, and highland and ballet dancing) invoke patterns of tibial strain that differ from those of running, thus the nature and location of tibial stress injury around the diaphyseal circumference can also differ. In general, jumping activities appear to incur mid-anterior tibial distraction injury (the ‘dreaded black line’)[12,96] while running induces compression- or shear-related medial tibial pathology. Dancers may be at particular risk of jumping-related bone injury as they normally perform jumps and landings in a ‘turned out’ position (full lateral rotation of the lower extremity). This unnatural alignment will engender an unusual pattern of strain for which normal tibial morphology is not optimally designed. Additional stress is applied to the tibia when the ankle is forced into dorsiflexion on landing, causing soleal stretching and periosteal traction at its origin. Special care must therefore be taken to incorporate gradual increases in impact intensity when initiating dance training.

5.3 Footwear

Most reports conclude that the use of appropriate sports footwear can reduce the incidence of overuse tibial pathology.[80] Running in shoes has been shown to reduce tibial deformation at midstance but to increase tibial strain during the swing phase,[97] suggesting that running shoe design should incorporate optimal shock absorbency with minimum weight. Others have stated that modern running shoes contribute to injury risk via the attenuation of sensory feedback from the foot, which, normally, would initiate impact-moderating behaviour.[98] Questions have been raised concerning the interpretation of the latter data[99] and the consensus remains that frequently replaced, lightweight, shock-absorbing footwear is the most appropriate running accessory. Fredericson[96] recommended that athletic footwear should be replaced after 500 to 700km of running, depending on the type of shoe, bodyweight of the runner, and terrain.

5.4 Terrain

Terrain also influences the magnitude of tibial strain. Walking down stairs increases the load at impact to 130% that incurred from walking up stairs and to 250% that incurred from walking on the level.[100] Burr et al.[101] reported large compressive strains in the tibia during uphill, zig-zag running, and very high shear strains during uphill and downhill running in 2 healthy middle-aged males. Brody[102] stated that running up and down curbs and on sloping or banked roads places increased shock on the skeleton. Grass, sand and road shoulders can be highly irregular and thus should not be considered as universally preferable to road running, as is commonly the case. Unusually soft surfaces such as sand or mud allow heel sink,[103] with the possible consequences of triceps surae strain, periosteal traction and abnormal tibial bending.

Asphalt, synthetic track surfaces and grass, respectively, have been found to decreasingly absorb shock.[100] This observation is enlightening in terms of the persistent notion that running on hard surfaces increases the risk of stress fracture.[96,104] While some recent studies have categorically reported that hard surfaces are not associated with increased risk of overuse injury,[90,91,105,106] results from a study specific to tibial stress injury are necessary before this finding can be considered to be entirely applicable. Undoubtedly, however, a level, uniform surface of moderate firmness provides the least stressful running surface. To promote maximal adaptation to all surfaces on which an individual may have to perform, athletes should vary the surfaces and terrain on which they train and should avoid sudden changes to prolonged, exclusive use of a new surface.

5.5 Muscle Loads

Bowerman[107] stated that ' . . . stress fractures can occur as a result of . . . repeated contractions of the muscles of the lower leg' (p. 131). Devas[14] hypothesised that contraction of the triceps surae causes the tibia to bow forward. Daffner[12] suggested that anterior tibial striations in jumping athletes are related to the bowstring effect of the gastrocnemius-soleus complex on the tibia when landing in plantar flexion from a leap, stating that ' . . . stretching of the bowstring produces a corresponding bend or curve in the shaft of the bow' (p. 652-3). Lanyon et al.[97] also reported that tibial deformations during locomotion were a combined effect of muscle tension and bodyweight. These observations suggest that an overly strong triceps surae muscle may contribute to tibial bending and compound strain-related injury. Indeed, greater plantar flexion strength has been observed in individuals with 'shin splints' compared with controls.[108]

Dorsiflexion inflexibility has long been associated with tibial stress fracture and MTSS.[78,96,109,110] When applied to the 'bowstring' theory, muscles whose length inhibits the full range of dorsiflexion are most likely to impart bending loads on the tibia. Attaining good calf flexibility prior to the initiation of weight-bearing training is thus strongly indicated. The extrapolation of this notion to the rehabilitative setting, however, is inappropriate. Once tibial stress injury has been sustained, inducing further tibial strain, such as would occur during triceps surae stretching, is contraindicated.

5.6 Muscle as a Shock Absorber

Bennell et al.[111] observed a decreased lower limb lean mass in athletes with stress fracture compared with a group without stress fracture. The role of muscle in the dissipation or neutralisation of stress on bone, by contracting in opposition to a bending moment, has been described by a number of authors.[8,112-118] Muscle weakness has been shown to reduce the ability of the muscle to dissipate these tensile and bending forces, thereby redistributing loads to bone.[119] Yoshikawa et al.[120] found that peak principal and shear strains in dog tibiae increased by up to 26 to 35% following exercise-induced muscle fatigue, and that strain distribution across the bone altered.

In addition, muscle fatigue has been shown to alter the mechanics of running[121,122] such that increases in ground reaction forces of 25% arise.[122] Local muscle fatigue may reduce the sensory feedback–related, shock-moderating behaviour of the foot and leg during running,[98] with a resultant elevation in the forces of impact to the skeleton.

As with leg muscle flexibility, establishing normal leg muscle strength and endurance capability may be an effective preventive measure for tibial stress injuries in the uninjured athlete. Instituting a regimen of muscle strengthening exercises for an injured leg, however, is counter-intuitive to reducing tibial strain and may exacerbate conditions of bone stress.

5.7 Lower Extremity Alignment

An individual running 1.6km (1 mile) cumulatively absorbs approximately 110 tons (111 760kg) on each foot.[123] This figure assumes greater significance in terms of the resultant pattern of abnormal or exaggerated tibial bending in runners with lower extremity alignment anomalies and poor running technique.[2,124,125] Grimston et al.[126] reported significant differences ($p < 0.05$) in external loading kinetics between female runners with and without a history of stress fracture. They observed greater vertical, posterior, medial and lateral forces during running in those with stress fracture than in the unaffected runners.

Many lower extremity alignment factors have been associated with the incidence of tibial stress injuries. Unfortunately, there is little accord in the literature regarding the nature and significance of each factor. A comparison of these studies is again limited by the generic use of the term ‘shin splints’ and inconsistency in the use of alignment terminology.

Genu varus has been associated with an increased incidence of MTSS.[83,127] Lilletvedt et al.[128] reported that an increase in varum position of the frontal plane of the tibia, with the subtalar joint in the static stance position, was associated with an increased incidence of MTSS. In a number of studies,[108,125,129] individuals with ‘shin splints’ have been observed to have greater mean angular displacement values and less stability at the ankle during the support phase while running. DeLacerda[130] found that increased femoral external rotation, increased tibial torsion and increased subtalar joint inversion were predictive of ‘shin splints’ (corresponding to a description of MTSS).

In the broadest sense, hyperpronation has been associated with an increased incidence of ‘shin splints’ in general,[131] and tibial stress injuries more specifically.[22,24,83,127,132-135] Indeed, in runners who hyperpronate, the transmission of force up the leg has been found to be exaggerated.[127] The velocity of pronation may also be a risk factor for tibial injury.[131]

Pes planus has been associated with an increased incidence of shin injury[89] and tibial stress fracture.[83,127] Similar to hyperpronation, the effect is likely to be one resulting from excessive midtibial torsion following exaggerated internal rotation during the stance phase of a stride. Pre-injury strengthening of the tibialis posterior and anterior muscles and the intrinsic muscles of the foot may assist in the prevention of tibial stress injury by enhancing active medial longitudinal arch support. Orthotic inserts or arch taping are thought to correct pes planus and limit pronation,[136] thereby reducing the incidence of, preventing exacerbation of, and sometimes assisting in the recovery from tibial overuse injuries,[2,6] although this is not always the case.[137]

Bennell et al.[111] reported that 70% of athletes presenting with stress fracture had a leg length discrepancy compared with 30% of a non–stress fracture group. It should be noted that lower limb alignment anomalies are not always present in individuals affected by tibial stress injury,[83,119] and that some investigators have found very few statistical relationships between alignment measures and overuse injury incidence.[89]

5.8 Previous Injury

Previous history of injury is often cited as a strong predictor of overuse injury incidence.[90-94] While this may be the case for tibial stress injuries secondary to training errors, alignment anomalies and poor technique, the generalisation of this observation from data drawn from a variety of very different pathologies limits the appropriateness of the association. It is intuitive, however, given the discussion of bone response to loading (section 4), that previous episodes of bone stress that are afforded inadequate time to resolve render an individual highly susceptible to re-injury. Training errors and alignment anomalies must be corrected and a graduated programme of rehabilitation implemented in order to prevent re-injury.

5.9 Female Athletes

There is evidence that stress fractures occur more commonly in female than in male athletes,[138,139] although some reports refute the suggestion.[91,140] Individuals with low bone mineral density (BMD) or osteoporosis are susceptible to fractures by virtue of a reduced bone mass upon which loads can be distributed. Myburgh et al.[141] observed a pattern of low BMD in highly trained female athletes who presented with stress fractures. Low BMD in these women is normally related to menstrual dysfunction.[105,142,143] It is prudent to determine the hormonal status of a female athlete with stress fracture injury and make efforts to establish normal levels of circulating estrogen. Estrogen replacement in the form of birth control pills have been found to have a protective effect on bone resorption in runners,[144] although, again, some disagreement exists regarding this effect.[145] Cameron et al.[146] presented an informative review of this topic.

6. Diagnosis of Tibial Stress Injury

There is a large body of literature available pertaining to the diagnosis of tibial stress injury, including the differential diagnoses of MTSS and tibial stress fracture.[88,147] Confirmation of clinical diagnoses can be obtained via a number of imaging techniques. Radiographic findings are likely to be absent in cases of MTSS and early stress fracture,[88,148,149] whereas triple-phase ^{99}Tc bone scans are highly sensitive in detecting both conditions, with a further advantage lying in the ability to distinguish between them.[73,147,149-155] Recently, magnetic resonance imaging (MRI) and computed tomography (CT) have also been found to be effective diagnostic tools, with MRI generally considered to be more useful than CT.[134,149,156-158]

7. Electrical Stimulation: A Promising Therapy

Through an effect thought to be related to the charged nature of bone and bone fluid,[159,160-162] the application of electric or electromagnetic fields has been shown to aid the healing of recalcitrant non-union fractures and bone grafts.[163-168] It is therefore reasonable to hypothesise that electric field stimulation can also enhance the healing of tibial stress injuries. In fact, preliminary reports have provided the first indication of a significant advance in bone stress injury treatment since the introduction of orthotics.[169,170]

Of 25 lower limb stress fractures treated with continuous, capacitively coupled electric fields (3.0 to 6.3V, 60 kHz) for an average time of 7.4 weeks (navicular fractures averaged 8.6 weeks), 88% healed, 8% improved and 4% did not heal.[169] (Casting of the limb was utilised in conjunction with treatment in some patients.) As the average time between stress fracture symptom onset and treatment initiation in the study was 21.1 weeks (32 weeks for navicular fractures), time to healing was substantially improved with the addition of electric field stimulation compared with rest alone.

Only one study has reported the effect of electrical stimulation on time to recovery from

MTSS,[170] and its findings must be interpreted with caution owing to a number of confounding factors and variation in treatment protocol between subjects. Results indicated that, in comparison with rest alone, a protocol of 5 to 8 minutes of interferential electrical stimulation at 50 to 100Hz three times a week reduced MTSS recovery time from an average of 3.8 to 1.3 weeks.[170]

Although the effects of electric field stimulation on bone have been documented for many years,[166,171-177] their application to the field of overuse injury has been slow. None of the surveyed orthopaedic surgeons previously mentioned (unpublished data, Beck 1996) considered electric field stimulation to be a first-choice treatment for MTSS or tibial stress fracture. In fact, only one clinician reported having ever used electric field stimulation as a treatment option. These findings reflect an appropriate reluctance to utilise a modality in the absence of data from placebo-controlled studies specific to stress fractures; however, the promising preliminary evidence suggests that such research is overdue.

Table I. Recommendations for minimising the risk of tibial stress injury

Before beginning or substantially modifying a weight-bearing training regimen
Obtain a history of previous injury and ensure that old injuries have been fully and appropriately rehabilitated (particularly if the individual has been in a cast for any length of time with resultant reductions in bone and muscle mass)
Evaluate lower limb alignment and correct anomalies via strength training and/or the use oforthoses (paying particular attention to correcting hyperpronation)
Correct improper running technique
Maximise triceps surae flexibility
Ensure the individual has attained normal triceps surae muscle strength, and enhance posterior and anterior tibialis muscle strength (do not overtrain the triceps surae)
During training
Wear lightweight, activity-specific athletic shoes that provide adequate shock absorption, and replace them after approximately 500 to 700km of running
Increase training intensity gradually over a period of weeks, only introducing hills, interval training, jumping exercises and high strain, sport-specific activities after approximately 6 weeks of graduated training
Begin training on surfaces that absorb shock to the greatest extent, such as level asphalt, and progress to synthetic track, then to grass, sand and uneven terrain, thereafter varying the training surface
Maintain an adequate (at least 1000 mg/day) dietary calcium intake to enable healthy bone mineralisation during modelling and remodelling
Female athletes should attempt to maintain normal circulating levels of estrogen, using menstrual dysfunction as a warning sign

8. Management Recommendations for Tibial Stress Injuries

As conditions such as MTSS and tibial stress fracture appear to be pathological expressions of the normal adaptive response of bone to modified or excessive loading, unloading (rest) remains an effective, if prolonged, treatment approach under most conditions. The most effective management technique, however, is undoubtedly prevention, in the guise of informed training and pretraining practices. In the final analysis, it is the responsibility of coaches to educate athletes and implement such practices. While these messages are not new, improved understanding of their foundation should not only facilitate the development of long-awaited innovations in treatment, but should encourage the abandonment of currently accepted, but inappropriate, rehabilitation practices.

Recommendations for minimising the risk of tibial stress injury and promoting recovery are given in tables I and II.

For athletes who have been unable to prevent tibial stress injury, methods to resolve acute inflammation and promote analgesia, such as nonsteroidal anti-inflammatory drugs (NSAIDS), ice, massage, ultrasound, whirlpool baths and acupuncture, may be employed.[96] Crutches should be utilised to prevent weight bearing in athletes with acutely painful stress fractures.[88] Casting of the limb is only recommended for noncompliant individuals with severe lesions at risk of progressing to complete fracture, or in individuals in whom there is a high index of suspicion of non-union.

It is important to note that the development of leg pain with exercise, while commonly caused by

Table II. Recommendations for promoting recovery from tibial stress injury

When injured, do
Rest from pain-provoking activities for brief periods (3 to 4 days) at the first sign of injury and resume running when pain-free during running
Maintain aerobic fitness via reduced weight–bearing exercise such as pool running
Resume training gradually, incorporating pool running during the latter stages of healing and early stages of return, building rest days into the regimen
If a particularly fast return to activity is necessary, use a pneumatic tibial brace to 'splint' the tibia and reduce strain during weight bearing[178]
When injured, do not
Excessively stretch the gastrocnemius and soleus muscles
Perform leg muscle strengthening exercises
Engage in high intensity activities
Train on unusually soft or uneven surfaces

tibial stress injury, can be indicative of many different, even life-threatening, conditions. The differential diagnosis of leg pain symptoms is essential to the appropriate management of all leg pathologies.

Previous reviews have concluded that running injuries are difficult to prevent owing to insufficient knowledge of their cause and the multifactorial nature of the problem.[179] This is indeed the case; however, these obstacles can be simply eliminated by focusing discussions on a single form of overuse injury at a time and addressing the pathology and aetiology on this basis. Considering all overuse injuries (including those to the muscle, bone, ligament, tendon and joint) as a single entity for the purposes of identifying specific risk factors and management practices is inappropriate and counterproductive.

9. Conclusion

An understanding of the fundamental pathology and aetiology of tibial stress injuries can assist in the establishment of effective management techniques. Many factors contribute to pathological patterns of tibial loading and resultant strain. There is a need for more dedicated attention to these factors from athletes, coaches and sports clinicians if we are to move towards the goal of tibial stress injury prevention.

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