MR imaging of stress fractures in foot and ankle

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Learning objectives

To know where stress fractures occur in foot and ankle

To know what kind of complications happen for stress fracture
Background

In athletes, stress fractures of foot and ankle are common and lead to considerable delay in return to play. We review various stress fractures of foot and ankle using MRI. In addition, we show complications associated with stress fractures.
Findings and procedure details

1. Stress fracture of medial malleolus (Figure 1)

Stress fracture of medial malleolus is one of the high risk fractures which require surgery because conservative therapy causes nonunion (Figure 2). Fracture line is usually recognized to the vertical direction, but we sometimes detect horizontal direction of fracture line (Figure 3). Players performing a jump like a volleyball and basketball player frequently have much stress fracture of medial malleolus because traction force from deltoid ligament by jump arises to stress fracture of medial malleolus.

2. Stress fracture of calcaneus

Calcaneal stress fracture usually occurs alone (Figure 4). Marathon runners and baseball players (younger patients than marathon runners) have much calcaneal stress fracture. Ankle X ray often shows no evidence of fracture line at calcaneus. On MR, irregular shaped fracture line that shows low signal intensity on both of T1 and T2 weighted images is demonstrated (Figure 4). High signal intensity area suggestive of bone marrow edema on STIR image is also visualized around fracture. Calcaneal fracture occurs to many places, such as calcaneal body, neck, head and so on (Figure 5).

3. Stress fracture of metatarsal

Metatarsal stress fracture usually involves the mid portion of second, third or fourth metatarsal (Figure 6 and 7). However, strong axial force toward the metatarsal bone causes stress fracture at basal potion of first and second metatarsal bone or head of second metatarsal bone.

Marathon runners typically have much this fracture, especially mid portion of 2nd-4th metatarsals. In younger athletes, football players also have this fracture. Ballet dancers lead to fracture of basal portion of 1st and 2nd metatarsal fracture, and head of 2nd metatarsal.

Stress fracture of 5th metatarsal is different prognosis ant treatment from other metatarsals (Figure 8). Stress fracture of 5th metatarsal is the same as medial malleolus stress fracture and requires surgery. Peroneus brevis tendon is attached to the fifth metatarsal bone. Actions, such as stopped or running suddenly of footballers become a burden of the peroneus brevis tendon and make traction force to 5th metatarsal attachment of proneus brevis tendon. Such a repetitive force is applied to the 5th
metatarsal, 5th metatarsal stress fracture occurs, and it leads to nonunion because of keeping the rest is difficult (Figure 9).

4. Stress fracture of navicular

Navicular bone is one of small tarsal bones and is located central area of them. Navicular has a lot of articular surface, so it has poor blood supply as compared to the other tarsal bones. Therefore, navicular tends prone to nonunion (Figure 10). Fracture line is usually found in the longitudinal direction, but it may become sometimes cruciform (Figure 11).

5. Stress fracture of Talus (Figure 12)

Stress fracture of talus is rare. Only a few small studies have been published. Sormaala MJ et al. reported that, of the 56 bone stress injuries, 40 occurred in the head, 15 in the body, and 5 in the posterior part of the talus. In addition, they also reported that stress fractures of the talus do not seem to seriously damage the foot, and in a middle-term follow-up, however, minor to moderate symptoms and radiological degeneration of the injured area prevailed in roughly half of the patients.

6. Stress fracture of cuboid and cuneiform (Figure 13,14)

Stress fracture of cuboid and cuneiform are extremity rare. Only a few small studies have been published. Both of cuboid and cuneiform stress fractures are elder patients than others stress fracture.

Regard to stress fracture of cuboid, Yu SM reported that an isolated stress fracture of the cuboid is most likely to occur in the lateral aspect of the cuboid. The cause is likely multifactorial and may include compressive and tensile forces, but plantar fascia dysfunction and age-related bone loss, which are more prevalent in women, may be additional contributing factors.

Regard to stress fracture of cuneiform, Bui-Mansfield LT et al. reported that plantar fascia injury, changes in gait, large body habitus, and excessive or new onset of exercise regimens are all potential causes of cuneiform stress fractures.

Considering from these reports, we have to check cuneiform and/or cuboid stress fracture if patients have plantar fascia dysfunction such as plantar fasciitis.

7. Stress fracture of sesamoids (Figure 15)
Stress fracture of sesamoid in the first metatarsal head often complicates avascular necrosis, sesamoiditis, osteochondral fractures and chondromalasia. This is because the sesamoids are located centrally and plantar to the first metatarsal head, where they are imbedded within the plantar plate, which transmits 50% of body weight and more than 300% during push-off, is susceptible to numerous pathologies\textsuperscript{5).}
**Fig. 1:** Stress fracture of medial malleolus (16 year old male) He has been playing football for 10 years. He has had ankle pain at medial aspect with swelling during playing football. Ankle X ray (a) shows linear radiolucent area with sclerotic rim at medial malleolus (arrow). The same finding is visualized on CT (b,c). This finding is consistent with stress fracture of medial malleolus.

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Fig. 2: Nonunion of medial malleolus fracture (16 year old male) He has been a marathon runner for 4 years. He was diagnosed as stress fracture of medial malleolus a half year ago, but his ankle pain continues for half a year. Ankle CT shows radiolucent line suggestive of fracture at medial malleolus (a) (arrow). Although osteosclerotic change adjacent to fracture line is demonstrated (b) (arrow), bone union is not detected.

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Fig. 4: Stress fracture of calcaneus (12 year old male). He is a baseball player in his school and has had a heel pain for a month. There is evidence of linear low signal intensity suggestive of fracture at posterior aspect of calcaneus (Figure 4ab, arrows). High signal area consisted with bone marrow edema on STIR image is also widely visualized in the calcaneus (Figure 4b, arrowheads).

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Fig. 5: Variation of stress fracture of calcaneus (a. 16 year old female, b. 27 year old female) a. There is evidence of low signal intensity line consisted with fracture in the calcaneal neck on FS-T2 weighted image (arrow). Bone marrow edema is demonstrated as high signal intensity. b. Small low signal area is visualized in the calcaneal body on T1 weighted image (arrow). This patient has a calcaneo-navicular coalition (arrowhead). This calcaneo-navicular coalition may cause limited calcaneal motion and occur to stress calcaneal fracture.

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**Fig. 6:** Stress fracture of 3rd metatarsal (12 years old male) He has played football for 6 years. He has dorsal foot pain during running. Foot X ray shows no evidence of fracture (a). Medial sesamoid bone is separated (arrow) and lateral sesamoid is indistinct. On STIR MR image, 3rd metatarsal shows high signal intensity suggestive of bone marrow edema. Periosteal reaction of 3rd metatarsal is also visualized (arrow) (b). These findings are consistent with stress fracture of 3rd metatarsal.

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Fig. 7: Stress fracture of 4th metatarsal (12 years old female) She has started as a track and field athlete for 3 months. She has had a lateral foot pain. Foot X ray is normal (a). On STIR MR image, there is evidence of fracture at proximal portion of 4th metatarsal with bone marrow edema (b) (arrow). Periosteal reaction is also seen. These are compatible with 4th metatarsal stress fracture.

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Fig. 8: Stress fracture of 5th metatarsal (17 year old male). He is a football player and has had lateral foot pain. There is evidence of bony fracture with callus formation at proximal aspect of 5th metatarsal (arrow) both of T1 weighted and STIR image (a, b). Bone marrow edema is visualized as high signal intensity at 5th metatarsal diffusely on STIR image (b). Fracture line of 5th metatarsal is irregular, so it is consistent with stress fracture.

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**Fig. 9:** Nonunion of 5th metatarsal stress fracture (16 year old female) She is a gymnast. She diagnosed 5th metatarsal stress fracture 2 months ago. She has received conservative therapy for 2 months, but on foot X ray (a), fracture line is clearly visualized (arrow). There is no evidence of callus formation. Bony fragment shows normal signal without bone marrow edema or callus formation on T2 weighted image (b, c). Fracture line is seen as a low signal linear area (c). These findings are consistent with nonunion.

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Fig. 10: Stress fracture of navicular (17 years old female). She is a tennis player. She has diagnosed stress fracture of navicular and received conservative therapy for 3 months; however, she has had her foot pain. Foot X ray shows evidence of radiolucent linear opacity suggestive of stress fracture in mid portion of navicular (arrow). Each bony fragment is slightly away (b) (arrow) on T1 weighted image. There is no evidence of callus formation. These are consistent with nonunion. Slight bone marrow edema is visualized on GRE-T1 weighted image (arrow).

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**Fig. 11:** Stress fracture of navicular (17 years old male). He is a member of Smou club (Smou is one of Japanese traditional sports). He has bilateral foot pain during doing Smou. Bilateral foot CT shows cruciform fracture line in his left navicular (b) (arrows). In his right navicular, there is a fracture line in the horizontal direction (a) (arrows). There are no evidence of callus formation in bilateral navicular. These findings are compatible with nonunion.

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**Fig. 12:** Stress fracture of talus is rare. Only a few small studies have been published. Sormaala MJ et al. reported that, of the 56 bone stress injuries, 40 occurred in the head, 15 in the body, and 5 in the posterior part of the talus\(^1\). In addition, they also reported that stress fractures of the talus do not seem to seriously damage the foot, and in a middle-term follow-up, however, minor to moderate symptoms and radiological degeneration of the injured area prevailed in roughly half of the patients\(^2\).

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Fig. 13: Stress fracture of cuboid (16 year old female) She is a member of Kendo club (Kendo is one of Japanese traditional sports, Budo). She has lateral foot pain when she depresses the foot. On CT, oblique linear opacity consisted stress fracture is visualized at anterior aspect of cuboid (a) (arrow). On FS-T2 weighted MR image, low signal fracture line is visualized (b) (arrow). Bone marrow edema is also demonstrated around the fracture.

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Fig. 14: Stress fracture of medial cuneiform (unknown age, female) She has had a foot pain for one month. On T1 weighted MR image shows small low signal line consisted with bony fracture in dorsal area of medial cuneiform (a) (arrow). Medial cuneiform shows faint high signal suggestive of bone marrow edema on STIR image. Stress fracture of medial cuneiform is suspected.

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Fig. 15: Stress fracture of sesamoid (18 year old male) He has 1st MTP joint pain. He has been an amateur football player for 12 years and has a history of that pain for a long time. On foot X ray, medial sesamoid is separated (a) (arrow). There is no evidence of joint space narrowing or osteophyte suggestive of osteoarthritis in 1st MTP joint. On CT, the same finding is visualized (b) (arrow). It is consistent with nonunion of sesamoid stress fracture.

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Conclusion

Stress fracture of foot and ankle is characteristic on each site.

Some of stress fracture is easy to detect on only X ray, but stress fracture such as tarsal bones (cuneiform, cuboid and so on) is often misdiagnosed.

Foot and ankle MRI and/or CT is the preferred exam for further characterization of the majority of these stress fractures. We catch characteristics of the stress fracture well and should perform MRI /or CT.
References