CHAPTER 10

Foot and Ankle High-Risk Injuries

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INTRODUCTION

Bone stress injuries (BSIs) in the foot and ankle can be divided into higher risk- and lower-risk anatomical locations for injury (Figures 10.1 and 10.2). This is based on differences in biomechanics, anatomical factors such as blood supply, and the specific considerations for populations treated such as athletes. The focus on this chapter is to review BSIs in high-risk locations, separated by anatomy, with details on evaluation and management.

TARSAL NAVICULAR BONE STRESS INJURY

Evaluation

Tarsal navicular BSIs are high-risk injuries that account for 14% to 25% of all stress fractures, with the highest incidence of these injuries occurring in sports that involve explosive movements, rapid cutting, and jumping.¹⁻⁴ These sports include basketball, football, track and field sports, rugby, and basketball.⁵⁻⁷ These injuries are important to identify as nonunion risk is much higher compared to other BSIs in the body.

The navicular is a concave bone that articulates with the talus, cuneiform, and cuboid. The posterior tibialis tendon inserts on the medial aspect of the bone. The talus and navicular, along with the cuboid and calcaneus, make up the transverse tarsal joints.

Biomechanically, the navicular and the rest of the transverse tarsal joints play an important role in allowing the hindfoot to pivot with the forefoot during the gait cycle. When the heel is inverted due to the pull of the posterior tibialis tendon, the transverse tarsal joint becomes rigid, preparing the foot for push off. It is during this push-off phase when the compressive forces to the navicular are generated through the 1st and 2nd metatarsocuneiform joints.¹ In conjunction with the pull of the posterior tibialis tendon medially, this creates a zone of maximal tensile load at the central third of the navicular body.

Furthermore, the central third is a watershed area of relatively poor blood supply, where the medial aspect is supplied by the posterior tibialis artery and laterally by the dorsalis pedis artery. As a result, this relatively avascular central third is prone to BSIs.

FIGURE 10.1 Bony anatomy of the foot and ankle on a lateral x-ray: (A) tibia, (B) talus, (C) calcaneus, (D) navicular, (E) cuboid, (F) cuneiform, (G) 5th metatarsal, (H) 1st metatarsal, (I) sesamoid, (J) proximal phalanx, and (K) distal phalanx.

FIGURE 10.2 Bony anatomy of the foot and ankle on an AP x-ray: (A) talus, (B) calcaneus, (C) navicular, (D) cuboid, (E) cuneiform, (F) 5th metatarsal, (G) 1st metatarsal, (H) tibial sesamoid, (I) proximal phalanx, (J) distal phalanx, and (arrowhead) fibular sesamoid.

AP, anteroposterior.

Risks for navicular BSI can be divided into biological and biomechanical factors. Biological factors include medications (i.e., steroids), consequences of low energy availability, and insufficient vitamin D. Biomechanical factors are improper training regimen, changes in exercise intensity, and low bone mineral density.⁸ Navicular BSI-specific risks include the hypovascularity seen in the central third of the bone, long 2nd ray or shortened 1st ray, metatarsus adductus, reduced ankle dorsiflexion, cavus foot, talar beaking, and stiffness in the subtalar joint.⁹

Clinically, patients present with vague pain around the dorsal proximal midfoot or the area overlying the navicular bone. The discomfort can be dorsal and even on the plantar aspect of the foot. Symptoms are generally worsened by activities especially when pushing off or landing. Many athletes have point-specific pain overlying the navicular on palpation, described as the “N” spot.¹⁰ Swelling is uncommon. Hopping may reproduce the index pain.¹ Plain radiographs are typically normal, with sensitivity of detecting a fracture at only 33%.^{2,3}

Advanced imaging is recommended when suspecting BSI of the navicular. MRI is the best modality to identify bone edema and stress reaction. Furthermore, it can help rule out other soft tissue or bony injuries to the area. If there is a high suspicion of a stress fracture on MRI as opposed to a stress reaction even if a fracture line is not visible on the MRI, a CT scan is recommended (Figure 10.3).¹¹ MRI alone may miss a potential fracture with a sensitivity of 71.4%.¹² Furthermore, CT scan can be used during treatment to evaluate fracture healing and ensure that union of the fracture has been obtained prior to returning to play.

A classification based on CT scan has been described.¹³ Type I involves fracture through only the dorsal cortex. Type II involves fracture through the navicular body, with type III involving the second cortex. Severity of the fracture pattern such as a complete fracture, displacement, presence of avascular necrosis, subchondral sclerosis, and cystic changes may be associated with increased risk of nonunion and delay in fracture healing.^{13,14}

Treatment

Navicular BSI have been shown to have a high union rate with the appropriate treatment that involves non-weight bearing for a minimum of 6 weeks. Whether the patient is treated with a short leg cast or operative fixation, non-weight bearing is critical for fracture union. Treatment involving protected weight bearing or partial weight bearing has a high rate of delayed union or nonunion. A meta-analysis done by Torg et al. in 2010 reported that only 47% of patients treated with weight bearing and rest had a successful outcome, with return to play at 5.7 months compared to 96% when treated with 6 weeks of non-weight bearing in a cast. Return to play for the non-weight-bearing group was 3.7 months.¹⁵ Khan et al. reported a similar high rate of union with conservative management, with an 86% union rate and return to play at 5.6 months. In patients treated with non-weight bearing for a duration less than 6 weeks, only 69% of patients were able to return to activities. Finally, in individuals who had no activity restrictions, only 20% were able to return to play.²

Complications from nonoperative treatment in general are low especially when treated with non-weight-bearing casts or tall walking boots for 6 weeks to maintain proper foot position in neutral dorsiflexion. Unfortunately, there are no studies that report specifically on fracture recurrence treated conservatively. In one study, the authors reported a recurrence rate of 11.2% in patients treated without surgery and 6 weeks of non-weight bearing.¹²

Other conservative treatment methods can augment standard treatment, such as bone stimulator, vitamin D supplementation, and teriparatide use. However, these

FIGURE 10.3 Eighteen-year-old gymnast with several weeks of dorsal proximal foot pain. (A) Initial x-rays were normal. MRI and subsequent CT were obtained. (B) Coronal T1-weighted MRI demonstrating a dorsal cortical defect of the navicular consistent with a stress fracture. (C) Coronal CT scan showing the type II navicular stress fracture with sclerotic bone.

modalities should not be used to supplant standard treatment methods as evidence for their efficacy is limited.

Absolute indications for surgical treatment include displaced fractures, presence of cystic formation, avascular necrosis, sclerotic bone, and fracture nonunion. Relative indications are delayed union, recurrence of the fracture, and complete fractures (type III) in elite athletes who cannot tolerate conservative management. For partial fractures or nondisplaced complete fractures, percutaneous screw fixation can be done without need for open reduction internal fixation. If there is fracture displacement or dorsal sclerotic bone, resection of the sclerotic bone and bone graft is recommended. Complications include hardware pain, nerve irritation, infection, nonunion, and recurrence of fracture. Saxena et al. reported that 7 of the 42 surgically treated patients required hardware removal (11.2%) and 1 patient (2%) developed complex regional pain syndrome that resolved with removal of hardware.¹² In individuals with more severe fracture patterns, such as displaced fractures and presence of cyst formation, time to healing may be delayed. In these individuals, surgery is recommended.^{13,16} In displaced fractures, nonunion risk even with bone graft can be as high as 20%.¹⁴

Torg et al. in their meta-analysis reported that 82% of patients had a successful outcome when treated with surgery.¹⁵ In a systematic review done by Mallee et al., the mean time to return to play was 16.4 weeks in the surgically treated patients versus 21.7

FIGURE 10.4 (A) Postsurgical plain radiographs demonstrating lateral to medial screw fixation. (B) Screws are placed on the dorsal and plantar halves of the navicular.

weeks in patients treated in non-weight-bearing casts for greater than 6 weeks.¹⁷ Other studies reported no difference in return to play with non-weight-bearing treatment versus surgical fixation.^{12,15,16} The rates of long-term posttraumatic arthritis after a stress fracture to the navicular regardless of treatment are unknown.

The author's preferred treatment for elite athletes is surgical fixation with a single partially threaded cannulated screw for type I fractures or two parallel screws for type II and type III fractures. Screws are placed lateral to medial to reduce injury to the posterior tibialis tendon and minimize hardware irritation. It is imperative that the screws be placed where the fracture is located and perpendicular to the fracture line (Figure 10.4). Iliac crest bone graft is used to augment fixation with any fracture displacement. If the navicular stress fracture has areas of avascular necrosis, subchondral sclerosis, or cystic formation, debridement of the abnormal bone and bone graft is done. Postoperative rehabilitation involves 6 weeks of non-weight bearing in a tall controlled ankle motion (CAM) boot with initiation of gentle active and passive motion including hindfoot mobilization at 2 weeks after surgery. Weight bearing as tolerated in a CAM boot is started after the 6th week. Closed chain exercise with physical therapy is allowed at 8 weeks. Repeat CT scan is done at 10 to 12 weeks to evaluate fracture healing (Figure 10.5). Once full union is obtained, patients are weaned out of the boot and advanced as tolerated back to their respective sport.

In summary, navicular BSIs are a high-risk injury that can have long-term consequences if they are not properly identified and treated. In an athlete with pain over the navicular in the setting of negative x-ray findings, MRI should be done to rule out navicular stress reaction or stress fracture. If there is high suspicion for a navicular stress fracture on MRI even if a fracture line is not visible, a CT scan is highly recommended. Both nonoperative and surgical treatments are effective in treating navicular BSIs. Regardless of treatment option, a minimum of 6 weeks of non-weight bearing in a cast or boot is needed to prevent delayed union or nonunion. Whether surgery can improve return-to-activity time is still unknown and debated. However, in more severe fracture types, surgical fixation may improve fracture union and reduce the time needed to return to play.

FIGURE 10.5 Repeat CT scan obtained at 10 weeks after surgery. The scan showed complete healing of the stress fracture, and the athlete was allowed to advance to full activities as tolerated.

CALCANEAL BONE STRESS INJURY

Evaluation

Unlike some of the stress fractures of the foot and ankle, which have a high rate of fracture nonunion without surgical intervention, most calcaneal stress injuries have a propensity to heal with conservative management. Calcaneal stress fractures are the second most common stress fracture in the foot and ankle among military recruits, with a higher incidence in female soldiers. The study found an incidence of all stress fractures in female recruits to be 1.09% with calcaneal fractures accounting for 39% of those injuries. Incidence in male recruits for all stress fractures was 0.91%, with calcaneal stress fractures making up 20%.¹⁸ Outside of military personnel, they most commonly occur in long-distance runners.¹⁹

The calcaneus is the largest bone in the foot. It articulates with the talus superiorly and cuboid distally. There are three muscular insertions on the calcaneus. The gastrocnemius and soleus insert on the posterior calcaneal tuberosity through the Achilles tendon. The third is the plantaris muscle, which can insert directly or through the Achilles tendon to the posterior calcaneal tuberosity. The bone is composed predominately of trabecular bone with a thin cortical shell.²⁰ The trabecular structure of the calcaneus runs in an arc extending from the subtalar articular surface to the posterior cortex (Figure 10.6A).

The mechanism of calcaneal BSIs may be due to the eccentric pull of the Achilles tendon on its calcaneal insertion with repetitive heel strike. As a result, the majority of fractures occur on the posterior aspect of the calcaneus with the fracture line perpendicular to the trabecular lines distal to posterior calcaneal tuberosity (Figure 10.6A).²¹ Fractures can also occur in the middle and anterior aspects of the calcaneus.²²

The most common risk factor for developing these injuries is being a military recruit. Other factors associated with stress fractures, such as the female athlete triad, relative energy deficiency in sport, changes in duration or frequency of exercise, poor nutrition, and medication use such as steroids, are also common. Calcaneus has greater trabecular bone content, and low bone mineral density has been observed to be more common with this injury.²³ There is also a small subset of older patients with osteoporosis

FIGURE 10.6 (A) Normal trabecular lines of the calcaneal body. Fractures occur perpendicular to these lines. (B) Central calcaneal stress fracture in a 45-year-old avid runner. Fracture extends anteriorly. Note that the fracture line is perpendicular to the calcaneal trabeculae.

developing calcaneal stress fracture in the postoperative period after a total hip arthroplasty or total knee arthroplasty.^{24,25} On average, the fractures occurred 10 weeks after a total hip arthroplasty.²⁴ This could be due to changes in gait after surgery. Another etiology could be increased mechanical load from reduced pain after joint replacement or postoperative analgesics.²⁶ In addition, the elongated anterior process of the calcaneus and navicular–calcaneal coalitions has been associated with stress fractures of the anterior process of the calcaneus.²⁷

Symptoms typically occur 1 to 3 weeks after changes in frequency, duration, or difficulty in exercise. Pain is localized along the posterior aspect of the tissues overlying the calcaneus. Patients can have pain along the medial and lateral wall of the calcaneus. Calcaneal squeeze test may provoke pain. Differential diagnosis includes plantar fasciitis, insertional Achilles tendonitis, retrocalcaneal bursitis, Baxter’s neuritis, and calcaneal apophysitis in patients with open growth plates.²⁸ The location of where the patient is tender can help narrow down the differential diagnosis (Figure 10.7).

Identification of the fracture on plain radiographs may lag behind symptoms by up to 3 to 4 weeks. Typically, when seen, a sclerotic line will be identified on the lateral view of the foot in the posterior calcaneus (Figure 10.6B). If there is high suspicion for calcaneal BSIs, MRI is the modality due to its high sensitivity and specificity.

Treatment

Conservative treatment consisting of protected weight-bearing, cessation of the inciting activity, and gradual resumption of impact sports is the standard of care as these injuries have a high rate of healing without long-term consequences or loss in the activity level.^{22,29–35} Outside of exercise modification, cast immobilization is rarely required.³⁶ A short period of boot immobilization with no weight-bearing restrictions can be done to rest the painful extremity.

Recurrence of the calcaneal BSI can occur with premature return to vigorous activity before resolution of the patient’s symptoms or within 8 weeks from initiation of treatment.³⁷ To prevent this, a two-phase treatment regimen is recommended. In the initial phase, rest with protected weight bearing and activity restriction is provided until the patient is pain free with weight bearing. This phase may take up to 8 weeks. The second phase consists of gradual reintroduction of activities over a 6- to 12-week period. If pain returns, the activity level should be decreased.

FIGURE 10.7 Typical location of pain when palpating the medial hindfoot. (A) Calcaneal stress fracture, (B) plantar fasciitis, (C) Achilles tendonitis/retrocalcaneal bursitis, and (D) Achilles tendonitis/apophysitis.

Additional nonoperative treatment measures for BSIs should be considered. These include vitamin D and calcium supplementation, identification and treatment of any nutritional deficits along with consideration for workup for underlying impaired bone density with dual-energy x-ray absorptiometry, and treatment of any endocrine or metabolic irregularities.

There is one case report of surgical treatment of bilateral displaced posterior calcaneal stress fractures in a 67-year-old female who sustained the injury from a 3-week hiking trek.³⁸ In addition, there are reports of anterior calcaneal stress fractures, especially in the setting of a calcaneal–navicular coalition that required surgical treatment including resection of the coalition and screw fixation of the stress fracture.^{27,39,40} Outside of these reports, however, there are no other reported surgical treatment of calcaneal stress fractures.

The author's preferred treatment involves controlled ankle boot immobilization and cessation of the inciting activity level with no restriction on weight bearing until the patient is able to ambulate with no discomfort or pain. Once the pain is resolved, the patient is weaned out of the boot and initiation of nonimpact activities can be done. A slow gradual return to activities is done over the subsequent 6-week period. A return to run progression including antigravity treadmill may be considered starting 6 to 8 weeks from initiation of treatment. Return to vigorous activity level is resumed only after the patient is completely asymptomatic. An exercise regimen including intensity, duration, and frequency is adjusted to prevent recurrence. Physical therapy to optimize strength and mobility of the foot and ankle should be considered, especially if the injury required immobilization. Vitamin D, calcium, and maintenance of good caloric intake are continued even after fracture healing.

In conclusion, calcaneal BSI is a common injury that can be confused with other foot and ankle ailments such as plantar fasciitis. This injury needs to be considered in any patient with suspicion of a stress injury. MRI may be needed to identify the fracture if plain radiographs are negative. Conservative treatment is the mainstay of care. Care should be taken to gradually return the patient to impact activities as recurrence of the fracture can occur.

PROMIXAL 5TH METATARSAL JONES FRACTURE

Evaluation

Stress fractures of the 5th metatarsal account for only 2% of all metatarsal stress fractures.⁴¹ Compared to a traumatic fracture of the 5th metatarsal, which occurs most commonly as a tuberosity avulsion fracture at the insertion of the peroneus brevis, 5th metatarsal BSIs occur generally at the metaphyseal and proximal diaphyseal portions of the bone. Although he described it first, in 1902, Sir Robert Jones himself suffered from the fracture due to dancing.⁴² Proximal 5th metatarsal fractures are classified into zones 1, 2, and 3 depending on the location of the fracture. Zone 1 fractures are a tuberosity avulsion fracture. Zone 2 involves the metaphysis or the articulation between the 4th and 5th metatarsals extending to the metaphyseal/diaphyseal junction. Finally, zone 3 fractures occur at the proximal diaphysis (Figure 10.8).^{43–45} A majority of stress fractures to the 5th metatarsal occur in the distal zone 2 and zone 3 areas of the bone or approximately 1.5 cm distal from the tuberosity.⁴⁶ These injuries are often associated with basketball and football. However, an athlete participating in any sport that involves

FIGURE 10.8 Locations of zone 1, zone 2, and zone 3 fractures of the base of the 5th metatarsal. Zone 1 fractures involve the proximal tubercle. Zone 2 fractures are located at the 4th and 5th metatarsal articulation and the metaphyseal/diaphyseal junction. Zone 3 fractures involve the proximal diaphysis or are distal to the metaphyseal/diaphyseal junction.

repetitive loading to the lower extremity, such as lacrosse, soccer, running, gymnastics, and dance, can result in a 5th metatarsal BSI.^{47–51}

There are two main tendon attachments to the proximal 5th metatarsal. The peroneus brevis inserts on the proximal tuberosity, a site common for avulsion fractures from inversion ankle injuries. The peroneus tertius inserts on the proximal diaphysis on the dorsal surface.⁵² The main blood supply to the 5th metatarsal comes from the metaphyseal arteries on both the proximal and distal aspects of the bone and the nutrient artery entering the bone at the middle third of the diaphysis. The nutrient vessels divide into the proximal and distal branches. The proximal branch is shorter compared to the distal branch and does not fully reach the metaphyseal and diaphyseal junction of the metatarsal.¹⁸ This watershed area can decrease the healing potential in the bone accounting for the propensity to develop stress fractures in the proximal 5th metatarsal and the delay in fracture healing.

There are multiple risk factors for base 5th metatarsal BSI including biological factors such as insufficient metabolic intake, female athlete triad/relative energy deficiency in sport, medications (i.e., steroids and anticonvulsants), and vitamin D deficiency. Biomechanical factors include an increase in volume or intensity in training regimen. This results in continued repetitive submaximal load, leading to failure of bone integrity and a stress fracture.⁸ Other factors more specifically associated with base 5th metatarsal stress fractures include cavus foot and varus hindfoot.^{50,53,54} These foot deformities can lead to increased load to the lateral column during ambulation, thereby increasing the risk of BSI in the area. Although cavus foot and/or hindfoot varus can be a risk factor for 5th metatarsal BSIs, surgical treatment of the deformity is typically not needed. Shoe modifications consisting of orthotics with a lateral post and forefoot posting was enough to allow fracture healing and prevent recurrence.⁵³

Patients typically present with localized pain over the lateral aspect of the 5th metatarsal. These symptoms can be present up to 18 months from presentation.⁵⁵ However, in some individuals, repetitive load stress reactions can manifest in a subclinical manner without the typical prodromal symptoms. An acute-on-chronic injury may occur, resulting in the localized typical pain overlying the base 5th metatarsal.

Initial radiographic assessment should begin with three view plain radiographs of the foot. Early radiographic findings can include cortical thickening at the lateral base of the 5th metatarsal.⁵¹ This can progress to a radiolucent fracture line (Figure 10.9).

FIGURE 10.9 Fifth metatarsal stress fracture in a 20-year-old football athlete involving zone 2 and extending into zone 3. (A) AP view and (B) lateral view.

AP, anteroposterior.

However, negative x-ray findings may not rule out an early BSI. In a setting of stress reaction without periosteal reaction, a fracture may not show up on plain radiographs. As a result, if there is continued clinical suspicion for a Jones fracture, an MRI should be obtained. An MRI is a much more sensitive modality compared to x-rays and can show localized bone edema, periosteal reaction, and cortical fracture line in higher grade injuries.^{36,56}

Treatment

Conservative treatment for BSIs of the base of the 5th metatarsal involves non-weight-bearing immobilization in a short leg cast or CAM boot for a minimum of 6 to 8 weeks or until radiographic evidence of fracture healing is identified. Clapper et al. reported 72% successful union in patients treated with non-weight-bearing immobilization with an average time to union of 21.2 weeks.⁵⁷

Due to the risk of delayed union and nonunion in this area, athletes should not be allowed to weight bear during this period. Weight bearing even in a cast or boot can lead to delayed union and high risk of a nonunion. Zelko et al. reported only 2 of 15 patients treated in a weight-bearing cast healed fully without surgical intervention. In those two individuals in whom healing occurred without surgery, time to union was 7 and 20 months.⁵⁸

Kavanaugh et al. reported a high rate of delayed union and nonunion in athletes treated conservatively. In their study, 12 of 18 patients had incomplete fracture healing at 6 months.⁴⁹ Konkel et al. reported delayed union in 4 of 13 patients with a Jones fracture or stress fracture of the base of the 5th metatarsal. Although in their series the delayed unions did heal, there was a considerable delay with average full union ranging from 3.5 months in Jones fractures to 4.8 months in stress fractures.⁵⁹

Case series of treatment with extracorporeal shockwave treatment exist in the literature for primary treatment of nonunion or in rare instances in failure to achieve union following surgical management; high-level evidence studies are currently lacking for evaluation of success in healing this injury.^{60,61}

Due to the delay in fracture healing, athletes may benefit from surgical treatment for earlier fracture healing and return to sport.^{55,57,62-64} Surgical treatment typically consists of an intramedullary screw fixation (Figure 10.10). If an area of sclerotic bone is observed in a chronic nonunion, curettage of the site with bone graft is recommended. Clapper et al. reported 100% union in their series of patients who underwent surgery for failure of conservative management. Average time to healing was 12.1 weeks versus 21.2 weeks for 18 patients treated with non-weight-bearing cast alone.⁵⁷

Delee et al. were the first to report the use of percutaneous intramedullary screw fixation with a 4.5-mm solid screw for 5th metatarsal diaphyseal stress fractures. They reported an average healing time of 7.5 weeks and return to sport in 8.5 weeks on average with no postsurgical complications or refracture.⁵⁵ Similar earlier fracture healing and return to play has been seen in other studies by Porter et al.⁶² and Pecina et al.⁶⁴ A systematic review of the literature between 1994 and 2010 demonstrated a return to sport at an average of 12 weeks for athletes treated with surgery versus 24 weeks for athletes treated conservatively.⁶⁵

Surgical technique options include solid screw fixation versus cannulated screws and which size screw to place at the fracture site. There is no clear clinical advantage between a solid and a cannulated screw. Theoretically, the solid screw will be less likely to break. However, Pietropaoli et al. in their biomechanical study found no difference between the two screws from a biomechanical standpoint.⁶⁶

Screw width should be a minimum of 4.5 mm or larger. Smaller screws have been shown to be correlated with delayed union and nonunion.⁶⁷ However, increasing the

FIGURE 10.10 Postoperative radiographs of the previously mentioned 20-year-old football athlete. (A) AP x-rays at 2 weeks after surgery. (B) Lateral view at 2 weeks after surgery. Note the screw threads extending just past the fracture line and filling the medullary canal to provide stability by improving pullout strength. (C and D) Radiographs obtained at 12 weeks after surgery demonstrating complete healing of the fracture.

AP, anteroposterior.

screw size to 5.0 and 6.5 mm has not been shown to improve fracture healing or improve fracture stiffness after fixation.^{68–70} One advantage of a larger screw compared to a 4.5-mm screw is the increased pull-out strength due to improved thread purchase.⁷⁰ In general, the widest screw that is needed to fill the medullary canal just distal to the fracture line should be placed (Figure 10.10). Although the 5th metatarsal can accommodate a 6.5-mm screw, this can result in stress shielding across the fracture and stress reactions distal to the screw fixation.

Another consideration for surgical fixation is screw length. Due to the lateral curvature and plantar bow, a long screw can result in perforation of the medial distal cortex and lead to fracture distraction or even a distal diaphyseal fracture.^{71,72} Based on the study done by DeSandis et al., screw length should be 50 mm or less with typical lengths of 40 mm or less.⁷¹ The distal screw threads of a partially threaded screw only need to pass the fracture site and should not extend to the distal diaphyseal cortex of the metatarsal (Figure 10.10).

Complications after surgical fixation include continued delayed union, refracture, hardware irritation, and sural nerve injury. The most common causes of delayed union or nonunion after surgical treatment are incomplete reaming of the sclerotic canal, undersized inlay bone graft, undersized screw, or early return to vigorous activity.^{67,73} Refracture can also occur from use of an undersized screw or after screw removal. In these situations, placement of a larger screw after reaming the canal is recommended.

In addition, resection of the sclerotic bone and autologous bone graft may be beneficial.⁷⁴ Athletes can also develop pain from the screw head and finally sural nerve injury. Pain from the hardware can typically be managed with shoe modifications.

The author's preferred treatment for athletes with a stress fracture in zones 2 and 3 is a solid, partially threaded intramedullary screw to allow earlier weight bearing, continuation of nonimpact conditioning, and earlier return to play.^{55,62–64} The widest screw that fills the intramedullary canal distal to the fracture on the anteroposterior fluoroscopy view is chosen to improve pull-out strength. Screw length is kept to the minimum needed to assure that all the threads are distal to the fracture line. If the fracture has a large area of sclerotic bone, the area is debrided and bone grafted using cancellous chips combined with iliac crest bone marrow aspirate.

Postoperatively, athletes are kept toe touch weight bearing for the first 1 to 2 weeks in a boot. They are then made weight bearing as tolerated in a boot for additional 4 weeks and progressed into a foot orthosis until radiographic fracture healing is observed. Athletes are not allowed to return to play until radiographic union of the fracture is observed. If the athletes have a cavus foot or varus hindfoot, they are placed into a custom orthotic with a lateral heel wedge and 1st metatarsal head well to reduce pressure to the lateral column.

To review, BSI localized to the base of the 5th metatarsal has a higher than typical risk of developing a delayed union or nonunion. Although there is evidence that these fractures can be treated with conservative management, elite athletes heal their fracture more reliably and with earlier return to play with surgical treatment. Fixation should consist of the widest screw that is needed to fill the distal intramedullary canal. Care should be taken to not place a screw that perforates the distal medial cortex. Athletes should return to play once fracture healing is observed radiographically. Activity level should be increased in a stepwise controlled manner as recurrence of the fracture can occur even with surgical fixation with early vigorous return to play.

SESAMOID BONE STRESS INJURY

Evaluation

Sesamoid is a bone that travels within a tendon typically situated near an angular structure in the body to improve mechanical strength of the tendon. An example of a large sesamoid bone is the patella of the knee. In the foot, the two main sesamoid bones are the tibial (medial) and fibular (lateral) hallucal sesamoid located plantar to the first metatarsal head. Stress fractures to these structures represent approximately 4% of foot and ankle injuries and less than 1% of all running disorders.⁷⁵

Of the two sesamoids, the tibial sesamoid is larger and slightly elongated in morphology. The tibial sesamoid is subjected to greater weight-bearing forces compared to the fibular sesamoid and thus is more commonly injured.^{46,76,77} Mechanically, the hallucal sesamoids have multiple functions, all of which help to improve the push-off ability of the hallux. First, they elevate the 1st metatarsal head to improve the strength of the flexor hallucis brevis as the tendon travels through the bone. Second, they function to protect the flexor hallucis longus as it travels between the two sesamoids. Finally, they modify and help dissipate the forces at the metatarsophalangeal joint.^{46,78} This last function is critical as greater than 50% of the body weight is transferred through the 1st metatarsophalangeal joint during gait cycle.⁷⁹

The main blood flow to the tibial and fibular sesamoid is from the medial plantar metatarsal artery and the plantar arch vessels.⁸⁰ The major vascular vessels enter the sesamoid at the proximal pole supplying up to two thirds of the blood flow to the bone with a small capsular vessel supplying the distal portion.^{81,82} The distal third with its

tenuous blood vascular supply along with the watershed area between the two vascular structures can lead to stress injuries in the sesamoid.

Ossification occurs between 9 and 11 years of age in multiple areas of the sesamoid.¹¹ The multiple ossification centers in a minority of individuals fail to fuse together during development. The incidence of tibial bipartite sesamoids ranges from 7.2% to 30.6%. The incidence of fibular bipartite sesamoid is from 0.6% to 2.5%.^{83–85} The rates of having a bipartite sesamoid on the contralateral side are approximately 25%.⁸⁶ The incidence of bipartite sesamoids can have significant implications in athletes as the presence of bipartite sesamoid on imaging studies, particularly x-ray can be interpreted as a sesamoid fracture in individuals having plantar first metatarsal head pain. It can be difficult to distinguish between the two.

Although the specific incidence of sesamoid BSIs in individual sports is not well studied, these injuries are most commonly observed in individuals participating in activities that require repetitive forced dorsiflexion such as dance, American football, gymnastics, and running.^{86–88} Rates of sesamoid stress fractures are more common in females than in males.⁸⁸ The mean age at the time of presentation ranged from 16.8 to 36.5 years.^{87,89} Similar to other stress fractures, biological and mechanical risk factors can be present, such as inadequate caloric intake, vitamin D deficiency, and improper training regimen.

Pain related to sesamoid BSIs typically has an insidious course with no specific acute injury or trauma. As a result, there can be a delay in presentation. Pain is localized to the plantar first metatarsal head. Symptoms are exacerbated by weight bearing, participating in impact sports, and climbing stairs. In addition, pain is worse with activities that require forced dorsiflexion at the 1st metatarsal phalangeal joint.⁸⁷ Discomfort and pain are generally improved with rest. On examination, athletes may have an effusion at the 1st metatarsophalangeal joint or swelling over the sesamoid. Pain is exacerbated by forced dorsiflexion.

Radiographic analysis includes a weight-bearing three view of the foot. Additional views to visualize the sesamoids can be done. This includes a medial oblique to help visualize the tibial sesamoid better and an axial sesamoid view (Figure 10.11A). However, initial radiographs may be negative as a periosteal reaction or fracture line may not be present if the athlete is evaluated soon after symptoms occur.

A true acute fracture of the sesamoids will exhibit sharp irregular borders on either side of the fracture, possible comminution, and fracture gap. In contrast, a bipartite sesamoid will have smooth cortical edges and may have a bipartite sesamoid on the contralateral side. Stress fractures are rarely bilateral.¹¹ Finally, the size of the bipartite sesamoid when measured together is larger than the nonpartite sesamoid.⁹⁰

MRI is sensitive and specific in evaluating for stress reaction consisting of sesamoiditis versus stress fracture as initial plain radiographs are routinely negative (Figure 10.11B).⁴⁶ In addition, MRI can help assess for osteonecrosis of the sesamoids and rule out adjacent tendinous and ligamentous injuries. A CT scan can also be obtained to identify a fracture line if there is high suspicion for a stress fracture on MRI or x-rays.

A bone scan can have a high rate of false positives. In one study of military recruits, it was shown that a mild to moderate increase in scintigraphic activity at the sesamoids was visualized in asymptomatic patients.⁹¹

Pain related to surface anatomy can be very helpful in narrowing the differential diagnosis. Sesamoid BSIs have pain localized directly over the bone at the plantar aspect of the first metatarsal head. Most commonly, it is pain over the tibial sesamoid. Pain at the dorsal, medial, or lateral aspect of the hallux can be due to other injuries such as collateral ligament tears, abductor hallucis tendonitis, and chondral injuries of the metatarsal head (Figure 10.12). Symptoms related to stress fractures of the sesamoids typically have an insidious course. An acute injury or trauma to the hallux with pain plantarly and inability to ambulate should direct you to consider turf toe until proven otherwise.

FIGURE 10.11 22-year-old runner with a 2-month history of increasing pain at the tibial and fibular sesamoids. (A) x-rays demonstrated a fibular sesamoid stress fracture best seen in the sesamoid view. (B) T1-weighted coronal MRI with findings consistent with those of a chronic stress fracture to the fibular sesamoid and patchy edema at the tibial sesamoid due to sesamoid stress reaction.

FIGURE 10.12 Typical location of pain in the forefoot due to the sesamoid injury/turf toe (A), medial collateral ligament injury (B), abductor hallucis injury (C), and 1st metatarsal chondral injury (D).

Treatment

Conservative treatment is the treatment of choice for sesamoid BSIs as a majority of athletes will improve without surgical intervention (Figure 10.13). Treatment involves anti-inflammatory medications, cessation of activities, treatment of any metabolic risk factors, and placement of the extremity into a short leg cast or boot and kept non-weight bearing for 6 to 8 weeks.⁸⁶ The athlete is then weaned into a custom-molded full-length orthosis with a proximal metatarsal pad and a relief well or viscoelastic polymer under the sesamoids. This can be combined with a carbon fiber forefoot plate or metal shank to restrict both forefoot motion and dorsiflexion.¹¹ Gradual resumption of activities can then be initiated. Other orthotic modifications include a Morton's extension once the fracture has healed to limit forced dorsiflexion through the 1st metatarsophalangeal joint. Cortisone injection is not recommended as this can be detrimental in fracture healing along with concerns of atrophy to the surrounding tissue. Low heel shoes should be utilized to reduce pressure to the metatarsal head.¹¹

Treatment of sesamoid stress reaction is similar to that of a stress fracture with activity modification and treatment of any risk factors. However, if symptoms are mild, they may be allowed to weight bear as tolerated in a boot for several weeks and weaned into an over-the-counter orthosis with a metatarsal pad. The orthotic can be placed into the boot for further comfort. A steel or carbon fiber shank can also be utilized to limit great toe dorsiflexion in their shoes. A custom-molded orthosis can also be used with the same modifications for a stress fracture.

Return to play with conservative treatment can take up to 14 weeks or longer. A recent meta-analysis demonstrated a return time to sport of 13.9 weeks with return rate of athletes to preinjury level of 64%.⁸⁸

The use of electromagnetic and low-intensity pulsed ultrasound bone stimulators can be considered. However, there are no reported studies that describe their efficacy in the treatment of sesamoid stress fractures.

Surgical indication is a failure of conservative management with symptoms occurring for greater than 6 months. Operative treatment can involve partial sesamoidectomy, complete sesamoidectomy, bone grafting without screw fixation, and percutaneous

FIGURE 10.13 The previous 22-year-old runner with fibular sesamoid and tibial sesamoiditis after 3 months of conservative management. Repeat radiographs demonstrated a healed stress fracture to the fibular sesamoid.

screw fixation. A complete sesamoidectomy should be done with caution as there can be a loss of up to 10% of push-off strength with this procedure.¹¹ Furthermore, tibial sesamoidectomy can increase the hallux valgus angle and intermetatarsal angle. In contrast, a fibular sesamoidectomy can decrease the hallux valgus angle and intermetatarsal angle. Athletes with a baseline hallux valgus deformity should be cautioned before proceeding. However, in a study done by Kane et al., the change in the hallux valgus angle and intermetatarsal angle was on average less than 1.1° and 0.8°, respectively, and did not result in any loss of function or activity level.⁹²

Biedert and Hintermann reported on a series of five athletes treated with proximal fracture fragment excision and repair of the flexor hallucis brevis. Four of the five patients returned to their sport without restrictions.⁸⁷

To avoid loss of push-off strength with a sesamoid excision, Anderson and McBryde described using bone autograft without internal fixation. Fracture gap was less than 3 mm. Of the 24 patients who underwent surgery, 19 healed radiographically and 17 athletes returned to their preinjury athletic activity and level.⁹³

Percutaneous screw fixation of a transverse sesamoid stress fracture has also been described with good results.^{89,94,95} Blundell et al., in their series of nine patients, used screw fixation. All of the patients had fracture union by 6 months and were able to return to their preinjury activity levels and sport with no complications.⁹⁴

Contraindications to both bone grafting and screw fixation include cartilage loss, hallux rigidus, and avascular necrosis of the sesamoid. Furthermore, sesamoidectomy should not be done if there is a congenital absence of the other sesamoid as this can significantly reduce push-off strength and result in a dorsiflexion deformity of the great toe.

A meta-analysis comparing conservative versus surgery treatment demonstrated that athletes returned to their sport significantly quicker with operative care by 2.9 weeks. Athletes with fractures treated with sesamoidectomy returned to play faster than those treated with internal fixation. In addition, athletes with fibular sesamoid BSIs regardless of treatment were found to return to play quicker than those with tibial stress fractures.⁸⁸

The author's preferred treatment for stress fracture to the sesamoids is conservative, nonoperative treatment for minimum of 6 months. Athletes are placed into a boot and kept non-weight bearing for 6 weeks. They are then allowed gradual weight bearing in a boot and weaned into a custom-molded orthosis with a 1st metatarsal pad and relief well at the sesamoids. Gradual resumption of activities is allowed thereafter (Figures 10.11 and 10.13).

If the athlete has failed 6 months of conservative management with continued fracture line or is unable to return to their activity level, repeat MRI is done to rule out avascular necrosis of the sesamoids and to evaluate for arthritis at the sesamoid metatarsal complex. If the fracture line is present with a fracture gap of 2 mm or less, bone grafting will be done. If, however, the fracture gap is larger or arthritis or avascular necrosis is observed, then complete sesamoidectomy will be done. Finally, if the fracture fragment is small, then a partial sesamoid excision with repair of the flexor hallucis brevis will be recommended.

Postoperatively, athletes are kept non-weight bearing for 3 weeks after a complete sesamoid excision or 6 weeks for bone grafting. They are placed into a short leg splint for 2 weeks after surgery and a boot thereafter. Athletes are weaned out of the boot into a regular shoe with a full-length semi-rigid foot orthosis, with a 1st metatarsal pad and relief well at 6 weeks in patients with sesamoid excision and in 10 weeks for those treated with bone graft. High-impact activities including running, jumping, and cutting are restricted until 16 weeks after surgery for both excision and bone graft athletes.

The most common complication from nonoperative treatment is the long duration of symptoms athletes may have even after radiographic union of the fracture. The rates of

persistent pain can range from 30% to 100%. In addition, 20% to 33% of patients may convert to operative management.^{86,96,97}

The risks related to complete sesamoid excision are most commonly related to an increase in varus or valgus angle at the 1st metatarsophalangeal joint depending on whether the fibular or tibial sesamoid is excised. The great toe goes into a more valgus position with a tibial sesamoid excision and varus with fibular sesamoid excision. Risks are low for a symptomatic hallux varus or valgus deformity with rates of 4% for each.^{98,99} Other risks of surgery include nonunion after bone grafting, postoperative scarring with neuroma symptoms at 8%,⁹⁸ transient paresthesia at 18%, and postsurgical continued pain at 18%.⁹⁹ A study by Anderson and McBryde found 10% of continued nonunion after bone grafting and 5% of neuropathic pain in their bone grafting patient group.⁹³ One of the most recalcitrant complications to treat is avascular necrosis of the sesamoids after a stress fracture. Kane et al. in their retrospective review of 37 patients with sesamoid fracture, either direct or stress related, found 9 cases of avascular necrosis of the sesamoids.⁹² However, other studies evaluating sesamoid stress fractures did not observe avascular necrosis as a potential complication.

In summary, sesamoid BSIs have an insidious course with typically delayed presentation. Localized pain to the plantar distal 1st metatarsal head is the most common symptom. The majority of these fractures will heal with conservative care and return to sport; however, symptoms can be present for a much longer period of time even after radiographic union of the fracture. Nonoperative care should be continued for up to 6 months before considering surgical intervention. Although many surgical techniques have been described, the most optimal technique is yet to be identified. Sesamoidectomy offers the earliest return to play; however, athletes can lose some push-off strength, and in a setting of baseline hallux valgus deformity, their deformity can worsen with tibial sesamoidectomy. The decision to operate should be made cautiously.

CONCLUSION

BSIs in the foot and ankle are a common cause of injuries in the athlete. Many of these are low-risk injuries and can be treated conservatively with activity modification and a short period of immobilization. However, some of these stress fractures can occur in bones that require very specific treatments such as at the navicular and 5th metatarsal. BSIs in these high-risk areas require very specific treatments such as extended non-weight bearing, and, in some situations, surgery may be needed to increase the healing rate. As a result, physicians must have astute knowledge of the foot and ankle to be able to differentiate between the two types of injuries. Understanding the mechanics of the foot and ankle along with knowing the key surface anatomy is critical so that correct diagnosis can be made to provide optimal and timely treatment. Failure to identify these high-risk injuries can result in not only incorrect diagnosis but also a delay in the proper treatment, which can have profound results in the athlete's ability to return to play. Finally, regardless of the type of injury, high-risk versus low-risk by anatomy it is important to identify and correct any biological and biomechanical risk factors for stress injuries to improve the healing rate and reduce future recurrences.

KEY REFERENCES

Only key references appear in the print edition. The full reference list appears in the digital product found on <http://connect.springerpub.com/content/book/978-0-8261-4424-9/part/sec02/chapter/ch10>

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