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EDITORIAL

Management of chronic disruption of the distal tibiofibular syndesmosis

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Abstract

Disruption of the distal tibiofibular syndesmosis is frequently accompanied by rotational ankle fracture such as pronation-external rotation and rarely occurs without ankle fracture. In such injury, not only inadequately treated or misdiagnosed cases, but also correctly diagnosed cases can possibly result in a chronic pattern which is more troublesome to treat than an acute pattern. This paper reviews anatomical and biomechanical characteristics of the distal tibiofibular joint, the mechanism of chronic disruption of the distal tibiofibular syndesmosis, radiological and arthroscopic diagnosis, and surgical treatment.

Key words: Ankle; Chronic injury; Distal tibiofibular joint; Distal tibiofibular syndesmosis; Surgical treatment

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ANATOMY AND BIOMECHANICS OF THE DISTAL TIBIOFIBULAR SYNDESMOSIS

The distal tibiofibular joint, which is formed by the distal fibula with convex configuration and the lateral side of the distal tibia with concave configuration, has been defined as a syndesmotic articulation with no articular cartilage. In spite of a small amount of motion, this joint has a very important role in ankle joint motion. In previous publications, the intermalleolar distance increases by approximately 1.5 mm through full plantar flexion to the dorsal flexed position of the ankle[1], and this widening is brought about by rotation, translation and migration of the fibula[1,2]. The fibula migrates distally and translates medially in plantar flexion and rotates laterally and migrates proximally in dorsal flexion to accommodate a wide anterior part of the talus into the widened space[1,2].

The distal tibiofibular syndesmosis contains 5 ligaments, the anterior inferior tibiofibular ligament (AITFL), posterior inferior tibiofibular ligament (PITFL), interosseous ligament (IOL), transverse tibiofibular ligament (TTFL), and the posterior intermalleolar ligament (PIML). Although the fibula has no contact with the weight bearing area of the talus, approximately 16% of the weight is transmitted through the fibula because of these strong syndesmosis ligaments[3]. The AITFL and PITFL have a role in holding the fibula tight to the tibia. The IOL represents the thickened distal part of the interosseous membrane[4] and the role of this ligament is still controversial[5-7]. Although Outland described this ligament as "the chief bond between the two bones"[5], some investigators have reported that this ligament was weaker than the AITFL and PITFL[6]. On the other hand, recent biomechanical experience has confirmed more stiffness and failure load of the IOL than those of the AITFL[7]. The TTFL is considered to be distal or located in a deep part of the PITFL and forms a part of the articular surface for the talus. This ligament deepens the articular surface of the distal tibia and prevents posterior translation of the talus. Although the PIML has been neglected in the anatomy literature, the existence of this ligament has been revealed recently to be a cause of posterior impingement syndrome which brings about posterolateral ankle pain during plantar flexion[8]. Furthermore, radiological study has demonstrated this ligament to be an almost invariably present anatomical entity[9-11], however, its anatomical role is still unknown.

RELATIONSHIP BETWEEN DIASTASIS OF THE DISTAL TIBIOFIBULAR SYNDESMOSIS AND MEDIAL STRUCTURES

Several cadaveric studies revealed the effect of disrupted medial structures of the ankle joint in diastasis of the distal tibiofibular syndesmosis[1,12-15]. Close sectioning of all the ligaments of the syndesmosis in the cadaver study showed that there was only a 2 mm widening of the mortise, however, when section of the deep deltoid ligament was added, the widening of the mortise reached up to 3.7 mm[1]. Rasmussen *et al*[12] performed complete cutting of the distal tibiofibular ligaments, which resulted in only minor abnormality in motion, however, external rotation was greatly increased by further cutting of the anterior part of the deltoid ligament. Boden *et al*[13] created two groups of the pronation-external rotation model which included disruption of the syndesmosis and interosseous membrane up to the level of the fibular fracture with different injury of medial structures. Group Ⅰ mimicked rupture of the deltoid ligament and Group Ⅱ mimicked internally fixed medial malleolus after fracture. Although Group Ⅱ showed only minimum widening of the syndesmosis (1.4 ± 0.3 mm), Group Ⅰ showed progressive widening of the syndesmosis (from 0.5 to 4.5 mm) as the level of disruption of the interosseous membrane increased from 1.5 to 15 cm proximal to the ankle[13]. Michelson and Waldman reported no significant change in motion of the talus even if there was a fibular fracture 4 cm above the plafond and disruption of the syndesmosis to 6 cm. When section of the deep deltoid ligament was added, the ankle dislocated in plantar flexion[14].

Although these studies did not reproduce exactly the condition of real ankle injury, the common results of these studies imply the involvement of medial structures, especially the deltoid ligament which is difficult to repair rigidly compared to the medial malleolar fracture on which it is possible to perform rigid internal fixation, to prevent diastasis of the distal tibiofibular syndesmosis. Burns *et al*[15] revealed in their cadaver study that there was a 39% reduction in the tibiotalar contact area and a 42% increase in the peak contact pressure in complete disruption of the syndesmosis with the addition of deltoid ligament sectioning.

MECHANISM OF INJURY

Although the mechanism of injury in the distal tibiofibular syndesmosis remains unclear, the correlation of external rotation force to the foot has been considered as a common mechanism[4,16]. This injury is accompanied frequently by some types of rotational ankle fracture such as pronation-external rotation and pronation-abduction fracture, and supination-external rotation fracture less frequently according to the Lauge-Hansen classification. Furthermore, rotational ankle injury with high fibular fracture which was named "Maisonneuve fracture" is well known to have a high complication rate[17,18]. In the case of acute syndesmosis injury, syndesmosis screw fixation continues to be a commonly used therapeutic option, and good results have been reported in several studies[4,16,19], although there are several controversies regarding the number, size, position and necessity for removal[4,16,19]. Recently, this information and the diagnostic methods for acute syndesmosis injury have been widely reported, however, there are still inadequately treated or misdiagnosed cases which result in a chronic pattern[20-24]. Furthermore, a recent study has reported that even if complicated syndesmosis injury had been diagnosed correctly and treated by means of syndesmosis screw fixation in an acute phase, malreduction of the tibiofibular syndesmosis could occur, which would also result in a chronic pattern[25].

The injury of distal tibiofibular syndesmosis without fracture has been rarely reported[26-31]. Edwards and DeLee described ankle diastasis without fracture in detail[26]. They defined "sprain" as tenderness over the deltoid and anterior syndesmosis ligaments but an intact deltoid ligament, and "diastasis" as similar tenderness with rupture of the deltoid and syndesmosis ligaments[26]. These were differentiated using stress roentgenography with external rotation and abduction stress[26]. Furthermore, they classified "diastasis" under two general types, one was latent diastasis which could not be diagnosed by routine radiographs but showed diastasis using stress radiography, and the other was frank diastasis which showed visible diastasis using routine radiography[26]. These injuries may be considered as slight injuries because radiography shows no fracture, however, if these injuries are misdiagnosed or inadequately treated, there is a possibility of advancement to a chronic pattern which is more troublesome to treat than an acute pattern.

CLINICAL SYMPTOMS

Patients with chronic disruption of the distal tibiofibular syndesmosis generally have persistent pain on weight bearing after their initial injuries of the ankle[21-23]. Pain is aggravated by a combination of dorsiflexion and external rotation force which enables the distal tibiofibular joint to stretch[22]. These patients also complain of instability of the syndesmosis as a giving way, especially when walking on uneven ground[32]. Physical examination generally reveals persistent swelling at the anterolateral region of the syndesmosis and restricted dorsiflexion of the talocrural joint[21-23].

DIAGNOSIS

Manual stress test

Hopkinson *et al*[29] reported on the efficacy of the squeeze test which could clinically diagnose syndesmosis sprain. The squeeze test was considered positive when compression of the fibula to the tibia above the midpoint of the calf produced distal pain in the area of the interosseous ligament or its supporting structures[29]. Biomechanical analysis confirmed motion at the distal tibiofibular joint by compressing the calf, and considered the cause of pain noted during a positive squeeze test, as tension in the remaining fibers of the syndesmosis ligament as the distal fibula moved away from the distal tibia[33]. Boytim *et al*[28] diagnosed syndesmotic ankle sprains by applying an external rotation stress test. This test was performed by applying an external rotation stress to the affected foot and ankle with the knee held at 90° of flexion and the ankle in a neutral position[28]. A positive test produced pain over the anterior or posterior tibiofibular ligament and over the interosseous membrane[28]. Ogilvie-Harris and Reed performed not only an external rotation stress test, but also a fibular translation test, which attempted to translate the fibula on the tibia in the anterior-posterior plane by grasping the fibula and the tibia directly to diagnose disruption of the ankle syndesmosis[34]. However, according to an evaluation by Beumer *et al*[35], these manual tests were not uniformly positive in chronic syndesmosis injury. Some investigators have reported on the usefulness of stress radiography to diagnose syndesmotic injury[36-38]. Recent studies have applied gravity stress to radiography to detect occult disruption of the deltoid ligament which may be accompanied by supination-external rotation fibular fracture[36,37]. Stoffel *et al*[38] compared the external rotation stress with the lateral stress in their cadaveric study to evaluate which stress was superior in detecting syndesmotic injury, and concluded that the lateral stress was the superior stress direction. However, these stress tests have practical difficulties as the procedures need sufficient anesthesia and are rarely used clinically.

Radiography

Generally, antero-posterior (AP), lateral and mortise views are evaluated for ankle disorders during radiographic examination, and three radiographic parameters have been established to evaluate diastasis of the distal tibiofibular joint: tibiofibular clear space[39,40], tibiofibular overlap[39,40] and medial clear space[41]. Tibiofibular clear space is the distance from the lateral border of the posterior malleolus in the distal tibia to the medial border of the fibula[39,40]. The measurement of this distance is performed at 1 cm above the plafond on AP and mortise views and defined as normal if the measurement is less than approximately 6 mm on both views[39]. Tibiofibular overlap is the distance from the medial border of the fibula to the lateral border of the anterior tibial prominence[39,40]. Although the measurement of this distance is also performed at the same level and using the same views as the tibiofibular clear space, normal criteria are different between these two views. On AP view, the measurement is defined as normal if the distance is greater than approximately 6 mm or 42% of fibular width[40]. On mortise view, the measurement is defined as normal if the distance is greater than approximately 1 mm[39]. Medial clear space is the distance from the lateral border of the medial malleolus to the medial border of the talus at the level of the talar dome on the mortise view, and the measurement of this distance is defined as abnormal if it is greater than 4 mm[41]. Another criterion often used, is whether the medial clear space is equal to or less than the superior clear space, which is the distance between the talar dome and the tibial plafond[41]. Although these three parameters are applied clinically, there is still controversy regarding the reliability of these parameters[41-43]. Pneumaticos *et al*[42] performed a cadaver study and concluded that the tibiofibular clear space on the AP view was the most reliable parameter because this parameter did not change significantly with rotation compared with tibiofibular overlap and medial clear space. On the other hand, Beumer *et al*[41] showed no optimal radiographic parameter which could assess syndesmotic integrity and tibiofibular overlap, and a comparison between medial and superior clear space was found to be the most useful in their cadaver study. Furthermore, Nielson *et al*[43] evaluated the accuracy of these parameters by means of magnetic resonance imaging (MRI), and observed no association between the tibiofibular clear space and overlap measurements on radiographs with syndesmotic injury on MRI. They emphasized the importance of a medial clear space greater than 4 mm to diagnose disruption of the deltoid and the distal tibiofibular ligaments[43].

Other radiological methods

Because of the controversial reliability of radiological parameters to diagnose disruption of the distal tibiofibular syndesmosis, other radiological assessments have been used[44-46]. Computed tomography (CT) scanning is more sensitive than radiography for detecting the minor degrees of syndesmotic injuries[44]. Furthermore, recent reports have revealed the diagnostic value of MRI for disruption of the distal tibiofibular syndesmosis[45,46]. Oae *et al*[45] demonstrated the efficacy of MRI in diagnosing injury of the tibiofibular syndesmosis, which had a sensitivity of 100% and a specificity of 94% for the diagnosis of AITFL disruption, and a sensitivity of 100% and a specificity of 100% for the diagnosis of PITFL disruption. Han *et al*[46] showed a sensitivity of 90.0% and a specificity of 94.8% for MRI in the diagnosis of chronic syndesmosis injury. Following these recent studies[44-46], CT and MRI have now replaced radiographic assessment in the preoperative diagnosis of chronic disruption of the distal tibiofibular syndesmosis.

Arthroscopy

Arthroscopic examination is very useful for the diagnosis

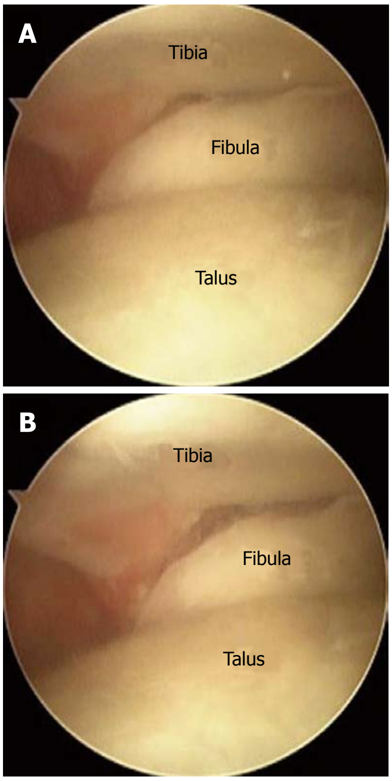

Figure 1 Arthroscopic findings of the anterior tibiofibular space in the neutral position (A) and under external rotation stress (B), which shows a widening of the anterior tibiofibular space of more than 2 mm.

of chronic disruption of the distal tibiofibular syndesmosis because it permits not only direct visualization of disrupted AITFL, PITFL and transverse ligament, but also direct visualization of instability by applying stress force to the ankle during examination[34,47,48]. Even in cases with the diagnosis of chronic disruption of the distal tibiofibular syndesmosis by radiological assessment, we routinely perform arthroscopic assessment at the same time as surgery to confirm the diagnosis directly. However, we have never performed arthroscopy alone as an examination to confirm the findings of other radiological examinations. For direct visualization, we use the anterolateral and anteromedial portal. The anteromedial portal is more suitable for best visualization of the disrupted AITFL, while the anterolateral portal is more suitable for the disrupted PITFL. To confirm instability of the distal tibiofibular syndesmosis, a stress test is performed by moving the ankle from the neutral position to external rotation. We consider that instability is present if an opening of 2 mm can be identified by rotation stress[47,48]. Arthroscopic assessment also provides information on the volume of the fibrous tissue which is interposed in the distal tibiofibular joint, and which should be debrided prior to open surgery. Furthermore, other intra-articular disorders such as osteochondral injury or synovitis which may accompany chronic disruption of the distal tibiofibular syndesmosis can be accessed and treated simultaneously. We consider arthroscopic examination to be the most reliable method for diagnosing disruption of the distal tibiofibular syndesmosis (Figure 1).

Treatment

The symptoms caused by disruption of the distal tibiofibular syndesmosis may be controlled, to some degree, by conservative therapy, however, patients who do not respond to such therapy require surgical intervention. Although several techniques had been reported in previous publications[49-58], there is still no gold standard for the management of chronic disruption of the distal tibiofibular syndesmosis. Beals and Manoli reported a case of late syndesmosis disruption after rotational ankle fracture, and a good prognosis was achieved by debridement of the distal tibiofibular joint and medial gutter accompanied by syndesmosis screw fixation[49]. A similar technique was used by Harper, who performed syndesmosis screw fixation with or without syndesmosis debridement in 6 patients with chronic disruption after pronation - external rotation stage 4 fracture[50]. As an additional procedure at surgery, arthrodesis of the tibiofibular interval was performed in a patient due to residual incongruity[50]. In this series, 4 of 6 patients were completely satisfied by this procedure[50]. A recent report also demonstrated the efficacy of arthroscopic debridement of the distal tibiofibular syndesmosis and medial gutter with percutaneous fixation of the syndesmosis using screws as a less invasive technique[51].

Using another method, Beumer *et al*[52] introduced a medialized advancement of the insertion of the AITFL on the tibia with a bone block to tense a slack but continuous AITFL. During this procedure, syndesmosis screw fixation was added after fixation of the bone block using a small screw[52]. Mosier-LaClair *et al*[53] recommended syndesmosis screw fixation and repair of the AITFL using two suture anchors for late reconstruction of the distal tibiofibular joint. These techniques seem to be indicated for patients with continuous AITFL, but are not indicated for patients with attenuated or ruptured AITFL.

On the other hand, some reconstructive surgeries using local or free autogenous substitute have been reported[54,55]. Grass *et al*[54] reconstructed not only the AITFL and PITFL, but also the IOL using a split autologous peroneus longus tendon graft for chronic instability of the distal tibiofibular syndesmosis, and reported pain relief in 15 of 16 cases treated using this procedure. Morris *et al*[55] harvested a free hamstring autograft for reconstruction of the AITFL and IOL in the distal tibiofibular syndesmosis. They performed this procedure for 8 patients with chronic syndesmotic instability after ankle fracture in 4 patients, isolated injuries with no fracture in 2 patients and without obvious trauma in 2 patients, and all patients achieved good clinical results[55]. Although these two reports commonly emphasized the importance of reconstructing the IOL[54,55], there is still no clear evidence on which ligament should be reconstructed. Furthermore, no studies have examined the optimal substitute for such reconstructive surgery.

Some authors have recommended arthrodesis of the distal tibiofibular joint for chronic cases[56-58]. Katznelson *et al*[56] performed arthrodesis of the distal tibiofibular joint in 5 patients, 4 of whom were pain-free and achieved a full range of motion of the ankle joint at one year after surgery. Espinosa *et al*[57] defined a chronic syndesmosis injury as persistent syndesmotic widening 3 months after injury and recommended open arthrodesis for such cases. Pena and Coetzee[58] suggested arthrodesis for cases with significant incongruity evaluated by CT at more than 6 mo after initial injury. They stated as the author's perception that final ankle function was definitely not sufficient to maintain an active athletic life[58]. It is unclear whether obliteration of distal tibiofibular joint motion will deteriorate ankle joint function in the future as there is no report which shows the clinical and functional results of arthrodesis of the distal tibiofibular joint after long term follow up.

Although each type of surgery has achieved good outcome and prognosis in previous publications[49-58], there are still some problems to be solved in order to establish a gold standard for the surgical management of chronic disruption of the distal tibiofibular joint.

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BRIEF ARTICLE

Analysis of stress fractures in athletes based on our clinical experience

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Abstract

AIM: To analyze stress fractures in athletes based on experience from our sports medicine clinic.

METHODS: We investigated the association between stress fractures and age, sex, sports level, sports activity, and skeletal site in athletes seen at our sports medicine clinic between September 1991 and April 2009. Stress fractures of the pars interarticularis were excluded from this analysis.

RESULTS: During this period (18 years and 8 mo), 14276 patients (9215 males and 5061 females) consulted our clinic because of sports-related injuries, and 263 patients (1.8%) [171 males (1.9%) and 92 females (1.8%)] sustained stress fractures. The average age of the patients with stress fractures was 20.2 years (range 10-46 years); 112 patients (42.6%) were 15-19 years of age and 90 (34.2%) were 20-24 years of age. Altogether, 90 patients (34.2%) were active at a high recreational level and 173 (65.8%) at a competitive level. The highest proportion of stress fractures was seen in basketball athletes (21.3%), followed by baseball (13.7%), track and field (11.4%), rowing (9.5%), soccer (8.4%), aerobics (5.3%), and classical ballet (4.9%). The most common sites of stress fractures in these patients were the tibia (44.1%), followed by the rib (14.1%), metatarsal bone (12.9%), ulnar olecranon (8.7%) and pelvis (8.4%). The sites of the stress fractures varied from sport to sport. The ulnar olecranon was the most common stress fracture site in baseball players, and the rib was the most common in rowers. Basketball and classical ballet athletes predominantly sustained stress fractures of the tibia and metatarsal bone. Track and field and soccer athletes predominantly sustained stress fractures of the tibia and pubic bone. Aerobics athletes predominantly sustained stress fractures of the tibia. Middle and long distance female runners who sustained multiple stress fractures had the female athlete triad.

CONCLUSION: The results of this analysis showed that stress fractures were seen in high-level young athletes, with similar proportions for males and females, and that particular sports were associated with specific sites for stress fractures. Middle and long distance female runners who suffered from multiple stress fractures had the female athlete triad.

Key words: Athletes; Bone mineral density; Female athlete triad; Stress fracture; Vitamin D insufficiency

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INTRODUCTION

Stress fractures are common injuries in athletes and military recruits. A stress fracture can be defined as a partial or complete fracture of bone that results from repeated application of stress lower than that required to fracture the bone in a single loading situation[1]. It is generally accepted that the tibia is the most common site of stress fractures, followed by the metatarsal and tarsal bones[2,3]. Running activities are the most common sports activities that result in stress fractures[2,3].

Epidemiological studies have identified the clinical risk factors of stress fractures in athletes and military recruits. The etiology of stress fractures is multifactorial and many clinical risk factors have been identified; polymorphism of vitamin D receptor (FokI and BsmI)[4], low serum levels of 25(OH)D[5], high serum parathyroid hormone level[6], low stiffness index (heel quantitative ultrasound parameter)[4,7], low bone mineral content and density (BMC and BMD, respectively) of the hip[6], tall stature[6,8], leanness[8], poor physical fitness/condition[6,9,10], sense of burnout[8], iron deficiency[8], higher age[9], gender (female)[9,11], low bone turnover[7], smoking[10], and amenorrhea[10]. However, no consensus has been reached. It is important for physicians to understand the features and etiology of stress fractures for the prevention and treatment of this crucial sports injury. The aim of this study was to analyze stress fractures in athletes based on experience from our sports medicine clinic. We investigated the association between stress fractures and age, sex, sports level, sports activity, and skeletal site in athletes seen at our sports medicine clinic. Cases with the female athlete triad (eating disorder, amenorrhea, and low BMD)[12] or vitamin D insufficiency were also included.

MATERIALS AND METHODS

During the 18 years and 8 mo period between September 1991 and April 2009, a total of 14276 patients consulted our sports medicine clinic because of sports-related injuries. Of these patients, the study subjects selected were athletes who sustained stress fractures.

A stress fracture was determined clinically as an area of marked focal, bony tenderness in association with evidence of a fracture on plain radiographs or magnetic resonance (MR) images, or a focal area of markedly increased uptake on the delayed phase of a technetium 99m-labeled bone scan. In particular, the bone scan was used to detect stress fractures of the rib in rowers, and MR images provided a rapid, anatomically precise diagnosis of stress fractures of the ulnar olecranon in baseball pitchers without additional radiation exposure. The uptake of technetium 99m, particularly in the tibial diaphysis, has had various interpretations; localized focal uptake of technetium 99m suggests a stress fracture (Figure 1), whereas its linear uptake along the periosteum suggests periostitis or stress syndrome (shin splints)[13-15]. Therefore, the tibiae showing localized focal uptake but not linear uptake of technetium 99m were diagnosed as having a stress fracture. Patients with

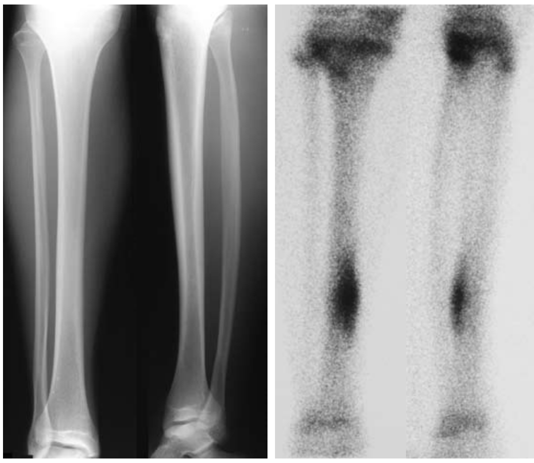

Figure 1 A case of stress fracture of the tibia diagnosed by technetium 99m-labeled bone scan. Although there were no abnormal findings on the plain radiographs of the tibia, the bone scan showed the uptake of technetium 99m in the tibial diaphysis. The localized focal uptake of technetium 99m suggests a stress fracture.

acute shin splints have a spectrum of MR findings (normal appearance, periosteal fluid only, abnormal marrow signal intensity, and stress fracture), which suggests this clinical entity is part of a continuum of stress response in bone[16]. However, the strong association between chronic symptoms and a normal-appearing MR image implies that this modality has less utility in these patients[16]. Thus, MR images were not useful for distinguishing shin splints and stress fractures in athletes.

Athletes were defined as young and middle-aged persons who engaged in low-recreational, high-recreational, and competitive sports activities according to the following categories; non-athlete (sports activity a few times a month), low-recreational (sports activity once or twice a week), high-recreational (sports activity three or more times a week, belonging to a high school sports team or a sports society), and competitive (competitive sports activity, belonging to a professional, industrial, or college sports team).

We analyzed the cases of stress fractures in athletes seen at our clinic and compared our results with those of previously published studies. In particular, the following features of each stress fracture patient were noted: age, sex, sports level, sports activity, and fracture site. Cases with the female athlete triad or vitamin D insufficiency were also included. Stress fractures of the pars interarticularis were excluded from the study.

RESULTS

Of the 14276 patients, 9215 were male and 5061 were female. Stress fractures were seen in 263 patients (171 males, 92 females). The proportion of stress fractures was 1.8% in all patients (1.9% in males, 1.8% in females). The age distribution is shown in Table 1. The average age of the patients with stress fractures was 20.2 years (range 10-46 years); 112 patients (42.6%) were 15-19 years of age and 90 (34.2%) were 20-24 years of age. Altogether,

Table 1 Age and sex of athletes with stress fractures

Age (yr)	*n* (%)	Male/Female
10-14	24 (9.1)	17/7
15-19	112 (42.6)	76/36
20-24	90 (34.2)	57/33
25-29	21 (8.0)	9/12
≥ 30	16 (6.1)	12/4
Total	263 (100)	171/92

Table 2 Sports represented in stress fracture series

Sport	*n* (%)	Male/Female
Basketball	56 (21.3)	32/24
Baseball	36 (13.7)	35/1
Track and field	30 (11.4)	9/21
Rowing	25 (9.5)	23/2
Soccer	22 (8.4)	20/2
Aerobics	14 (5.3)	2/12
Classical ballet	13 (4.9)	0/13
Rugby	8 (3.0)	6/2
Tennis	7 (2.7)	7/0
Volleyball	6 (2.3)	1/5
Others	46 (17.5)	36/10
Total	263 (100)	171/92

90 patients (34.2%) were active at a high recreational level and 173 (65.8%) at a competitive level.

The distribution of sports activities associated with stress fractures is shown in Table 2. The highest proportion of stress fractures was seen in basketball athletes (21.3%), followed by baseball (13.7%), track and field (11.4%), rowing (9.5%), soccer (8.4%), aerobics (5.3%), and classical ballet (4.9%). The distribution of stress fracture sites is shown in Table 3, and includes reports by other investigators[2]. The most common sites of stress fractures in these patients were the tibia (44.1%), followed by the rib (14.1%), metatarsal bone (12.9%), ulnar olecranon (8.7%) and pelvis (8.4%). The proportions of olecranon and rib stress fractures were higher in our clinic than in other facilities (Table 3).

The sites of the stress fractures varied from sport to sport. The ulnar olecranon was the most common stress fracture site in baseball players, and the rib was the most common in rowers. Basketball and classical ballet athletes predominantly sustained stress fractures of the tibia and metatarsal bone. Track and field and soccer athletes predominantly sustained stress fractures of the tibia and pubic bone. Aerobics athletes predominantly sustained stress fractures of the tibia.

Four young elite middle and long distance female runners sustained multiple stress fractures as well as low body mass index and the female athlete triad (eating disorder, amenorrhea, and low lumbar spine BMD) (Table 4).

One athlete who sustained a stress fracture had vitamin D insufficiency; a young Kendo female athlete (19 years of age) was diagnosed as having a stress fracture in the medial malleolus of the tibia by a technetium 99m-labeled bone scan (Figure 2) and vitamin D insufficiency as determined by serum 25(OH)D concentration (< 30 ng/mL). Following conservative treatment with the active form of vitamin D_3 (alfacalcidol), this patient returned to play in 6 mo.

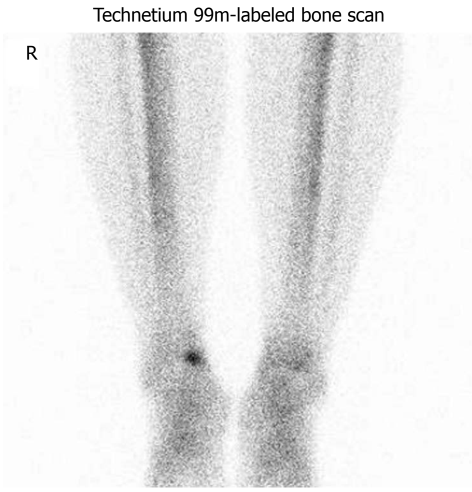

Figure 2 A case of stress fracture of the medial malleolus of the tibia. Although there were no abnormal findings on the plain radiographs of the ankle, the bone scan showed the uptake of technetium 99m in the medial malleolus of the tibia. The localized focal uptake of technetium 99m suggests a stress fracture.

DISCUSSION

An analysis of stress fractures treated in our sports medicine clinic showed that running and jumping activities were the most common sports activities that resulted in stress fractures in the lower limbs, and that stress fractures were commonly seen in the tibia (Table 3). Particular sports were associated with specific stress fracture sites. Furthermore, in our experience, multiple stress fractures can be associated with the female athlete triad. One athlete who sustained a stress fracture had vitamin D insufficiency.

The ulnar olecranon was the most common stress fracture site in baseball players. Because the athletes in two professional baseball teams were obliged to consult us, the proportion of olecranon stress fractures might have been higher in our clinic than in other facilities (Table 3). Stress fractures of the olecranon may be caused by repeated extensor tug on the olecranon by the triceps muscle[17], or impaction force on the olecranon due to impingement between the olecranon and the olecranon fossa with valgus stress[18].

The rib was the most common stress fracture site among rowers. Because rowers in the high school and university related to our university hospital were obliged to consult us, the proportion of rib stress fractures might have been higher in our clinic than in other facilities (Table 3). The most frequently reported cause of rib stress fractures is direct pull on muscles, (i.e. serratus anterior and rectus abdominis muscles)[19]. Recently, however, rib loading (which mostly occurs during the drive phase of the rowing stroke) has been hypothesized to contribute to the occurrence of these fractures[19].

The female athlete triad including eating disorders, functional hypothalamic amenorrhea, and low BMD is a

Table 3 Proportion of stress fractures in athlete[2]

Investigator (yr)	Ovara (1978)	Sugiura (1983)	Matheson (1987)	Tajima (1997)	Muto (1998)	Sakai (1999)	Iwamoto (2009)
No. of case	142	162	330	111	251	183	263
Upper limb							
Metacarpal bone	1.4				0.3		
Humerus	0.7				1.2		
Ulna	0.7	1.2			5.2	1.6	8.7
Trunk							
Rib	8.6		3.6	1.8	4.0	2.7	14.1
Spine	0.7	2.4	0.6		11.9	4.9	0.8
Pelvis	1.4		1.6		2.4	4.9	8.4
Lower limb							
Femur	6.3	3.7	7.2	0.9	3.2	3.3	1.5
Patella		1.2		1.8	0.3		0.4
Lower leg	67.6	67.3	55.7	68.5	37.8	51.9	48.3
Tibia		54.3			32.3	42.6	44.1
Fibula		13.0			5.6	9.3	4.2
Tarsal bone	0.7		25.3	2.7	3.6	5.4	1.1
Metatarsal bone	18.3	15.4	8.8	20.7	28.7	25.1	12.9
Sesamoid	1.4		0.9		0.5		2.7
Toe phalanx	0.7						0.8

Table 4 Stress fractures in middle and long distance female runners

	Case 1	Case 2	Case 3	Case 4
Age (yr)	19	22	22	20
Body mass index (kg/m^2)	18.2	17.5	17.7	17.7
Menstruation status	Amenorrhea	Amenorrhea	Amenorrhea	Amenorrhea
Estradiol[1] (pg/mL)	32	36	< 20	21
Bone mineral density (Z score, %)				
Lumbar spine	72	81	91	81
Femoral neck			102	92
Stress fracture				
Number of fracture	4	2	3	2
Fracture site	R. Metatarsus R. Metatarsus Bil. Femur	Bil. Tibia	L. Metatarsus L. Calcaneus 8th thoracic spine	R. Calcaneus L. Pubic bone

[1]< 35 pg/mL in postmenopausal women. R: Right; L: Left; Bil: Bilateral.

serious problem in athletes[12]. Middle and long distance female runners who suffered from multiple stress fractures had the female athlete triad, suggesting that the risk of stress fractures was increased in cases with the female athlete triad. There is a potential link between body mass index, energy deficit, and hypothalamic dysfunction, and the pathophysiology underlying low BMD in hypothalamic amenorrhea is directly related to nutritional issues[20-22]. There may be both a nutritional component affecting formation and an estrogen-related component affecting resorption (uncoupling of bone formation and resorption). The first aim is to increase energy availability by increasing energy intake and/or reducing exercise energy expenditure; weight gain and an increase in energy availability (> 30 kcal/kg of fat-free mass per day) in those young women are clinical priorities to facilitate resumption of their menses[20-22]. Adequate amounts of bone-building nutrients such as calcium (1000-1300 mg/d), vitamin D (400-800 IU/d), and vitamin K (60-90 μg/d) are also needed to maintain bone health[20-22]. Leptin administration for relative leptin deficiency in women with hypothalamic amenorrhea was reported to improve reproductive, thyroid, and growth hormone axes and markers of bone formation, suggesting that leptin, a peripheral signal reflecting the adequacy of energy stores, is required for normal reproductive and neuroendocrine function[23].

Many clinical risk factors of stress fractures have been identified. In particular, polymorphism of vitamin D receptor (FokI and BsmI), vitamin D insufficiency, low bone mass, low body mass index, poor physical fitness/condition, gender (female), low bone turnover, and amenorrhea were suggested to be clinical risk factors of stress fractures[4-11].

One athlete in our study who sustained a stress fracture had vitamin D insufficiency. Hypovitaminosis D may result from reduced sun exposure and the widespread use of sun blockers, resulting in less efficient formation of vitamin D in the skin, as well as from dietary deficiency. Hypovitaminosis D is classified into two categories: vitamin D deficiency as a severe form, and vitamin D insufficiency as a mild form[24,25]. According to current recommendations, serum 25(OH)D concentrations < 30 ng/mL are considered to indicate insufficiency[25], while values < 10 ng/mL are classified as deficiency[26]. Vitamin D deficiency causes rickets in children and osteomalacia in adults. Vitamin D insufficiency can lead to secondary hyperparathyroidism, bone loss, osteoporosis, and increased risk of fractures[27]. Vitamin D insufficiency is frequently encountered in the general population and even in elite athletes[28-30].

A lower level of serum 25(OH)D concentration was found to be a general predisposing factor for stress fractures in military recruits[5], indicating a relationship between vitamin D insufficiency and the occurrence of stress fractures. Thus, the need for additional vitamin D in the prevention of stress fractures was suggested and calcium and vitamin D supplementation was shown to decrease the incidence of stress fractures in female recruits[31]. Thus, it is important to evaluate vitamin D status in athletes and military recruits for the prevention of stress fractures. Generally, athletes do not meet the US dietary reference intake for vitamin D, and inadequate endogenous synthesis is the most probable reason for insufficient/deficient status[32]. It is imperative that sports dietitians and physicians routinely assess vitamin D status and make recommendations to help athletes achieve a serum 25(OH)D concentration of ≥ 32 ng/mL and preferably ≥ 40 ng/mL[32].

Vitamin D is now recognized as important for cardiovascular health and its deficiency as a potential risk factor for several cardiovascular disease processes[33]. A report on calcium and vitamin D supplementation and coronary artery calcification in the Women's Health Initiative suggested that treatment with moderate doses of calcium plus vitamin D_3 did not seem to alter coronary artery calcified plaque burden among postmenopausal women[34]. A systematic review suggests that vitamin D supplements at moderate to high doses may reduce cardiovascular disease risk, whereas calcium supplements seem to have minimal cardiovascular effects[35]. Thus, we have recognized that calcium and vitamin D supplementation may not be harmful in athletes with calcium and vitamin D insufficiency/deficiency.

In conclusion, an analysis of stress fractures, based on experience from our sports medicine clinic, showed that particular sports were associated with specific stress fracture sites. In addition, some female athletes who sustained multiple stress fractures also had the female athlete triad. One athlete who sustained a stress fracture had vitamin D insufficiency.

COMMENTS

Background

Stress fractures are common injuries in athletes and military recruits. Epidemiological studies have identified the clinical risk factors of stress fractures in athletes and military recruits. Although the etiology of stress fractures is multifactorial and many clinical risk factors have been identified, no consensus has been reached.

Research frontiers

It is important for physicians to understand the features and etiology of stress fractures for the prevention and treatment of this crucial sports injury. In this study, we analyzed stress fractures in 263 athletes based on experience from our sports medicine clinic. The association between stress fractures and age, sex, sports level, sports activity, and skeletal site in athletes seen at our sports medicine clinic was investigated and cases with the female athlete triad [eating disorder, amenorrhea, and low bone mineral density (BMD)] or vitamin D insufficiency were also included.

Innovations and breakthroughs

Running and jumping activities were the most common sports activities that resulted in stress fractures in the lower limbs, and stress fractures were commonly seen in the tibia. Particular sports were associated with specific stress fracture sites. The ulnar olecranon was the most common stress fracture site in baseball players, and the rib was the most common in rowers. Basketball and classical ballet athletes predominantly sustained stress fractures of the tibia and metatarsal bone. Track and field and soccer athletes predominantly sustained stress fractures of the tibia and pubic bone. Aerobics athletes predominantly sustained stress fractures of the tibia. Middle and long distance female runners who sustained multiple stress fractures had the female athlete triad. One athlete who sustained a stress fracture had vitamin D insufficiency.

Applications

Physicians may be able to establish the strategy for prevention and treatment of stress fractures by understanding the features and etiology of this crucial sports injury.

Terminology

A stress fracture can be defined as a partial or complete fracture of bone that results from repeated application of stress lower than that required to fracture the bone in a single loading situation. The female athlete triad includes eating disorders, functional hypothalamic amenorrhea, and low BMD. Hypovitaminosis D is classified into two categories: vitamin D deficiency as a severe form, and vitamin D insufficiency as a mild form. According to current recommendations, serum 25(OH)D concentrations < 30 ng/mL are considered to indicate insufficiency, while values < 10 ng/mL are classified as deficiency.

Peer review

The authors show the case history of stress fractures in their sport medicine center; moreover they review the literature about stress fracture causes, risk factors and nutritional therapy. The study of bone features in young healthy people presenting bone weakness represents a topical issue.

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Meetings

Events Calendar 2011

January 16-20, 2011
Combined 4th International Conference of the Saudi Orthopaedic Association & SICOT Trainee Day, Abha, Saudi Arabia

January 24-27, 2011
7th Middle East Orthopaedics Conference 2011, Dubai International Convention Centre, Dubai, Saudi Arabia

January 28-30, 2011
National Orthopedic Conference 2011, San Francisco, California, United States

February 15-19, 2011
American Academy of Orthopaedic Surgeons, San Diego, CA, United States

February 16-20, 2011
2011 Annual Meeting of the American Academy of Orthopaedic Surgeons, San Diego, CA, United States

February 19, 2011
Pediatric Orthopaedic Society of North America Specialty Day, San Diego, CA, United States

March 09-11, 2011
Annual London Imperial Spine Course, London, United Kingdom

March 21-25, 2011
31st Caribbean Orthopaedic Meeting, Anse Marcel, Saint Martin

March 28-April 02, 2011
The Association of Children's Prosthetic-Orthotic Clinics 2011 Annual Meeting, Park City, UT, United States

April 01-04, 2011
Ain Shams 2nd Orthopaedic intensive course (Orthopaedics from A to Z), Cairo, Egypt

April 20-22, 2011
IMUKA 2011: Masterclass in Arthroscopy and Related Surgery, Maastricht, Netherlands

May 11-14, 2011
2011 POSNA Annual Meeting, Montreal, Quebec, Canada

May 12-15, 2011
84th Annual Meeting of the Japanese Orthopaedic Association, Yokohama, Japan

May 15-19, 2011
8th Biennial ISAKOS Congress (International Society of Arthroscopy, Knee Surgery and Orthopaedic Sports Medicine), Rio de Janeiro, Brazil

May 25-28, 2011
16th Pan Arab Orthopedic Association Congress & 27th SOTCOT Congress, Tunis, Tunisia

June 01-04, 2011
12th EFORT Congress in cooperation with the Danish Orthopaedic Association (European Federation of National Associations of Orthopaedics and Traumatology), Copenhagen, Denmark

June 08-12, 2011
2011 ABJS Annual Meeting (Association of Bone and Joint Surgeons), Dublin, Ireland

June 15-18, 2011
11th Annual Meeting of the International Society for Computer Assisted Orthopaedic Surgery, London, United Kingdom

July 07-09, 2011
66th Annual Meeting of the Canadian Orthopaedic Association, St. John's, Newfoundland and Labrador, Canada

July 13-16, 2011
18th International Meeting on Advanced Spine Techniques, Copenhagen, Denmark

July 22-24, 2011
Sri Sathya Sai International Orthopaedic Conference- 2011 0n Pelvis And Lower Extremity Trauma", Sri Sathya Sai Institute of Higher Medical Sciences, Prasanthigram, Puttaparthi, Andhra Pradesh, India

July 25-28, 2011
2011 Update in Orthopaedics, Grand Wailea Hotel Resort & Spa,Wailea, Maui, Hawaii, United States

September 06-09, 2011
SICOT 2011 XXV Triennial World Congress, Prague, Czech Republic

September 13-16, 2011
BOA/IOA Combined Meeting(British Orthopaedic Association & Irish Orthopaedic Association), Dublin, Ireland

September 14-17, 2011
23rd SECEC-ESSSE Congress (European Society for Surgery of the Shoulder and the Elbow), Lyon, France

September 14-17, 2011
46th SRS Annual Meeting & Course (Scoliosis Research Society), Louisville, Kentucky, United States

September 15-18, 2011
2011 World Congress on Osteoarthritis, San Diego, California 92167, United States

September 21-23, 2011
HIP IMPROVEMENTS AND PROCEEDINGS, Toulouse, France

October 25-28, 2011
DKOU 2011-Deutscher Kongress für Orthopädie und Unfallchirurgie, Berlin, Germany

November 7-11, 2011
86ème Réunion Annuelle SOFCOT, Paris, France

December 12-15, 2011
EOA 63rd Annual International Conference, Cairo, Egypt

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Instructions to authors

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Acknowledgments
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2 **Lin GZ**, Wang XZ, Wang P, Lin J, Yang FD. Immunologic effect of Jianpi Yishen decoction in treatment of Pixu-diarrhoea. *Shijie Huaren Xiaohua Zazhi* 1999; **7**: 285-287

In press

3 **Tian D**, Araki H, Stahl E, Bergelson J, Kreitman M. Signature of balancing selection in Arabidopsis. *Proc Natl Acad Sci USA* 2006; In press

Organization as author

4 **Diabetes Prevention Program Research Group**. Hypertension, insulin, and proinsulin in participants with impaired glucose tolerance. *Hypertension* 2002; **40**: 679-686 [PMID: 12411462 PMCID:2516377 DOI:10.1161/01.HYP.0000035706.28494.09]

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5 **Vallancien G**, Emberton M, Harving N, van Moorselaar RJ; Alf-One Study Group. Sexual dysfunction in 1, 274 European men suffering from lower urinary tract symptoms. *J Urol* 2003; **169**: 2257-2261 [PMID: 12771764 DOI:10.1097/01.ju.0000067940.76090.73]

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Volume with supplement

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Patent (list all authors)

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Statistical data

Write as mean ± SD or mean ± SE.

Statistical expression

Express *t* test as *t* (in italics), *F* test as *F* (in italics), chi square test as χ^2 (in Greek), related coefficient as *r* (in italics), degree of freedom as υ (in Greek), sample number as *n* (in italics), and probability as *P* (in italics).

Units

Use SI units. For example: body mass, m (B) = 78 kg; blood pressure, p (B) = 16.2/12.3 kPa; incubation time, t (incubation) = 96 h, blood glucose concentration, c (glucose) 6.4 ± 2.1 mmol/L; blood CEA mass concentration, p (CEA) = 8.6 24.5 μg/L; CO_2 volume fraction, 50 mL/L CO_2, not 5% CO_2; likewise for 40 g/L formaldehyde, not 10% formalin; and mass fraction, 8 ng/g, *etc*. Arabic numerals such as 23, 243, 641 should be read 23 243 641.

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