Posttraumatic Avascular Necrosis of the Talus

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KEYWORDS

- Osteonecrosis
- Avascular necrosis
- Talus
- Posttraumatic
- Traumatic
- Joint-sparing
- Joint-sacrificing

Avascular necrosis (AVN) of the talus is one of the most challenging problems encountered in posttraumatic reconstruction of the hindfoot. Since the first description of the talus injury in 1608 by Fabricius of Hilden,1 our knowledge of the talar anatomy, injuries, sequelae, and management has increased significantly. Adequate knowledge of the etiology, the extent of the disease, and the degree of patient symptoms are required to determine optimal treatment.

Talar osteonecrosis occurs when the vascular supply to the talus is interrupted and the bone is deprived of its oxygen source. Avascular necrosis of the talus can be isolated or associated with bone loss, collapse, sepsis, deformity, and severe arthritis of adjacent joints. Surgical alternatives include joint-sacrificing and joint-sparing procedures. Reconstructive procedures include isolated or extended fusions, osteotomies, bone grafting, soft tissues release, and joint replacement, alone or in combination; amputation remains a salvage option as well.

ANATOMY OF THE TALUS

The talus is the second largest tarsal bone and has a unique anatomy. Sixty percent of its surface is covered by articular cartilage and there are no muscular or tendinous attachments to the bone.2,3 The inherent vascular supply of the talus is tenuous and, thus, predisposes it to avascular necrosis. The talus is characterized by extra-osseous arterial sources and variable intra-osseous blood supply. The extra-osseous vascularity is through the branches of the posterior tibial artery, the dorsalis pedis artery, and the perforating peroneal artery, which enter through nonarticulating surfaces of the bone.

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The major blood supply to the talar body is provided by the artery of the tarsal canal. The tarsal canal artery supplies the central and lateral two-thirds of the talar body. Deltoid branches arising from this artery supply the remaining medial third of the talar body.1 Branches of the anterior tibial artery supply the superomedial half of the talar head and neck. The inferolateral half of the talar head and neck are supplied by the tarsal sinus artery and or the lateral tarsal artery. The intra-osseous anastomoses are variable among individuals and may explain why some patients develop AVN and while others do not.

CLASSIFICATION, ETIOLOGY, AND EPIDEMIOLOGY OF TALAR INJURY

In 1919, Anderson reported 18 cases of talus fracture in aviators.5 Anderson identified the mechanism of injury as a hyperdorsiflexion force exerted on the sole of the foot by the rudder bar of the aircraft on impact, and coined the term “aviator’s astragalus” for this injury because of its occurrence in belly landings of small aircraft. More recent reports6–8 have described direct impact—a combination of axial and dorsiflexion energy—with the foot in inversion or eversion to explain the injury.

The risk of AVN of the talus is related to the degree of displacement of the injury and the resultant damage to the vascular component supplying the talus.9,10 Hawkins9 developed a classification in 1970 for vertical fractures of the talar neck, which was later modified by Canale and Kelly:11 a Hawkins type 1 is a nondisplaced talar neck fracture and has 0% to 15% AVN risk; a Hawkins type 2 is a talar neck fracture associated with a subluxation or a dislocation of the subtalar joint and has a 20% to 50% AVN risk; a Hawkins type 3 is a talar neck fracture associated with subluxation or dislocation of the subtalar and ankle joint and has a 90% AVN risk; a Hawkins type 4 is a talar neck fracture associated with subluxation or dislocation of the subtalar, ankle, and talonavicular joints and has a 100% AVN risk. Patients in these series were treated with closed reduction and casting or primitive internal fixation techniques, which may have contributed to AVN rates. AVN rates from more recent series using modern internal fixation techniques have been substantially lower.12,13

The Marti-Weber classification has gained popularity for its inclusion of all talus injuries and its prognostic value with regard to AVN.14 Type I injuries include lateral process fractures, posterior process fractures, osteochondral flake fractures, and talus head with very distal neck fractures, none of which are associated with the development of AVN. Type II injuries include vertical fractures of the proximal neck or talar body without displacement, in which AVN is rarely seen. Type III injuries are type II injuries with displacement plus dislocation or subluxation of the subtalar or ankle joint, which are typically associated with AVN. Type IV injuries include a neck or body fracture with complete talar body dislocation from both the subtalar and the ankle joints, which are almost always associated with AVN.

Inokuchi and colleagues15 found that the vertical fracture of the talus that extends inferiorly in the posterior facet of the talus is a talar body fracture with a higher prevalence of AVN, and a worse prognosis than a vertical talar body fracture not involving the posterior facet. Recent studies12,13 have shown that a delay in surgical fixation does not appear to affect the outcome, union, or prevalence of osteonecrosis.

CLINICAL INVESTIGATION

Posttraumatic sequelae of talus injury are common and include chronic pain, stiffness, or loss of function. Adequate evaluation as to the personality of the disease is needed. A thorough clinical and physical evaluation is crucial. Clinical and physical assessment includes type of pain, local or systemic signs of infection, and assessment of
deformity, motion, soft-tissue quality, and neurovascular examination. If infection is suspected, C-reactive protein, sedimentation rate, and nuclear medicine should be obtained.

RADIOLOGIC ASSESSMENT OF TALUS AVN

Plain radiography remains the primary diagnostic tool for AVN of the talus; however, CT scanning and MRI provide additional insight in delineating subtle disease and to more thoroughly evaluate deformity and adjacent sequela. Plain radiographs and CT scans can help identify the presence of arthritic changes, bone loss, bone quality, and deformity. Selective injections can assist in distinguishing pain sources in the ankle joint, subtalar joint, talonavicular joint, or combinations thereof.

Plain Radiology

Initially, the necrotic bone and surrounding viable bone are equal in opacity. Over time, local hyperemia promotes the resorption of healthy bone, making the viable bone appear osteopenic. Conversely, the lack of blood supply in necrotic bone prevents its resorption, making necrotic bone appear more radiopaque than the surrounding osteopenic bone. At this point, radiographic evidence of talar AVN becomes obvious. With time, reossification of the necrotic bone occurs and increases its sclerotic appearance.

AVN is diagnosed on plain radiography by the absence of the Hawkins sign. The Hawkins sign is a radiolucent band in the talar dome that is indicative of viability and typically appears at 6 to 8 weeks following a talus fracture (Fig. 1). Tezval and colleagues found that the presence of the Hawkins sign is an excellent predictor of vascularity of the talus after a talus fracture. If a full or partial Hawkins sign is detected, it is unlikely that AVN will occur. However, the absence of the Hawkins sign does not reliably correlate with AVN of the talus; in their series, the presence of a Hawkins sign had a sensitivity of 100% and specificity of 57.7%.

Fig. 1. Hawkins sign in a 20-year-old female who had undergone open reduction internal fixation for injuries sustained in a car accident. Radiograph (mortice view) shows a thin subchondral area of radiolucency involving the entire talar dome (positive Hawkins sign), a finding that signifies talar viability and excludes future development of AVN.
CT Scan and MRI

CT Scan also reveals characteristic talar AVN patterns and can be used to confirm radiographic findings. It helps to assess subtle depression, collapse, fragmentation, and arthritic changes. MRI is the most sensitive technique for detecting osteonecrosis of the talus, especially in the early stages.19

CONSERVATIVE TREATMENT

The presence of AVN of the talus before collapse is initially managed nonoperatively. Creeping substitution of the talus body can require 36 months to occur. Some investigators, including Hawkins, advocated extended nonweight-bearing;20–22 Canale recommended nonweight-bearing until revascularization is obtained.21 Other investigators have recommended a patellar tendon-bearing brace until reconstitution of the talar body is complete.23–25 However, patient compliance is rarely possible for 36 months.26 Penny and colleagues27 showed that weight-bearing on a sclerotic and avascular talus poses no real danger for dome collapse, and found no correlation between poor results with AVN of the talus and time of nonweight-bearing.27 The current trend is to permit weight-bearing as tolerated.

CORE DECOMPRESSION

Core decompression has been suggested as an alternative for treatment of nontraumatic AVN of the talus without collapse by decreasing intra-osseous pressure and enhancing revascularization. Mont and colleagues28 concluded that core decompression is a viable method of treatment for symptomatic avascular necrosis of the talus before collapse. At 7 years, 82% of the 17 ankles treated by core decompression had excellent or good result. Delanois and colleagues29 also supported core decompression in symptomatic atraumatic AVN of the talus before collapse. They reported fair-to-excellent results in 29 of 32 patients with AVN of the talus without collapse treated with core decompression.

SURGICAL RECONSTRUCTION OF A NONINFECTED TALUS AVN WITH COLLAPSE

Several treatment options are available for a patient who has pain and disability associated with isolated or combined arthrosis of the ankle, subtalar, talonavicular joint, and osteonecrosis of the body of the talus. These options include joint-sacrificing and joint-sparing procedures. Joint-sacrificing options include resection of the talar body with or without tibiocalcaneal arthrodesis, conventional resection of the joint and arthrodesis, arthrodesis with use of an anterior-sliding tibial bone graft, and posterior tibiotalocalcaneal arthrodesis. Joint-sparing procedures include standard or custom-made total ankle replacement, nonvascularized allograft, and vascularized autograft.

JOINT-SACRIFICING PROCEDURES

Total Talectomy

Simple subtotal or total talectomy without fusion has historically been met with poor results, as almost all patients have a residually painful foot.9,30–33 More recently, Marsh and colleagues34 presented two patients with three tалектомies performed at 4 and 10 months after injury for infection. Favorable results were reported at follow-up of 21 and 14 years, respectively.
Arthrodesis

Principles of arthrodesis
Successful arthrodesis will improve the patient function but will still be disabling. Preparation of the fusion site requires removal of cartilage and necrotic bone to provide a viable bleeding bone surface for fusion. The fusion site may need bone grafting to fill smaller defects; structural grafting may be necessary for larger defects. Successful fusion depends on stable, rigid fixation achieved by screws, or plate and screws; alternatively, fixation may be obtained with a nail or external fixation. Absence of sufficient bone may preclude an isolated arthrodesis and may thus require extending the fusion to multiple joints. The primary goal is to recreate a plantigrade foot.

Ankle arthrodesis
Ankle arthrodesis is a reliable alternative for AVN of the talus with collapse in cases where symptoms are isolated to the ankle joint. Sufficient talus bone stock following debridement of the AVN is required for adequate fixation of the ankle joint. Structural defects of the talus are filled with a structural autograft or allograft. Kitaoka and Patzer35 reported reliable results after arthrodesis for talar AVN in 19 patients; 3 had an isolated ankle fusion and 16 had a combined ankle and subtalar fusion. Standard fixation for ankle arthrodesis includes multiplanar screws or plate fixation. Tarkin and colleagues showed that compared with screws alone, anterior plate supplementation increases construct rigidity and decreases micromotion at the ankle-fusion interface.36 A preliminary clinical study reported a union rate of 96% with anterior plate supplementation.37 External fixation has also been used to achieve an ankle fusion.38 Antegrade nailing of the ankle joint has been described, but with suboptimal results because of bad fixation in the talus. Retrograde nailing is not recommended because it violates the subtalar joint. Because the success of ankle arthrodesis depends on achieving and maintaining rigid fixation of the prepared tibiotalar interface, the authors recommend fixation with screws and anterior plate supplementation (Fig. 2).

Subtalar fusion
Subtalar arthrodesis is a reliable alternative for AVN of the talus with an intact talar dome where symptoms are isolated to the subtalar joint, which is uncommon. After adequate debridement, restoration of the anatomy of the hindfoot may require

Fig. 2. Postoperative AP (A) and lateral (B) radiographs of an ankle arthrodesis performed with a combination of screws supplemented with an anterior plate.
a structural bone graft. Rigid fixation of the subtalar joint is achieved by standard (large fragment) cancellous screws or cannulated screws. Sufficient talus bone after debridement of the AVN is similarly required for adequate fixation of the subtalar joint.

**Talonavicular fusion**
Isolated talonavicular joint symptoms are still preferably treated by talonavicular fusion than by a triple arthrodesis. After adequate debridement, restoration of the anatomy of the medial column may require a structural bone graft. Standard fixation of the talonavicular joint requires screws (small fragment 3.5-mm or 4.0-mm cancellous). A small or minifragment plate or staples can be used to supplement the fixation construct where necessary.

**Blair tibiotalar fusion**
Blair fusion involves removal of the talar body with maintenance of the talar neck and head. The distal anterior tibia is then fused with the remaining talus. Some have modified the initial technique by adding a structural graft anteriorly or by adding fixation devices. The advantages of the Blair fusion compared with a tibiocalcaneal arthrodesis include the preservation of some hindfoot motion, less limb shortening, and a relatively normal looking foot. However, unfavorable results have been reported by Morris and colleagues, Canale and Kelly, and Dennis and Tullos. Most recently, Marsh and colleagues presented one case of Blair fusion for osteomyelitis 9 months after injury, with an excellent result.

**Tibiocalcaneal fusion and tibiotalocalcaneal fusion**
Removal of the entire talar body will necessitate a double-hindfoot fusion. Maintenance of limb length and foot shape aid in fitting shoe wear. Double fusion without structural grafting has fallen out of favor because it shortens the leg. Reckling described a technique whereby a subtotal or total takedown with resection of both malleoli was performed to allow the cut surfaces of the distal tibia and the calcaneus to fuse.

Tibiotalocalcaneal (TTC) fusions can be accomplished using cancellous screws, cannulated screws (Fig. 3), plates and screws, intramedullary nails (Fig. 4), external fixation, and free vascularized fibula grafts. Kile and colleagues reported on the use of a retrograde femoral supracondylar nail to stabilize an extra-articular construct in 30 consecutive patients, including 3 patients with AVN of the talus. Using

![Fig. 3. Postoperative AP (A) and lateral (B) radiographs of a successful double hindfoot fusion with cannulated screws.](image-url)
anterior plate techniques, Sanders and colleagues\textsuperscript{47} were able to obtain a 100% fusion rate in a series of 11 patients who required TTC or pantalar fusion for severe grade IIIB open-tibial pilon and talus fractures. Options to fill the defect include tricortical iliac crest autograft, structural allograft, or femoral head allograft.\textsuperscript{48}

\textbf{Triple and pantalar arthrodesis}

When the subtalar and talonavicular joints are involved, triple arthrodesis is required. Involvement of the ankle, subtalar and talonavicular joints necessitates a pantalar fusion.

\textbf{JOINT-SPARING PROCEDURE}

Impaired residual function and the development of adjacent joint arthritis following fusion have prompted surgeons to look for joint-sparing alternatives. Bone substitutes or joint replacement for AVN of the talus are promising new techniques.

\textbf{Allograft Reconstruction}

AVN of the talus involving only the talar dome with ankle arthritis can be addressed with fresh osteochondral total ankle allograft transplantation. Gross and colleagues\textsuperscript{49} reported nine cases of osteochondral defects of the talus treated with fresh osteochondral allograft transplantation. Eight patients had osteochondritis dissecans and one had an open talus fracture. All underwent partial talar allograft transplantation and the survival rate at 11 years was six out of nine patients. When the talar AVN is associated with collapse and ankle arthritis, allograft total ankle replacement is an alternative. Jeng and Myerson\textsuperscript{50} described 29 patients that underwent bipolar osteochondral allograft of the ankle joint, including 2 patients with talar AVN treated, and had a 50% success rate (Fig. 5). There are no long-term results for talar allograft survival rates in larger cohorts or studies; there are currently no data on revascularization, which is considered to be the most important factor for remodeling of the talus.
Vascularized Autograft Reconstruction

Successful treatment of AVN of the femoral head with a fibula vascularized graft has encouraged some surgeons to apply the same concepts to the talus. In 1989, Hussl and colleagues reported use of a vascularized bone graft from the iliac crest for revascularization of the talus in posttraumatic AVN in a 16-year-old patient. In 2001, Gilbert and colleagues studied 14 fresh-frozen cadaver lower extremities and were able to identify a consistent blood supply to the distal fibula, cuboid, and cuneiform I and III with reliable nutrient arteries. Zhang and colleagues reported on the curative effect of vascularized bone graft in the treatment of 24 AVNs of the talus, with a success rate of 83.3% at 3 to 5 years follow-up. Horst and colleagues have reported the use of this technique as well but without results yet.

Joint Replacement

Joint replacement is an alternative to fusion but currently without knowledge of long-term outcome (Fig. 6). Joint replacement requires a stable and solid bony surface to support the implant over time. Complete debridement of the AVN will often prevent

Fig. 5. Preoperative AP (A) and lateral (B) radiographs of a patient with ankle arthritis secondary to a talar AVN. Postoperative AP (C) and lateral (D) radiographs of the same patient following a successful fresh osteochondral total ankle allograft transplantation. (Courtesy of Mark Myerson, MD, Baltimore, Maryland.)
a standard tibiotalar replacement. A customized talar component can be ordered to address the defect and even replace the talar body completely. Harnroongroj and colleagues published satisfactory results of talar body prosthetic replacement in 14 of 16 patients in Thailand, with average follow-up of 9.5 years. Currently, however, there are no other long-term results available for ankle arthroplasty in these, often, young patients.

SURGICAL RECONSTRUCTION OF AN INFECTED AVN OF THE TALUS

Salvage of an infected AVN of the talus has to be addressed similar to an unstable infected nonunion in that it presents two difficult problems: osteomyelitis and nonunion. Simultaneous treatment of each can be difficult or impossible because the treatment of one can negatively influence the treatment of the other. In general, a fusion requires stability to promote union of the bone interfaces, typically provided in the form of metal implants. Metal implants, however, promote both adherence of microbes and biofilm formation, and adversely affects phagocytosis, thereby making eradication of infection more difficult.
The successful treatment of infected talar AVN should include a multidisciplinary approach designed to treat each component of the problem while taking into consideration confounding patient factors. Therefore, the authors favor a two-stage protocol, with the initial stage consisting of removal of all implants, aggressive debridement and irrigation, temporary stabilization of the defect, prevention of dead-space formation, and bacterial-specific antibiotic treatment. To prevent any resultant dead space being filled by unwanted tissue or fluid collection, and to help local administration of antibiotic, an antibiotic-impregnated cement block can be placed within the defect. The antibiotic-impregnated polymethyl methacrylate (PMMA) delivers high local concentrations of antibiotics and maintains space for later bone grafting. A PMMA block can reduce soft tissue in-growth, augment the local stability, and maintain length and space for the later reconstruction stage of the treatment (Fig. 7).

To provide a mechanically stable environment without internal implants requires either the use of an external fixator or a cast. Medical management of the infection includes administration of local and systemic antibiotics. In collaboration with an infectious disease specialist, appropriate selection and duration of intravenous antibiotic administration is based upon the type of bacteria found at the infection site and the quality of the host. After 6 weeks of antibiotic treatment, confirmation that the infection has been eradicated can be made with some degree of certainty with physical examination, laboratory tests (erythrocyte sedimentation rate, C-reactive protein), and a biopsy of the area. A culture-negative biopsy taken after antibiotics have been discontinued for at least 5 to 7 days will also support that the infection has been eradicated.

At that time, definitive reconstruction of the talus can safely be performed. Optimizing the treatment of infection also includes optimal control of the immunologic and healing process, which includes careful control of blood glucose levels and patient nutrition. The second stage is initiated once the infection has been eradicated and includes fusion, as described above. Joint-sparing procedures are not recommended in a previously infected environment.

Fig. 7. (A) AP and lateral ankle radiographs showing a (B) PMMA cement block used during stage 1 of a salvage of an infected posttraumatic AVN of the talus.
AMPUTATION

Salvage of a nonfunctional limb is not reasonable. Sanders and colleagues\(^47\) raised the question of salvage versus amputation for complex and open hindfoot injuries. Amputation may be the better solution in certain situations.

SUMMARY

Avascular necrosis of the talus is one the most challenging problems encountered in posttraumatic reconstruction of the hindfoot. Adequate knowledge of the etiology, the extent of the disease, and the degree of patient symptoms are required to optimally treat this condition. If the patient has failed nonoperative treatment, then reconstruction or salvage is considered. These options include joint-sacrificing and joint-sparing procedures. Although there are many published treatments for posttraumatic AVN of the talus, critical outcome studies are still lacking.

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