Lisfranc Fracture-Dislocation/Arthrodesis

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Introduction

The term "Lisfranc" was coined by Jacques Lisfranc, a field surgeon of Napoleon's army, whose original description referred to an amputation at the tarsometatarsal joint (TMTJ) level secondary to vascular injury. Today, this term is used mainly in reference to a ligamentous or frank, fracture dislocation at the Lisfranc joint. These injuries can result from low- to high-energy incidents [1]. Low-energy injuries may occur indirectly with bending stress or twisting motion [2]. Higher-energy injuries occur more directly from crush injuries [3] or motor vehicle accidents. Lisfranc injuries are said to occur in 1 per 55,000 people in the United States annually which represents about 0.2% of all fractures. Due to the subtle nature of some injury patterns, a missed or delayed diagnosis is not uncommon. Reports show this may occur up to 20% of the time [4]. Because of a delayed diagnosis, misdiagnosis, or complications of a treated Lisfranc injury, arthritis of the midtarsal and tarsometatarsal joints (midfoot) has emerged as a challenging problem leading to high potential for chronic foot pain and functional disability. To truly understand the injury patterns, one must have a thorough knowledge of the anatomy. The joint complex consists of articulations between the bases of the metatarsals with the cuneiforms and cuboid as well as the intermetatarsal articulations. The medial column articulation consists of the first metatarsal and medial cuneiform; the central column consists of the second and third metatarsals and their articulation with the intermediate and lateral cuneiforms, respectively; and the lateral column consists of the fourth and fifth meta-

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tarsal articulations with the cuboid [5]. The joint configuration forms an arch, sometimes referred to as a "Roman" arch, which is inherently stable (Fig. 16.1). Tarsometatarsal (TMT) pathologic change is a debilitating condition characterized by midfoot malalignment, severe functional impairment, and pain. When faced with this challenging problem, the primary aim of treatment is to balance the foot and provide pain relief by enhancing midfoot stability. Treatment should be attempted initially through non-operative management such as orthoses and bracing followed by surgery.

Functional Midfoot Pathomechanics

A neglected and/or a poorly treated Lisfranc injury can lead to midfoot instability and significant secondary malalignment. A lack of midfoot stability during mid stance phase of gait will have an impact on the patient's lower extremity structurally and functionally. Based on the extent of the primary injury and the time of the revision surgery, the extent of involvement can vary significantly. The lack of stability in the midfoot often results in excessive motion at the Lisfranc joint leading to degenerative joints to varying degrees. The forefoot is often affected by the changes with forefoot overload and secondary contractors at the metatarsal phalangeal joints. If severe enough, the lack of stability can lead to severe disabling soft tissue changes secondary to the bony malalignment. In addition arthritic conditions of the diseased joints may develop. Osteophytes can progress and create increased pressure on the tendons and soft tissues that are worsened with shoes and/or weight bearing. The loss of the midfoot stability eventually will have a consequence of secondary functional changes which may lead to the inability to position the foot effectively during mid stance or for push-off in the gait cycle. The loss of midfoot stability is indicative in patient's complaints and symptoms during stance, ambulation, and activities. Also, as the midfoot loses stability, the foot develops an abnormal foot posture. These changes are consistent with the collapsing of the arch and
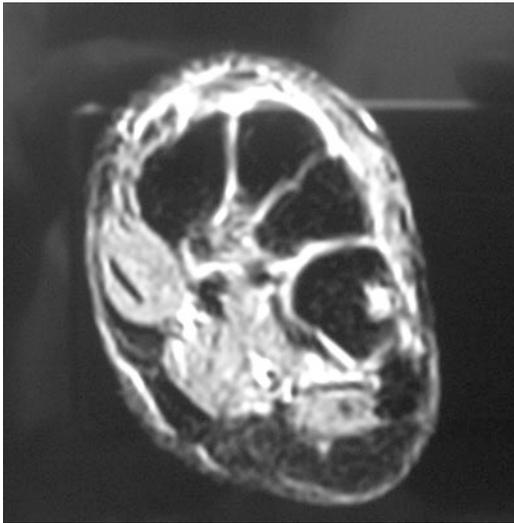
Fig. 16.1 A cross section of the cuneiforms and cuboid similar to a "Roman Arch." Note the natural occurring arch and how the cuneiforms and cuboid are anatomically wedged together. The middle cuneiform is most superiorly positioned relative to the medial and lateral cuneiform. The base of the cuneiforms are situated dorsally and the apex is planetary, which provides for the naturally occurring support in the frontal plane

increased stress to the plantar soft tissue and osseous structures as the foot is loaded, resulting in foot and ankle pain (Fig. 16.2) [6]. These architectural changes of the foot typically lead to greater demands on muscular and ligamentous structures, resulting in fatigue and pain in the foot and ankle. It has been the author's experience that degenerative arthritis along with abnormal foot postures and/or gait patterns makes the foot more susceptible to foot and ankle pain due to mechanical overloading. The changes in alignment lead to abnormal mechanical forces which in turn have a direct effect causing an increase of stress on the soft tissues. As a consequence of the injury, patients with a compromised sensory system may experience a breakdown in their soft tissues with the focused abnormal pressures (Fig. 16.3).

Indications of Procedure

Following complex trauma in the foot, oftentimes there is a loss of mechanical integrity that leads to structural breakdown and secondary soft tissue changes. Injuries that may cause the pain and breakdown of the Lisfranc joint consist of unsuccessful ligamentous repair, severe articular fractures, failed open reductions and internal fixation, chronic neglected/misdiagnosed Lisfranc injury, deformity at the tarsal metatarsal joint, posttraumatic osteoarthritis, and Charcot arthropathy/neuropathic midfoot. These injuries may cause pain, malalignment, atrophy, impairment of the soft tissue envelope, contractures, soft tissue loss, joint adhesions, malunion,

Fig. 16.2 A patient who underwent an unsuccessful open reduction and internal fixation of a Lisfranc injury. Subsequently the patient experienced failed pathomechanics of the midfoot leading to abnormal alignment and pain with a deformity. Note the abduction of the forefoot, the prominent medial bone, and significant alignment relative to the tibia

Fig. 16.3 A plantar view of a patient with a previously attempted Lisfranc repair with malalignment. Note the large callus tissue at the first metatarsal phalangeal joint because of the pathomechanics

nonunion, dystrophic changes, and neurologic and/or vascular injury. When the index procedure has been misdiagnosed, mistreated, or ineffective, the proposed revision procedure must take into consideration the length of time since the original disability and the quality of the soft tissue envelop. Expectations on functional activities following a revision procedure are directly related to the individual patient's given condition. In patients with residual deformity, the extent of the arthrodesis depended on the number of affected joints and the severity of deformity. Selecting the appropriate procedures is key to providing realignment and stability to the foot.

In Situ Arthrodesis

Patients that present with a failed or mistreated Lisfranc injury and are in need of a revision Lisfranc arthrodesis without significant malalignment can proceed with an in situ arthrodesis. An in situ arthrodesis is indicated for those patients with a condition that is limited to the medial or middle column and/or both and without malalignment. The surgeon needs to evaluate the entire lower extremity with a focus at the Lisfranc joint. The patient should be evaluated weight bearing and nonweight bearing. A Silfverskiold test should be performed to assess if there is a contracture of the posterior muscle group [7]. It has been the experience of the authors with revision surgery at the Lisfranc joint that the adaptive changes in this patient population typically exhibit a tight posterior muscle group and are in most instances in need of lengthening the posterior muscle group. The results of the Silfverskiold test will dictate the indication of an Achilles tendon lengthening or a gastrocnemius recession. When indicated, it has been the author's choice to perform the Achilles tendon lengthening percutaneous or the gastrocnemius release through endoscopic technique [8, 9].

A single curvilinear incision is made over between the first and second tarsal metatarsal joint. The incision is made with care to identify and protect the superficial and deep peroneal nerves, dorsalis pedis artery, and vein. A full-thickness flap is created exposing the deformity. All soft tissue retraction is performed with either double-pronged skin hooks or mini Hohmann retractors in best efforts to protect the soft tissue envelop. If previous hardware is present, it is removed. If the hardware is fractured and can be easily obtainable, it is removed. Attention is directed to the involved joints and is exposed and checked under fluoroscopy. Typically there is a great deal of fibrous and capsular tissue in the involved joints. An extended period of time should be spent resecting this tissue and mobilizing the joints. This will expose the involved joints very well, will allow for mobilization, and also by removing this fibrous tissue and debris will prevent an unsatisfactory reduction in attempt to prevent a failed bony union. Next, manipulation of the forefoot from


Fig. 16.4 An intraoperative AP view demonstrating a lamina spreader being utilized to help enable the surgeon to view the joints

the midfoot is done with an osteotome and mallet and insertion of a laminar spreader (Fig. 16.4). The adjacent joints are checked for instability or malalignment. If the adjacent joints are involved, then attention is directed to the necessary joints, and debridement with joint preparation is performed. The cartilage and subchondral bone are removed with an osteotome and mallet to the intended joints. It is important to resect the plantar aspect of the joint in order to prevent dorsal angulation and malunion. A significant amount of time should be spent debriding and preparing the necessary joints. The authors typically utilize an osteotome, mallet, 2.0 drill bits, pics, and curettage technique to be sure extensive subchondral bone is debrided while maintaining the osseous integrity. Once all the required joints are adequately prepared for arthrodesis, a laminar spreader is inserted to each joint to inspect for loose fragments, and to be certain, the joint is prepared adequately.

The Lisfranc joint is deep and has a large surface area, and special attention is focused plantarly. In reducing the deformity, the aim is to restore alignment of the medial aspect of the base of the first metatarsal with the medial edge of the first cuneiform. Next, restoring alignment of the medial aspect of the base of the second metatarsal with the medial edge of the second cuneiform in the transverse plane is necessary. Alignment of the long axis of the talus with the long axis of the first metatarsal in both the sagittal and transverse planes is required to restore anatomical alignment (Fig. 16.5).

This is facilitated by initially correcting the position of the first metatarsal. This is performed by grasping the great toe, dorsiflexing the great toe joint, and rotating the first metatarsal into a neutral position (varus direction-out of valgus), while the base of the first metatarsal is pushed firmly against a stable well-aligned midfoot [10]. If there is noted
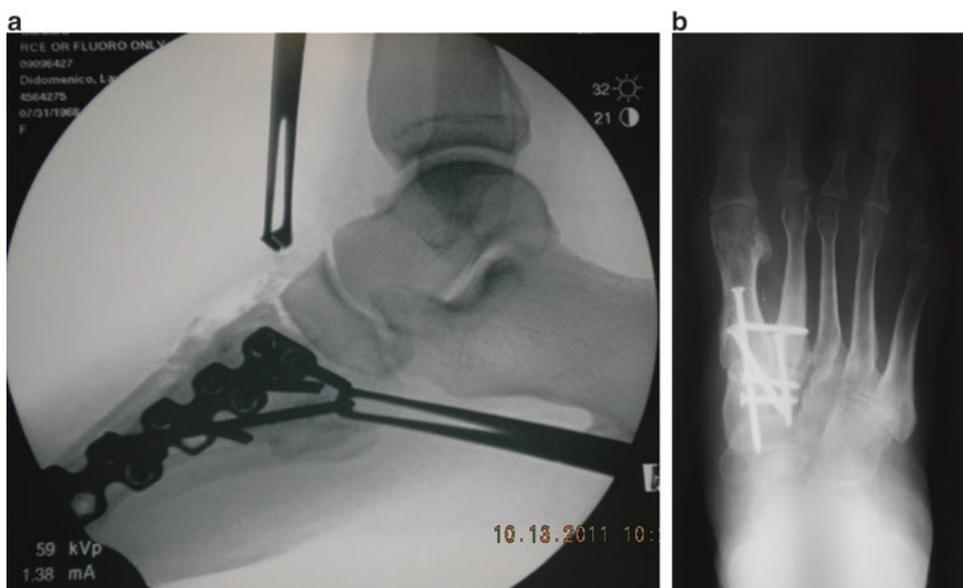
instability of the proximal tarsal bones, medial, and/or lateral cuneiforms of the midfoot, these joints are debrided, aligned, and temporary stabilized prior to reducing the first tarsal metatarsal joint. Stabilization should occur from proximal to distal. Following reduction of the first metatarsal to a stable proximal midfoot, it is temporarily secured with a 2.0 Kirschner wire and is inserted from the first metatarsal proximally into the medial cuneiform while maintaining alignment. Next, the base of the second metatarsal is positioned appropriately followed by the third tarsal metatarsal. A large bone-reduction Weber clamp and/or Kirschner wire is placed obliquely to close the gap between the base of the second metatarsal and the medial cuneiform. A Kirschner wire is inserted from the proximal medial cuneiform aiming distally toward the base of the second metatarsal. If the third tarsal metatarsal joint is involved, this is reduced, and a 2.0 Kirschner wire is inserted from the proximal shaft of the third metatarsal into the respected cuneiform. If the fourth and fifth metatarsal tarsal joints are involved, it has been the author's experience that once the first three tarsal metatarsal joints are positioned, the fourth and fifth metatarsal tarsal joints will be reduced anatomically [11]. The second and the third metatarsal are secured with additional Kirschner wires used in multiple planes stabilizing the metatarsals into the respective cuneiforms. Anteroposterior, medial oblique, and lateral fluoroscopic images are made to confirm the corrected alignment (Figs. 16.6 and 16.7).

Fixation is achieved using a lag technique involving solid 3.5 or 4.0 solid cortical screws and/or plating techniques. If there is noted proximal joint involvement, the proximal joints need to be fixated first to provide a stable midfoot in order to successfully align and fixate the Lisfranc joint [11]. A screw hole technique as described by Manoli and Hansen [12] allows for a difficult angulation, and the first screw is inserted from the first metatarsal to the medial cuneiform creating inter-fragmentary compression. The next screw is inserted from the stable superior proximal medial cuneiform obliquely oriented into the second metatarsal base. It is important that the surgeon understands the anatomy as the base of the second metatarsal is elevated or is at the peak of the "Roman Arch." When inserting this screw, the surgeon should be aiming slightly superior so that the base of the second metatarsal is fixated adequately. This screw also employs inter-fragmentary compression. Additional screws can be inserted from the proximal metatarsal base into the cuneiform and from the base of the first metatarsal into the base of the second and/or third metatarsal. A high-speed burr is then used to debride the edges of the involved joints, and bone voids are then packed with autogenous or allogenic cancellous bone graft for a shear strain relief graft as described by Perren [13]. The gaps are filled with local bone graft which can be harvested from the calcaneus, and if additional bone graft is needed, allogenic bone or a bone graft substitute can be utilized [14]. Typical soft tissue and skin closure is performed.

Postoperatively, the patient is placed in a dorsally slotted non-weight-bearing plaster cast for 2 weeks [15]. Provided there are no wound problems and the reduction and construct is stable, a fiberglass below the knee cast is applied for an additional 4–6 weeks and until radiographic consolidation is evident. Full weight bearing in a fracture boot with physical therapy is then prescribed for 4 weeks.

Realignment Arthrodesis

Patients who present with malalignment and deformity of the forefoot require a realignment arthrodesis of the Lisfranc joint. Oftentimes, a severe or progressed failed Lisfranc

Fig. 16.6 (**a**) A preoperative AP radiograph with fractured hardware. Note the fracture of the screw is at the run out portion of the cannulated screw. This patient presented with continued pain following the index procedure which consisted of an open reduction and internal fixation and of Lisfranc injury. (**b**) An intraoperative view during a revision in situ Lisfranc arthrodesis. The original injury consisted of an open reduction and internal fixation. While preparing for an in situ arthrodesis, an osteotome and mallet were used preparing the intercuneiform joint in preparation for arthrodesis and the use of autogenous bone graft for an in situ arthrodesis revision arthrodesis. (**c**) An intraoperative AP fluoroscopic image while performing a revision surgery for a Lisfranc injury. A long 3.5 mm fully threaded "home run screw" is inserted from the distal first metatarsal into the plantar most proximal cuneiform. A large Weber clamp is used to assist with temporary intercuneiform compression while preparing to apply a medial base locking plate. (**d**) An intraoperative AP fluoroscopic image of an in situ revision arthrodesis with a stable rigid internal fixation construct for an intercuneiform and Lisfranc arthrodesis prior to inserting a shear strain relief graft

joint will require additional procedures in order to reduce the foot into an anatomical position. There are varying degrees of deformity based on the initial injury, the original treatment, the type of treatment, and the secondary bony and soft tissue pathological changes to the adjacent joints. The medial and middle column arthrodesis requires fixation of the first, second, and sometimes the third tarsal metatarsal joints along with their intercuneiform joints. The naviculo-cuneiform and other adjacent joints may need to be included

in this fusion if found to be unstable. In addition, the summation of time from the index injury and original treatment will have a secondary effect on the pathological bone and soft tissue changes. Patients needing a realignment arthrodesis typically present with an abduction of the forefoot and lateral translation and dorsiflexion of the metatarsals (Fig. 16.8).

A valgus deformity may present with medial soft tissues that may be stressed and the lateral soft tissues maybe contracted.

Fig. 16.7 (**a**) An attempted open reduction with K-wire fixation for an original Lisfranc injury. (**b** and **c**) Advanced imaging demonstrating failure of adequate reduction and malalignment following open reduc- tion with K-wire fixation from the original Lisfranc injury. (**d**) An in situ arthrodesis was performed with long fully threaded solid cortical screws repairing the failed K-wire reduction at the Lisfranc joint

In most cases, these patients present with a differing degree a flatfoot deformity along with a collapsing arch in associa- tion with abduction of the forefoot, lateral translation and dorsiflexion of the metatarsals, and a potentially progressed hindfoot valgus. The surgeon needs to evaluate the entire lower extremity. The patient should be evaluated weight bearing and nonweight bearing. A Silfverskiold test needs to be performed to assess if there is a contracture of the poste- rior muscle group [7]. It has been the experience of the

authors that this patient population exhibits a tight posterior muscle group and is in need of lengthening the Achilles ten- don or gastrocnemius. It is the author's choice to most com- monly perform the indicated Achilles tendon lengthening percutaneous or the gastrocnemius release through endo- scopic technique [8, 9].

Incision planning is based on the quality of the soft tissue, the extent and the degree of deformity, and the previous his- tory of the injury and treatment (Fig. 16.9).

Fig. 16.8 A patient who presents following a failed Lisfranc treatment who now is experiencing an abducted forefoot and dorsiflexion of the metatarsals

Fig. 16.9 This patient was a poly trauma patient who experienced a failed reduction of the Lisfranc joint and experienced soft tissue injuries from the initial trauma

The soft tissue envelope needs to be taken in to consideration. In some instances, there may have been previous incisions, there may be soft tissue changes as a result of the initial trauma, and/or the attenuation of the soft tissues changes from malalignment. The incisions are planned according to the deformity. For a severe deformity, two longer incisions are made: one dorsal medial over the first meta-

tarsal and one over the third metatarsal. In some instances, the authors have been able to utilize one large curvilinear incision over the second tarsal metatarsal joint. If planned appropriately, the first, second, and third tarsal metatarsal joints as well as adjacent joints can be exposed appropriately. Regardless of the incision, the incision needs to be full thickness, and care must be taken to avoid the neuromuscular bundles of the dorsal aspect of the Lisfranc joint (Figs. 16.10, 16.11, and 16.12).

In reducing the deformity, the aim is to restore alignment of the medial aspect of the base of the first metatarsal with the medial edge of the first cuneiform. Next, restoring alignment of the medial aspect of the base of the second metatarsal with the medial edge of the second cuneiform in the transverse plane is needed. Next, alignment of the long axis of the talus with the long axis of the first metatarsal in both the sagittal and transverse planes is needed to restore anatomical alignment.

In patients who present with significant abduction of the forefoot, the surgeon must assess the stability or lack of stability of the lesser tarsal metatarsal joints and the lateral column and investigate the hindfoot for malalignment. Based on Lisfranc reduction, as well as clinical and radiographic findings, the surgeon may need to supplement the lateral column and hindfoot for stability. It is possible that the peroneus brevis tendon and other lateral soft tissues are contracted and may need to be lengthened. If the contracture is severe, an external fixator may need to be used intraoperatively to assist with the reduction [16].

An osteotome and a mallet are used to identify and determine which joints are pathologic. These joints are mobilized, and aggressive resection of scar tissue, fibrous tissue, and debris is removed allowing mobilization of the pathologic joints into a more normal alignment. Once the extent of the joint involvement is identified, the osteotome is utilized to denude the cartilage of the joint with little bone resection attempting to maintain the osseous integrity. A significant amount of time is spent at this junction of the surgery ensuring that the joints are appropriately prepared and plantar ossicles are removed. It is important to remove the plantar aspect of the joint in order to prevent dorsal angulation and malunion. This is facilitated by initial correction of the position of the first metatarsal. In most instances, the forefoot is adducted, plantar flexed, and de-rotated into a varus direction. When dealing with a large deformity, the surgeon must be cautious not to overcorrect or realign in adduction, in plantar flexion, or in the frontal plane. This is performed by grasping the great toe, dorsiflexing the great toe joint, and rotating the first metatarsal into a neutral position (varus direction), while the base of the first metatarsal is pushed against a stable aligned midfoot [10, 11]. If there is noted instability of the proximal tarsals of the midfoot, these joints are debrided, aligned, and temporary stabilized prior to
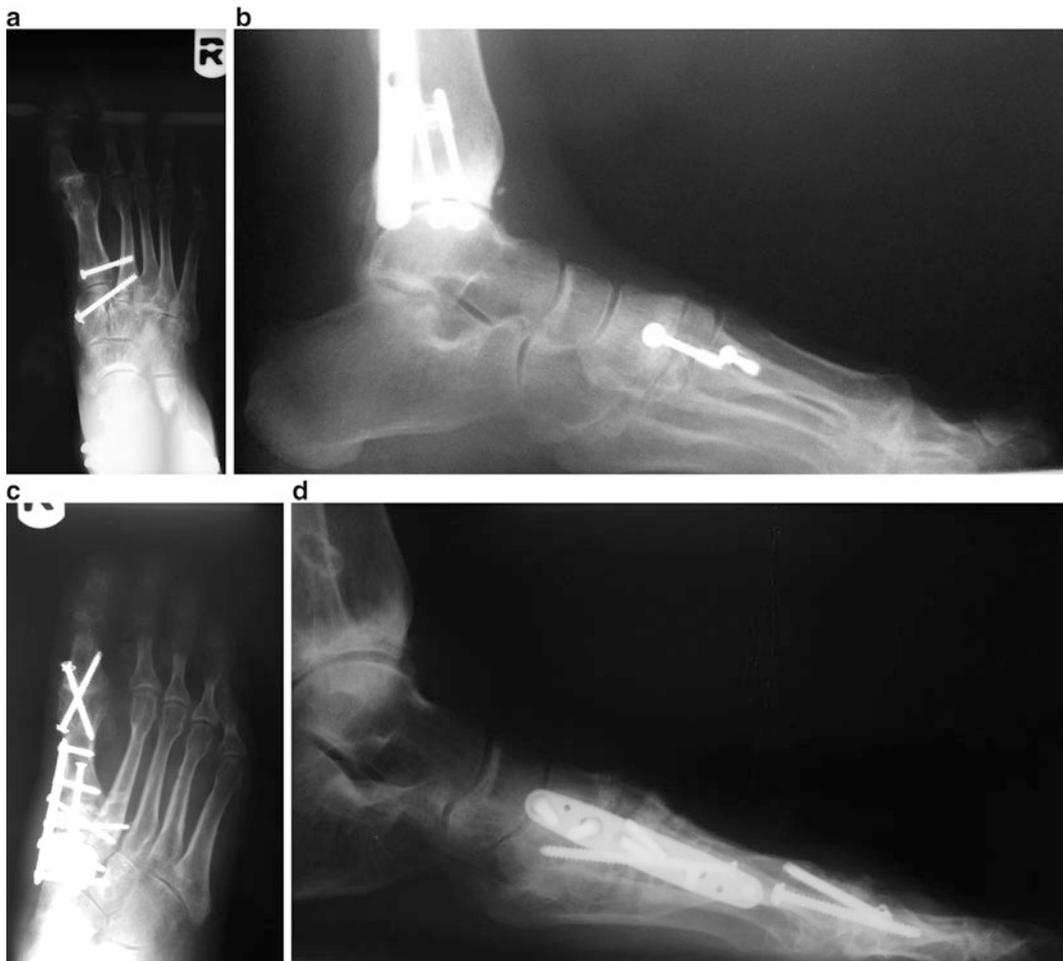
Fig. 16.10 (**a** and **b**) A anterior-posterior and lateral radiograph projection demonstrating a failed open reduction and internal fixation of a Lisfranc injury. Note that the failed reduction in the sagittal plane resulting in an elevatus, subsequently resulting in significant malalignment and pathological changes at the tarsal metatarsal joint, first meta- tarsal phalangeal joint, and the interphalangeal joint. (**c** and **d**) Postoperative radiograph following an realignment arthrodesis of the Lisfranc joint and arthrodesis of the first metatarsal phalangeal joint and percutaneous K-wire fixation (and removal) of the interphalangeal joint

reducing the first tarsal metatarsal joint. The first metatarsal is then temporary fixated with a 2.0 Kirchner wire and is inserted from the dorsal surface of the metatarsal proximally into the medial cuneiform while maintaining alignment. Next, the base of the second metatarsal is positioned appropriately followed by the third tarsal metatarsal. If the fourth and fifth metatarsal tarsal joints are involved, it has been the author's experience that once the first three tarsal metatarsal joints are positioned anatomically, the fourth and fifth metatarsal tarsal joints will be reduced anatomically similar to the vassal principle of an ankle fracture reduction [11]. A large bone-reduction clamp is placed obliquely to close the gap between the base of the second metatarsal and the medial cuneiform. Both the second and the third metatarsal are secured with multiple 2.0 Kirschner fixation through their respective cuneiforms in multiple planes. A 2.0 Kirschner wire is inserted from the medial cuneiform proximally

toward the base of the second metatarsal. Anteroposterior, medial oblique and lateral fluoroscopic images are made to confirm the corrected alignment.

The reduction is held temporarily with multiple Kirschner wires, and radiographs are made to confirm the anatomical reduction. The authors prefer the use of 3.5 or 4.0 long, fully threaded solid cortical screws in a lag fashion with or without plating. In cases that involved extended proximal joints and significant deformity, the authors have employed interfragmentary screw compression, screw fixation, and an application of a plantar plate to the tension side of the foot [17]. The initial lag screw is inserted from the distal first metatarsal into the medial cuneiform. To avoid splitting of the dorsal cortex of the first metatarsal, the hole must be burred so that the screw can be countersunk carefully. A screw hole technique as described by Manoli and Hansen [12] allows for a difficult angulation, and the first screw is inserted from the
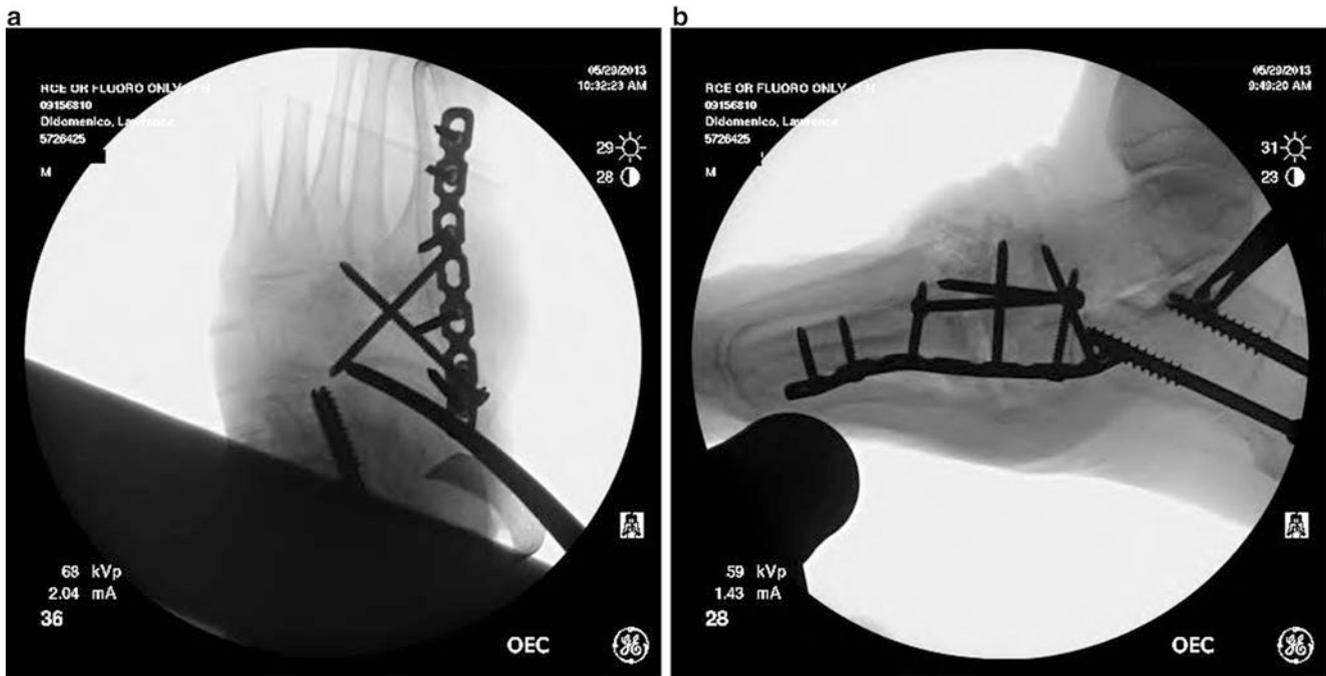
Fig. 16.11 (**a** and **b**) Intraoperative AP and lateral fluoroscopic images following a endoscopic gastrocnemius recession, a percutaneous medial calcaneal slide osteotomy, and a realignment arthrodesis with a large wedge resection at the Lisfranc joint. The base of the wedge resection was medial and plantar, and the apex was lateral and dorsal allowing for adduction, plantar flexion, and derotation in the frontal plane placing the Lisfranc joint into anatomic alignment. Fixation consisted of a 3.5 recon plate with independent long fully threaded solid cortical screws. This anatomically reduced the significant forefoot abduction, dorsally translated metatarsals and the forefoot values deformity, and realigned the hindfoot under the long axis of the tibia. Adjacent joint arthrodesis was additionally needed to control and realign the foot. Note the alignment of the talus first metatarsal alignment on the lateral and AP radiographs
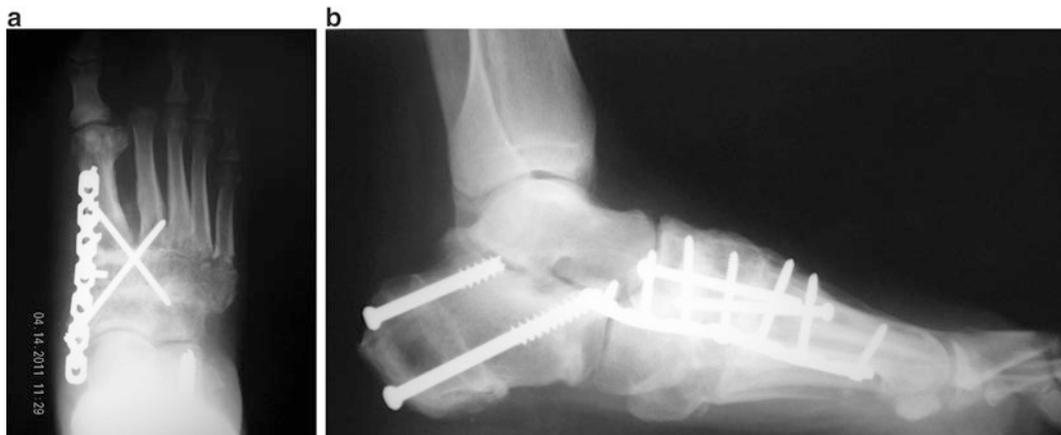

Fig. 16.12 (**a** and **b**) AP and lateral X-rays demonstrating an interfragmentary compression fixation coupled by a plantar plate on the tension side of the Lisfranc joint. Preoperatively the patient suffered a failed Lisfranc reduction and had an abducted forefoot, hindfoot values, and an unstable midfoot. The surgery consisted of an endoscopic gastrocnemius recession to address the equinus contracture, the percutaneous calcaneal slide osteotomy addressed the hind foot valgus, an Evans lateral column lengthening addressed the unstable mid foot, and a Lisfranc arthrodesis with adjacent joint fusions addressed the pathologic midfoot

first metatarsal to the medial cuneiform creating inter fragmentary compression. If there is noted proximal joint involvement, the proximal joints need to be fixated first to provide a stable midfoot in order to successfully align and fixate the Lisfranc joint. The next screw is an inter-fragmentary compression screw inserted from the stable superior proximal medial cuneiform obliquely oriented into the second metatarsal base. Understanding the anatomy of the Lisfranc joint in the frontal plane is required in order to successfully fixate the lesser metatarsal and lateral cuneiforms. Additional screws

can be inserted from the proximal metatarsal base into the respected cuneiform and from the base of the first metatarsal into the base of the lesser metatarsals and/or lesser cuneiforms. A high-speed burr and rongeur is then used to debride the edges of the involved joints, and all bone voids are packed with autogenous or allogenic cancellous bone graft for a shear strain relief graft as described by Perren [13]. The gaps are preferably filled with local bone graft which can be harvested from the calcaneus [14], and if additional bone graft is needed, allogenic bone or a bone graft substitute can be utilized. It has been our experience that despite substantial radiographic changes, usually there is no symptomatic clinical pain in the joints between the fourth and fifth metatarsals and the tarsal bones, postoperatively, provided that the alignment has been corrected. If the fourth and fifth metatarsals are displaced, once anatomically reduced, 2.0 K-wire fixation can be used to maintain the position. Typical soft tissue and skin closure is performed. Postoperatively, the patient is placed in a dorsally slotted non-weight-bearing plaster cast for 2 weeks and is to keep the extremity elevated [15]. Provided there are no wound problems and the reduction and construct is stable, a fiberglass below the knee cast is applied for an additional 4–6 weeks and until radiographic consolidation is evident. Full weight bearing in a fracture boot with physical therapy is then prescribed for 4 weeks [11].

Neuropathic Arthrodesis

Lisfranc joint dislocation secondary to injury and/or Charcot arthropathy is a debilitating condition that can result with an ulceration and/or infection. After conservative care fails, treatment may be limited to realignment arthrodesis of the Lisfranc joint or amputation. Charcot neuroarthropathy is characterized by episodes of active and inactive periods. In the active phase, an edematous, erythematous, warm foot can show progressive destruction and dislocation. In the chronic phase, the foot can reveal a stiff malaligned, rocker bottom foot with soft tissue contractures and compromised skin integrity.

In a patient with a neuropathic Lisfranc joint, attention is directed to the posterior muscle where a Silfverskiold test is performed [7]. Based on the results, an Achilles tendon lengthening or a gastrocnemius recession is performed. Next, a straight incision is made, beginning at the talonavicular joint and extending to the distal one-third of the first metatarsal shaft. The incision is deepened, and a full-thickness flap is retracted superiorly and inferiorly off the tarsometatarsal joints. If previous hardware was utilized, it is removed. Attention is directed toward the base of the tarsal metatarsal articulation. Typically there is significant subluxation/dislocation with significant bony changes. An osteotome is used to resect this bone in order to identify the first

tarsal metatarsal joint. Intraoperative fluoroscopic imaging is needed to assist in identifying the first tarsal metatarsal joint. Evaluation of the extent of the fracture/subluxation/dislocation proximal and lateral is necessary. The authors often utilize a 2.0 Kirschner wire inserted from medial to lateral for the most distal portion of the healthy tarsal bones and to the most proximal portion of the healthiest bone at base of the metatarsals. This acts as a rail system for the surgeon and provides a guide for an aggressive bone resection that can correct the deformity in all three planes. Based on the extent of involvement, the bone across the Lisfranc joint is resected to good, healthy, bleeding bone. The resection is typically performed as a wedge resection which allows for a tri-planar correction. The base of the wedge is medial and the apex lateral in the transverse plane. In the sagittal plane, the base is plantar, and the apex is dorsal. This allows the forefoot to be corrected by adducting and plantar flexing and rotated into a neutral position. Based on the extent of the lateral involvement of the Lisfranc joint, a second incision can be made on the lateral aspect of the foot between the fourth and fifth metatarsals; however, in most scenarios, the authors have been able to perform this through one large medial utility incision. If a lateral incision needed, it is deepened down to the base of the fourth and fifth metatarsals and cuboid. All diseased bone from medial to the lateral is removed. Depending on the extension of the Charcot destruction, bone resection may need to be performed through the naviculocuneiform, talonavicular joints, or other adjacent joint in order to restore the medial arch of the foot. If the more proximal joints are destabilized, they must be realigned and stabilized first starting proximally. The Lisfranc joint is adducted, rotated, and held in a plantar-flexed position with multiple 2.0 Kirschner wires. The first metatarsal, fifth metatarsal, and calcaneus must be on the same plane creating a tripod effect with the foot loaded. With the foot loaded, the ankle joint motion is checked to demonstrate that the equinus contracture is no longer present allowing the ankle to get into a neutral position. Alignment is checked using fluoroscopic imaging to ensure the talus first metatarsal angle in the transverse and sagittal plane is aligned. Next, a plate is eccentrically loaded plate is applied to the plantar aspect of the first metatarsal, medial cuneiform, and navicular.

A 3.5 cm or 4.0 solid cortical screw is placed outside the plate in an oblique fashion, beginning on the medial wall of the first metatarsal and aiming at the lateral edge of the navicular. A second cortical screw is inserted from the medial cuneiform or navicular into the second or third metatarsal base. The fourth and fifth metatarsals reduce to an anatomic position as the soft tissue and muscular attachments maintain consistency with anatomic reduction of the first and second tarsal metatarsals. Again, typically no fixation is used on the fourth and fifth rays. Autogenous or allogenic cancellous bone is used to back fill any voids at the arthrodesis site [11].

Typical soft tissue and skin closure is performed. Postoperatively, the patient is placed in a dorsally slotted non-weight-bearing plaster cast for 2 weeks and is to keep the extremity elevated [15]. Provided there are no wound problems and the reduction and construct is stable, a fiberglass below the knee cast is applied for an additional 6–8 weeks and/or until radiographic consolidation is evident. Partial weight bearing in a fracture boot with physical therapy is then prescribed for four additional weeks followed by full protective weight bearing. The postoperative course included serial radiographs every 3 weeks until radiographic evidence of consolidation is noted.

Contraindications/Limitations

An absolute contraindication for correcting a Lisfranc deformity is a dysvascular limb or a patient who is afflicted with a medical conditions prohibiting surgery. Also if a patient has an open wound and an active infection, the infection and wound management must be treated and stabilized prior to attempt at surgical corrections. Relative contraindications included altered bone quality, advanced age, tobacco use, patients who suffer from chronic regional pain syndrome, wound problems, ischemia due to peripheral vascular disease, osteomyelitis, and infections.

Prior to embarking on a revision reconstruction surgery, consideration must be given to the soft tissue envelop and assessing the vascular status of the patient. Given the history of the index injury and the previous failed treatment, the soft tissues must be closely examined. It is imperative that the soft tissue have the ability to respond to the proposed surgery. Obtaining vascular studies is often needed to predict the healing ability.

Due to the extent of the presenting deformity, some patients may present with chronic open wounds. It is essential for the surgeon to evaluate these patients thoroughly, use appropriate testing, and consult with the proper and needed specialties to manage these complex problems to determine if and when the best time is to address the deformity. Patients with a diagnosis of osteomyelitis from a previous infection or secondary to an ulcer deformity must be managed appropriately before, during, and after the surgery. If an active osteomyelitis is present, then the infection must be addressed first. In cases of a chronic osteomyelitis, a bony resection to clean margins and arthrodesis can be performed along with the appropriate comanagement of the chronic osteomyelitis. The bony resection serves as a function of a surgical treatment by removing the infected bone. The bony resection of infected bone to clean, heathy margins coupled with treatment of intravenous antibiotics has been a successful combination for the authors. Fixation provisions may be impacted based on the circumstances. In cases with a chronic osteo-

myelitis, resection of the infected bone serves as a surgical treatment; however, this may affect the quantity of bone and alter the fixation needed to reduce the deformity.

Given the magnitude of the deformity, in some cases, the foot may be shortened (medial column). The patient should understand that the operative foot may change the size of the foot compared to the preoperation size and compared to the contralateral side. As described earlier, if the hindfoot is unstable, the surgeon must be prepared to perform additional surgical procedures that most likely will need additional hardware and/or bone graft. With large deformities, the surgeon needs to be prepared to employ the use of an external fixator to assist in the reduction of the deformity.

Technique Pearls and Pitfalls to Avoid Complications

The recommended incision should be curvilinear over the first tarsometatarsal. This provides excellent exposure to the first, second, and third tarsometatarsal joints while avoiding the deep peroneal nerve and dorsalis pedis artery. Additionally, this prevents unnecessary traction on the skin and neurovascular structures. If a second incision is needed, it should be over the fourth metatarsal shaft. It should be noted that the soft tissue island between the incisions needs to be adequate in size to prevent tissue necrosis. If only the medial tarsometatarsal joints are involved, it has been the experience of the authors to make a large dorsal curvilinear incision starting at the dorsal lateral first metatarsal and extending to the naviculocuneiform joint. Care should be taken not to undermine/separate the tissues in order to prevent soft tissue injury. The exposure must be adequate once the incision is made; the tissues should be reflected off the bony structures as a full-thickness flap. Preferred retraction is accomplished with small fine tooth double prong retractors and/or mini Hohmann retractors to reduce trauma to the tissues and to avoid trauma to the neuromuscular structures [11].

The goal of the treatment is a stable, painless, plantigrade foot. The goal is achieved by anatomical reduction, alignment, and stable fixation. Preparation of the joints to ensure adequate consolidation is essential. Joint distraction can be achieved with tarsal distractors or a laminar spreader. The use of drills, osteotomes, picks, curettes, and rongeurs is utilized to prepare the joint(s) for arthrodesis. Debridement is performed down the level of healthy, bleeding bone with the goal of maintaining normal articular surfaces as much as possible. Specific attention should be made to the plantar tarsal metatarsal joints during preparation to confirm there is no residual bone/cartilage remaining which could predispose the reduction to dorsal angulation and malunion. Excellent reduction must be accomplished. An AO (Arbeitsgemeinschaft für Osteosynthesefragen) pointed reduction forcep may be

used to aid in reduction. The use of intraoperative fluoroscopic imaging is extremely helpful in ensuring appropriate and anatomic alignment.

Prior to fixation of the Lisfranc joint, the surgeon needs to assess the proximal and adjacent joints. If the nearby joints are unstable and overlooked, the surgery may result with complications.

The fixation construct is extremely important to the success of the surgery. Solid fully threaded screws are recommended. A stable solid fixation construct is necessary and should be designed specifically for each particular case with a great deal of thought. When inserting the fixation specifically from the metatarsal into the cuneiforms, a burr hole technique as described by Manoli and Hansen [12] is extremely helpful for drilling the difficult angles and inserting the screws from distal to proximal. Additionally, the burr hole allows the screw to be recessed so it is not proud and palpable. Lastly it prevents stress risers in the cortical bone of the metatarsals and prevents fracturing of the bone.

To avoid inefficient fixation, while inserting screws from the medial cuneiform or first metatarsal into the base of the respective second metatarsal and intermediate cuneiform, the screw should be directed more superiorly to successfully obtain a good purchase. The anatomy of the midfoot in the frontal plane mimics a "Roman Arch"; thus, the base of the second metatarsal and intermediate cuneiform is positioned more superiorly than the base of the first metatarsal and the medial cuneiform.

Bone to bone contact while maintaining anatomic alignment is a key to a successful outcome and bony union when attempting an arthrodesis at the Lisfranc joint. Due to the challenges of Lisfranc joint configuration, preoperative malalignment, the given number of joints involved following articular cartilage, and bone debridement, it can be difficult to appropriately anatomically align multiple aspects of each joint while trying to maintain as much bone to bone contact. Because anatomic alignment is paramount, in situations where dorsal gaps are noted in order to preserve anatomic alignment while attempting to have as much bone to bone contact (usually the plantar edges of the joints), a shear strain relief bone graft is used to backfill the voided areas of the joints [11]. For example, when revising the first tarsal metatarsal joint, it is critical to align the first metatarsal appropriately with the long axis of the talus in the sagittal plane. In order to appropriately align the joint with bone to bone contact, the first metatarsal may need to be plantar flexed relative to the cuneiform in order to maintain the talus first metatarsal angle in the sagittal plane. The result oftentimes will leave the first metatarsal cuneiform joint with nice bone to bone contact at the plantar edges of the joint and gapped at the dorsal surface. This is a perfect scenario where tightly

backfilling of a joint with bone graft while maintaining alignment without sacrificing position.

Lastly in order to prevent increased stress across the tarsal metatarsal joint, equinus contractures should be appropriately managed intraoperatively. This is important to reducing load and weight-bearing forces through the forefoot and midfoot, thus, increasing the rate of union and chance for a successful outcome.

Management of Specific Complications

Malunion

Anatomic reduction is the goal of any Lisfranc injury. However, the type and extent of the injury as well as the previous treatment may prove to make revision surgery difficult. Patient comorbidities may also play a role. A malunion may ensue leading to arch collapse, arthritis, and lesser metatarsalgia. Malunion of the second TMTJ has been reported to be the most common with displacement in a dorsolateral direction [27]. Typically, Lisfranc injuries involve multidirectional instability so all planes need to be addressed and reduced appropriately. For example, if the first ray is inadequately reduced, particularly in the sagittal plane, an elevatus may ensue. This could alter the joint mechanics of the hallux at the more distal metatarsophalangeal and interphalangeal joint (see Fig. 8a, b) and predispose the patient to lesser metatarsal overload. Gross malalignment or the neuropathic foot may require a medial- and plantar-based wedge arthrodesis at the Lisfranc joint [17, 18].

Brunet reported on the long-term sequela of Lisfranc fracture dislocations at an average follow-up of 15 years for 33 patients. The purpose of their paper was to determine the anatomical, functional, and radiographic results at over a 10-year follow-up. Even though the large majority of patients had Hardcastle type B injuries, most patients were treated with closed reduction and immobilization, closed reduction with immobilization and pinning, or no reduction with a cast. Open reduction was performed in only one patient. Foot pain was attributed to malunion of metatarsal fractures in three patients, sesamoiditis in four patients, and adjacent joint arthritis in six patients. Hallux rigidus was common in three patients. Posttraumatic arthritis on radiographs did not correlate to functional outcomes as most patients returned to full work-and non-work-related activities despite the presence of severe to mild arthritis. This study stresses the importance of anatomic reduction as malalignment will alter mechanics through the forefoot [19].

Basic principles consisting of excellent joint debridement, precise anatomic alignment, and a stable, solid fixation

construct are essential in order to avoid a malunion. Most of the time spent during the surgical procedure should be identifying the appropriate joints involved, joint preparation in cases requiring arthrodesis, and building the fixation construct. Attention to detail with these principles will help prevent malunion.

Revising a malunion of the Lisfranc joint typically consists of hardware removal and aggressive joint resection to healthy bleeding bone. Wedge resection is often needed in order to align the malunion joint, and bone graft is often needed in gapped areas in order to retain anatomic alignment.

Lesser Metatarsalgia

Lesser metatarsalgia can develop in case where malalignment exist and the foot is not balanced appropriately. If there is gross angulation of the lesser metatarsals particularly in the sagittal plane, the patient may present with pain and/or calluses of the adjacent lesser metatarsals. When performing revision arthrodesis, the key suggestions to prevent lesser metatarsalgia from developing is to be sure the talar first metatarsal angle in both the transverse and sagittal plane are aligned well. Focused attention to the medial tarsal metatarsal joint ensures the joints are aligned appropriately and that weight bearing will be restored through the first ray. Once reduction of the medial (dominant segment) tarsal metatarsal is successfully reduced, the remaining lesser tarsal metatarsal joint will become anatomically aligned. It has been the author's experience that once the first three tarsometatarsal joints are positioned, the fourth and fifth metatarsal tarsal joints will be reduced anatomically [11]. The fixation utilized should be long and begin as far distal in the metatarsals to provide a cantilever effect which in turn will help to prevent ground reactive forces from causing dorsal drifting of the metatarsals. Also the forefoot pressures are reduced by addressing the tight posterior muscle group through an Achilles tendon lengthening or a gastrocnemius recession. In unfortunate cases which an isolated metatarsal is maligned, an isolated lesser metatarsal osteotomy can be performed to address the malalignment. Lesser metatarsal osteotomies should be limited to cases of only isolated metatarsal deformity or isolated malalignment. Lesser osteotomies applied to cases of global metatarsal deformity or malalignment often will not resolve the issue and can provide transfer lesions and metatarsal pathology.

Komenda et al. reported on 32 patients who underwent arthrodesis following traumatic Lisfranc injuries. Metatarsalgia was a complaint postoperatively in two patients secondary to malunion. Both patients were treated with a dorsal-based wedge osteotomy [20]. Mann et al. reported on five patients with prominent metatarsal heads following tarsometatarsal arthrodesis.

Arthrosis of the Fourth and Fifth Tarsometatarsal Joints

Based on the author's experience, fusion of the fourth and fifth tarsal metatarsal joints in the non-neuropathic patient is rarely indicated if appropriate alignment is maintained. When arthritis is present in the fourth and fifth tarsal metatarsal joints, it has been the experience of the authors that excellent reduction and anatomic alignment with stable fixation of the medial column coupled with anatomic alignment of the fourth and fifth tarsal metatarsal joints creates a predictable satisfactory outcome. In the neuropathic patient population, arthrodesis of the fourth and fifth tarsal metatarsal is well tolerated and provides stability provided it is well aligned. Management strategies for lateral column arthritis are varied and controversial. Because the lateral column is more mobile compared with the other columns, attempt is made to preserve the motion. Despite the fact that arthritis may be present, it is usually asymptomatic [18, 20]. There is a concern that fusing the lateral column could cause stiffness and increase the chances for a stress fracture [21]. As discussed previously, the motion through the lateral column is the greatest as compared to the medial and central columns [22], and therefore these joints should typically be preserved. With this increased motion, there is also a greater risk for nonunion [21] if an arthrodesis is attempted.

Raikin and Shon in 2003 retrospectively reviewed 23 patients (28 feet) who had undergone a complete midfoot arthrodesis. The large majority had neuroarthropathy, 22 patients, with the other six patients being sensate. Clinical and radiographic fusion was achieved in 26/28 patients. The overall AOFAS scores improved from 35.3 points preoperatively to 77.7 points postoperatively. Average pain scores overall also decreased from 5.1 points preoperatively to 1.3 points postoperatively. Lateral column stiffness was reported postoperatively in 13 patients; however, it did appear to alter their function according to the study. They concluded that lateral column arthrodesis may be indicated for patients with lateral column collapse, a rocker bottom deformity, or significant arthritis not amenable to conservative care [23].

Berlet et al. in 2002 retrospectively reviewed 12 patients who underwent tendon, interpositional arthroplasty for arthritis of the fourth and/or fifth tarsometatarsal joints. At an average of 25 months of follow-up, the mean AOFAS midfoot rating scale was 64.5. They noted that patients that scored higher postoperatively typically had preoperative pain relief with a diagnostic, intra-articular injection. They recommended an injection preoperatively as both a therapeutic and prognostic indicator for patients one may consider for surgical intervention [24].

Viens et al. reported on five patients who underwent ceramic interpositional arthroplasty for fourth and fifth TMTJ arthritis. The mean clinical and radiographic follow-up was 18 months. All patients reported subjective improvement in pain. There

was complete resolution of pain in three patients. Two patients experienced complications postoperatively consisting of wound dehiscence and delayed healing, respectively. No scoring systems were evaluated before or after the surgery [25].

Shawen et al. also reported on interpositional arthroplasty via a ceramic implant in 2007. They reported on 13 patients who underwent this procedure after failing non-operative care. Eleven patients were available for follow-up at an average of 34 months. Their results showed an average midfoot AOFAS score of 52.5 which was an 87% overall increase compared to preoperative values. The VAS pain scores improved on average by 42%. A large majority of patients (11/13) reported that they would have the procedure performed again [26].

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