Current Physical Medicine and Rehabilitation Reports
https://doi.org/10.1007/s40141-024-00437-7

REVIEW

Current Concepts in the Evaluation, Management, and Prevention of Common Foot and Ankle Injuries in the Runner

Alexis S. Tingan[1,2] · Aisha Bowen[1] · Chelsea Salas-Tam[1] · Matthew Roland[2] · Apurva Srivastav[2]

Accepted: 20 January 2024

Abstract

Purpose of Review Running-related injuries (RRIs) are a common cause of dysfunction among runners. Foot and ankle injuries are among the most common RRIs. The purpose of this review is to detail current concepts in the pathophysiology, evaluation, management, and prevention of foot and ankle RRIs.

Recent Findings Running gait analyses are helpful in identifying biomechanical and kinematic abnormalities that can be targeted in rehabilitation. Musculoskeletal ultrasonography is now being used to both qualitatively and quantitatively assess tissue integrity to guide diagnosis, prognosis, and return to run decision-making. Recent treatment analyses have demonstrated that rehabilitation exercises are vital for restoring tissue function. The effectiveness of gait retraining and shoe modification is unclear. There is emerging evidence that training the foot core muscles is preventative against RRIs. Although injections such as orthobiologics have recently gained popularity, their long-term effectiveness in the management of foot and ankle RRIs remains inconclusive.

Summary A comprehensive review of RRI risk factors and a thorough physical examination are vital for identifying RRIs. Ultrasonography is an emerging diagnostic modality for RRIs. Treatment should center around extrinsic risk factor reduction, activity modification, rehabilitative exercise, and a gradual return to run progression. Caution should be used when considering injections, particularly orthobiologics, for the management of RRIs. Future research should be performed to investigate the effectiveness of gait modification and the effectiveness of orthobiologics in the treatment of RRIs.

Keywords Running injury · Foot and ankle injury · Tendinopathy · Injury prevention · Running injury treatment · Running evaluation

Introduction

It is estimated that 40% of runners are injured on a yearly basis [1]. The foot and ankle are the first structures in the running gait cycle to accept the vertical ground reaction force at initial contact and the final structures propelling the body forward at takeoff [2]. The foot and ankle function as force attenuators at initial contact and springs at takeoff. It is no surprise then that the foot and ankle are common sites of running-related injuries (RRIs) [1, 3].

This review will discuss the pathophysiology, evaluation, management, and prevention of common foot and ankle RRIs. In a 2016 review, Tenforde explored the evaluation management of running-related tendinopathies, ligament and fascia conditions, bone conditions, joint disorders, and nerve disorders [4]. We will take a similar approach with our review of the overuse injuries in the foot and ankle with an emphasis on the most recent developments in evaluation

✉ Alexis S. Tingan
alexis.tingan@jefferson.edu

Aisha Bowen
aisha.bowen@jefferson.edu

Chelsea Salas-Tam
chelsea.salas-tam@jefferson.edu

Matthew Roland
matthew.roland@jefferson.edu

Apurva Srivastav
apurva.srivastav@jefferson.edu

[1] Division of Sports and Exercise Medicine, Department of Family and Community Medicine, Thomas Jefferson University, 1015 Walnut St. Suite 401, Philadelphia, PA 19107, USA

[2] Department of Rehabilitation Medicine, Thomas Jefferson University, 1015 Walnut St. Suite 401, Philadelphia, PA 19107, USA

Published online: 24 February 2024

and management. Our focus will be on the most common injuries and those injuries with the most recent clinical findings. Where appropriate, we will also emphasize preventative techniques for these conditions.

While traumatic injuries are frequent among runners, the majority of RRIs are due to overuse [1, 3]. We will therefore primarily focus on injuries affected by the repetitive nature of running. We will begin with a discussion of the core principles of the pathophysiology, evaluation, management, and prevention of foot and ankle RRIs. We will then proceed to a discussion of specific injuries.

Pathophysiology of Running-Related Injuries

There is evidence that humans are specifically adapted to run, but the prevalence and incidence of overuse injuries in modern runners suggests an environmental mismatch between the applied load to the body and the body's ability to repeatedly accept this load [5–8]. This disequilibrium in tissue homeostasis causes tissue damage in specific foot and ankle structures which then causes pain related to these structures. Modulating tissue load and tissue integrity is therefore vital in the management and prevention of RRIs.

Evaluation of Foot and Ankle Running-Related Injuries

The initial evaluation of overuse of foot and ankle RRIs should begin with understanding why the patient is running. There are various reasons for running: health, recreation, athletic scholarship, competition, mental health, and even transportation [9–11]. Understanding the reason for running allows the clinician to craft an individualized treatment plan for the injured runner.

The clinician should next identify the source of the tissue load disequilibrium. This should begin with a detailed history and physical examination. History should identify the extrinsic sources of injury and focus on the level of competition, past injuries, training volume, running surfaces, shoe wear, age, sex, body weight, systemic diseases, and risk factors for relative energy deficiency in sport (RED-S). Physical examination identifies the intrinsic sources of injury and should follow the typical musculoskeletal systematic approach of inspection, palpation, range of motion, strength, neurovascular testing, and special tests. Observation of walking gait is also useful to evaluate the degree of dysfunction the injury is causing. In high-level athletes and patients with chronic foot and ankle injuries, a running gait analysis is performed to identify biomechanical and kinematic features that may predispose the runner to injury. However, caution should be used with findings from running gait analyses as they are typically performed in a controlled setting indoors on a treadmill and do not reflect the typical running environment of most runners [12].

Many overuse running injuries in the foot and ankle are clinical diagnoses and do not require diagnostic testing. Diagnostic testing in these cases is indicated when the diagnosis and cause are not clear, there is concern for a more serious condition, or symptoms are persistent despite appropriate conservative management. For two of the diagnoses discussed in this review, bone stress injuries (BSI) and osteoarthritis, diagnostic imaging is necessary to definitively establish the diagnosis [13, 14].

Management and Prevention of Running-Related Injuries

The crux of the treatment and prevention of overuse of RRIs lies in modulating the load applied to the foot and ankle with the integrity of the tissues accepting the load. The most straightforward method to treat and prevent these injuries is running volume modification [7, 8, 15]. For example, in our practice, many runners have an inadequate understanding of the appropriate amount of running volume. In these cases, we have found that simply decreasing the running load can heal the running injury without the need for medications, rehabilitation exercises, or invasive treatments.

Other treatments include rehabilitation, orthotics, non-steroidal anti-inflammatory drugs (NSAIDs), injections, and surgical management. Of these, rehabilitation most effectively restores optimal biomechanics needed to withstand the repetitive stress of running [16–20]. Foot core training is emerging as an effective rehabilitation method [21]. Foot core exercises train the intrinsic muscular, extrinsic muscular, and neuromuscular function of the foot and ankle [18]. This optimizes the force dampening function of the foot and ankle on initial contact and the spring-like function on takeoff. Such training can be used for the treatment and prevention of foot and ankle RRIs. In a 2020 randomized trial, Taddei demonstrated that foot-core-trained running athletes were 2.42 times less likely to sustain any RRI, including foot and ankle RRIs [22••].

Much has been made of the relationship between foot strike pattern and RRIs. It is notable that the foot and ankle experience higher impact forces with rear foot striking (RFS) compared to forefoot striking (FFS) [2, 23] However, to date, there is no strong evidence suggesting that modification of foot strike pattern is preventative against RRI. Nonetheless, gait retraining can be used to treat specific foot and ankle diagnoses [19]. Further, increasing running cadence has been shown to improve running kinematics and reduce impact loading on the lower extremities [23, 24]. A 2022

analysis by Shen showed that combining foot core exercises with gait retraining (RFS to FFS) positively affects foot biomechanics and kinematics [25•].

Shoe wear and shoe wear modifications are also an area of inconclusive evidence. The debate between shod and barefoot running began in earnest with the publication of the popular book *Born to Run* in 2009 [26]. Although running kinematics are improved with barefoot running, there is no consensus if barefoot running confers specific advantages to the treatment and prevention of RRIs [27]. In a 2021 randomized single-blinded controlled trial, Hollander demonstrated that switching from shod to barefoot running decreases running stability over time [28]. Further, barefoot runners preferentially FFS which may predispose the foot to more stress on the forefoot on initial contact and increase the eccentric loading forces in the posterior compartment of the lower leg [2, 27]. In our practice, we do not advise a change in shod condition if a runner is running pain-free and achieving their desired fitness goals. For those that wish to change their shod conditions, we recommend moderation and a slow transition from shod to barefoot or barefoot to shod.

The typical advice given to runners is to replace running shoes every 300 to 500 miles or every 3 to 6 months [29]. In one of the earliest shoe-wear biomechanical studies, Cook showed that shoes retain less than 60% of their initial shock absorption capacity between 250 and 500 miles [30]. Therefore, runners should habitually exchange their shoes at regular intervals. Orthotics are sometimes prescribed to runners to alter foot mechanics with specific injury patterns. However, there is a paucity of evidence for their effectiveness as a preventative strategy.

NSAIDs and injections are primarily temporizing treatments that do not significantly alter foot and ankle biomechanics. Injection care includes corticosteroids, anesthetics, prolotherapy, botulinum toxin, hyaluronic acid, and orthobiologics. Regenerative medicine using orthobiologic injections such as platelet-rich plasma (PRP) and stem cells continue to be an emerging treatment option that we will discuss further in specific diagnoses. Surgery is typically reserved for recalcitrant cases of overuse injuries.

Achilles Tendinopathy

Achilles tendinopathy (AT) is one of the most common RRIs with an incidence and prevalence of 10.3% and 6.6% respectively among non-ultramarathoners [1]. It carries a lifetime cumulative incidence of 52% [31]. The medial and lateral gastrocnemius join the deep soleus to form the Achilles tendon. The Achilles tendon inserts onto the posterior calcaneus and functions as the primary plantar flexor of the foot and ankle [32, 33] Acutely, Achilles tendinitis refers to inflammation involving the Achilles tendon and paratenon. This is distinguished from the more accurate term Achilles tendinopathy which refers to a chronic histopathologic degenerative process due to overuse and cumulative microtrauma causing remodeling of the tendon tissue [4, 32, 34, 35].

AT is primarily a clinical diagnosis. Patients typically report developing Achilles or calcaneal pain associated with running. Evaluation begins with a thorough history examining extrinsic risk factors [36]. The clinician should also inquire about a history of acute injury. Physical exam follows the previously described typical systematic approach to musculoskeletal injuries in runners. Examination begins with inspection for deformity, swelling, bruising, and erythema. Observation of antalgic gait can reveal a more severe tendinopathy. On palpation, special attention should be paid to the two most common sites of injury at the tendon insertion site and the hypovascular zone 2 to 6 cm proximal to the tendon insertion [37, 38]. Deficits in ankle dorsiflexion between the affected and nonaffected ankle can be seen in AT. Special tests include the painful arc test and the Royal London Hospital test to assess the focal point of pain [17]. Functional tests such as the heel-rise test and the hop test are also useful to assess the degree of injury [16]. Other special tests have utility in ruling out other Achilles and calcaneal pathologies. The Thompson test can rule out tendon ruptures in cases of acute presentation of Achilles tendon pain [39]. The calcaneal squeeze test evaluates for a bone stress injury (BSI) at the calcaneus.

Imaging is typically not initially indicated for the diagnosis of AT. Weight-bearing lateral and axial radiographs can show calcaneal enthesopathy and calcific tendinitis, indicating the source of pain. Magnetic resonance imaging (MRI) is valuable in ruling out Achilles tendon rupture and calcaneal stress injury. On MRI, AT is associated with a dysmorphic, enlarged tendon, and retrocalcaneal bursitis [40, 41].

Musculoskeletal ultrasonography has emerged as a very useful modality to assess the Achilles tendon. Ultrasonography evaluates tendon morphology and the presence of pathologic conditions. In particular, the presence of neovascularization on ultrasonography is a useful indicator of the source of pain. There is evidence that pain pathways associated with tendinopathy are due to the proximity of nerve structures to new blood vessel formation [42, 43]. Recently described shear-wave elastography (SWE) is a type of ultrasonography that measures the mechanical properties of the Achilles tendon [16, 44, 45]. Newer analyses employ radiomics with ultrasonography to quantitatively assess AT [46]. Although ample evidence exists showing morphologic changes in the Achilles tendon in asymptomatic individuals, ultrasonographic analyses can nonetheless be useful to predict future development of AT and to track prognosis and progression with treatment [16, 47, 48].

Running gait analyses evaluate biomechanical and kinematic risk factors for the development of AT. Historically, foot overpronation was thought to significantly contribute to the development of AT [49, 50]. However, a recent systematic review and metanalysis demonstrated the primary difference between runners with AT and controls is rearfoot eversion at the initial heel strike [50].

Acute phase AT management focuses on achieving adequate pain reduction with a trial of rest, stretching, ice, and NSAIDs as needed. Immobilization in a boot may be helpful for particularly painful cases, but the length of time in a boot should be limited to avoid the development of ankle stiffness. Long-term management of AT centers around modifying running volume and optimizing Achilles tendon load capacity [16]. Rehabilitation continues to be the treatment with the highest level of evidence for the treatment of Achilles tendinopathy [16, 17]. AT rehabilitation phases emphasize tendon loading to promote tendon remodeling, decrease pain, and improve lower leg strength and endurance [16, 51]. Rehabilitation also addresses biomechanical and kinematic abnormalities in the foot, ankle, and entire kinetic chain identified on running gait analysis.

Runners with refractory disease may consider extracorporeal shock wave therapy (ESWT), prolotherapy, or orthobiologic injections. All of these treatments have shown potential for pain relief in case series but have not proven to be superior to rehabilitation for long-term pain relief and return to running [17]. In a 2023 systematic review and meta-analysis by Masiello comparing PRP injection for AT against placebo, PRP did not show statistically significant improvement versus the control group [52]. Due to the well-established link between steroid injection and risk for rupture in high load–bearing tendons, we do not recommend steroid injection into the Achilles tendon. Given these findings, our recommendation is to educate the runner on the risks and benefits of these treatments in a shared decision-making treatment plan.

Prevention of AT centers around appropriate running volume and optimizing running mechanics. Foot core training has shown promise in preventing AT and other RRIs [22••]. Avoiding fluoroquinolones and other medications that are associated with tendinopathy is advised to lower the risk of AT [32]. There are inconsistent findings on alcohol intake, but higher consumption may inhibit collagen synthesis and increase risk [53]. Collagen supplements may be beneficial, but specific dosage, timing, and duration are unknown ([53].

Plantar Fasciopathy

Plantar fasciopathy represents one of the more common running-related injuries and affects up to 17.4% of the running population [3, 20, 54]. The plantar fascia originates from the posteromedial calcaneal tuberosity and inserts into each metatarsal head to form the longitudinal arch of the foot. It functions as a static and dynamic stabilizer of the medial longitudinal arch of the foot. Plantar fasciopathy is the preferred term as it encompasses the entirety of the inflammatory and degenerative components of the condition [55]. Repetitive stress of the plantar fascia results in this histopathologic process.

The runner will typically present with pain on the medial plantar surface of the foot. The symptoms are often worse in the morning upon taking the first steps of the day. With running, symptoms typically improve during the run and worsen upon completion of the run.

Physical examination begins with inspection for pes cavus, pes planus, and leg length discrepancy, all of which are associated with plantar fasciopathy [56, 57]. Observation of antalgic gait can reveal a more severe fasciopathy. Palpation of the medial calcaneal tubercle often elicits sharp pain. Decreased ankle range of motion is an important risk factor for plantar fasciopathy [56, 57]. The calcaneal squeeze test evaluates for a BSI at the calcaneus.

Diagnostic imaging is not initially needed if history and physical examination clearly indicate plantar fasciopathy. Weight-bearing foot radiographs can reveal calcaneal enthesophytes; however, there is not a direct association between heel spurs and plantar heel pain. MRI more specifically evaluates the integrity of the plantar fascia, assesses for the presence of plantar fascia rupture, and can evaluate for a BSI. As with other foot and ankle RRIs, ultrasonography is proving to be a useful diagnostic modality [20].

As with other overuse injuries, rest and running volume modification are the initial steps for the management of plantar fasciopathy. Rehabilitation exercises are the cornerstone of management. There is high-level evidence that passive stressing and progressive eccentric loading are effective exercise approaches [20, 58, 59]. Injection care with corticosteroids, botulinum toxin, and PRP has shown long-term benefit. However, these studies were primarily performed on non-runners, and their application to the long-term care of runners is unclear [20, 58]. We recommend plantar fascia injections be performed using ultrasound guidance to minimize complications such as neurovascular damage, fat pad atrophy, and plantar fascia rupture. Other treatments include manual therapy, iontophoresis, low-dye and calcaneal taping, ESWT, and acupuncture. These treatments can help with symptoms but there is no high-quality evidence demonstrating their long-term effectiveness [20, 58]. There is not good evidence that a specific gait retraining program for plantar fasciopathy confers long-term benefit.

Posterior Tibial Tendon Dysfunction

Posterior tibial tendon dysfunction (PTTD) has an incidence and prevalence of 0.4% and 1.1% respectively among non-ultramarathon runners [1]. The tibialis posterior is the primary inverter of the foot and ankle. PTTD is a four-stage process starting from acute inflammation and ending in tendon degeneration and painful pes planus deformity [60, 61]. The retromalleolar region is hypovascular and susceptible to tendinopathy [62].

The runner typically presents with medial foot and ankle pain and difficulty with tendon loading activities [63]. Loss of the medial longitudinal arch may be seen [64]. Positive exam findings are pain on palpation of the tendon, swelling around the tendon, pain/weakness with ankle/foot inversion, and pain or weakness with a single leg heel raise [62, 65]. Radiography is useful to rule out fracture in acute injury and to evaluate foot/ankle morphology predisposing to PTTD [66]. MRI is useful to evaluate abnormalities in the surrounding medial ankle structures. Ultrasonography has emerged as an indispensable tool in the evaluation of PTTD as it allows for direct visualization of the posterior tibial tendon and tendon sheath along the four-stage pathophysiologic process [66].

PTTD treatment is primarily non-operative with NSAIDs, immobilization, bracing, and foot orthoses for arch support Rehabilitation focuses on eccentric exercises to stretch the tight gastrocnemius and strengthen the tibialis posterior muscles [64, 67]. There is low-quality evidence for prevention with orthotics or shoe type [18]. There is little research on the role of kinematics and gait retraining for PTTD in runners, but qualitative abnormalities seen on gait analyses can be targets for orthotic and rehabilitative management. Corticosteroids should be used with caution in this high load–bearing tendon. We are not aware of any peer-reviewed case reports or clinical studies involving PTTD and orthobiologic treatment. Surgical management is considered in recalcitrant or late-stage cases [62, 64, 66].

Bone Stress Injuries

Bone stress injuries (BSI) in runners are a common injury with an incidence and prevalence of 4% and 5.7% respectively [1]. Opposed to many other overuse RRIs, the initial mismanagement of BSIs can lead to significant morbidity, and the clinician should maintain a healthy suspicion of BSI in certain clinical settings. The most common sites of foot and ankle BSI are in the tibia, fibula, metatarsals, tarsal navicular, and calcaneus [68]. BSIs are caused by microdamage from repetitive mechanical loading and overuse that surpasses the adaptive ability of bone remodeling [69]. High-risk BSIs in the foot and ankle are the navicular, base of the fifth metatarsal, great toe sesamoids, talus, and the medial malleolus [13]. These bones are at risk either due to their delayed clinical diagnosis or their relative hypovascularization leading to improper healing or non-union [13].

BSIs typically present in runners as an insidious foot or ankle pain in an acute to subacute period. Clinical evaluation begins with the assessment of intrinsic and extrinsic risk factors with an emphasis on sudden changes in running regimen, female gender, hormonal disorders, low bone density, increased physical activity, irregular or angled running surface, improper footwear, vitamin D levels, calcium deficiency, and smoking [70]. Particular emphasis is placed on screening for RED-S and the female athlete triad which include low energy availability, disordered eating, irregular menses, and low bone mineral density.

Initial gait evaluation may reveal antalgic gait involving the affected limb. Specific palpation of the foot and ankle anatomy accurately gauges tenderness for specific fractures [71]. The hop test also assesses for pain by stressing the bone. Radiographs, computed tomography, and MRI can confirm the diagnosis of a BSI. MRI is considered the gold standard for its ability to evaluate the bone and surrounding tissues simultaneously [13]. MRI is also very useful in determining return to run progression for competitive running athletes [72, 73].

The management of BSIs is guided by classification based on risk, ranging from low to high risk of complicated healing. High-risk fractures require non-weight-bearing status and referral to a foot and ankle surgeon for appropriate management [74]. Low-risk BSIs respond well to immobilization or use of a walking boot to achieve pain-free ambulation. The advancement of weight bearing and running should involve a progressive, systematic approach such that each stage is pain-free. Treatment of risk factors for RED-S and the female athlete triad continues to be a vital component in the treatment and prevention of BSIs. In particular, recent analyses have demonstrated a decrease in BSIs with a supplementation of 800 IU 25(OH)D and 2000 mg calcium [75]. Preventative use of bisphosphonates has not shown a significant impact on BSI incidence [76].

Bone stimulation to promote BSI healing has received some recent attention. PRP, stem cells, pulsed parathyroid hormone treatment, electrical osseous stimulation, and extracorporeal shockwave therapy have all been recently described as means to accelerate BSI recovery. There is conflicting evidence to the wide-scale efficacy of these treatments; therefore, careful patient selection and risk vs benefit discussion are vital prior to implementing any of these interventions [77–82].

Osteoarthritis

As more individuals of advanced age wish to participate in physical activity, the prevalence of degenerative joint conditions will increase accordingly. The relationship between foot and ankle osteoarthritis and running is not well described. There does not appear to be a direct link between running and the development of osteoarthritis [83]. Nonetheless, given the prevalence of osteoarthritis in the general population, an understanding of osteoarthritis and the treatment options is vital for the clinician treating runners with this condition. The talonavicular and first metatarsophalangeal joints are the most affected joints in foot and ankle osteoarthritis [14, 84].

Clinical evaluation begins with history acquisition to rule out other sources of pain and dysfunction. The patient will typically report chronic bilateral pain associated with weight bearing and joint stiffness that is alleviated by activity and may be only present in the mornings. The examination begins with observation for antalgic gait and other gait abnormalities. On physical exam, crepitus, swelling, joint-line tenderness, and bony enlargement of the affected joint can be seen. Deformities and abnormal mobility with hallux valgus and hallux rigidus can also be observed [14, 85]. Radiography remains the gold standard for the initial diagnosis of foot and ankle osteoarthritis [14, 86].

Conservative management involves reducing modifiable risk factors such as weight and smoking while also optimizing pain control and tissue strength with medications and rehabilitation exercises. For recalcitrant cases, injections may be considered. Traditional injections include corticosteroids and hyaluronic acid. These have shown benefit in inflammatory osteoarthritis [87]. Newer techniques involving PRP and stem cells have shown conflicting results [87]. As with any interventional pain treatment for RRI, the clinician should thoroughly explain the risks and benefits of treatment before proceeding. Running progression with foot and ankle osteoarthritis should follow the patient's symptoms. Patients should be encouraged to advance their running as symptoms allow.

Morton's Neuroma

The exact prevalence of Morton's neuroma is not known; however, it tends to affect middle-aged women [88, 89]. Morton's neuroma is not a true neuroma, but a neuropathy characterized by fibrosis of the common interdigital nerve. It is thought to develop from chronic repetitive microtrauma [89]. In runners, it may be exacerbated by repetitive hyperextension of the metatarsal arch [90]. It most commonly affects the second or third intermetatarsal space [91].

Patients typically present with localized pain at the plantar aspect of the third webspace that may be associated with paresthesia. Physical exam findings include pain with palpation of the affected area. The squeeze test is performed by squeezing the metatarsals together, which further compresses the neuroma and elicits symptoms [89]. Diagnosis is typically clinical, but ultrasonography or MRI may be helpful in difficult cases. Both ultrasonography and MRI are highly sensitive and specific, with MRI slightly more specific than ultrasonography (100% vs 85% respectively) [89, 92].

Initial conservative management includes footwear modifications (e.g., wider toe box) and metatarsal pads. Mobilization and manipulation have been shown to decrease pain, likely by decreasing the stiffness of connective tissue surrounding the nerve [93]. Several randomized controlled trials report that corticosteroid injections provide clinically significant pain relief at 12 months [94]. Younger patients and larger neuromas (> 5 mm) predict the need for repeat injection or surgical excision [95]. Other newer modalities include ESWT, laser therapy, radiofrequency ablation, cryotherapy, and botulinum toxin injections. Published reports of these treatments are primarily case reports and retrospective studies. More high-quality randomized controlled trials are needed to study the efficacy of these newer modalities. There is no proven method of preventing Morton's neuroma, although proper footwear that avoids significant compression is recommended.

Tarsal Tunnel Syndrome

Tarsal tunnel syndrome (TTS) is the fifth most common entrapment neuropathy [96]. Women are more likely to be affected than men [97]. The two common causes are idiopathic and posttraumatic. Long-distance runners are especially at risk due to repetitive stress at the peri-articular ankle region [96].

TTS is an entrapment neuropathy of the posterior tibial nerve. The posterior tibial nerve provides sensory innervation to the plantar and medial aspect of the foot as well as motor innervation to the intrinsic muscles of the foot. Pathology occurs when there is compression of the tunnel by any space-occupying lesions, vascular malformations or varicose veins, lower extremity edema, inflammation, or repetitive trauma. Running athletes may be predisposed due to hyperpronation and poor mechanics, causing repetitive trauma and entrapment of the tibial nerve [90]. In athletes, tarsal tunnel syndrome is caused by fibrosis of periarticular ankle tissues, deltoid ligament injury, or osseous changes [96].

Patients may present with a burning or cramping pain at the medial ankle that radiates to the plantar arch of the foot. If the medial calcaneal nerve is affected, then the patient may have heel pain [98]. Fifty percent of patients with tarsal tunnel syndrome report a cold sensation in the medial and lateral plantar nerve distribution [99]. Running, jumping,

and tight-fitting shoes tend to exacerbate symptoms. Pes planus and hindfoot valgus are anatomic risk factors. Tinel's sign is positive if symptoms are reproduced with the percussion of the tarsal tunnel. Eversion with great toe dorsiflexion can be performed to provoke symptoms [98]. With the Trepman test, the foot is passively plantarflexed and inverted to provoke symptoms. The triple-compression test combines the Trepman and Tinel's tests [99]. Initial imaging with foot and ankle x-rays can show osteophytes, deformities, or talocalcaneal coalition [98]. MRI and ultrasonography can reveal lesions causing compression. Electromyography is helpful in identifying which branches of the posterior tibial nerve are affected [99].

Conservative management should be trialed for 12–24 months before surgery is considered, unless there is evidence of muscular atrophy. Custom orthotics with medial arch support and wedges can be used to address hyper-pronation and hindfoot valgus. Heat and ice have been demonstrated to be successful in prior studies. Pharmacologic management with non-steroidal anti-inflammatory medications, tricyclic antidepressants, and GABA analogs are shown to have some benefits. Physical therapy is recommended to focus on strengthening the gastrocnemius, soleus, peroneal, and tibialis muscles, as well as Achilles tendon flexibility [98, 99]. Corticosteroid and anesthetic injections can be beneficial in patients with an inflammatory etiology, such as rheumatoid arthritis or tenosynovitis [96, 97]. Ultrasonography-guided anesthetic and corticosteroid injections are often used before considering surgery [97]. Classically, surgical management is achieved with an open tarsal tunnel release. Recent studies have demonstrated success with minimally invasive techniques using endoscopy and ultrasonography [99, 100]. Ultrasound-guided pulsed radiofrequency was recently used in a case study for intractable symptoms [99]. There are no studied methods for prevention although proper running mechanics and shoe wear are likely to provide benefit.

Jogger's Foot

Jogger's foot is an entrapment neuropathy of the medial plantar nerve (MPN). It is a common pathology in runners, particularly in those with heel valgus and hyper-pronation [90]. The MPN provides sensory innervation to the medial plantar aspect of the foot, including the first three digits and the medial aspect of the fourth digit. The MPN can be compressed via repetitive eversion as it passes through the flexor retinaculum in proximity to the master knot of Henry. Pes planus and abductor hallucis hypertrophy are thought to be anatomic risk factors [101, 102].

Jogger's foot presents with paresthesias and pain at the medial arch that radiates to the first through third toes exacerbated by activity and shoes. On physical exam, there is pain with palpation of the abductor hallucis near the navicular tuberosity [98]. Reproducible pain or paresthesias may be induced by eversion, heel raise, or Tinel's at the MPN [90]. Imaging is not necessary for diagnosis; however, a recent study demonstrated the utility of abnormal signal intensity on MRI [101]. We recommend imaging only if the diagnosis is not clear.

The management of jogger's foot is similar to that of tarsal tunnel syndrome. Conservative management with proper footwear and orthosis is first line of treatment. Surgical release of the medial plantar nerve is recommended in those who have failed conservative treatment [98].

Conclusion

Foot and ankle injuries are a common cause of RRIs due to the foot and ankle's role throughout the running gait cycle. Most foot and ankle RRIs are due to overuse. Injury occurs because of a disequilibrium in tissue homeostasis. It is vital to employ a systematic approach to the history of and physical exam of the injured runner. Running gait analysis is a helpful tool to assess RRIs in high-level athletes and runners with chronic foot and ankle injuries. Musculoskeletal ultrasonography has emerged as a very useful modality to assess RRIs qualitatively and quantitatively. Running volume modification and reduction of extrinsic risk factors are the initial steps in the treatment and prevention of RRIs. Recent evidence suggests that rehabilitative exercises should remain the cornerstone of recovery in RRIs. Recent analyses have also shown that foot core exercises can be preventative in foot and ankle RRIs. There is unclear evidence that shoe modification and gait retraining are protective against RRIs or effective in treating RRIs. Caution should be used when considering injections, particularly orthobiologics, for the management of RRIs. The decision to proceed with this treatment should be a shared decision-making process in which the patient clearly understands the risks, benefits, and limitations of injection care. Future research should be performed to investigate the effectiveness of gait modification and the effectiveness of orthobiologics in the treatment of foot and ankle RRIs.

Author Contribution AT wrote the Abstract, Introduction, and Conclusion. He also provided editorial oversight for the entire manuscript. AB wrote the following sections: Achilles Tendinopathy, Posterior Tibial Tendon Dysfunction. CST wrote the following sections: Morton's Neuroma, Tarsal Tunnel Syndrome, Joggers' Foot. MR wrote the following section: Plantar Fasciopathy. AS wrote the following sections: Bone Stress Injuries, Osteoarthritis.

Declarations

Conflict of Interest The authors declare that they have no conflict of interest.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

References

Papers of particular interest, published recently, have been highlighted as:
- • Of importance
- •• Of major importance

1. Kakouris N, Yener N, Fong DTP. A systematic review of running-related musculoskeletal injuries in runners. J Sport Health Sci. 2021;10(5):513–22.
2. Lieberman DE, Venkadesan M, Werbel WA, Daoud AI, D'Andrea S, Davis IS, et al. Foot strike patterns and collision forces in habitually barefoot versus shod runners. Nature. 2010;463(7280):531–5.
3. Lopes AD, HespanholJúnior LC, Yeung SS, Costa LOP. What are the main running-related musculoskeletal injuries? A Syst Rev Sports Med. 2012;42(10):891–905.
4. Tenforde AS, Yin A, Hunt KJ. Foot and ankle injuries in runners. Phys Med Rehabil Clin N Am. 2016;27(1):121–37.
5. Bramble DM, Lieberman DE. Endurance running and the evolution of Homo. Nature. 2004;432(7015):345–52.
6. Dye SF. The pathophysiology of patellofemoral pain: a tissue homeostasis perspective. Clin Orthop Relat Res. 2005;436:100–10.
7. Bertelsen ML, Hulme A, Petersen J, Brund RK, Sørensen H, Finch CF, et al. A framework for the etiology of running-related injuries. Scand J Med Sci Sports. 2017;27(11):1170–80.
8. Harper-Hanigan K, Gruber AH. The missing link in running injury research: nonrunning physical activity. J Orthop Sports Phys Ther. 2022;52(11):705–8.
9. Men's Running . Running to work: all you need to know. Men's Running [Internet]. 2016 Sep 27 [cited 2023 Sep 9]; Available from: https://mensrunninguk.co.uk/news/running-to-work/
10. Lee D-C, Pate RR, Lavie CJ, Sui X, Church TS, Blair SN. Leisure-time running reduces all-cause and cardiovascular mortality risk. J Am Coll Cardiol. 2014;64(5):472–81.
11 Oswald F, Campbell J, Williamson C, Richards J, Kelly P. A scoping review of the relationship between running and mental health. Int J Environ Res Public Health. 2020;17:21.
12 Benson LC, Räisänen AM, Clermont CA, Ferber R. Is this the real life, or is this just laboratory? A scoping review of IMU-based running gait analysis. Sensors. 2022;22:5.
13. McInnis KC, Ramey LN. High-risk stress fractures: diagnosis and management. PM R. 2016;8(3 Suppl):S113–24.
14. International Foot and Ankle Osteoarthritis Consortium, Arnold JB, Bowen CJ, Chapman LS, Gates LS, Golightly YM, et al. International Foot and Ankle Osteoarthritis Consortium review and research agenda for diagnosis, epidemiology, burden, outcome assessment and treatment. Osteoarthr Cartil. 2022;30(7):945–55.
15. Ramskov D, Rasmussen S, Sørensen H, Parner ET, Lind M, Nielsen R. Progression in running intensity or running volume and the development of specific injuries in recreational runners: run clever, a randomized trial using competing risks. J Orthop Sports Phys Ther. 2018;48(10):740–8.
16. Silbernagel KG, Hanlon S, Sprague A. Current clinical concepts: conservative management of achilles tendinopathy. J Athl Train. 2020;55(5):438–47.
17. Martin RL, Chimenti R, Cuddeford T, Houck J, Matheson JW, McDonough CM, et al. Achilles pain, stiffness, and muscle power deficits: midportion achilles tendinopathy revision 2018. J Orthop Sports Phys Ther. 2018;48(5):A1-38.
18. Jastifer JR. Contemporary review: the foot and ankle in long-distance running. Foot Ankle Orthop. 2022;7(3):24730114221125456.
19. Gaudette LW, Bradach MM, de Souza Junior JR, Heiderscheit B, Johnson CD, Posilkin J, et al. Clinical application of gait retraining in the injured runner. J Clin Med. 2022;11:21.
20 Rhim HC, Kwon J, Park J, Borg-Stein J, Tenforde AS. A systematic review of systematic reviews on the epidemiology, evaluation, and treatment of plantar fasciitis. Life (Basel). 2021;11:12.
21. McKeon PO, Hertel J, Bramble D, Davis I. The foot core system: a new paradigm for understanding intrinsic foot muscle function. Br J Sports Med. 2015;49(5):290.
22.•• Taddei UT, Matias AB, Duarte M, Sacco ICN. Foot Core Training to Prevent Running-Related Injuries: A Survival Analysis of a Single-Blind, Randomized Controlled Trial. Am J Sports Med. 2020 Dec;48(14):3610–9. **Findings from this study show that foot core exercises are preventative against all running related injuries including foot and ankle running injuries**.
23. Doyle E, Doyle TLA, Bonacci J, Fuller JT. The effectiveness of gait retraining on running kinematics, kinetics, performance, pain, and injury in distance runners: a systematic review with meta-analysis. J Orthop Sports Phys Ther. 2022;52(4):192-A5.
24. Schubert AG, Kempf J, Heiderscheit BC. Influence of stride frequency and length on running mechanics: a systematic review. Sports Health. 2014;6(3):210–7.
25.• Shen B, Zhang S, Cui K, Zhang X, Fu W. Effects of a 12-week gait retraining program combined with foot core exercise on morphology, muscle strength, and kinematics of the arch: A randomized controlled trial. Front Bioeng Biotechnol. 2022 Oct 5;10:1022910. **Findings from this study show that combining foot core exercises with gait retraining from rear foot striking to forefoot striking improve foot biomechanics and kinematics. This can be preventative against foot and ankle injuries and used in the treatment of foot and ankle running injuries**.
26. McDougall C. Born to run: a hidden tribe, superathletes, and the greatest race the world has never seen. New York: Knopf; 2009.
27. Altman AR, Davis IS. Prospective comparison of running injuries between shod and barefoot runners. Br J Sports Med. 2016;50(8):476–80.

28. Hollander K, Hamacher D, Zech A. Running barefoot leads to lower running stability compared to shod running - results from a randomized controlled study. Sci Rep. 2021;11(1):4376.
29. Gardner LI, Dziados JE, Jones BH, Brundage JF, Harris JM, Sullivan R, et al. Prevention of lower extremity stress fractures: a controlled trial of a shock absorbent insole. Am J Public Health. 1988;78(12):1563–7.
30. Cook SD, Kester MA, Brunet ME. Shock absorption characteristics of running shoes. Am J Sports Med. 1985;13(4):248–53.
31. Kujala UM, Sarna S, Kaprio J. Cumulative incidence of achilles tendon rupture and tendinopathy in male former elite athletes. Clin J Sport Med. 2005;15(3):133–5.
32. von Rickenbach KJ, Borgstrom H, Tenforde A, Borg-Stein J, McInnis KC. Achilles tendinopathy: evaluation, rehabilitation, and prevention. Curr Sports Med Rep. 2021;20(6):327–34.
33. Doral MN, Alam M, Bozkurt M, Turhan E, Atay OA, Dönmez G, et al. Functional anatomy of the Achilles tendon. Knee Surg Sports Traumatol Arthrosc. 2010;18(5):638–43.
34. Knapik JJ, Pope R. Achilles tendinopathy: pathophysiology, epidemiology, diagnosis, treatment, prevention, and screening. J Spec Oper Med. 2020;20(1):125–40.
35. Cook JL, Purdam CR. Is tendon pathology a continuum? A pathology model to explain the clinical presentation of load-induced tendinopathy. Br J Sports Med. 2009;43(6):409–16.
36. Magnan B, Bondi M, Pierantoni S, Samaila E. The pathogenesis of Achilles tendinopathy: a systematic review. Foot Ankle Surg. 2014;20(3):154–9.
37. Chen TM, Rozen WM, Pan W-R, Ashton MW, Richardson MD, Taylor GI. The arterial anatomy of the Achilles tendon: anatomical study and clinical implications. Clin Anat. 2009;22(3):377–85.
38. Carr AJ, Norris SH. The blood supply of the calcaneal tendon. J Bone Joint Surg Br. 1989;71(1):100–1.
39. Thompson TC, Doherty JH. Spontaneous rupture of tendon of Achilles: a new clinical diagnostic test. J Trauma. 1962;2:126–9.
40. Schweitzer ME, Karasick D. MR imaging of disorders of the Achilles tendon. AJR Am J Roentgenol. 2000;175(3):613–25.
41. Szaro P, Nilsson-Helander K, Carmont M. MRI of the Achilles tendon - a comprehensive pictorial review. Part two European J Radiol Open. 2021;27(8):100343.
42. Alfredson H, Cook J. A treatment algorithm for managing Achilles tendinopathy: new treatment options. Br J Sports Med. 2007;41(4):211–6.
43. Bjur D, Alfredson H, Forsgren S. The innervation pattern of the human Achilles tendon: studies of the normal and tendinosis tendon with markers for general and sensory innervation. Cell Tissue Res. 2005;320(1):201–6.
44. Cortes DH, Suydam SM, Silbernagel KG, Buchanan TS, Elliott DM. Continuous shear wave elastography: a new method to measure viscoelastic properties of tendons in vivo. Ultrasound Med Biol. 2015;41(6):1518–29.
45. Corrigan P, Zellers JA, Balascio P, Silbernagel KG, Cortes DH. Quantification of mechanical properties in healthy Achilles tendon using continuous shear wave elastography: a reliability and validation study. Ultrasound Med Biol. 2019;45(7):1574–85.
46. Wang L, Wen D, Yin Y, Zhang P, Wen W, Gao J, et al. Musculoskeletal ultrasound image-based radiomics for the diagnosis of achilles tendinopathy in skiers. J Ultrasound Med. 2023;42(2):363–71.
47. Hullfish TJ, Hagan KL, Casey E, Baxter JR. Achilles tendon structure differs between competitive distance runners and non-runners despite no clinical signs or symptoms of midsubstance tendinopathy. J Appl Physiol. 2018;125(2):453–8.
48. McAuliffe S, McCreesh K, Culloty F, Purtill H, O'Sullivan K. Can ultrasound imaging predict the development of Achilles and patellar tendinopathy? A systematic review and meta-analysis. Br J Sports Med. 2016;50(24):1516–23.
49. Ryan M, Grau S, Krauss I, Maiwald C, Taunton J, Horstmann T. Kinematic analysis of runners with achilles mid-portion tendinopathy. Foot Ankle Int. 2009;30(12):1190–5.
50. Xu Y, Yuan P, Wang R, Wang D, Liu J, Zhou H. Effects of foot strike techniques on running biomechanics: a systematic review and meta-analysis. Sports Health. 2021;13(1):71–7.
51. Alfredson H, Pietilä T, Jonsson P, Lorentzon R. Heavy-load eccentric calf muscle training for the treatment of chronic Achilles tendinosis. Am J Sports Med. 1998;26(3):360–6.
52. Masiello F, Pati I, Veropalumbo E, Pupella S, Cruciani M, De Angelis V. Ultrasound-guided injection of platelet-rich plasma for tendinopathies: a systematic review and meta-analysis. Blood Transfus. 2023;21(2):119–36.
53. Hijlkema A, Roozenboom C, Mensink M, Zwerver J. The impact of nutrition on tendon health and tendinopathy: a systematic review. J Int Soc Sports Nutr. 2022;19(1):474–504.
54. Agyekum EK, Ma K. Heel pain: a systematic review. Chin J Traumatol. 2015;18(3):164–9.
55 La Porta GA, La Fata PC. Pathologic conditions of the plantar fascia. Clin Podiatr Med Surg. 2005;1:1–9.
56. Goff JD, Crawford R. Diagnosis and treatment of plantar fasciitis. Am Fam Physician. 2011;84(6):676–82.
57. Trojian T, Tucker AK. Plantar fasciitis. Am Fam Physician. 2019;99(12):744–50.
58. Berbrayer D, Fredericson M. Update on evidence-based treatments for plantar fasciopathy. PM R. 2014;6(2):159–69.
59. Thong-On S, Bovonsunthonchai S, Vachalathiti R, Intiravoranont W, Suwannarat S, Smith R. Effects of strengthening and stretching exercises on the temporospatial gait parameters in patients with plantar fasciitis: a randomized controlled trial. Ann Rehabil Med. 2019;43(6):662–76.
60 Bluman EM, Title CI, Myerson MS. Posterior tibial tendon rupture: a refined classification system. Foot Ankle Clin. 2007;2:233–49.
61. Johnson KA, Strom DE. Tibialis posterior tendon dysfunction. Clin Orthop Relat Res. 1989;239:196–206.
62. Henry JK, Shakked R, Ellis SJ. Adult-acquired flatfoot deformity. Foot Ankle Orthop. 2019;4(1):247301141882084.
63. Ross M, Smith M, Vicenzino B. Using the international classification of functioning to characterise tibialis posterior tendinopathy. J Sci Med Sport. 2021;24:S40.
64. Wang J, Mannen EM, Siddicky SF, Lee J-M, Latt LD. Gait alterations in posterior tibial tendonitis: a systematic review and meta-analysis. Gait Posture. 2020;76:28–38.
65. Ross MH, Smith MD, Mellor R, Durbridge G, Vicenzino B. Clinical tests of tibialis posterior tendinopathy: are they reliable, and how well are they reflected in structural changes on imaging? J Orthop Sports Phys Ther. 2021;51(5):253–60.
66. Soliman SB, Spicer PJ, van Holsbeeck MT. Sonographic and radiographic findings of posterior tibial tendon dysfunction: a practical step forward. Skeletal Radiol. 2019;48(1):11–27.
67. Ross MH, Smith MD, Mellor R, Vicenzino B. Exercise for posterior tibial tendon dysfunction: a systematic review of randomised clinical trials and clinical guidelines. BMJ Open Sport Exerc Med. 2018;4(1):e000430.
68. Vasiliadis A. Common stress fractures in runners: an analysis. Saudi J Sports Med. 2017;17(1):1.
69. Kakagia DD, Karadimas EJ, Stouras IA, Papanas N. The ageing foot. Int J Low Extrem Wounds. 2023;26:15347346231203280.
70. Kahanov L, Eberman LE, Games KE, Wasik M. Diagnosis, treatment, and rehabilitation of stress fractures in the lower extremity in runners. Open Access J Sports Med. 2015;27(6):87–95.

71. Kaiser PB, Guss D, DiGiovanni CW. Republication of "stress fractures of the foot and ankle in athletes." Foot Ankle Orthop. 2023;8(3):24730114231195044.
72. De Souza MJ, Nattiv A, Joy E, Misra M, Williams NI, Mallinson RJ, et al. 2014 female athlete triad coalition consensus statement on treatment and return to play of the female athlete triad: 1st International Conference held in San Francisco, California, May 2012 and 2nd International Conference held in Indianapolis, Indiana, May 2013. Br J Sports Med. 2014;48(4):289.
73. Nattiv A, Kennedy G, Barrack MT, Abdelkerim A, Goolsby MA, Arends JC, et al. Correlation of MRI grading of bone stress injuries with clinical risk factors and return to play: a 5-year prospective study in collegiate track and field athletes. Am J Sports Med. 2013;41(8):1930–41.
74. Kiel J, Kaiser K. Stress reaction and fractures. StatPearls. Treasure Island (FL): StatPearls Publishing; 2023
75. Knechtle B, Jastrzębski Z, Hill L, Nikolaidis PT. Vitamin D and stress fractures in sport: preventive and therapeutic measures-a narrative review. Med (Kaunas). 2021;57:3.
76. Saunier J, Chapurlat R. Stress fracture in athletes. Joint Bone Spine. 2018;85(3):307–10.
77. Miller TL, Kaeding CC, Rodeo SA. Emerging options for biologic enhancement of stress fracture healing in athletes. JAAOS - J Am Acad Orthop Surg. 2020;28:1.
78. Murphy EP, McGoldrick NP, Curtin M, Kearns SR. A prospective evaluation of bone marrow aspirate concentrate and microfracture in the treatment of osteochondral lesions of the talus. Foot Ankle Surg. 2019;25(4):441–8.
79. Vidane AS, Nunes FC, Ferreira JA, Fukumasu H, Freitas SH, Pallone EM, et al. Biocompatibility and interaction of porous alumina-zirconia scaffolds with adipose-derived mesenchymal stem cells for bone tissue regeneration. Heliyon. 2023;9(9):e20128.
80. Nicksic PJ, Donnelly DT, Verma N, Setiz AJ, Shoffstall AJ, Ludwig KA, et al. Electrical stimulation of acute fractures: a narrative review of stimulation protocols and device specifications. Front Bioeng Biotechnol. 2022;10:879187.
81. Beling A, Saxena A, Hollander K, Tenforde AS. Outcomes using focused shockwave for treatment of bone stress injury in runners. Bioeng (Basel). 2023;10:8.
82. Ding H, Wang S, Feng H, Xu Y, Yan J, Duan X, et al. Clinical efficacy of individual extracorporeal shockwave treatment. Orthopade. 2019;48(7):610–7.
83. Timmins KA, Leech RD, Batt ME, Edwards KL. Running and knee osteoarthritis: a systematic review and meta-analysis. Am J Sports Med. 2017;45(6):1447–57.
84. Ruiz Santiago F, Moraleda Cabrera B, Láinez Ramos-Bossini AJ. Ultrasound guided injections in ankle and foot. J Ultrasound. 2023. Epub ahead of print
85. Abhishek A. Diagnosis and clinical presentation of osteoarthritis. Clin Rheum Dis [Internet]. 2013 Feb [cited 2023 Oct 11];39(1):45–66. Available from: https://www.rheumatic.theclinics.com/article/S0889-857X(12)00119-6/fulltext
86. Khlopas H, Khlopas A, Samuel LT, Ohliger E, Sultan AA, Chughtai M, et al. Current concepts in osteoarthritis of the ankle: review. Surg Technol Int. 2019;10(35):280–94.
87. Urits I, Smoots D, Franscioni H, Patel A, Fackler N, Wiley S, et al. Injection techniques for common chronic pain conditions of the foot: a comprehensive review. Pain Ther. 2020;9(1):145–60.
88. Valisena S, Petri GJ, Ferrero A. Treatment of Morton's neuroma: a systematic review. Foot Ankle Surg. 2018;24(4):271–81.
89. Jain S, Mannan K. The diagnosis and management of Morton's neuroma: a literature review. Foot Ankle Spec. 2013;6(4):307–17.
90. Ferkel E, Davis WH, Ellington JK. Entrapment neuropathies of the foot and ankle. Clin Sports Med. 2015;34(4):791–801.
91. Bhatia M, Thomson L. Morton's neuroma - current concepts review. J Clin Orthop Trauma. 2020;11(3):406–9.
92. Bignotti B, Signori A, Sormani MP, Molfetta L, Martinoli C, Tagliafico A. Ultrasound versus magnetic resonance imaging for Morton neuroma: systematic review and meta-analysis. Eur Radiol. 2015;25(8):2254–62.
93. Matthews BG, Hurn SE, Harding MP, Henry RA, Ware RS. The effectiveness of non-surgical interventions for common plantar digital compressive neuropathy (Morton's neuroma): a systematic review and meta-analysis. J Foot Ankle Res. 2019;13(12):12.
94. Thomson L, Aujla RS, Divall P, Bhatia M. Non-surgical treatments for Morton's neuroma: a systematic review. Foot Ankle Surg. 2020;26(7):736–43.
95. Mahadevan D, Salmasi M, Whybra N, Nanda A, Gaba S, Mangwani J. What factors predict the need for further intervention following corticosteroid injection of Morton's neuroma? Foot Ankle Surg. 2016;22(1):9–11.
96. Vij N, Kaley HN, Robinson CL, Issa PP, Kaye AD, Viswanath O, et al. Clinical results following conservative management of tarsal tunnel syndrome compared with surgical treatment: a systematic review. Orthop Rev (Pavia). 2022;14(3):37539.
97. Atesok K, Pierce J, Small B, Perumal V, Cooper T, Park J. The course of tarsal tunnel syndrome after ultrasound-guided injections. Orthop Rev (Pavia). 2022;14(4):35455.
98. Meadows JR, Finnoff JT. Lower extremity nerve entrapments in athletes. Curr Sports Med Rep. 2014;13(5):299–306.
99. Fortier LM, Leethy KN, Smith M, McCarron MM, Lee C, Sherman WF, et al. An update on posterior tarsal tunnel syndrome. Orthop Rev (Pavia). 2022;14(4):35444.
100. Iborra A, Villanueva M, Sanz-Ruiz P. Results of ultrasound-guided release of tarsal tunnel syndrome: a review of 81 cases with a minimum follow-up of 18 months. J Orthop Surg Res. 2020;15(1):30.
101. Collins MS, Tiegs-Heiden CA, Frick MA. MRI appearance of jogger's foot. Skeletal Radiol. 2020;49(12):1957–63.
102. De Maeseneer M, Madani H, Lenchik L, KalumeBrigido M, Shahabpour M, Marcelis S, et al. Normal anatomy and compression areas of nerves of the foot and ankle: US and MR imaging with anatomic correlation. Radiographics. 2015;35(5):1469–82.