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REVIEW ARTICLE

Stress fracture of the navicular bone

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Navicular stress fractures in athletes are notoriously difficult to diagnose, resulting in an average delay in diagnosis of 4 months after the onset of symptoms. There are various reasons for this delay. Navicular stress fractures are characterised by an unspecific symptomatology combined with a paucity of physical findings. Furthermore there is difficulty in visualising stress fractures on plain radiographs, with only 33% of fractures visible on the initial films. There are several factors contributing to this : the vast majority (83%) of fractures are incomplete fractures at initial presentation and those that are complete are often non displaced and not visible because bony resorption at the fracture site requires 10 days to 3 weeks to occur. For this reason, 3-phase Tc^{99}bone scan is the examination of choice, with almost 100% sensitivity after 72 hours.

A favourable outcome can be expected with early diagnosis and proper management. Delayed diagnosis and subsequent improper management can lead to a poor outcome with adverse effects on the activities of the athlete.

Treatment consists of 6-8 weeks in a non weight bearing cast for incomplete fractures and non displaced complete fractures. Surgical treatment consists of screw fixation with or without bone graft. Some authors advocate aggressive treatment of non displaced complete fractures.

It is imperative to maintain a high index of suspicion when treating patients, especially sprinting athletes, who present with vague mid-foot or ankle pain associated with weight bearing.

Keywords : navicular stress fracture.

INTRODUCTION

In 1855, Briethaupt, a Prussian military physician first described the clinical signs and symptoms of stress fractures of the metatarsals in military recruits. In 1958, Bateman (*2*) first described navicular stress fractures in racing greyhounds : these fractures occurred systematically in the right hind foot and were termed "Broken Hock". It was assumed that on the counterclockwise banked track the uphill hind foot was subjected to greater stresses.

Navicular stress fractures were first reported in humans by Towne *et al* in 1970, in a case study involving two high school boys (*35*). In 1982 Torg *et al* (*34*) published a retrospective review of 21 cases, followed in 1985 by a study by Hulkko *et al* (*16*) involving 9 cases.

The most extensive review was published by Khan *et al* (*20*) in 1994, involving 150 cases.

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In recent years the awareness of stress fractures has increased among professional athletes, military recruits and with the rapidly growing interest in recreational sports and physical fitness, in the general population as well. Added to this the improved diagnostic techniques, stress fractures are more commonly identified. In the study performed by Burne *et al* (*8*) 8 of 20 patients with navicular stress injuries were elite athletes, 7 were college athletes and 5 were recreational athletes. Stress fractures are estimated to account for 10% of all injuries in the athletic population (*25*).

Stress fractures of the navicular bone are fairly uncommon. Early studies in the 1980's estimated their incidence between 0.7% and 2.4% of all stress fractures. However, as awareness increased, combined with greater availability of superior imaging techniques, the incidence has been estimated to be between 14% and 35% of all stress fractures (*4,7,20*).

Navicular stress fractures are notoriously difficult to diagnose ; there is an average delay in diagnosis of 4 to 7.2 months after the onset of symptoms (*19,34*).

Misdiagnosis and consequent inadequate treatment of these lesions can have disastrous consequences for the athlete.

It is imperative for the physician treating an athlete presenting with vague unclear symptoms of midfoot or ankle pain and discomfort to maintain a high index of suspicion.

Aetiology

Navicular stress fractures can be distributed into two different categories : insufficiency fractures and fatigue types.

Insufficiency fractures involve normal muscular activity or stresses on an abnormal navicular as seen in dysplasia, osteoporosis, osteonecrosis and Muller-Weiss disease (fig. 1). When considering insufficiency fractures, it is important to always keep in mind the "female athlete triad" consisting of disordered eating, amenorrhea and osteoporosis (*39*). Female athletes with lower bone mineral density (BMD) have been shown to be at greater risk for developing stress fractures (*27,36*). Bennell *et al* (*5*) found that lower BMD in the foot and spine was

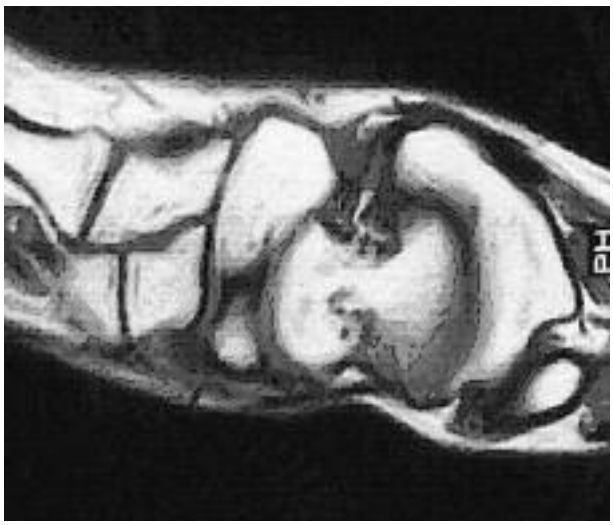

Fig. 1. — MRI image of a navicular stress fracture due to dysplasia in Muller-Weiss disease.

a significant predictor for the development of stress fractures in female athletes. In another study by Bennell *et al* (*6*) the age of menarch was significantly older in athletes with a history of stress fractures. Stress fractures occur more commonly in female athletes with amenorrhea or oligomenorrhea than in those with normal menses (*3,6,14,38,39*).

Fatigue fractures occur when excessively repetitive stresses are applied to previously healthy bone. Bone is a dynamic structure and undergoes remodelling under physiological stress. This remodelling is a continuous process which begins with osteoclastic resorption (*9-11*), which reaches a maximum at 3 weeks (*17,30,32*). This is followed by osteoblastic bone formation, which takes approximately 3 months (*15,30*).

Bone becomes weakened and susceptible to fracture when the osteoclastic resorption of remodelling outpaces the osteoblastic new bone formation (*23*).

Anatomy

The navicular is the keystone of the plantar vault of the foot. The medial longitudinal and transverse arch of the foot transmit the body weight from the hind foot to the forefoot. The navicular is an oval

shaped bone covered by articular cartilage on three sides. The distal convex articular surface has three facets forming the rigid naviculo-cuneiform articulations. There is minimal movement at these articulations.

Proximally it is concave and articulates with the head of the talus. This articulation has substantial motion, which controls 80% of hind foot motion and is responsible for hindfoot inversion and eversion (*24*).

On the lateral side it sometimes articulates with the cuboid. Medially the navicular tuberosity provides insertion for the posterior tibial muscle, the superomedial calcaneonavicular ligament (ligamentum neglectum) on the superomedial aspect and the plantar or inferior calcaneo-navicular ligament. The medial margin of the inferior calcaneo-navicular ligament is continuous with the superomedial calcaneo-navicular ligament and dissection of the two ligaments is difficult due to their fibrocartilaginous nature.

Pathophysiology

Navicular stress fractures are orientated in the sagittal plane and are located in the central third of the bone.

The vascular anatomy and the biomechanics make the navicular susceptible to stress fractures. The navicular is covered with articular cartilage on three sides and receives its blood supply via small branches from the dorsalis pedis and tibialis posterior arteries entering via the posterior tibial tendon insertion and the dorsal and plantar surfaces (fig. 2). Torg *et al* (*34*) performed a microangiographic study of cadaveric feet which confirmed this and further showed that upon entering the navicular, the vascular network branched out toward the medial and lateral poles, leaving the central third relatively avascular.

This becomes significant when one considers the biomechanics of the navicular. During weight bearing the navicular is subjected to shear stresses due on the one hand to torsion between the 1st and 2nd metatarsals transmitted via rigid naviculo-cuneiform articulations and on the other hand to talar impingement on the medial proximal pole.

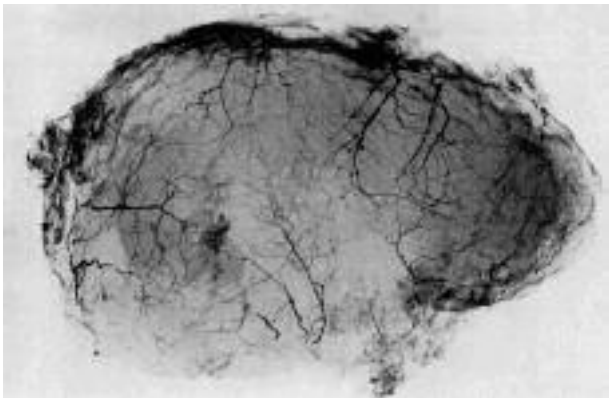

Fig. 2. — Vascular anatomy of the navicular, showing the relatively avascular central third.
From Waugh W. The ossification and vascularisation of the tarsal navicular and their relationship to Kohler's disease. *J Bone Joint Surg* 1958 ; 40-B : 765 (reprinted with permission).

Analysis of the stresses across the navicular during weight bearing showed that these were greatest across the central third (*18,28,37*). In a study on cadavers Kitaoka *et al* (*22*) found that during weight bearing the stresses were greatest in the dorsal central zone of the navicular.

Several authors have described anatomic variations as being predisposing factors for the development of stress fractures. Cavus, cavo-varus, metatarsus adductus, long second metatarsal, short first metatarsal, calcaneal pitch angle, talo-metatarsal angle, pronation velocity, medial narrowing of talo-navicular joint, talar beaking, limited subtalar motion and limited ankle dorsiflexion have all been described as being possible contributing factors (*13,29,33,34,37*).

However, there is no consensus and in a study comparing athletes who had had a navicular stress fracture to others without stress fractures, no significant differences were found (*33*).

As with all stress fractures training errors and repetitive overuse conditions are the common factors noted in generating navicular stress fractures.

Illustrative case report

A 17-year-old female started complaining of hind foot pain which first appeared after a football

match. Prior to her injury she was a very active recreational athlete, participating in jogging and football. The pain improved with rest, but was aggravated by her sporting activity and finally lead to cessation of her sporting activities.

Her diagnostic workup took 2.5 years and involved multiple radiographs – all reportedly negative –, a bone scan which showed increased uptake over the left navicular, and an MRI which showed focal oedema at the level of the navicular. She received no treatment during this period.

She was transferred to our institution with the diagnosis of avascular necrosis of the navicular bone.

A review of her record and especially her MRI disclosed a fissure in the navicular, consistent with a diagnosis of navicular stress fracture.

A CT scan was performed and showed an incomplete fracture of the navicular, which showed signs of healing (fig. 3). The presence of focal chondropathy at the level of the sclerotic bone could not be ruled out.

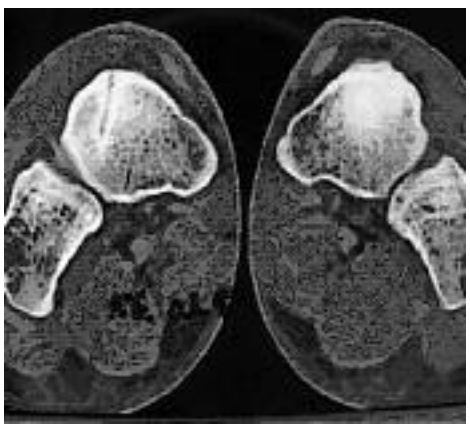

Fig. 3. — CT images showing an incomplete navicular stress fracture with sclerotic margins.

The patient was treated with a 6 week non weight bearing cast, followed by functional rehabilitation and without weight bearing. She received in total 2 infiltrations of cortisone for the oedema.

After 6 months a further MRI showed no oedema and an almost completely healed navicular with only a small sclerotic zone on the superior border.

The patient was allowed to start jogging 6 months after her initial treatment and resumed full sporting activity after one year.

This case highlights the regrettable, yet all too common, delay in diagnosis often associated with navicular stress fractures.

Clinical presentation

Stress fractures of the navicular are classically seen in athletes who practice sports which involve sprinting and changes in speed and direction, resulting in high-intensity cyclical loading of the foot. Patients typically present with ill-defined complaints of hind- and mid-foot soreness, aching or ankle pain during weight bearing activities. The symptoms often have a slow and insidious evolution. Pain is initially present at the beginning and end of training, and subsides during periods of rest. As the stress reaction evolves the pain becomes more intense and occurs earlier, eventually occurring throughout training and even during the intervals of rest between training, resulting in cessation of sporting activities.

Physical examination

Navicular stress factures are notorious for their lack of physical findings ; there is often no swelling, deformity or ecchymosis. Strength and range of motion are usually normal. Patients are commonly misdiagnosed with having tibialis anterior or tibialis posterior tendonitis, a mid-foot sprain or plantar fascia injury.

Careful physical examination often reveals tenderness on palpation and percussion over the dorsal mid-foot that may radiate toward the medial arch (*24*). Torg *et al* (*34*) described an area between the tibialis anterior tendon and the extensor hallucis longus tendons corresponding to the dorsal central portion of the navicular which is tender on palpation in 81% of the cases. Khan *et al* (*20*) later referred to this as the "N-Spot" (fig. 4). Symptoms may be provoked by single toe hopping or on single leg weight bearing with the foot in plantar flexion (*13*).

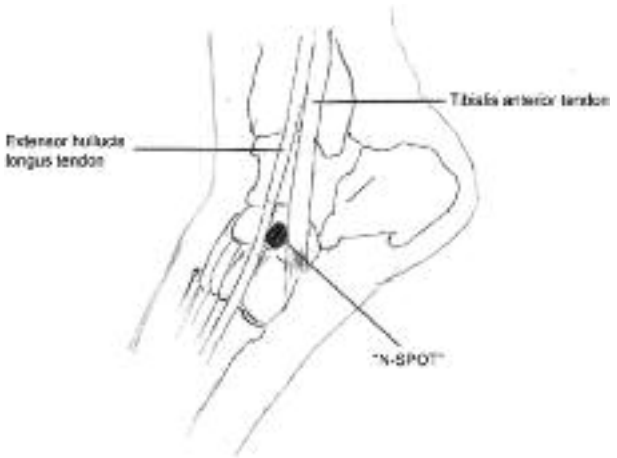

Fig. 4. — Illustration of the 'N-Spot'

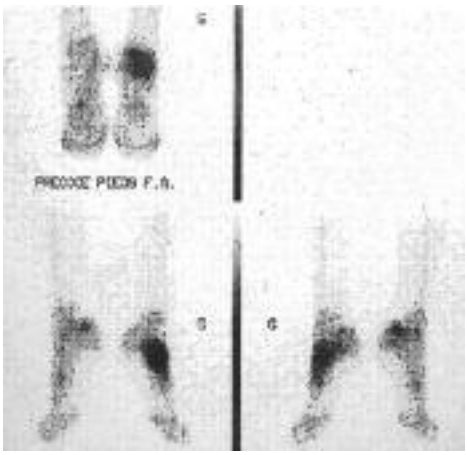

Fig. 5. — Bone scintigraphy showing increased uptake in the navicular.

Radiographic analysis

Plain radiographs of the foot have a poor sensitivity for navicular stress fractures. This was illustrated in a study by Pavlov *et al* (*29*) in which retrospective analysis showed that only 5 out of 23 navicular stress fractures were identified on plain radiographs. When analyzing the plain radiographs after a positive bone scan, only 9 of the 23 navicular stress fractures were identified. The literature review by Khan *et al* (*20*) found that 83% of navicular stress fractures were incomplete at initial presentation and only 24% of these were identified on plain radiographs, versus 81% of complete fractures. There are two reasons for the low sensitivity of plain radiographs : incomplete stress fractures only become visible after osteoclastic resorption has taken place (*1*) and a true antero-posterior view of the navicular is difficult to obtain (*29*).

There is a delay in diagnosis which ranges from 4 to 7.2 months after the onset of symptoms (*19,34*). There are several factors contributing to this. Athletes will often change their gait to decrease the load on the forefoot to be able to continue their activities (*13*) ; initial symptoms rapidly resolve with rest, often in less than a week, which also delays consultation (*12*). Considering the vague and ill-defined complaints and the low sensitivity of plain radiographs, this delay in diagnosis is not surprising.

Three-phase bone scintigraphy with Tc^{99} is the examination of choice when plain radiographs are negative or inconclusive (fig. 5). The sensitivity of the 3-phase scan approaches 100% (*20*) ; it becomes positive between 6 to 72 hours after initial injury (*26*). For a bone scan to be considered positive, the entire navicular should demonstrate uptake in all three phases. Due to the low specificity of bone scans, further imaging is necessary.

Computed tomography is considered the gold standard for the diagnosis of navicular stress factures. The most common algorithm used is 1.5 mm axial and 3 mm coronal slices. Kiss *et al* (*21*) reported missing 6 out of 55 (11%) navicular stress fractures on initial CT. In another study, the CT was estimated to have a 7% false negative rate, ,which was attributed to confusion between fracture lines and nutrient arteries (*19*). The CT images are useful to demonstrate the characteristics of the fracture, making it possible to differentiate between partial and complete fractures and displaced and non displaced fractures. Fractures develop at the proximal dorsal cortex and propagate in the sagittal plane to the distal plantar aspect of the navicular. The images can also show the presence of sclerotic margins and cysts. The presence of a sclerotic notch at

the proximal articular rim does not represent an early fracture and is considered a result of the normal stress of weight bearing (*21*).

Saxena *et al* (*31*) proposed a classification system based on CT images which separates fractures into three groups : Type I – dorsal cortical break, Type II – fracture propagation in the navicular body and Type III - propagation to the opposite cortex. These were further subdivided according to the presence or absence of avascularity, sclerosis and cysts. Despite the correlation between types and time to healing with conservative therapy, this classification system has however not enjoyed widespread popularity.

MRI has a high sensitivity in detecting acute navicular stress injuries (*21*). Bone oedema on T2-weighted images is an early finding. This does not always imply a fracture and may reflect bone strain. False negatives can be expected when dealing with chronic stress fractures with sclerotic borders (*8*).

A recent study comparing follow-up with NMR and CT, performed by Burne *et al* (*8*) found that 9 navicular bones with positive bone scans and negative CT demonstrated a navicular stress reaction on MRI. Of these 9 patients, 7 developed fractures detected on CT at follow-up. A possible explanation for this is that CT scan will detect disruption of cortical bone , but due to limitations in spatial resolution it will have difficulty in visualizing disruption of the fine trabeculae. MRI on the other hand has high contrast resolution and can disclose the presence of oedema, blood and fibrous tissue in the fracture line. It should be noted that, owing to the heterogeneous nature of the treatments implemented for the navicular stress reaction, one cannot conclude whether the fractures subsequently visualized were due to bone remodeling or to aggravation of the initial condition due to incorrect treatment.

Unless CT is unavailable the use of MRI cannot be justified as primary choice of investigation after a positive 3-phase bone scan due to its higher cost and lack of additional information.

Treatment

The treatment strategy for navicular stress fractures depends on the type of fracture. Conservative treatment consisting of non weight bearing cast immobilisation during 6 weeks is advocated in incomplete and complete non displaced fracture without sclerotic margins (*13,20,34*). Khan *et al* (*19*) reported healing with a return to sporting activities after an average of 5.6 months in 86% of cases. Results were significantly poorer when the fractures where treated with weight bearing casts (69%), activity modification with full weight bearing (50%) and no activity restriction (20%). The paper by Khan *et al* (*19*) did not take into account the fracture type nor the presence of sclerosis at the fracture site. In the study by Saxena (*31*) *et al* fracture morphology was found to significantly correlate with the time to healing and return to activity. For type I fractures return to activity averaged 3.0 months, for type II 3.2 months and for type III, 6.8 months.

After 6 weeks the cast is removed, the absence of tenderness over the N-spot marks the start of rehabilitation and a gradual return to sporting activities 6 weeks later. Close clinical follow-up is necessary to re-evaluate for any foot pain. Post immobilisation stiffness may cause discomfort and can be expected, it generally responds well to physical therapy (*13,19,20,34*). If pain persists over the N-spot after the initial 6 weeks of NWB cast immobilisation, the foot is immobilised in a NWB cast for a further 2 weeks and re-evaluated. Conservative therapy may take as long as 8 months and can have detrimental effects on the career of the athlete.

Follow-up after conservative treatment is clinical. Radiographic follow-up is clinically not useful, as plain radiographs are not reliable. The 3-phase bone scan will remain positive up to 2 years after healing has occurred and CT images may reveal significant bone demineralization, sclerosis and cysts even in a normal healing fracture (*2,12,19, 20,34*).

The use of a repeat CT scan has been suggested in resilient cases in which pain persists after 12 weeks (*24*). The value of CT in such cases would be to evaluate the fracture for displacement or sclerosis which would call for more aggressive surgical management.

Gait analysis is advised to rule out and treat any underlying biomechanical abnormalities which could predispose to recurrence (*2,20,34*).

Training errors, possible nutritional problems and flexibility of the foot should also be addressed (*12*).

Surgical treatment should be considered in all patients with non displaced complete fractures with sclerotic margins, displaced fractures, fractures with evidence of fragmentation at the fracture site and after failure of conservative treatment. Surgical treatment should also be considered if a problem of compliance with NWB cast immobilisation is to be expected or if the professional demands of the athlete cannot tolerate a prolonged recovery (*13*).

Surgery performed as primary treatment has a success rate of 83% with an average return to sporting activities at 3.8 months, this result drops to 68% with an average return to sporting activities at 5.4 months if surgery is the secondary treatment. Revision surgery only has a 40% success rate.

Due to the long duration and unpredictable result of conservative therapy certain authors advocate a more aggressive approach for complete non displaced fracture, type III (*13,31*).

Surgical technique

The patient should be positioned in the supine position, with a pneumatic tourniquet placed at the thigh. A longitudinal mid-axial dorso-medial incision is made, care must be taken not to damage the neurovascular structures ; these can be retracted medially and the extensor tendons laterally. Opening of the talonavicular joint is often necessary to help identify the fracture and examine the degree of articular damage. Non displaced fractures are usually difficult to identify, palpation with a needle, Kirschner wire or knife blade as well as fluoroscopic images can be of aid. The fracture is debrided of sclerotic bone with care being taken not to damage the articular cartilage ; allogenic or autogenic bone graft, which can be taken from the ipsilateral tibia, is used to fill the bone defect. The fracture is stabilised in compression using 2 partially threaded cannulated screws placed percutaneously (fig. 6). To ensure maximal thread purchase in the larger medial fragment the screws are placed transversely from lateral to medial with the thread crossing the fracture site. The screws should be parallel and oriented dorsally to plantarly. Care must be taken to minimize dissection to preserve the already fragile blood supply to the navicular. If surgical treatment is chosen for incomplete and non displaced complete fractures without signs of sclerosis percutaneous screw fixation without debridement is an option (*24*). Fitch *et al* (*13*) report an 80% success rate and return to sport in patients treated with bone grafting with internal fixation.

Fig. 6. — Percutaneous screw fixation

Correction of anatomic variations considered to predispose to recurrence may be considered, but since no consensus exists concerning these factors, this should be left to the orthopaedic surgeon's personal experience and judgement. Postoperative NWB cast immobilisation is advocated for 6 weeks, followed by protective weight bearing, full weight bearing and eventually return to sporting activities. Lee *et al* (*24*) recommend the use of a custom fitted, medial longitudinal arch support with shock absorbing characteristics as well as a turf toe plate within the shoe to help dissipate the impact forces.

The follow-up is done clinically : the absence of tenderness over the N-spot gives the green light for progression to the next stage of rehabilitation. Post operative CT images are useful to confirm fracture union and to decide on the resumption of preoperative activities (*24*). If symptoms persist without improvement, a CT scan can be performed to rule out non union (*21*).

Complications

Non union and delayed union are the two most common complications of both conservative and surgical treatment. For those treated conservatively, surgery is advised. Revision surgery may also be performed, but its success rate is only 40% (*20*). Surgery of course carries with it the risks seen with every surgical intervention such as infection or neurovascular injury.

Talonavicular arthrosis is without any doubt the most invalidating and disastrous complication of this injury and it may occur after conservative or surgical therapy.

Fusion of the talonavicular joint (fig. 7) has serious implications for foot stiffness and function and is considered a last-resort treatment. Talonavicular and triple arthrodesis are the two options which remain available if further treatment is necessary. Talonavicular arthrodesis should be considered with caution. The functional difference between a triple arthrodesis and an isolated talonavicular arthrodesis is minimal, with the latter resulting in a loss of up to 80% of subtalar motion. Considering that rates of non union are greater than with a triple arthrodesis, the advantage of the talonavicular arthrodesis is debatable.

Fig. 7. — Talo-navicular arthrodesis

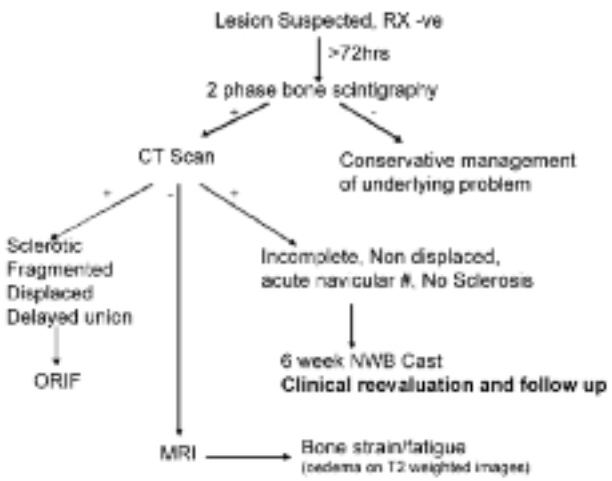

Fig. 8. — Treatment algorithm

Discussion

Based on the data from the multi centre study by Burne *et al* (*8*), one can conclude that many sports physicians do not implement the recommended treatment (fig. 8).

Only 2 out of 11 patients with navicular stress fractures were treated with 6 weeks or more NWB cast immobilisation as recommended, and the results were alarmingly poor with only 6 out of 11 athletes returning to the previous level of activity (*8*).

Navicular stress fracture represents a dilemma in diagnosis and treatment of an active individual. Often the vague symptoms and negative plain radiographs delay the diagnosis and when the diagnosis is made the treating physicians have difficulty implementing the recommended treatment to an active patient.

However when considering the results of patients not treated according to the recommended treatment in the literature the results are indeed very poor (*8,20,34*).

It is imperative for the treating physician, especially the doctor working at the emergency ward and the orthopaedic resident to have a high index of suspicion when confronted with an active patient presenting with ill-defined foot pain and negative plain radiographs. The 3-phase bone scan is a relatively inexpensive and effective examination with a

very high sensitivity that should not be overlooked when the diagnosis is unclear.

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