

THE MANAGEMENT OF ANKLE AND PANTALAR ARTHRITIS

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In: Foot and Ankle Disorders

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"God has so constructed the body as to give greater honor to the lowly members, that there may be no dissention in the body, but that all the members may be concerned for one another. If one member suffers, all the members suffer with it..."

The first epistle of Paul to the Corinthians, Chapter 12, verses 24 through 26.

"Doc, when your feet hurt, you hurt all over."

Recent statement of patient to his orthopaedic surgeon.

The surgeon caring for disorders of the foot and ankle will encounter many types of arthritis, including primary and secondary osteoarthritis, neuropathic arthrosis, inflammatory arthritis, and, rarely tuberculous arthritis. Since reports in the late 19th Century, arthrodesis has been a successful accepted treatment method for painful arthritic disorders of the ankle, subtalar and transverse tarsal joints.* While the portion of this chapter addressing surgical management of ankle and hindfoot pathology will in large part involve arthrodesis - the intentional fusion of a joint - as a form of reconstruction, this chapter will address not only surgical technique, but nonoperative methods of care as well. The pathophysiology leading to ankle and hindfoot disability and the biomechanical basis for this disability will be addressed. Pathomechanics will be highlighted, and this chapter will help

*footnotes= 2,4,5,7-16,18,19,21,22,25-27,29-35,37,40-51,53-64,68-72,74,77-83,85-87,89,92

to establish the diagnosis, indications and preoperative planning when surgery is indicated in managing these disorders. Rehabilitation of the postoperative patient, as well as the complications that may arise after operative management for ankle and pantalar arthritis will be discussed.

Primary osteoarthritis, formerly known as degenerative joint disease, is characterized by loss of

joint cartilage and hypertrophy of bone. Osteoarthrosis is a term used to de-emphasize the inflammatory component of this disorder when it was formerly described as osteoarthritis or hypertrophic arthritis. It has been estimated that over 40 million Americans have radiological evidence of osteoarthrosis, including 85 percent of people over the age of 70. Fortunately, however, many of these patients have no musculoskeletal complaints that correlate with their radiographs. The exact mechanisms for loss of cartilage in osteoarthrosis have not been defined, but subchondral bone injury and mechanical stress contribute to the damage.⁶⁷

Radiographic hallmarks of osteoarthrosis consist of osteophyte formation, radiographic joint space narrowing (that correlates with loss of joint cartilage), and the appearance of subchondral bone cysts and subchondral sclerosis.⁶⁶ There is usually an absence of juxta-articular osteoporosis in this type of hypertrophic arthritis (Figure 1).

Secondary or post-traumatic osteoarthrosis usually occurs after intra-articular fracture most commonly in weight bearing joints such as the ankle or subtalar joint (Figure 2).^{22,32,58,72}

Hemophilic arthropathy may somewhat resemble secondary osteoarthrosis in its radiographic presentation.⁶⁷

Neuropathic arthrosis (Charcot neuroarthropathy) develops most often in the weight bearing joints such as the tarsometatarsal joints, the ankle subtalar joint, transverse tarsal joints, and knees. In the United States and the remainder of North America, Charcot's joints are most often seen in patients with diabetes mellitus who have peripheral neuropathy.⁶⁷ Fortunately the incidence of tabes dorsalis and leprosy have diminished in developing countries, but these too have in the not too distant past been leading causes of trophic disturbances of the ankle and hindfoot.

Syringomyelia is the most common cause of neuropathic arthrosis in the upper extremities.⁶⁷ Congenital indifference to pain, vascular or neoplastic injuries to the proprioceptive nervous system,

alcoholism, spinal cord injury, hereditary sensorimotor neuropathy, and peripheral nerve injury are other causes of neurotrophic arthropathy.^{63,67,69,70,83}

Neuropathic arthrosis of the foot and ankle is characterized by painless swelling, increased warmth, significant crepitus, and often very significant deformity (Figure 3). The radiographic hallmarks of a neuropathic foot and ankle include the presence of numerous fractures in various stages of healing, hypertrophic and hypermineralized new bone formation, and the loss of normal weight bearing architecture in advanced cases. Significant osteolucency at the fracture site may be seen, along with vascular calcification and significant joint subluxation or dislocation (Figure 4).^{63,69,70,83}

The category of inflammatory arthritis includes the various presentations of rheumatoid arthritis - both seropositive and seronegative - mixed connective tissue disorders, arthritis due to gout and pseudogout, and those primary synovial inflammatory conditions of unknown etiology, such as pigmented villonodular synovitis. Septic arthritis, psoriatic arthritis, arthritis associated with spondylo arthropathy and that of Reiter's syndrome are also in this category. Rheumatoid arthritis is a chronic systemic disease of unknown etiology manifested by inflammatory arthritis, usually in a symmetrical distribution. This disorder may be associated with many systemic manifestations. Rheumatoid arthritis is characterized by the formation of hyperplastic synovium, which can spread to cover the articular cartilage and periarticular surfaces with a tissue referred to as pannus. This pannus may destroy the underlying articular cartilage, subchondral bone and supportive musculotendinous and ligamentous tissues.^{23,39,67}

Radiographically, inflammatory arthritis is characterized by joint space narrowing, joint subluxation secondary to the imbalance of opposing muscle groups about a joint, juxta-articular erosions and osteopenia (Figure 5) (Figure 6).^{14,67,87}

There are many clinical differences of consequence to the orthopaedist managing osteoarthritis and inflammatory arthritis. Nonoperative considerations include the use of braces, normal biomechanics

and pathomechanical alterations about a joint, and often very involved medical management of the patient with diabetes, neuropathy or systemic manifestations of rheumatoid arthritis. Surgical considerations that are quite different for the patient with osteoarthritis and the patient with rheumatoid arthritis include the presence or absence of osteopenia, the degree of ankle and hindfoot deformity, and the quality of the soft tissue envelope.^{37,60,77} The choice of instrumentation is often very important in dealing with a patient who has inflammatory arthritis and osteopenia (Figure 7).^{14,25,51,54,84} In the patient with polyarticular rheumatoid arthritis, it is often difficult to decide which joints should be operated first. In many cases it makes sense to perform hip replacement surgery before knee replacement arthroplasty in the patient with polyarticular rheumatoid disease so that preoperative hip flexion contractures which would influence the ability to completely straighten the knee could be corrected before the knee is operated. It is often advisable to perform hip and knee surgery if it is indicated for a particular patient, before considering ankle or hindfoot arthrodesis. The appropriate realignment of coronal plane deformity in the total knee arthroplasty patient dictates the position in which the ankle and hindfoot would be fused in order to make the foot plantigrade.

Also, in the rare patient who requires both ankle and forefoot reconstructive surgery for the sequelae of rheumatoid arthritis, it is important to operate the ankle and hindfoot first in order to make the forefoot plantigrade before considering forefoot arthroplasty.⁶⁹ Of course, the surgeon caring for patients with rheumatoid arthritis must always assess preoperatively arthritic involvement of the patients cervical spine and upper extremities. If a patient being considered for ankle or pantalar arthrodesis has severely limited use of his upper extremities, then this patient would have a difficult time complying with a postoperative regimen of protected weight bearing after lower extremity arthrodesis. For these patients, preoperative consideration should be given to the use of a platform walker, Canadian (Loftstrand) crutches, and/or wheelchairs with elevated leg rests.

Nonoperative options available for the treatment of ankle and pantalar arthritis include pedorthic

management, foot and ankle and patellar tendon bearing bracing techniques, oral pharmacotherapy, rest and physical therapy modalities, and intra-articular injections of steroids.^{63,64,67,69,71} The author has no personal experience with the use of intra-articular viscous hyaluronate injection (Hyalgan, Sanofi Pharmaceuticals, New York, New York), but early results may be promising, albeit speculative.²⁰

Operative options available for the treatment of ankle and pantalar arthritis may be either minimally invasive or extensile. These operative options also may be either joint sparing or ankylosing. Joint sparing surgeries include arthroscopic or open synovectomy or arthroscopic debridement and chondroplasty employing either mechanical high speed shavers or the Holmium:YAG laser (Figure 7.5, intraoperative arthroscopic video print if MSM wants). Anterior tibiotalar cheilectomy is another joint sparing procedure that can be performed arthroscopically or through a small arthrotomy (Figure 8).

Total ankle replacement arthroplasty also spares motion of the ankle joint and is a viable option for the appropriately selected, low-demand patient (Figure 9a) (Figure 9b).^{44,45} Ankylosing procedures used in the surgical management of ankle and pantalar arthritis include minimally invasive ankle arthrodesis techniques that can be performed arthroscopically or by mini-arthrotomy techniques.^{57,60,62} Extensile approaches for ankle arthrodesis include the transfibular and bimalleolar osteotomy approaches, as well as extra-articular fusion.* Talectomy as described by Blair is also considered an open, extensile approach to ankle arthrodesis.^{10,59}

*footnotes= 2,4,7,11,13-16,18,19,21,22,25,29,33,34,37,43-45,51,54-58,60,77-80,82,83,85,92

Pantalar arthrodesis is the most extensive ankylosing procedure available for the management of ankle and hindfoot arthritis.^{5,8,27,30,31,35,41,46, 49,50,53,63,64,69,70,72,74,77,79,81,86,87,89}

Before discussing in detail each of these aforementioned operative and nonoperative options available for treatment of the arthritic ankle and hindfoot, I will discuss briefly the history of the treatment of

arthritis.

HISTORY OF THE TREATMENT OF ARTHRITIS

Poplar and willow barks containing salicin have been used since antiquity to treat fever, pain and gout. Colchicine, which was included in the extracts of autumn crocus, was used for the treatment of acute gout as early as the Sixth Century, A.D. It was not until 1820 that colchicine was isolated, and by 1900 salicylic acid and aspirin had been synthesized. Phenylbutazone was the first agent to which the term nonsteroidal anti-inflammatory drug was applied. This drug was introduced into clinical practice in 1949. Three years prior to this the dramatic anti-inflammatory properties of the glucocorticoids had been demonstrated.^{23,73,88}

Swedish investigators believed that infection was the main etiology of rheumatoid disease and in 1938 commenced synthesizing compounds that incorporated salicylic acid and antibacterial sulfonamides.⁸⁴ Salicylic acid and sulfapyridine joined by an azo bond by Swedish researchers created the compound now known as sulfasalazine.⁸⁴ Later, interest in the antirheumatic properties of sulfasalazine diminished while the efficacy of the drug in ulcerative colitis therapy was established.⁷⁶ More current studies have unequivocally established the effectiveness and safety of sulfasalazine as an antirheumatic in rheumatoid arthritis. The drug seems to uniquely show its most potent efficacy in the treatment of ankylosing spondylitis and human leucocyte antigen - B27 - related arthritic disease. Sulfasalazine is also proving effective in the treatment of juvenile rheumatoid arthritis and psoriatic arthritis.^{73,76,84}

In the 1950's and 1960's, a very useful animal model involving the injection of carrageenan into the rat paw was established. Pharmacologic history was made when indomethacin was found to dramatically diminish inflammation in the rat paw injection model. A great many other compounds have been found to suppress the acute development of rat paw edema following the injection of carrageenan in the time since indomethacin was first marketed in 1965. Almost all of the currently available nonsteroidal anti-

inflammatory drugs were initially discovered by identifying their in vivo effects on this model of acute inflammation.^{23,75,88}

In 1933, Goldblatt discovered prostaglandin activity in seminal fluid.²⁸ The identification of arachidonic acid and the cyclo-oxygenase pathway for arachidonic acid metabolism was not detailed until the 1960's.⁷⁵

Vane, in 1971, reported that aspirin-like drugs inhibit prostaglandin synthesis.⁸⁸ Subsequent work has shown that there is a good correlation between the order of potency of various nonsteroidal anti-inflammatory drugs in the suppression of prostaglandin synthesis and in the suppression of inflammation. Aspirin irreversibly inhibits this process by acetylating the enzyme cyclo-oxygenase. The other nonsteroidal anti-inflammatory drugs reversibly inhibit cyclo-oxygenase by competitive inhibition. Thus, the nonsteroidal anti-inflammatory agents reduce the synthesis of prostaglandin's, thromboxane, and prostacyclin, thereby mediating the inflammation of arthritis.^{23,75,88}

Antimalarial medications, which are also antirheumatic drugs, are found in the bark of the Peruvian cinchona tree. The active agents in this bark are quinine and cinchonine and were isolated by Pelletier and Caventau in 1820. The first description of the successful use of quinine for treatment of a rheumatic disease was given in 1894 by J. P. Payne in a postgraduate lecture on lupus erythematosus. In recent years, a broad spectrum of connective tissue diseases have been reported to respond to antimalarials.^{65,73,90}

For centuries, Gold has been advocated for the treatment of many human diseases, including tuberculosis, pemphigus and bronchial asthma. Forestier described the use of gold compounds in 1929 for the treatment of rheumatoid arthritis. Today gold is often recommended for the treatment of ankylosing spondylitis affecting peripheral joints, for patients with psoriatic arthritis, and for patients with juvenile arthritis.^{1,24,39}

Low-dose weekly methotrexate was approved in 1988 by the United States Food and Drug Administration as a therapy for very active rheumatoid arthritis. Low-dose methotrexate is also used as a therapy for a variety of other inflammatory, autoimmune, and rheumatologic conditions.⁹¹

Glucocorticoids and their dramatic anti-inflammatory effect on patients with rheumatoid arthritis have both been a boon and a bane to the treatment of patients with this disease. The anti-inflammatory effect of glucocorticoids has long been associated with the untoward manifestations of Cushing's syndrome.⁶⁶

With regard to the surgical management of arthritis of the ankle and hindfoot, ankle arthrodesis was first reported by Albert in 1882.⁴ Fusion of the tibia to the talus and the talus to the os calcis has been performed using posterior extra-articular methods, employing techniques described by Staples.⁷⁹ Intramedullary fixation for extended hindfoot and ankle arthrodesis was described by Loxor as early as 1906.⁴⁹ Pantalar arthrodesis proved to be a reliable, reproducible surgical procedure for addressing the flail foot and ankle often associated with the sequelae of poliomyelitis, paralysis, and tuberculous and bacterial infection in the earlier part of this century. Few, if any of the articles published before the 1950's include recommendations on internal fixation for pantalar arthrodesis.* Many more recent articles and monographs exist detailing more modern techniques for achieving ankle and hindfoot arthrodesis and the successful management of arthritis.+

THE EVOLUTION OF COMPRESSION ARTHRODESIS

Most early reports for ankle and pantalar arthrodesis published before the 1950's contain little or no recommendations on the use of internal or external fixation. Most patients were merely casted and had protected weight bearing until union. The work of the Swiss group, Association for Osteosynthesis, afforded an understanding of the biology of rigid fixation and compression in fracture care and arthrodesis.

In 1932, Key described an operation to fuse the tuberculous knee joint by applying positive

pressure across the arthrodesis site by means of a turnbuckle applying compression between supramalleolar and proximal tibial

*footnotes= 3,5,9,13,16,31,34,35,40,48-50,53,77,79,81,89

+footnotes= 8,14,18,19,25,27,30,33,37,41,43,47,51,54,56,57,59-64,68-72,74,82,83,85-87,92

stainless steel pins. This operation was based upon Key's belief that "other things being equal, two bones will most readily unite if they are placed in contact and absolutely immobilized until union by bone has occurred". The external compression was supplemented with at least 12 to 16 weeks of casting or until union occurred.⁴⁰

Encouraged by success with arthrodesis of the knee by compression, first described in 1948, Charnley applied the technique of compression to arthrodesis of the ankle and shoulder in an article published in 1951. Charnley felt that one of the most beneficial effects of compression across and arthrodesis site is to eliminate shearing strains, as well as preventing the maintenance of a gap between the cut bone surfaces. He recognized that compression arthrodesis occurred more accurately and in a much different fashion than did union of a displaced fracture, which usually heals with the production of callus. Charnley felt that the approach that best lent itself to his compression technique for ankle fusion employed a transverse anterior incision, even though it involved dividing the extensor tendons, the anterior tibial vessels and nerves, and the terminal branches of the cutaneous nerves. Charnley thought that in practice the concerns about using the transverse anterior incision "proved insignificant".^{16,17}

To apply external fixation and compression, Charnley passed a Steinmann nail through the anterior portion of the talar body and another more proximal nail through the lower end of the tibia parallel to the first. Screw clamps were tightened until the nails were slightly bent under the compressive force and manual attempts at moving the talus on the tibia produced no motion. His patients were kept recumbent with their ankle elevated for four weeks. Pins were removed at four weeks and a walking cast applied for

another month. The patient was allowed to start rehabilitation and walking without a cast eight weeks after surgery.¹⁶

More modern external fixators allowing a precise measurable amount of compression across the arthrodesis site are readily available. These range from the tripod Calandruccio apparatus to through-and-through whole pin external fixators to half pin external fixators.⁹²

Interfragmentary screws placed in a compression technique can also achieve a satisfactory degree of compression across an arthrodesis site by means of internal fixation, thus avoiding some of the pin tract and mechanical concerns associated with external fixation.^{25,33,85}

ANKLE AND HINDFOOT ARTHRITIS: PATIENT EVALUATION

Patients with significant arthritis of the ankle and hindfoot will relate a history of pain, swelling and stiffness of the distal limb. Almost all of these patients will have a limp due either to their antalgic limb while weight bearing or fixed deformity precluding normal progressive heel-toe gait. Patients with osteoarthritis or rheumatoid arthritis confined to the ankle will often complain of early morning or start-up stiffness and pain upon arising. Patients with intra-articular loose bodies or large abutting anterior tibiotalar osteophytes often complain that their joint catches or locks in position, causing sudden paroxysmal pain. These patients with arthritis localized only to the tibiotalar joint will not necessarily notice any increase difficulty while walking on uneven ground compared to walking on level surfaces. Patients will often remark, however, that if they encounter a stone or other similar object in their path, it may cause great difficulty during the stance phase of gait when the object applies extreme varus or valgus force to their ankle.

Patients who have maintained normal subtalar and transverse tarsal joint function will always be better than patients who have combined ankle and subtalar or transverse tarsal pathology.^{36,52,69} The patient with isolated tibiotalar arthritis may be able to function surprisingly well even on uneven ground because of the adaptive and energy absorbing effect of a healthy subtalar joint.⁵²

Patients with unstable and very symptomatic ankles, in addition to any tibiotalar arthritic symptoms they may have, will have the added disability of joint laxity. These patients who have insufficiency of the soft tissue supports of their ankle joint will notice that descending stairs is often more difficult and painful for them than ascending stairs. Similarly, wearing heels is much more difficult for them than ambulating in flats or while barefoot because of the limited lateral support caused by insufficiency of the tibiotalocalcaneal and tibiotalar ligament complex, worse when the ankle is in equinus than when dorsiflexed. I have encountered many patients in my office with significant pes cavovarus of either a familial or neuropathic etiology whose main pain complaint and mechanical disability is the unstable ankle requiring either hindfoot realignment or arthrodesis. These latter patients may avoid the need for tibiotalar arthrodesis if their weight bearing mechanical axis can be improved with a valgus-producing calcaneal osteotomy and ankle ligament reconstruction. The patient with Charcot-Marie-Tooth disease and cavovarus foot deformity, accompanied by ankle instability, may also require tendon transfer to improve foot eversion power (Figure 10).

Physical examination of the patient with ankle and pantalar arthritis includes assessment of the entire ipsilateral and contralateral lower extremity. Joint contracture of the hip or knee is noted. The circulatory system is assessed, as is a good neurologic exam done. The patient with polyarticular rheumatoid disease should also be checked for cervical spine subluxation or myelopathy, as well as arthritic involvement of the upper extremities that may preclude the postoperative use of crutches or a walker. The presence or absence of callosities and abnormal shoe wear should be noted. A thorough range of motion exam for the ankle, hindfoot and transverse tarsal joints, as well as a manual motor test of the major muscular groups about the foot and ankle should be performed. The surgeon should observe the patient's shod and barefoot gait pattern. The presence of warmth, swelling, synovial proliferation, rheumatoid nodules and joint effusion are noted. The presence of crepitus may correlate with the formation of palpable osteophytes in the ankle.

The use of selective local anesthetic injection is often helpful in ascertaining the exact anatomic etiology of the patient's pain.

Weight bearing x-rays of the foot in the AP and lateral projections must be obtained. At a minimum, I order standing AP and mortise x-rays of the patient's ankle, as well as a standing lateral x-ray of the patient's entire foot (Figure 11). These films are inspected for the presence or absence of subchondral sclerosis, joint space narrowing, or subluxation of the talus within the ankle mortise. The presence or absence of subchondral cysts, osteophytes, talar bone loss, porosity or avascularity of the subchondral bone, and any existing hardware is ascertained. We also inspect these films for osteolytic or osteomyelitis processes as well. The status of the transverse tarsal and subtalar joints is also inspected. The angle which the long axis of the tibia makes with the floor is important on review of the standing lateral foot film and is often noted to be in a position of equinus because of large abutting anterior tibiotalar osteophytes. On the standing AP and mortise film, one can appreciate whether the tibiotalar joint remnant is parallel to the floor and deductively infer its relationship to the knee joint.

In cases of bone loss, suspected neoplasia or infection, or suspected subtalar pathology, computed tomography with both feet and ankles in the gantry at the same time is quite a useful preoperative clinical tool (Figure 12).^{15,19} Magnetic resonance imaging can help greatly in ascertaining the presence or absence of bone marrow edema, soft tissue pathology, synovial proliferation, or tibiotalar avascular necrosis (Figure 13).

Nuclear medicine scans with technetium and indium-labeled white blood cell scans can be useful preoperatively in planning surgery for the indication of osteomyelitis. Extensive work on the topic of arthrodesis of the tibiotalar joint for sepsis has been done by Cierny and others.¹⁹

NORMAL AND POSTOPERATIVE ANKLE, HINDFOOT, AND MIDFOOT BIOMECHANICS

The ankle is a modified hinge type of joint, whose axis is oriented obliquely and directed laterally

and posteriorly as projected on the transverse plane of the leg. Clinically, this axis of rotation can accurately be estimated by the examiner as the line between the tips of readily palpated medial and lateral malleoli. Since the ankle joint axis is obliquely oriented, it allows horizontal rotations to occur in the foot or the leg with ankle movement. In normal walking, ankle motion ranges from 20 degrees to 36 degrees with an average of 24 degrees. The obliquity of the ankle axis ranges from 88 to 100 degrees with an average of 93 degrees from the vertical.⁵²

Studies of the forces occurring across the ankle joint during the gait cycle demonstrate that they reach a peak during the transition from ankle dorsiflexion to plantar flexion. The force across the ankle joint can reach approximately 4_ times body weight at this time, potentially explaining the exacerbation of pain in the patient with an arthritic ankle during gait, and probably serving as the reason for loosening of the components of total ankle joint replacements.⁵²

The subtalar joint is a single axis joint that acts like a mitered hinge joining the talus and the calcaneus. The axis of the subtalar joint passes from medial to lateral at an angle of approximately 16 degrees and upward from the horizontal plane approximately 42 degrees. Individual variations are numerous. The subtalar joint influences the performance of the more distal articulations and modifies the forces imposed upon the supramalleolar skeleton.^{16,52}

Functioning as a mitered hinge between the talus and calcaneus, the subtalar joint is, therefore, aligned in about 45 degrees to the horizontal and allows translation of transverse rotation occurring in the tibia into the foot. With subtalar arthrodesis, these rotational and other forces are transferred to adjacent nonfused joints in the foot and ankle.^{16,52}

The talonavicular and calcaneocuboid joints together make up the transverse tarsal articulation. Each possesses some independent motion, but from a clinical and functional standpoint they perform together.⁵²

When the calcaneus is in an everted position, these two joints are parallel. When the calcaneus is inverted, the talonavicular and calcaneocuboid joints are nonparallel. In the latter position there is much less flexibility within the transverse tarsal joint. The transverse tarsal joint transmits the motion occurring in the calcaneus distally into the forefoot. At the time of toe-off, the calcaneus is in an inverted position, and, therefore, stability of the transverse tarsal joint and the longitudinal arch of the foot is achieved. If a subtalar joint is fused in excessive inversion, resultant stiffness of the midfoot causes excessive weight on the lateral border of the foot and a tendency to vault over the rigid midfoot.⁵²

It is important for the orthopaedic surgeon planning an operation to treat ankle and pantalar arthritis to understand thoroughly the biomechanical consequences of such procedures. The loss of rotation through the subtalar joint such as occurs after trauma or with significant arthritis or surgical arthrodesis, causes increased stress to be applied to the ankle and transverse tarsal joints.⁶⁹

Arthrodesis of the ankle places increased stress on the knee joint above and the subtalar joint below. To avoid increased stress within the foot after ankle fusion, rotation symmetric with the uninvolved contralateral side should be the goal of surgery. If the ankle is fused in excessive internal rotation, the patient will experience difficulty as the center of gravity passes over the foot. In excessive internal rotation, subtalar and transverse tarsal joints may become painful as a result of increased stress. If the ankle is fused in too much external rotation, the patient will have a tendency to roll over the medial border of the foot to avoid knee and possibly hip pain. This position will permit the patient to easily pass over the foot, but greater stress will be applied to the transverse tarsal joints and first metatarsophalangeal joint on its medial side. Similarly, increased stress will be applied along the medial compartment of the knee. Fusing an ankle joint in too much varus will cause the patient to walk on the lateral border of the foot, and the significant varus position of the subtalar joint will cause increased rigidity of the transverse tarsal joints. An ankle must be fused in appropriate valgus, especially in the foot with a stiff subtalar joint, so that the foot

may remain plantigrade.^{26,38,52}

An ankle joint can be fused in slight equinus to compensate for an ipsilateral short lower extremity or an ipsilateral unstable knee in the presence of quadriceps weakness. If the ankle joint is fused in excessive plantar flexion, however, the involved limb will be lengthened with a recurvatum thrust on the knee joint, an uneven gait pattern, and stress across the midfoot. Fusing the ankle in excessive dorsiflexion will concentrate pressures on the heel at the beginning of the stance phase.^{6,31,32,69}

King, Watkins and Samuelson studied 24 patients with a solid ankle fusion. Review demonstrated that when the ankle was fused in neutral position, the patient would have on average 10 degrees of plantar flexion occurring in the midfoot. Patients who had 10 degrees or more of plantar flexion at their ankle arthrodesis site, showed a vaulting gait pattern and greater difficulty ambulating barefoot. These authors concluded that fusion in a neutral dorsiflexion position is indicated and that midtarsal motion occurs in the plantar direction, but that no dorsiflexion is present in the midtarsal area after ankle arthrodesis.⁴²

A long-term follow-up of 12 patients, including gait analysis after ankle arthrodesis, was carried out by Mazur, et al. These authors concluded that when the ankle was fused in neutral position, the loss of ankle motion was compensated for by motion of the small joints of the ipsilateral foot, altered motion of the ankle in the contralateral limb, and appropriate footwear. These authors still saw, however, some adverse effects of ankle arthrodesis when their patients walked barefoot. Velocity of gait was slowed, and the length of stride was shortened in all 12 patients. One patient who was inadvertently fused in equinus position was unable to walk well without shoes with the appropriate heel lift.⁵⁵

Gellman, et al, have shown that deficits in dorsiflexion and plantar flexion after isolated tibiotalar arthrodesis are 50.7 percent and 70.3 percent respectively. After tibiotocalcaneal arthrodesis, however, the dorsiflexion and plantar flexion deficits are only 53 percent and 71.3 percent respectively. Thus, linking the calcaneus to the fused ankle does not cause an appreciable loss of dorsiflexion or plantar flexion.

Inversion and eversion, however, undergo a diminution at least 40 percent greater after tibiototalcalcaneal arthrodesis than with ankle fusion alone.²⁶

Pantalar arthrodesis has been noted to cause deficits in dorsiflexion and plantar flexion of 62.8 percent and 82.2 percent, respectively. Inversion and eversion are reduced by 71.7 percent and 67.4 percent, respectively, after pantalar arthrodesis.²⁶ These values stress the absolute importance of achieving appropriate position of the foot and ankle if the pantalar arthrodesis is to be successful.⁶⁹

ANKLE AND HINDFOOT PATHOANATOMY IN RHEUMATOID ARTHRITIS

Rheumatoid nodules, skin ulcerations, peripheral neuropathy and digital ischemia represent some of the nonarticular manifestations of rheumatoid arthritis that impart on the foot and ankle. Virtually any conceivable deformity may occur about the foot and ankle due to musculotendinous and ligamentous insufficiencies in these weight bearing joints. Generalized ligamentous laxity, posterior tibial tendon insufficiency, and the loss of ankle and subtalar cartilage and bone will contribute to the observed deformity.^{14,37,69,87}

It is estimated that between 16 and 20 percent of patients with rheumatoid arthritis have their first presenting complaint of an arthritic joint in the foot or ankle. Early involvement of the ankle is more common in children than in adults.⁶⁷ Anterior weight bearing ankle pain is the most common complaint. Tenosynovitis is most often retromalleolar and involving the posterior tibial and peroneal tendons. Tenderness over the anteromedial and anterolateral ankle portals, associated with warmth and swelling, suggest the ankle is the primary site of involvement. Functional restrictions such as difficulty walking on uneven ground, are the usual presenting complaints for the patient with hindfoot and subtalar arthritis. Rheumatoid arthritis of the subtalar joint causes pain with both passive hindfoot inversion and eversion and most often leads to a significant valgus deformity of the heel due to hypermobility of the joint.^{37,69,87} Subfibular impingement may be present, and there may be peroneal tendon restriction (Figure 14).⁶¹

Midfoot arthritis is usually well localized to the specific joints by the patient, and barefoot walking is more uncomfortable than while the patient is shod. Midfoot rheumatoid arthritis is usually worse during the toe-off phase of the gait cycle.

NONOPERATIVE MANAGEMENT OF ANKLE AND HINDFOOT ARTHRITIS

Nonoperative management for the patient with isolated tibiotalar arthritis and/or deformity includes the use of oral and occasionally parenteral anti-inflammatory medications, the use of a high-top shoe which restricts ankle and hindfoot motion, or the judicious and infrequent use of intra-articular corticosteroid and local anesthetic injection.

Pedorthic management of the arthritic patient includes the use of a stiff-soled shoe, which may incorporate a steel shank and a rocker sole, appropriate shoe wedges, or a single axis cushioned heel (Figure 15).⁶ The patient with an abnormal or arthritic tibiotalar joint may be successfully managed nonoperatively with an ankle foot orthosis. Patients with normal sensation and little deformity or bony prominence may do well with a custom-molded, solid ankle, polypropylene ankle-foot orthosis. A unidirectional hinged ankle for this orthosis may be added to the patient with a limited arc of pain free motion (Figure 16).⁶⁴

Although they are occasionally considered antiquated, certain patients with greater deformity, bony prominence or diminished peripheral sensation due to nerve injury or peripheral neuropathy may be shod with an appropriate oxford shoe attached by means of double metal upright bars to a proximal calf sleeve. This calf sleeve may be a laced leather or Velcro closure device associated with a patellar tendon bearing plastic sleeve. Often such double metal upright ankle foot orthoses incorporate a drop lock or dial lock hinge medially and laterally. Patients with significant valgus or varus deformity through the ankle and hindfoot may also have applied distally to the double metal upright AFO a medial or lateral, respectively, T-strap (Figure 17).

These orthoses will serve to limit the amount of weight bearing pain and excursion of the painful joints to which they are applied. Holding the joint still by means of these orthoses or even with the use of a short leg cast will limit the amount of pain arthritic patients have because of their diseased joint. Indeed, the application of a short leg walking cast for three or four weeks' time for the patient with an arthritic ankle may serve a useful diagnostic and educational tool. If the patient experiences a good deal of pain relief while wearing the cast, one can conclude that most likely the patient would do well with a successful arthrodesis or appropriate orthosis as well. Also, during the time that the patient walks with his cast in place, he can gain some perspective of what it might be like to walk with a fused ankle postoperatively.

If these patients fail the nonoperative options mentioned here, and if indeed their pathology is limited to the tibiotalar joint, then they may be acceptable candidates for ankle arthrodesis. It is the patient with daily pain refractory to nonoperative care and/or the one with progressive and disabling nonbraceable deformity for whom ankle arthrodesis is indicated.^{7,69} Preoperative assessment and planning for the ankle arthrodesis patient will occasionally include the use of selective Lidocaine or Marcaine blocks. These injections are a useful clinical tool in ascertaining the exact anatomic location of the patient's most significant pain.⁶¹ It is often difficult to ascertain whether the patient's pain is due to the ankle joint alone, ankle and subtalar pathology, or even the peroneal tendons in the presence of subfibular impingement. If a diagnostic injection of local anesthetic into only the ankle joint alleviates the majority, if not all of the patient's pain, then successful ankle arthrodesis will be expected to eliminate just as much of this patient's preoperative discomfort. Conversely, if an extra-articular injection within the peroneal tendon sheath alone relieves the patient's pain, then arthrodesis may not be indicated.

There are more than thirty different viable techniques that have been described in order to achieve successful ankle and hindfoot arthrodesis. It is not the purpose of this chapter to serve as compendium of all the techniques ever described. The author will, rather, attempt to distill into a useful amount of clinically applicable material this vast body of information that the literature and clinical experience provide.

Ankle arthrodesis is defined as surgical fusion of the tibia to the talus. Surgical fusion of the ankle (tibiotalar) and subtalar (talocalcaneal) joints at the same operative sitting is termed tibiotalocalcaneal arthrodesis. Fusion of the talus to all the bones articulating with it (distal tibia, calcaneus, navicular, and cuboid) is termed pantalar arthrodesis. Despite the myriad techniques existing for surgical approach to fusion and implants employed, these techniques all have in common a similar goal: the formation of a solid, pain free arthrodesis in a biomechanically stable and functional position.⁶⁹

Ankle arthrodesis can eliminate pain and improve function in even the most severely disabled

patient when the technique is clinically indicated. This technique is not without its pitfalls and biomechanical alterations of the extremity, however. Even more so, tibiotalocalcaneal and extended pantalar arthrodeses are quite technically demanding, though useful procedures, that may be employed for a variety of indications. These latter procedures, however, should be viewed as salvage techniques to be used for what otherwise would be an extremely disabling or even limb threatening clinical situation.

Indications for ankle arthrodesis include primary or post-traumatic osteoarthritis, rheumatoid arthritis, and avascular necrosis of the talus. Tibiotalar fusion can also be done for the painful sequelae of septic arthritis and hemophilic arthrosis.

Tibiotalocalcaneal arthrodesis is indicated for any of the reasons just listed and additionally may be employed for the failed total ankle arthroplasty with subtalar intrusion or a failed attempt at ankle fusion with resultant insufficient talar body. Other indications for tibiotalocalcaneal fusion include the severe deformity of untreated clubfoot or neuromuscular disease, Charcot neuroarthropathy, or skeletal defects after tumor reconstruction. Pseudarthrosis of any etiology, as well as fixed or flail ankle and hindfoot deformities due to other causes are also indications for tibiotalocalcaneal arthrodesis.

A pantalar arthrodesis may be employed for any of the reasons listed above that also include significant instability, subluxation, or arthritis involving the ankle, hindfoot and transverse tarsal joints.⁶⁹

Contraindications for performing ankle and hindfoot arthrodesis include the dysvascular extremity or one involved with severe, active infection. Contraindications specific to ankle arthrodesis performed by arthroscopic or mini-arthrotomy techniques and contraindications to closed medullary nailing techniques for tibiotalocalcaneal and pantalar arthrodesis include the presence of moderately severe or severe and fixed deformity of the ankle, hindfoot and distal tibia.^{69,70} Such closed or minimally invasive techniques are contraindicated because of the difficulty in obtaining collinear reduction in satisfactory position and alignment of the tibia and hindfoot employing these techniques. Such significant deformity often requires

an open, realigning, reconstructive procedure often employing osteotomy, talectomy, or resection of appropriate wedges of bone to obtain satisfactory functional position and alignment by arthrodesis.

ANKLE ARTHRODESIS

The author has found successful ankle arthrodesis to be one of the most gratifying procedures for providing pain relief and improving the patient's function. The key to a successful result when employing ankle arthrodesis for these patients is obtaining and maintaining a solid arthrodesis in the appropriate position. Whether fixed internally or externally, rigid fixation is the key to a successful result and an early relief of the patient's preoperative pain.

Alternatives to arthrodesis include total ankle replacement arthroplasty, but this procedure has very specific, limited indications. Existing implants, even in the appropriately selected patient, often fail at the bone cement or bone implant interface due to the unique biomechanical stresses applied to the tibiotalar articulation. Resection of adequate amounts of talar body and distal tibial articular surface in order to accommodate existing ankle joint replacements, often adversely affect the motion and mechanics of the joint, as well as leave very little native talus intact.^{44,45,80}

The appropriate patient for total ankle replacement is one who has excellent bone stock, little deformity, is not overweight, and places little demand on the extremity. Suffice it to say that at the date of publication, the patients appropriate for total ankle replacement arthroplasty are few in number.

The optimal position of the fused ankle in most cases is neutral plantar flexion so that the plantar aspect of the foot is at a right angle to the long axis of the leg, 0 to 5 degrees of hindfoot and ankle valgus, and external rotation symmetric with the contralateral uninvolved side. This usually is about 5 to 10 degrees of external rotation or the position in which the anteromedial crest of the tibia and tibial tubercle line up with the second ray of the normal foot on the ipsilateral side.^{32,52,55,58}

The notion of fusing an ankle in 5 to 10 degrees of plantar flexion for the female patient who wishes

to wear a heeled shoe postoperatively is not well founded.^{7,9,13,27,29,50} Not only is it more difficult to obtain the arthrodesis in this position due to intraoperative and postoperative mechanical concerns, but fusion in slight equinus often leads to the development of symptomatic transverse tarsal arthrosis. The transverse tarsal joints after ankle arthrodesis are usually much more supple in plantar flexion from the transverse position than they are in dorsiflexion. These joints often have very little capacity to dorsiflex beyond the neutral talonavicular inclination. It has been this author's experience that if the foot is fused perpendicular to the long axis of the leg, active and passive transverse tarsal joint plantar flexion are much greater than dorsiflexion. Transverse tarsal motion in the parasagittal plane will often increase and even double its preoperative value after ankle arthrodesis as the patient ambulates more after cessation of postoperative casting.^{26,38} I have often been pleasantly surprised at how much motion through the transverse tarsal joint remains six to twelve months after successful ankle arthrodesis, easily allowing my patients to accommodate up to a 1 to 1½ inch heel height, even if the tibiotalar joint is fused at neutral in the parasagittal plane (Figure 18).

The patient presenting for ankle arthrodesis who also has ipsilateral quadriceps weakness, e.g. secondary to poliomyelitis or CVA, may constitute a relative indication for ankle arthrodesis in slight equinus.^{35,42,50,55} Floor reaction forces through an ankle fused in equinus will pass anterior to the knee, thus stabilizing the weak knee in recurvatum. Fusing the ankle in excessive plantar flexion, however, contributes to painful recurvatum forces at the normal knee. Fusion in excessive dorsiflexion, while slightly better tolerated than too much plantar flexion, will often lead to recalcitrant heel pain from the repetitive impact sustained at heel strike. Excessive dorsiflexion also results in diminished push-off strength.⁴² Postoperative tibiotalar varus malunion is poorly tolerated and often leads to lateral foot pain and callosities at the fifth metatarsal head and/or base.⁵² Such varus-valgus malunion will also lead to ipsilateral knee and contralateral greater trochanteric discomfort (bursitis).

The patient whose ankle has been fused in too much equinus will often walk with the operated extremity externally rotated at the hip in order to circumduct the plantar flexed foot. This abnormal gait also highlights the limited dorsiflexion available through the transverse tarsal joints. Fusing the ankle in slight external rotation symmetric with the contralateral uninvolved side allows for a more normal foot progression angle during postoperative gait. At least 75 percent of the author's patients undergoing ankle arthrodesis for isolated tibiotalar arthritis have demonstrated no postoperative limp, even to the trained eye.

It has been recommended in the past that in order to reduce the anterior lever arm of the foot under an arthrodesis site, the talus should be translated posteriorly under the tibia at the time of ankle fusion.^{16,29,34,35,50} Although anterior translation should definitely be avoided, the theoretical advantage of translating the foot posteriorly to improve ground clearance and diminish the lever arm of the foot on the arthrodesis site has not proved to be as clinically significant as was indicated in the older literature.

Arthroscopic Ankle Arthrodesis Surgical Technique

The arthroscopic procedure is performed under general or spinal anesthesia with the patient positioned supine on a radiolucent table in a manner that would facilitate fluoroscopic imaging, appropriate access to the ankle anteriorly and posterolaterally, and the use of internal fixation. Leg holding devices are not always necessary and often are in the way when applied too far distally on the limb (Figure 19). Preoperatively, superficial anatomic landmarks including the tendons and superficial neurovascular structures are all identified. The anteromedial portal located medial to the tibialis anterior tendon and the anterolateral portal, located lateral to the extensor communis digitorum tendon, are usually the only portals necessary for this technique. An accessory lateral portal, located lateral to the peroneus tertius tendon and inferior to the anterolateral portal, may occasionally be used to facilitate removal of articular debris. Because access and visualization are complete with the first two portals mentioned, posterior or anterior central portals are not necessary and are often quite dangerous (Figure 20).⁶⁰

The initial arthroscopic debridement entails distracting the joint with any of a number of available alternative fixation devices. It is very difficult to quantify the amount and force of distraction required for visualization of any one ankle arthroscopically. Capsular and ligamentous scarring is often quite advanced in the severely arthritic ankle. Severely distorted or malaligned ankles present a relative contraindication to the arthroscopic method of arthrodesis.

As the arthroscopic procedure progresses, the surgeon may take advantage of the viscoelasticity of the surrounding soft tissue structures, facilitating more distraction over time. Care must be taken not to over distract the joint in cases of severe arthrofibrosis and post-traumatic arthritis with soft tissue compromise.

Once articular surface debridement commences, the space available for intra-articular surgery increases, further facilitating posterior access for debridement. The surgeon must avoid the tendency to debride small segments of the tibiotalar surfaces too deeply when the operative field is limited. This can be avoided by the frequent use of intraoperative roentgenograms or fluoroscopy.

A 4 millimeter 30 degree arthroscope can readily be introduced through the arthrotomy portals described. The preferred full radius resector/shaver employed for this initial debridement and synovectomy is a 4_ millimeter device. Smaller shavers and resectors, while requiring less tibiotalar space and distraction, often are tedious and slow in performing the amount of resection necessary to complete arthrodesis (Figure 21).

Once the anterior synovectomy and debridement are completed, there is improved visualization, and cartilage removal from the distal tibial and dorsal talar surface is easier. Cartilage from the medial side of the fibula and the lateral side of the medial malleolus can also be removed. Thorough debridement of the talofibular recess is recommended.

Curettes of various sizes, shapes and angles are helpful in denuding the articular surfaces.

Simultaneous large bore cannula suction through an accessory anterolateral portal removes this articular debris. Also, pituitary forceps may be used to extract the larger fragments. Arthroscopy pumps are available in improving visualization and constant irrigation through the scope. High-speed cannulated burs ranging from 4_ to 5_ millimeters in diameter can be employed to remove cartilage remnants and expose bleeding subchondral bone. To avoid maceration of the skin by frequently switching instruments through the portals, plastic disposable cannulas can be used to protect the skin at the site of the portals (Figure 22).

After debridement of the joint surface is complete, the external fixator distracting device is removed unless it is to be used for compression postoperatively. Compression and rigid fixation are mandatory for a successful arthroscopic ankle arthrodesis and can be provided with either internal or external fixation. If the fixator is to be used for postoperative compression, it is important to place the calcaneal pins in such a manner that the compression force is centered directly under the tibia and talus, thereby avoiding eccentric compressive loading (Figure 23).

External fixation can lead to postoperative stiffness of the subtalar joint if the distal transfixation pins are located in the calcaneus. Often the external fixator construct is bulky and not well tolerated by the patient. Other problems such as pin tract infection, pin loosening, patient compliance with pin care, and impingement of medial fixators against the contralateral limb make external fixation less desirable than internal fixation after arthroscopic ankle arthrodesis.

As mentioned elsewhere in this work, the foot is positioned in neutral dorsiflexion with approximately 5 degrees of hindfoot valgus and appropriate, symmetric external rotation. The preferred method of internal fixation is 6_ millimeter or 7 millimeter cannulated screws. A small 2_ centimeter posterolateral incision can be made between the peroneal and Achilles tendons, 2_ centimeters proximal to the ankle joint and taking appropriate care to avoid injury to the lesser saphenous vein and sural nerve.

This portal serves as a useful site for introducing the threaded guide wire from the cannulated screw set to position the first screw from the posterolateral tibia obliquely into the head and neck of the talus. This approach is also useful in the case of the small talus. Alternatively, since the arthroscopic technique leaves intact the majority of the ankle mortise and thereby leaves the tibiotalar arthrodesis site relatively stable, crossed screws may provide enough fixation that this posterolateral tibiotalar screw is not necessary (Figure 24).

Another guide wire can be inserted from posteromedial on the tibia 2 to 3 centimeters proximal to the joint line at the supramalleolar flare and directed slightly anterolaterally into the talus. The guide wire for the second screw can be introduced from lateral superiorly on the tibia and directed slightly vertically and medially into the talus. Eccentric loading of the arthrodesis may occur as the first screw is inserted and tightened because the screws are not introduced in parallel fashion. Alternately tightening each screw until compression is obtained can avoid eccentric loading of the arthrodesis site. Other combinations of screw placement are feasible. The first screw can be inserted anteromedial on the tibia and be directed posterolaterally into the talus. The length of this screw is deceptive, however, and one must avoid penetration of the normal subtalar joint. Mobility of the subtalar joint should be checked fluoroscopically and clinically before the case is completed. Permanent roentgenograms of the ankle and subtalar joint in orthogonal planes are recommended, and the surgeon should not rely solely on intraoperative fluoroscopy to ascertain appropriate position, alignment and fixation (Figure 24).

Skin closure is followed by application of a soft bulky dressing incorporating the appropriate splints. Elevation of the extremity is recommended, followed by touch-down weight bearing and short leg cast application as clinically and radiographically indicated. Full weight bearing in a short leg cast commences approximately four to five weeks after the procedure until the arthrodesis is clinically and radiographically united.

This arthroscopic technique was compared with an open tibiotalar arthrodesis technique employing malleolar osteotomy by Myerson and Quill.⁶⁰ Internal fixation with compression across the tibiotalar arthrodesis site was utilized for both methods using either 6.5 millimeter or 7.0 millimeter cannulated screws. Arthroscopic arthrodesis was performed in 17 patients, and open arthrotomy with malleolar osteotomy employed for 16. The mean time to fusion after arthroscopic procedure was 8.7 weeks (range 6 to 14 weeks), compared to 14_ weeks with the open technique (8 to 26 weeks; $p < 0.004$).

Each of these techniques carries with it certain advantages and disadvantages. Arthrodesis was achieved in the arthroscopic group considerably faster than it was for the patients undergoing arthrotomy and malleolar osteotomy. Theoretically, the arthroscopic technique involves limited exposure and, therefore, significantly diminished periosteal and capsular stripping. The arthroscopic technique also preserves the overall contour of the ankle mortise. Patient selection also may contribute to shorter time to fusion in the arthroscopic group, as those with greater preoperative deformity were included in the arthrotomy group undergoing ankle arthrodesis.

The arthroscopic technique may also have as its advantage less perioperative morbidity and pain and a shorter hospital stay. The disadvantages commonly incurred with arthroscopic ankle arthrodesis include the relatively long time it takes for a surgeon to gain facility with this technique, slightly higher nonunion rate, sometimes tenuous percutaneous fixation, and the longer operative time associated with greater fluoroscopic exposure for the surgical team. Again, the arthroscopic technique is relatively contraindicated in the patients with significant deformity or bone loss requiring large bone graft.

Ankle Arthrodesis: Mini-arthrotomy Surgical Technique

The mini-arthrotomy technique for achieving ankle arthrodesis was initially described by Miller and Myerson and published in September of 1996.⁵⁷ This technique consists of a limited anterior resection of the tibiotalar joint surfaces employing two small anterior incisions. These authors report a very high (31 of 32 cases) successful fusion rate with an average time of radiographic arthrodesis at eight weeks.

This technique employs two 1_ centimeter incisions, one anteromedial and one anterolateral, in approximately the same location as the portals used for the arthroscopic technique described above. Patients have this procedure performed while under general, spinal or regional anesthesia with IV sedation. The first incision is medial to the anterior tibial tendon at the level of the ankle joint line, and a second incision is anterolateral to the peroneus tertius tendon placed to avoid the cuticular branches of the superficial peroneal nerve (Figure 26). Curettes, rongeurs and small sharp bone chisels are used in debriding synovium and cartilage from the anterior ankle. A small lamina spreader facilitates visualization of the joint surface to be resected and can be alternated between the two wounds. Removing the teeth of the lamina spreader allows this instrument to be placed between the bones of even very narrow arthrodesis sites. After this initial debridement by hand, the ankle is then irrigated for the final time with saline (Figure 27).

A pneumatic bur generating a bone slurry, which can be collected for later use as an autogenous bone graft, is then placed within the joint to debride any further cartilage and bone to the healthy subchondral level (AM 10 bit, Midas Rex, Fort Worth, Texas). Excessive burring should be avoided, as it may cause necrosis of subchondral bone. Satisfactory resection and debridement of the posterior one-third of the ankle joint is not possible with this technique. Medial and lateral gutters, however, can be easily debrided using the bur. Appropriate ankle position is then obtained, and threaded guide wires from available cannulated screw sets are used to maintain the position (7.0 or 7.3 millimeter screws, Synthes,

Paoli, Pennsylvania or 6.8 millimeter screws, Orthopedic Biosystems, Phoenix, Arizona).

Guide wire insertion for at least two and possibly three screws can be oriented as described above for the arthroscopic technique. An additional screw can be placed from the fibula into the talus after lateral gutter debridement in order to enhance stability and fusion rates (Figure 28).

Position, alignment and appropriate depth of the screws and wires are checked intraoperatively with the fluoroscope. The bone slurry can then be packed circumferentially around the joint through the two mini-arthrotomies. In order to prevent postoperative leakage of the autogenous bone graft and minimize transient anterior ankle inflammation (often seen by Miller and Myerson at up to four to ten weeks postoperatively), the ankle joint capsule must be closed meticulously. Routine wound closure superficially of the ankle is followed by application of a bulky padded dressing incorporating coaptation and posterior plaster splints.

Patients are discharged in the initial dressing to follow-up in the office in ten to fourteen days' time for wound inspection, suture removal and application of a short leg nonweight bearing cast. If signs of clinical stability and even radiographic early union are present, this cast can be changed six weeks postoperatively to a short leg walking cast until arthrodesis appears solid by clinical and radiographic examination. A posterior heel may be applied to the cast to provide an axial force across the ankle joint with weight bearing.

Early satisfactory results with the mini-arthrotomy technique may also be attributed to the less invasive nature of the procedure compared with open larger arthrotomies and/or transmalleolar approaches. In Miller and Myerson's early reports, 22 of the 32 patients undergoing ankle arthrodesis by means of the mini-arthrotomy technique did so as outpatients incurring sedation and regional ankle block anesthesia. Postoperative radiographs will demonstrate fusion at the anterior two-thirds of the joint, and the clinical significance of partial surface contact healing pattern for long-term stability is as yet

undetermined (Figure 29).

Transfibular Approach For Ankle Arthrodesis

The author's preferred method of arthrotomy for arthrodesis of the tibiotalar joint is through a lateral transfibular approach with the patient positioned supine on the operating table. While the patient is under general or spinal anesthesia a well-padded roll is placed under the ipsilateral buttock in order to slightly internally rotate the involved lower extremity. A thigh tourniquet is used for intraoperative hemostasis (Figure 30).

The author prefers a transfibular approach for ankle arthrodesis because of the ease of exposure, positioning, and obtaining internal fixation.^{2,25,34} Even very significant preoperative deformity is easily corrected with this approach, employing distal tibial osteotomy, medial malleolar osteotomy, or resection of the appropriate wedges of bone in order to position the foot plantigrade in neutral position for fusion. By removing at least the lateral and sometimes even the medial malleolus using this approach, the patient often experiences greatly improved shoe wear postoperatively.^{63,64} The distal fibula once resected serves as an excellent source of autogenous bone graft material. The transfibular approach may be combined with a small anteromedial arthrotomy for further exposure, but since the author has begun to favor a congruous type of tibiotalar reduction, I usually avoid medial malleolar osteotomy. Often it is a matter of the surgeon's preference whether he resects planar flat surfaces of distal tibia and talar dome for apposition across the arthrodesis site, but this author prefers to resect in a more anatomic fashion the concave distal tibial surface and retain the convex talar dome surface.

The preferred lateral incision is made along the posterolateral border of the distal fibula well anterior to the expected course of the sural nerve, but still posterior to the expected course of the superficial peroneal nerve as it perforates the fascia from the peroneal to the anterior compartment over the distal fibula. This incision is extended distally and curved anteriorly over the sinus tarsi so that the whole

tarsal canal and lateral process of the talus can easily be exposed through this same wound (Figure 31).

Next a low beveled fibular osteotomy is done just barely proximal to the level of the ankle joint line. This distal resection of the fibula still affords excellent exposure while keeping the syndesmosis intact. The distal fibula is retained on the back table, where later it will be used to harvest the autogenous bone graft material (Figure 32).

At this point it is very important to expose the anterior tibiotalar capsule and remove any impinging anterior tibiotalar osteophytes. These osteophytes, if not appropriately resected, will prohibit a successful reduction of the foot in neutral dorsiflexion. The posterior tibiotalar capsular exposure may be somewhat less than is stripped anteriorly (Figure 33).

The author prefers to prepare the tibiotalar arthrodesis site with the use of sharp chisels rather than high-speed spurs, which can cause osteonecrosis of the subchondral bone. I prefer to contour the bone on either side of the arthrodesis site in the appropriate congruous concave-convex fashion as noted above. Enough diseased cartilage and subchondral bone is removed so that the joint can be reduced in a position of 0 dorsiflexion and no more than 3 to 5 degrees of valgus. Leaving the joint in a congruous fashion, if it has not been grossly altered by significant preoperative trauma, affords the surgeon great ease of reducing rotation symmetrically. The anterior medial crest of the tibia and the tibial tubercle should line up with the second ray of the ipsilateral foot (Figure 33).

The next most important part of this step is the insertion of guide wires to facilitate passage of interfragmentary cannulated screws used for internal fixation. I usually insert a guide wire from the posterior portion of the lateral process of the talus in a distal lateral to proximal medial direction across the arthrodesis site and lying just prominent to the tented skin at the medial metaphyseal flare of the tibia. The second guide wire can be inserted quite readily through the lateral wound proximally and anteriorly from the lateral distal tibial tubercle, which had once articulated with the distal fibula before it was removed across

the arthrodesis site into the body of the talus distally and more medially. In this fashion the first two guide wires are crossed in the frontal plane and may be either crossed or parallel in the sagittal plane. Lab bench studies have demonstrated that two crossed screws provide better torsional and load rigidity than two parallel screws alone. If the talus is of sufficient size, then a third screw may either be inserted parallel to the first or from posterolateral on the distal tibia directed anteriorly and medially into the head and neck of the talus. Three screws when appropriately inserted and tightened in a sequential fashion can provide quite a rigid construct with good interfragmentary compression (Figure 24).

Even though the first guide wire was inserted from distal to proximal, I have found that if this wire is brought out through the skin posteromedially on the distal leg and then the screw inserted from proximal/medial to distal/ lateral, excellent countersinking of the head in the distal tibial metaphysis, as well as avoidance of a large bulky head near the lateral subtalar joint can be avoided. It, therefore, is more productive to insert the medial to lateral screws from proximal to distal rather than distal to proximal.

After the guide wires are inserted and their length ascertained, but before the screws are actually drilled tapped in placed, it is wise to obtain an intraoperative x-ray in both the AP and lateral projections. This film is used to study not only the position of the ankle that will be achieved at arthrodesis, but also the alignment, fixation and length of the cannulated screws to be inserted.

Counter sinking measuring tapping is then done, followed by insertion of the appropriate 6.5 or 7 millimeter cannulated screw over each of the guide wires (Figure 35).

A second set of intraoperative radiographs is advised before closing the wound, again checking alignment, position and fixation. One must take great care to check radiographically and clinically that the subtalar joint is free and clear of bone graft and fixation materials. An abundant amount of cancellous bone can usually be harvested from the metaphyseal area of the distal fibula that has been resected.

Corticocancellous materials can also be morselized and packed anteriorly, as well as posteriorly and

laterally across the arthrodesis site. The surgeon should take care not to have any graft impinging the peroneal tendons, sinus tarsi or subtalar joint before closure.

Usually the extensive nature of the exposure, the abundant amount of bone graft material inserted, and the large leading surfaces of cancellous bone that have been fashioned during this procedure will necessitate the placement of a closed suction drainage tube. The tourniquet is deflated at this point, and hemostasis obtained. The osteoperiosteal flap remaining after fibular resection in the fascia near the peroneal tendons provides an excellent deep layer of closure. The dermis is closed usually without any tension, and the skin edges apposed as well. The drain is placed to suction, and the appropriate noncircumferential postoperative splints are applied over a bulky bandage.

The patient is in most cases admitted to the hospital for one or two nights postoperatively and discharged in the operative dressing if there are no complications. The patient is followed in the office two weeks postoperatively when the dressing and staples are removed, dressing changed, and a nonweight bearing short leg cast applied. These patients are best kept nonweight bearing for six weeks postoperatively. The subsequent six weeks of the postoperative convalescence can be done in a short leg walking cast. With rigid internal fixation, the patients remark very early in their postoperative recovery that there preoperative pain is gone.

If the ankle is fused in the appropriate position, most patients undergoing this procedure will not require shoe wear modification, brace wear or orthotic usage. The patient who has difficulty with transverse tarsal dorsiflexion, difficulty at the end of the stance phase of gait, or concomitant ipsilateral forefoot pathology may best be managed with a shoe that includes either a SACH heel or rocker bottom over a longitudinal steel shank. External shoe wear adjustments for leg length inequality may be necessary in severe cases.

TIBIOTALCALCANEAL AND PANTALAR ARTHRODESIS

Methods of peritalar fusion published before 1922 were reviewed by Arthur Steindler.⁸¹ On this date Steindler also described his technique for panastragaloid arthrodesis by way of denuding articular cartilage. Other studies in 1936 and in the Spanish literature in 1951 detailed the orthopaedic experience of hundreds of patients followed after panastragaloid arthrodesis for neuromuscular imbalance or flail feet and ankles.^{5,78}

It was recommended in 1939 by Liebolt that the "pantalar" arthrodesis be accomplished in two stages because of prolonged operating time and the difficulty in obtaining correction of all the deformities simultaneously.⁵⁰ It was recommended by that author that the subtalar arthrodesis be performed first, fusing the ankle at a second operative procedure when it was perceived to be easier to obtain the desired final degree of equinus and dorsiflexion. A one-stage operation for pantalar arthrodesis was published by Hunt and Thompson in 1954.³⁵ Employing this technique, the authors used an anterolateral approach to disarticulate and remove the talus from the hindfoot, subsequently peeling off its articular cartilage, cortex and ligaments on the operating room table before this denuded talus is replaced in its bed and the patient's wounds closed. This report does not include any data regarding the incidence of talar avascular necrosis following such a procedure. Orthopaedic surgeons' experience in treating numerous patients with knee extensor weakness was reflected in their recommendations that the ankle and hindfoot be fused in 8 to 10 degrees of plantar flexion, thus stabilizing the knee in slight recurvatum during stance.⁵⁰

Many excellent clinical evaluations after pantalar arthrodesis exist, and some provide very long-term follow-up.* Many of these authors have concluded that extensive arthrodesis of the ankle and hindfoot is a technically demanding and easily complicated procedure. Current scientific opinion regards pantalar and tibiotalocalcaneal arthrodesis procedures as salvage operations capable of producing satisfactory results when applied by experienced surgeons for the correct indications. Successfully

completed, these procedures may provide a reasonable alternative to what otherwise would be severely disabling conditions or even amputation if left untreated. Many authors have concluded that pantalar arthrodesis can provide a much more satisfactory result than can talectomy.^{41,63,64,69,70}

Tibiototalcaneal Arthrodesis

For patients who have arthritis, infection or deformity of not only the tibiotalar, but also the talocalcaneal joint, the surgeon must not only fuse

*footnotes= 4,5,8,27,29-31,35,41,48,50,64,69,72,74,81,86,87

the ankle, but the subtalar joint as well. Adding subtalar arthrodesis to a tibiotalar fusion can be accomplished with a cannulated screw technique.⁶⁴ Success has been reported with sliding fibular struts anchored to the tibia, talus and calcaneus.^{9,43,56,85} Plates applied to the tibia, talus and calcaneus have also been employed for the fixation and maintenance of the desired position of arthrodesis of the tibia to the talus to the calcaneus.³⁰

The author believes, however, that intramedullary nailing is a solid method of fixation for achieving tibiototalcaneal arthrodesis.^{41,46,69,70} A medullary nail inserted through the plantar aspect of the foot can afford excellent stability and maintain satisfactory position and alignment (Figure 36). This medullary nail is a load sharing device used for internal fixation and not as prone to failure in heavy patients, neuropathic patients, or those with osteopenic bone, as are cannulated screws alone. In the author's experience patients undergoing intramedullary fixation for tibiototalcaneal arthrodesis need not be casted as long or have their activities restricted as severely as patients undergoing similar procedures employing other methods of fixation. Furthermore, the neuropathic patient, even in the presence of an acute Charcot process, can be managed quite readily by medullary fixation with an acceptable complication rate when undergoing ankle and hindfoot arthrodesis.

Gerhard Kuntscher described the method of combined arthrodesis of the ankle and subtalar joints.

He performed closed medullary nailing with a conical nail inserted over a guide pin through the sole of the foot.⁴⁶

In 1979, Tomeno presented 45 panarthroses using a variety of fixation techniques, but his infection rate was very high. He obtained an 80 percent consolidation rate.⁸⁶ Russotti and Johnson reported in 1988 on 21 tibiotalocalcaneal arthroses employing Steinmann pins and external fixation. Radiographic union was achieved at 85 percent with satisfactory results in 75 percent of patients employing a posterior Achilles splitting approach.⁷⁴ Pappa and Myerson published a series of 21 pantalar and tibiotalocalcaneal arthrodesis for osteoarthritis. An 86 percent fusion rate was obtained by these authors employing a transfibular approach with cannulated screws for fixation.⁶⁴

Kile, et al, also reported the use of an intramedullary nail for tibiotalocalcaneal fusion. Employing their technique, the patient is positioned prone, and an Achilles splitting approach is employed.⁴¹

This author prefers to perform tibiotalocalcaneal arthrodesis using an intramedullary nail, placed percutaneously, and combined with arthrotomy and debridement of the diseased surfaces of the ankle and subtalar joints. The nail can be placed transcalcaneally through the talus into the tibia and locked proximally in the tibia from lateral to medial. Impaction can be obtained and lateral to medial, as well as posterior to anterior interlocking screws used distally (Figure 36).⁷⁰ Currently, a number of different ankle fusion nails are being developed and marketed. As early as 1986, experience has been gained with the use of a bowed supracondylar femoral nail inserted retrograde for ankle fusion.⁶⁹ Straight and curved nails are available from different manufacturers. Exciting new fixation options are available that also include posterior to anterior partially and fully threaded distal locking screws. These posterior to anterior distal screws provide much better purchase of the calcaneus in a reliable fashion and, when extended across the transverse tarsal joints, can simplify the method in which a medullary nail can be used not only to achieve tibiotalocalcaneal, but also transverse tarsal (pantalar) fixation and arthrodesis.

Tibiototalcalcaneal Arthrodesis: Surgical Technique

The patient is positioned supine on a radiolucent operating table with a well-padded bump under the ipsilateral buttock to rotate internally the involved extremity. Another pad can be placed under the heel to facilitate cross-table fluoroscopic imaging. General or spinal anesthesia is usually required, and a thigh tourniquet may be used for hemostasis, greatly facilitating the plantar dissection. Intraoperative fluoroscopy is used as indicated.

An anterolateral ankle arthrotomy with an incision carried over the sinus tarsi is used to correct any deformity that may be present across the tibiotalar and/or subtalar joints and to prepare the joint surfaces by removing what is left of the diseased articular cartilage. These arthrotomies also give the surgeon a site for inserting bone graft as indicated (Figure 37).

A fibular osteotomy or distal fibular osteotomy should be considered at the time of hindfoot fusion if there is significant varus deformity or loss of tibial length relative to the fibula. If fibular osteotomy is not done in these cases, the fibula may actually hold the tibiotalar and talocalcaneal arthrodesis sites distracted postoperatively (Figure 38).

A longitudinally oriented plantar incision is placed just anterior to the weight bearing subcalcaneal heel pad. After the incision is made and carried through dermis sharply, blunt dissection is taken down to the plantar fascia, which is split longitudinally. The intrinsic muscles can be swept aside and the neurovascular bundle identified at the medial portion of the wound (Figure 39). A sharp awl is used to make a plantar calcaneal corticotomy. Alternatively a guide wire and cannulated drill can be used to provide access to the talus and tibial medullary canal after calcaneal corticotomy. The insertion site of either the awl or the cannulated drill bit must be checked intraoperatively with fluoroscopy before proceeding with exposure through the talus of the tibial medullary canal (Figure 40).

A spade-tipped or bulb-tipped guide wire can then be passed through the calcaneus and talus into

the distal tibial medullary canal. A series of progressively larger flexible reamers are then passed over the guide wire and used to prepare and enlarge the tibiotalar canal. It is wise to ream a full 1 to 1.5 millimeter larger than the anticipated nail's outside diameter in order to avoid serious stress risers and a significant risk for postoperative fracture at the proximal tip of the nail (Figure 41).

The nail is attached to its alignment guide. The nail is slightly internally rotated so that when the screws are inserted from lateral to medial, they will pass into the tibia without impinging the fibula.

The nail is usually readily inserted manually without need for the guide wire and then impacted. The distal aspect of the nail is usually countersunk a few millimeters below the plantar surface of the os calcis. Fluoroscopy is used to ascertain the appropriate position and make sure that the distal locking screw holes are lined up to provide satisfactory purchase of the talus and calcaneus. Further compression and impaction can be done across the arthrodesis sites after inserting the proximal interlocking screws. The remaining interlocking screws are inserted after compression across the arthrodesis site is obtained. The author rarely uses screws longer than 25 millimeters to gain bicortical purchase of the distal tibia. Lateral to medial locking screws from 35 to 45 millimeters in length may be required to gain adequate purchase of the talus and calcaneus. Posterior to anterior locking screws are usually no longer than 80 millimeters unless the surgeon intends to also fuse the transverse tarsal joints (Figure 42).

Pantalar Arthrodesis

The existing literature on pantalar arthrodesis is fairly old, dating to orthopaedic surgeons' experience with treating the sequelae of poliomyelitis and other neuromuscular conditions. These reports would also indicate that the technique of pantalar arthrodesis is one of the most technically demanding and involved procedures encountered in foot and ankle surgery today. Also, these procedures are usually done in the salvage setting for severely disabling or even limb threatening conditions.

Pantalar arthrodesis proved to be a reliable, reproducible surgical procedure for addressing the flail

foot and ankle associated with poliomyelitis, paralysis, and tuberculous and bacterial infection in the earlier part of this century.⁵ Most early reports of this technique focused, therefore, on achieving a rigid stable hindfoot in satisfactory position, and few if any articles published before the 1950's include recommendations on internal fixation.

To this day, patients with post-traumatic osteoarthritis involving both the ankle and subtalar joints still pose a difficult therapeutic challenge. Spinal cord injury, longer life expectancy, high-speed motor vehicular trauma and the popularity of sports and active lifestyle, have again focused attention on the foot and ankle. With a better appreciation of lower extremity biomechanics, orthopaedic surgeons are producing articles on the topic of pantalar arthrodesis on a much more frequent basis today than in the recent past.^{30,41,63,64,69,70,74,77,86}

Alternatives to pantalar arthrodesis for patients with arthritis or bone deficiency of the ankle and hindfoot include Syme or below-the-knee amputation. Modern articles are detailing the expected functional results in patients who have an arthrodesis of the hindfoot and ankle. Debate continues regarding the relative attributes of a one-stage versus a two-stage technique in achieving pantalar arthrodesis. For reasons of economics, patient desire for expedient care and an interest in rehabilitating the patient more quickly and returning to a more normal lifestyle, this author prefers a one-stage procedure for pantalar arthrodesis.⁶⁹

A satisfactory pantalar arthrodesis can be achieved using the intramedullary nail for tibiotalar arthrodesis and, in turn, linking this fused hindfoot to the midfoot with cannulated screws or bone staples (Figure 43). Alternatively, a triple arthrodesis of the foot can be performed in standard fashion, and then this construct can be linked to the ankle in the desired position of neutral dorsiflexion-plantar flexion, 3 to 5 degrees of hindfoot valgus, and symmetric external rotation with either a medullary nail or more cannulated screws.⁷¹

The patient's first and fifth metatarsal heads must strike the ground at the same time in ambulation. If the ankle and hindfoot are fused in too much equinus, the patient will have a tremendous tendency to recurvatum at the knee and have heel off too early in the gait cycle. These patients will often walk with the extremity externally rotated in an effort to vault more easily over the involved foot that is held in equinus.

If the ankle and hindfoot are fused in too much dorsiflexion, the gait will seem more natural and stride length more symmetric with the other uninvolved side. The pressures of weight bearing at heel strike will quickly become uncomfortable, however, and the patient will lack satisfactory push-off.

Pantalar Arthrodesis: Surgical Technique

When pantalar arthrodesis is performed employing a cannulated screw technique through open arthrotomy as described by Pappa and Myerson, the patient is positioned supine with a well-padded bump underneath the ipsilateral buttock.⁶⁴ A pneumatic thigh tourniquet is used, and the ipsilateral iliac crest is prepped, as well as the entire lower extremity from the knee distally. It is also quite helpful to note the contralateral uninvolved lower extremity anatomy to ascertain the appropriate position and rotational alignment. The contralateral limb can be prepped into the field or readily palpable through a thin layer of sterile drapes. An extended lateral approach is made using an incision longitudinally oriented over the distal fibula and curving anteriorly over the sinus tarsi. The cuticular branches of the superficial peroneal nerve and sural nerve are protected throughout the case (Figure 31). A distal fibular osteotomy is performed with an oscillating saw at a level just proximal to the tibiotalar joint (Figure 32). In this fashion wide exposure of the ankle and hindfoot is obtained; yet the proximal fibula is still well anchored to the tibia by the syndesmotic ligaments. The fibula is saved and used later in the case as autogenous bone graft in piecemeal fashion.

A second anteromedial incision can be made midway between the medial malleolus and the tibialis anterior tendon, protecting the greater saphenous vein and its cuticular nerve. The second incision can be

used to resect the medial malleolus if it is prominent, or preferably, to leave the medial malleolus in place and denude the articular cartilage from its medial aspect (Figure 44).

If significant deformity is not present at the level of the ankle joint, a sharp bone chisel can be used and, in a congruous fashion, the articular cartilage and hard subchondral bone can be removed from both sides of the ankle joint, taking appropriate resections of bone as necessary to make the foot plantigrade (Figure 33). Alternatively, as described by Pappa and Myerson, an oscillating saw held perpendicular to the long axis of the tibia could be used to make planar cuts, preserving as much bone stock as possible.⁶⁴

A lamina spreader is helpful when exposing the subtalar and transverse tarsal joints. Chisels, rongeurs and curettes can be used to denude the cartilage from these joints, and appropriate wedges of bone can be removed as necessary to make the foot plantigrade. Final alignment of the hindfoot in 0 to 5 degrees of valgus, 0 to 5 degrees of calcaneus, and external rotation equal to that of the contralateral extremity is desired. In the older orthopaedic literature, a position of 5 to 10 degrees of equinus was recommended at the ankle, but these pantalar arthrodeses were often performed for a flail foot in the presence of quadriceps weakness, in which case plantar flexion floor reaction forces caused recurvatum at the knee to stabilize this joint. In a patient with normal quadriceps function, however, 0 to 5 degrees of calcaneus is more desirable.

Fixation at the arthrodesis sites can be achieved with threaded guide wires, facilitating passage of 6_ millimeter or 7 millimeter cannulated screws for permanent fixation. An autogenous bone graft harvested either from the distal fibula or the anterior iliac crest can be tamped into available spaces to insure mechanical support and quicker union.

The author finds it easiest to first fix, from dorsal to plantar with guide pin and cannulated screw, the talocalcaneal joint. Next, taking care to rotate the foot appropriately through the transverse tarsal joint, a proximal to distal calcaneocuboid screw and a distal to proximal talonavicular screw can be inserted over

guide wires (Figure 45).

Next a guide wire is inserted from just anterior to the lateral process of the talus in the sinus tarsi in a distal to proximal and lateral to medial direction across the tibiotalar joint. On the lateral view, this guide wire and subsequent cannulated screw would be passed in the anterior body of the talus, exiting the medial tibia at the supramalleolar level. It is easier to insert the screw, however, over this guide wire from proximal medial to distal lateral, gaining better purchase in the talus with the thread and countersinking the head of the screw in the medial cortex of the metaphyseal tibia.

The last screw can be placed anterolaterally on the distal tibia to posteromedial in the posterior body of the talus. On the lateral radiograph, this screw appears to be parallel over the first tibiotalar screw, and on the anterior-posterior film it appears to cross the medial tibiotalar screw at nearly a right angle (Figure 46).

After further irrigation and bone grafting, the wounds can be closed in layers over suction drainage tubes, and a bulky dressing reinforced with plaster splints applied. The drains can be removed 24 to 48 hours postoperatively with the patient discharged from the hospital usually within 48 hours from surgery.

At approximately two weeks postoperatively, if no special circumstances exist, the operative bandages and sutures are removed, and a well-padded, well-molded short leg cast is applied. Patients are routinely kept nonweight bearing for at least six weeks, followed by weight bearing to tolerance in a cast for the subsequent six to eight weeks. Clinical and radiographic correlation is used to modify this recommended postoperative regimen. Shoe lifts may be necessary to compensation any limb length discrepancy caused by the shortening inherent in this procedure. Ideally the operated extremity should be approximately $\frac{1}{2}$ to 1 centimeter shorter than the contralateral uninvolved limb to allow clearance during the swing phase of the gait cycle (Figure 47).

Most patients can wear regular athletic or walking shoes after a period of adjustment and

experimentation and removing the final cast. Some patients, however, will benefit greatly from the application of a rocker sole or single access cushioned heel to the plantar aspect of the shoe on the involved side.

The ankle is the most frequently reported site of pseudarthrosis after a pantalar arthrodesis, followed by the talonavicular joint. The more rigid the fixation and the more the surgeon respects the local vascular anatomy, the less the likelihood of nonunion developing. Malunion is a fairly frequent complication of pantalar arthrodesis because of the great technical demands of performing this procedure. A precise determination of appropriate final alignment is the key. Intraoperative radiographs should be employed in almost every case. Hindfoot valgus is better tolerated than varus, and if the surgeon must error, it should be to the side of valgus. Avoidance of internal rotation and the use of mild posterior subluxation of the talus under the tibia can enhance postoperative gait.

Other complications after pantalar arthrodesis include superficial or deep wound infection, wound slough, malunion and nonunion. Hardware failure and/or prominence can be remedied with subsequent removal after radiographic union is achieved. Cuticular neuromas have been reported, and prevention is the key to minimizing the symptoms here. Patients with normal plantar sensation and arthrodesis in the appropriate position should have minimal incidence of ulceration. Avascular necrosis was reported after pantalar arthrodesis primarily when talectomy and reinsertion of the talus were employed in earlier reports.

Tibiototalcaneal and extended pantalar arthrodeses are quite demanding, though useful procedures that may be used for a variety of indications. These procedures should be used as salvage techniques to be used for what otherwise would be extremely disabling or even limb threatening situations and applied for patients with osteoarthritis, rheumatoid arthritis, neuropathic joint destruction, and paralytic or flail extremities.

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