Current Concepts Review

Displaced Intra-Articular Fractures of the Calcaneus*

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Most calcaneal fractures occur in male industrial workers, making the economic importance of this injury substantial. Many authors have reported that patients may be totally incapacitated for as long as three years and partially impaired for as long as five years after the injury[1,11,39,73,94,133]. Although modern operative intervention has improved the outcome in many patients, there still is no real consensus on classification, treatment, operative technique, or postoperative management. In this article, the current thinking regarding the treatment of these very difficult fractures will be reviewed.

Historical Treatment

As early as 1908, Cotton and Wilson suggested that open reduction of a calcaneal fracture was contraindicated[27]. McLaughlin agreed, likening attempts at operative fixation to the "nailing of a custard pie to the wall."[76] Cotton and Wilson recommended closed treatment with use of a medially placed sandbag, a laterally placed felt pad, and a hammer to reduce the lateral wall and "reimpact" the fracture[27]. Although initially they were enthusiastic about this technique, by the 1920s they had abandoned the treatment of acute fractures altogether and had turned instead to the treatment of healed malunions[29].

Despite the fact that Böhler[11] advocated open reduction in 1931, the principal reasons for the predominance of nonoperative treatment were the technical problems associated with operative treatment. Anesthesia was not always effective, radiography and fluoroscopy were not well developed, antibiotics did not exist, and a sound understanding of the principles of internal fixation was lacking[105]. The resulting complications of infection, malunion, and nonunion, and the possible need for amputation, made most surgeons believe that treatment should be nonoperative.

In 1935, Conn, who was dissatisfied with standard treatment methods, reported on the use of delayed primary triple arthrodesis, with which he had excellent results[26]. In 1943, Gallie championed subtalar arthrodesis as definitive treatment but only for fractures that had healed[42]. He thought that Conn's operation involving a lateral approach and moving of peroneal tendons[26] was too much operative manipulation, and he did not believe that the midfoot should be treated with an arthrodesis[42]. Although he never reported results (except those for one patient, anecdotally), and despite the fact that no bibliography was ever published, this technique became standard treatment for healed, malunited calcaneal fractures.

Dissatisfied with both nonoperative and late treatment of these injuries, Palmer described the operative treatment of acute displaced intra-articular calcaneal fractures in his classic work, published in 1948[93]. He used a standard lateral Kocher approach to reduce the joint, holding up the fragment with bone graft. He stated that his patients did well and that many returned to work. Essex-Lopresti reported similar findings in 1952[39]. He suggested that, when the articular surface was displaced, a tongue or joint-depression fragment resulted. Although tongue-type fractures were reduced with percutaneous leverage, joint-depression fractures necessitated formal open reduction and internal fixation. The results in patients less than forty years old were as encouraging as those in older patients[39].

Not all surgeons were pleased with the results of reduction and fixation, however, and Dick[35], in Scotland, and Harris[55], in Canada, began to advocate Gallie's technique[42] of subtalar arthrodesis for malunited fractures of the calcaneus as the treatment of choice for acute calcaneal fractures. They cited excellent results, with early return to work. This prompted orthopaedic surgeons in Canada to perform primary subtalar arthrodesis as the treatment of choice for acute displaced intra-articular calcaneal fractures. Lindsay and Dewar evaluated many of these patients in a long-term follow-up study[73]. Although more than half were lost to follow-up, the findings indicated that primary subtalar arthrodesis was being performed unnecessarily, that operative intervention was fraught with problems, and that the best results were in patients who were managed nonoperatively. As a result of that article, which received wide acceptance in the United States and elsewhere, the operative treatment of acute calcaneal fractures once again fell into disfavor. During the 1960s and 1970s, most authors continued to advocate nonoperative treatment[3,5,6,24,66,74,94,96,100].

In the last twenty years, better anesthesia, the introduction of antibiotics, the AO/ASIF principles of internal fixation, and computed tomography and fluoroscopy have allowed surgeons to obtain good outcomes with

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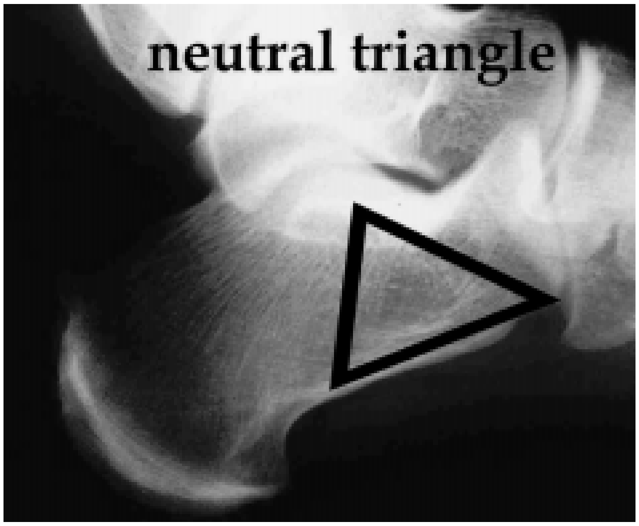

FIG. 1

Radiograph showing traction trabeculae radiating from the inferior cortex of the calcaneus and compression trabeculae converging to support the posterior and anterior articular facets. The area between these trabeculae is known as the neutral triangle[56].

use of operative intervention for most fractures[105]. Most fracture surgeons believe that the benefits of these improvements should also be offered to patients who have a displaced intra-articular calcaneal fracture, and a concerted effort to apply operative techniques to these fractures is again being made[19,31,32,69,84,87,106,111,123,127,137]. Although these extensive attempts have indeed improved the functional outcomes after displaced intra-articular calcaneal fractures, it is recognized that treatment remains challenging and can still be fraught with difficulties.

Radiographic Anatomy

The calcaneus transmits body weight to the ground and creates a strong lever for the muscles of the calf. Traction trabeculae radiate from the inferior cortex of the calcaneus, while compression trabeculae converge to support the posterior and anterior articular facets (Fig. 1). Soeur and Remy termed this condensation of bone trabeculae the thalamic portion of the calcaneus[116]. The area between these trabeculae creates a space known as the neutral triangle[56].

Two important angles are seen on the lateral radiograph of the calcaneus (Figs. 2-A and 2-B). The tuber angle of Böhler, usually between 20 and 40 degrees, is formed by two lines[11]. The first line is drawn from the highest point of the anterior process of the calcaneus to the highest point of the posterior facet. The second line runs tangential to the superior edge of the tuberosity. A decrease in this angle may indicate that the weight-bearing surface of the calcaneus (the posterior facet) has collapsed, shifting the weight of the body anteriorly. McLaughlin pointed out that reduction or reversal of this angle indicates only the degree of proximal displacement of the tuberosity and therefore the angle can be decreased in both intra-articular and extra-articular fractures, thus limiting its usefulness[74,123]. The second angle, the crucial angle of Gissane, is seen directly inferior to the lateral process of the talus[110] and is represented by two strong cortical struts that extend laterally and form an obtuse angle[39,50]. The first strut extends along the lateral border of the posterior facet, and the second extends anteriorly to the beak of the calcaneus.

Mechanism of Injury and Pathological Anatomy

Intra-articular fractures of the calcaneus with displacement are the result of high-energy trauma, usually due to a fall from a height, with the patient's weight concentrated on the heels on landing, or to a motor-vehicle accident. The position of the foot at the time of impact, the force of the impact, and bone quality all determine the pattern of comminution as well as the location of the fracture lines. Although the exact mechanism of injury is still controversial, the findings of

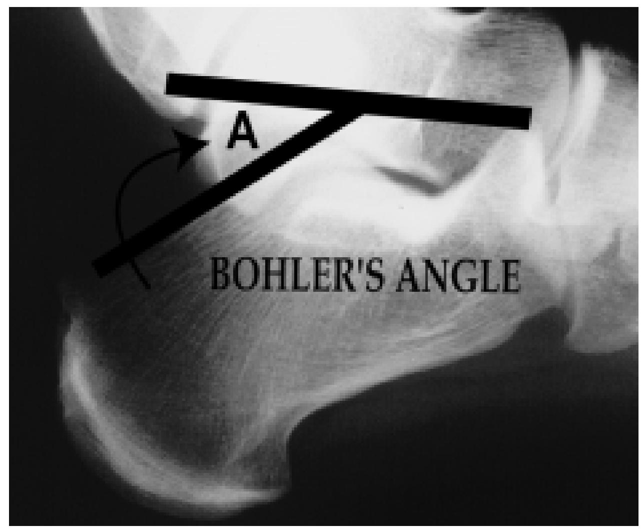

FIG. 2-A

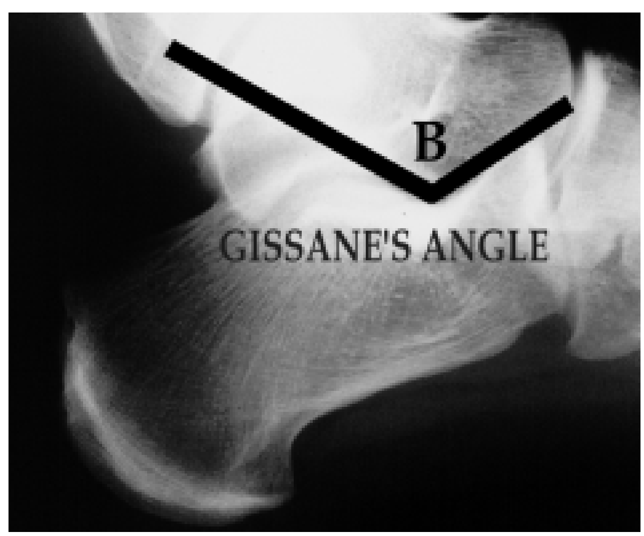

FIG. 2-B

Fig. 2-A: Radiograph showing the tuber angle of Böhler[11].
Fig. 2-B: Radiograph showing the crucial angle of Gissane[110].

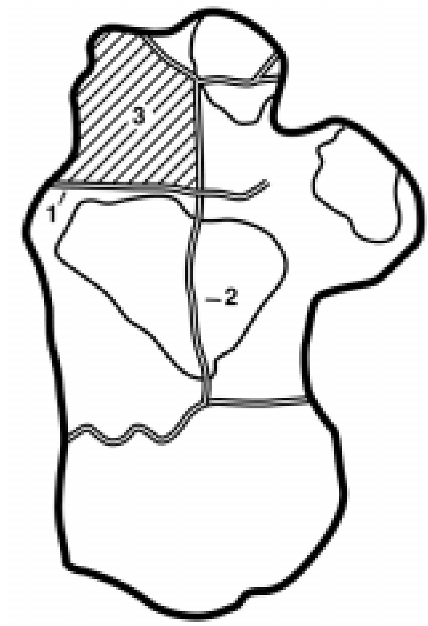

FIG. 3-A

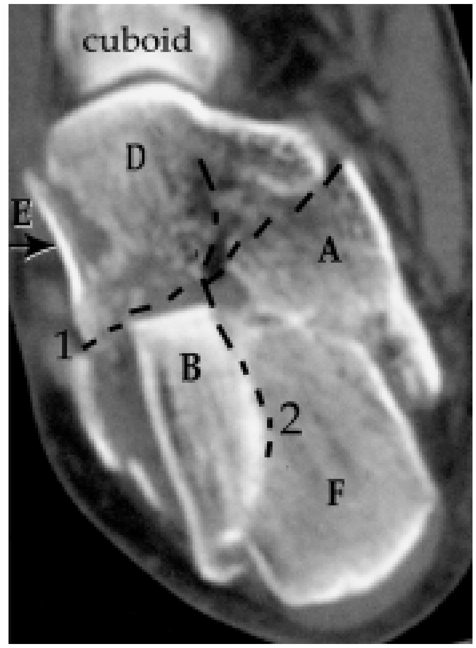

FIG. 3-B

Figs. 3-A and 3-B: The pathological anatomy of an intra-articular calcaneal fracture, according to the description by Carr et al.[22].
Fig. 3-A: Schematic drawing showing the primary fracture lines (1 and 2) and the anterolateral fragment (3).
Fig. 3-B: Transverse computed tomographic scan showing the fracture fragments. A = superomedial fragment (also known as the sustentacular or constant fragment), B = superolateral fragment (also known as the semilunar or comet fragment), C (not shown) = tongue fragment (the superolateral fragment attached to a piece of the posterior tuberosity, which includes the Achilles tendon insertion), D = anterior main fragment (the anterior half of the calcaneus), E = anterolateral fragment (the lateral wall of the anterior process), and F = posterior main fragment (the posterior tuberosity fragment).

Essex-Lopresti[39], Burdeaux[17], Thorén[128], and Carr[23] are in general agreement.

Essex-Lopresti thought that the primary fracture line is first produced laterally by the lateral process of the talus and then travels medially[39]. He believed that the energy follows two separate paths: an outer and an inner path. His understanding was that, at the time of impact, the subtalar joint is forced into eversion and “the sharp outer taloid spur is driven like an axe into the crucial angle, splitting it and the outer wall of the bone along its grain.”[39] The inner route then consisted of the remainder of the force, which “descends through the anterior subtaloid joint on to the sustentaculum tali, which may be sheared off the inner side of the body together with the medial one-third or one-half of the posterior subtaloid joint.”[39] If the force continues, the fracture line can exit as far forward as the anterior process or the calcaneocuboid joint, creating an anterolateral fragment. With increased force, a secondary fracture line is created. If the foot is flat on the ground and the force is directed posteriorly, the fracture will run behind and superior to the posterior facet, resulting in a free superolateral fragment of posterior facet. Alternately, an inferiorly directed force results in a tongue-type fracture[39].

More recently, Carr et al. created experimental intra-articular calcaneal fractures in eighteen below-the-knee amputation specimens[22]. Different weights at different heights were dropped over a guide-rod inserted into the tibial medullary canal. Two primary fracture lines were consistently observed (Figs. 3-A and 3-B). One fracture line divided the calcaneus into medial and lateral portions. In some specimens the fracture line continued into the calcaneocuboid joint, whereas in others it split the anterior facet. The other primary fracture line divided the calcaneus into anterior and posterior portions, starting laterally from the angle of Gissane and running medially. In several specimens, the fracture line ran medially, splitting the middle facet. Laterally, the fracture line ran inferiorly, either toward the plantar surface or anteriorly. Together, these two fracture lines resulted in a variety of tongue and joint-depression-type fractures and in the creation of anterolateral, superolateral, and superomedial fragments, thereby validating the work of Essex-Lopresti[39] (Figs. 4-A and 4-B), Soeur and Remy[116], and others[135].

Radiographic Evaluation

The initial assessment of the patient should include plain radiographs. If these radiographs reveal an intra-articular component to the fracture, a computed tomographic scan should be made. Many projections and detailed studies of radiographic views have been described, but most of these images are hard to interpret and difficult to reproduce[4,60,116,132]. When interpreted correctly, computed tomographic scans provide a wealth of data for both diagnosis and treatment. Because of the association of calcaneal fractures with spine injuries,

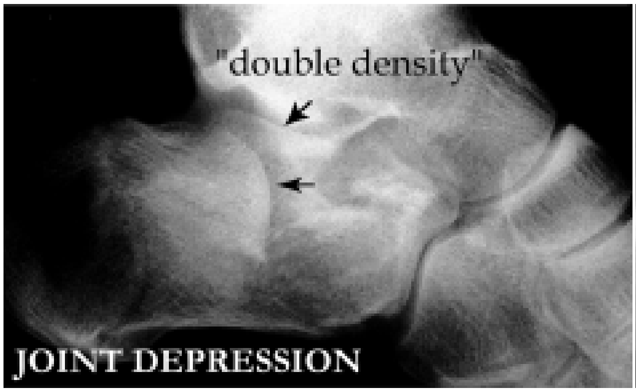

FIG. 4-A

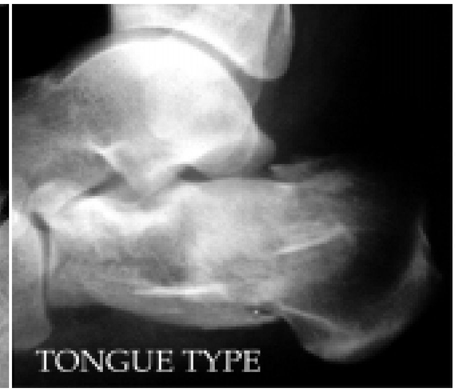

FIG. 4-B

Figs. 4-A and 4-B: Radiographs showing the fracture classification of Essex-Lopresti[39].
Fig. 4-A: Joint-depression fracture. The double density indicates a split fracture of the articular surface.
Fig. 4-B: Tongue-type fracture.

routine radiographs of the lumbar spine also should be made[58].

Conventional Radiography

Plain radiographs consist of a lateral radiograph of the hindfoot, an anteroposterior radiograph of the foot, and a Harris axial radiograph of the heel[60]. The lateral radiograph should confirm the diagnosis of a calcaneal fracture. Radiographs of intra-articular fractures usually show a loss in the height of the posterior facet, with a decrease in the angle of Böhler and an increase in that of Gissane, but only if the entire facet is separated from the sustentaculum and depressed. If only the lateral half of the posterior facet is fractured and displaced, a split in the articular surface will be seen as a double density and Böhler's angle will be normal (Fig. 5-A). The articular surface can be found within the body of the calcaneus; usually, it is rotated 90 degrees in relation to the remainder of the subtalar joint. The lateral radiograph also indicates whether the fracture is of the joint-depression or tongue type according to the classification of Essex-Lopresti[39]. The anteroposterior radiograph of the foot shows extension of the fracture line into the calcaneocuboid joint (Fig. 5-C). This radiograph provides very little information and usually may be omitted. The Harris axial radiograph of the heel allows visualization of the joint surface as well as loss of height, increase in width, and angulation of the tuberosity fragment (Fig. 5-B). Unfortunately, this radiograph is very difficult to make in the acute setting because of pain.

Tomograms are rarely indicated, as they provide no additional information when computed tomography is available and they expose the patient to increased doses of radiation[53]. Deutsch et al. pointed out that tomograms may fail to show the extent of articular incongruity[34]. Brodén's view, however, is a reproducible means of demonstrating the articular surface of the posterior facet on plain radiographs[14]. This view, known as Brodén Projection I, is obtained with the patient supine and the x-ray cassette under the leg and the ankle. The foot is in neutral flexion, and the leg is internally rotated 30 to 40 degrees (Fig. 6-A). The x-ray beam then is centered over the lateral malleolus, and four radiographs are made with the tube angled 40, 30, 20, and 10 degrees toward the head of the patient (Figs. 6-B and 6-C)[14]. These radiographs show the posterior facet as it moves from pos-

FIG. 5-A

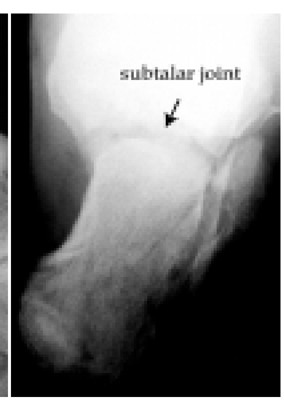

FIG. 5-B

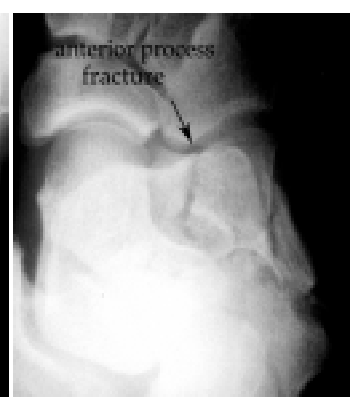

FIG. 5-C

Fig. 5-A: Lateral radiograph showing a calcaneal fracture.
Fig. 5-B: Harris axial radiograph of the heel. The clarity is limited because the image was difficult to make due to pain.
Fig. 5-C: Anteroposterior radiograph of the foot, showing the fracture extending into the calcaneocuboid joint.

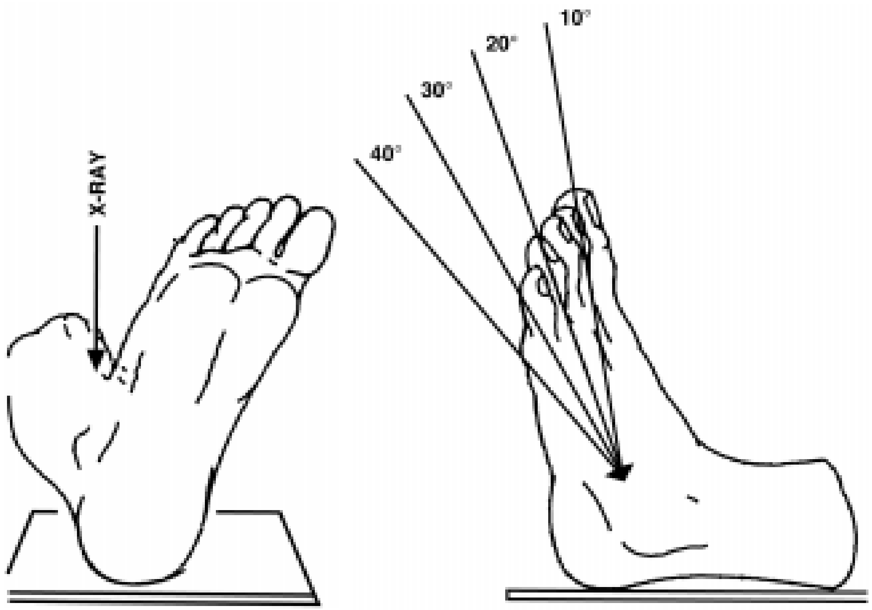

FIG. 6-A FIG. 6-B

Figs. 6-A and 6-B: Schematic drawings showing the technique for making Brodén's views[14]. (Reproduced, with modification, from: Burdeaux, B. D., Jr.: Reduction of calcaneal fractures by the McReynolds medial approach technique and its experimental basis. Clin. Orthop., 177: 96, 1983. Reprinted with permission.)

Fig. 6-A: With the patient supine, the x-ray cassette is placed under the leg and the ankle. The foot is in neutral flexion, with the leg internally rotated 30 to 40 degrees.

Fig. 6-B: The x-ray beam is centered over the lateral malleolus and four radiographs are made, with the tube angled 40, 30, 20, and 10 degrees toward the head of the patient.

terior to anterior; the 10-degree view shows the posterior portion of the facet, and the 40-degree view shows the anterior portion. Importantly, these radiographs can be used in the operating room to verify the reduction of the articular surface[108].

Computed Tomographic Scanning

Computed tomographic scanning has improved our understanding of these fractures substantially and has allowed for consistent analysis of the results of treatment (Figs. 7-A and 7-B). There are several excellent review articles on this subject[14,46,53,57,79,99,114,117,118].

Normal Anatomy

Coronal images reveal information about the articular surface of the posterior facet, the sustentaculum, the shape of the heel, and the position of the peroneal and flexor hallucis tendons.

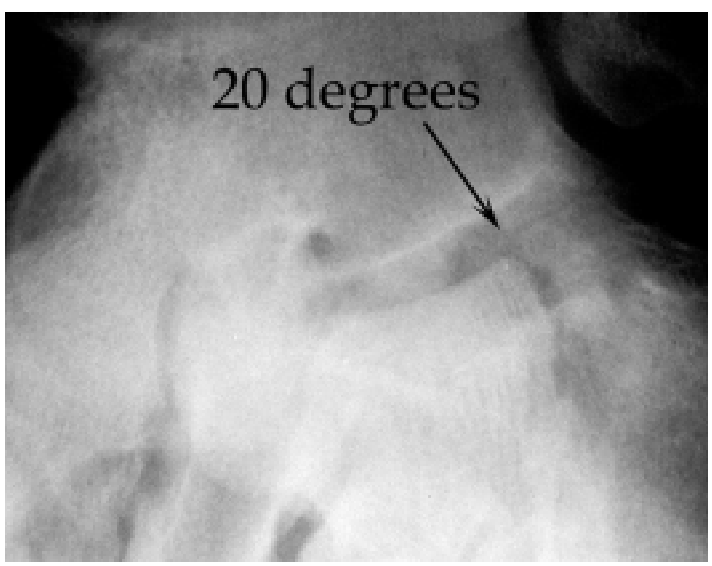

FIG. 6-C

Brodén's view made with the tube angled 20 degrees.

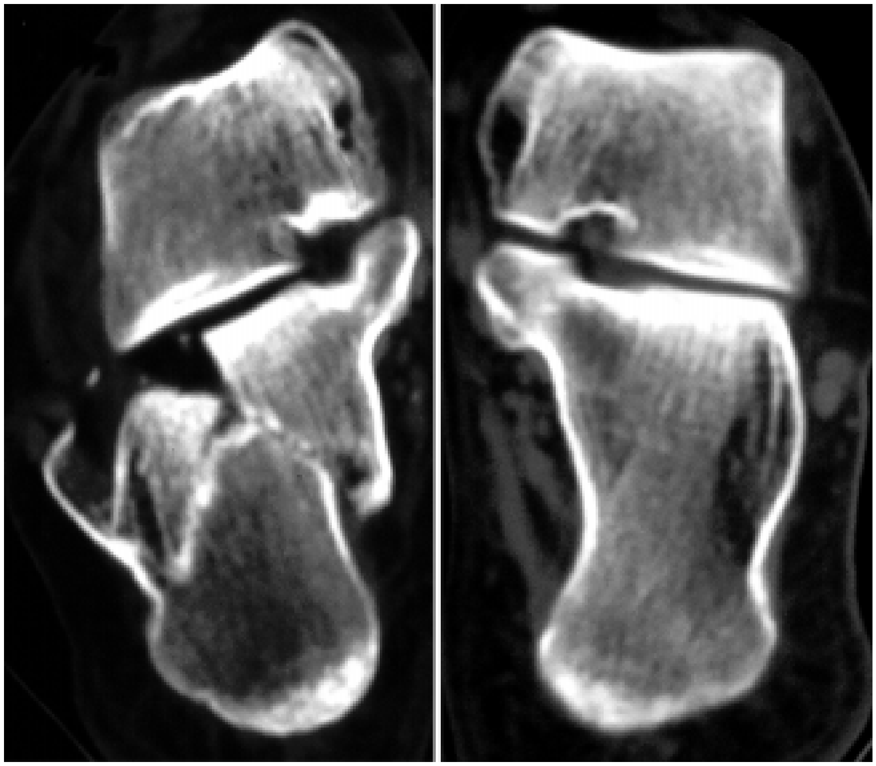

FIG. 7-A

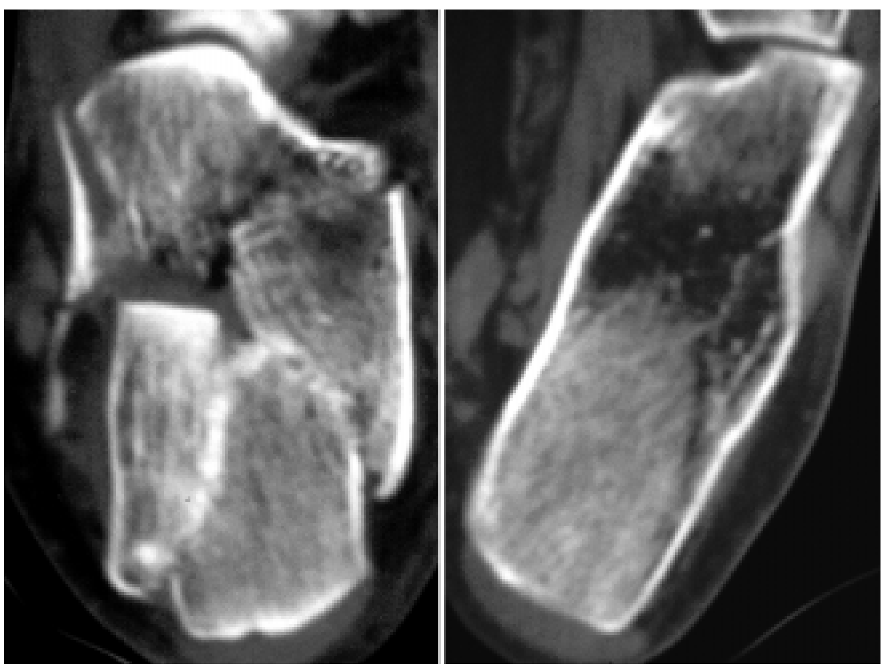

FIG. 7-B

Coronal (Fig. 7-A) and transverse (Fig. 7-B) computed tomographic scans showing a calcaneal fracture.

Transverse (axial) images provide information about the calcaneocuboid joint, the anteroinferior aspect of the posterior facet, and the sustentaculum.

Pathological Anatomy

Coronal images can be analyzed to determine displacement of the articular surface of the posterior facet and the number and location of articular fracture fragments, as these findings have prognostic importance. The calcaneal body should be evaluated for widening, shortening, and bulging of the lateral wall. The peroneal tendons should be evaluated carefully to rule out impingement. Varus shift of the tuberosity fragment also should be ruled out.

Transverse (axial) images provide information about fractures extending into the calcaneocuboid joint. Fractures at the anteroinferior base of the posterior facet (Gissane's angle) and those extending into the sustentacular fragment also can be seen. Finally, the amount of adduction of the tuberosity fragment can be determined.

The use of three-dimensional computed tomographic scanning for intra-articular calcaneal fractures was recently evaluated in several studies[2,130]. Although this is an interesting modality, the definition of the articular surface was not sufficient to assist in preoperative planning or to justify the costs. Vannier et al. concluded that the diagnostic value of three-dimensional computed tomography was equivalent to that of conventional two-dimensional computed tomography[130].

Classification of Fractures

One reason why so much difficulty has been encountered in the treatment of calcaneal fractures is the surgeon's inability to successfully classify these injuries. Before the advent of computed tomographic scanning, numerous systems for the classification of calcaneal fractures were proposed[39,93,100,132,133]. The accuracy and utility of all of these systems have been limited by standard radiographic technique. Also, because similar fracture patterns were not analyzed, similar treatment regimens resulted in varying degrees of success. The treatment of calcaneal fractures has been greatly enhanced by the advent of computed tomographic scanning.

Classifications Based on Conventional Radiographs

In 1948, Palmer reported on two distinct types of intra-articular fractures of the calcaneus[93]. This description was refined in 1952 by Essex-Lopresti, who also found two distinct fracture patterns: those with a tuberosity fragment attached to the articular fragment, which he called tongue-type fractures, and those without it, which he termed joint-depression-type fractures[39]. Correct classification of the fracture determined the treatment but not the prognosis. Although Warrick and Bremner described various types of fractures in an atlas published in 1953, they discussed neither treatment nor prognosis[132]. Careful study of their findings indicates that they essentially reproduced the fracture patterns described by Essex-Lopresti. Similarly, Widen[133], Arnesen[5], and others[44] used variations of the Essex-Lopresti classification.

In 1975, Soeur and Remy reported on their experience with calcaneal fractures[116]. Unique to their discussion was a classification based on the number of articular bone fragments, as determined with use of anteroposterior radiographs of the midfoot and lateral and Harris radiographs of the heel. First-degree fractures were defined as nondisplaced shear fractures with widening of the joint surface. Second-degree fractures included secondary fracture lines, resulting in a minimum of three pieces, two of which included the articular surface. Clinical radiographs in their text indicated that the posterior main fragment could be broken into as many as three fragments (lateral, middle, and medial). Third-degree fractures were so highly comminuted they could not be classified; therefore, the authors could not specify if the comminution referred to the calcaneal body or to the articular surface of the posterior facet. Although they indicated that displaced fractures should be internally fixed and that good results could be expected, they did not stratify the results on the basis of their classification.

Classifications Based on Computed Tomographic Scanning

In 1985, Segal et al. described the usefulness of computed tomographic scanning for the diagnosis and treatment of calcaneal fractures[111]. Although Stephenson used computed tomographic scans for a few of his patients[124], Zwipp et al. were the first, to my knowledge, to integrate computed tomographic scans into a rational understanding of the injury[137]. The entire calcaneus was considered in their classification (Fig. 8-A). There was a total of five possible fragments, similar to the classifications of Essex-Lopresti[39], Soeur and Remy[116], and Carr et al.[22], and fractures had two, three, four, or five parts. Although the outcomes of the operations were evaluated, no prognosis was made on the basis of the fracture classification[137].

Crosby and Fitzgibbons, in 1990, associated the clinical outcome with the type of fracture according to a classification system based on computed tomographic findings[30]. They evaluated displacement of the articular surface and, on this basis, categorized the fractures into three types: type I — nondisplaced, type II — displaced, and type III — comminuted. Sanders et al. developed a computed tomographic scanning classification that was based on the number and location of articular fracture fragments[105,106] (Fig. 8-B). This classification was a natural progression of the fracture-pattern classification as described by Soeur and Remy[116]. All patients were examined preoperatively and postoperatively with computed tomography to determine the success of the reduction of the calcaneal body and the subtalar joint. The classification was found to be useful in determining treatment as well as prognosis[106]. The system is based on coronal computed tomographic scans. Although all coronal sections were analyzed, the section showing the widest undersurface of the posterior facet of the talus was arbitrarily used. The talus was divided into three equal columns by two lines. These lines and a third line, located just medial to the medial edge of the posterior facet, divided the posterior facet into three potential pieces: a medial, a central, and a lateral fragment. These fragments and the sustentaculum comprised a total of four potential articular pieces. All nondisplaced articular fractures, irrespective of the

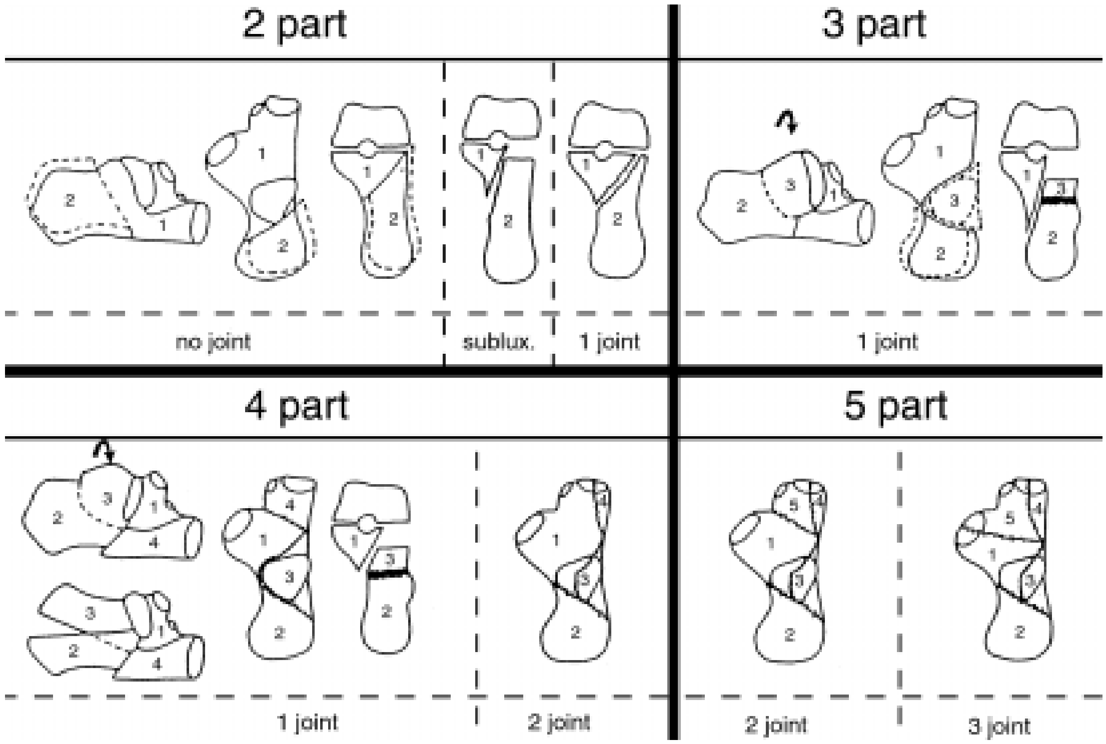

FIG. 8-A

Figs. 8-A and 8-B: Classification systems based on computed tomographic scanning.

Fig. 8-A: Classification of calcaneal fractures according to Zwipp et al.[137]. 1 = sustentacular fragment, 2 = tuberosity fragment, 3 = subtalar joint fragment, 4 = anterior process fragment, and 5 = anterior subtalar joint fragment. The most frequently involved joint is the posterior subtalar joint, followed by the calcaneocuboid joint and the anterior subtalar joint (middle and anterior facets). (Reprinted, with permission, from: Zwipp, H.; Tscherne, H.; Thermann, H.; and Weber, T.: Osteosynthesis of displaced intraarticular fractures of the calcaneus. Results in 123 cases. Clin. Orthop., 290: 78, 1993.)

number of fracture lines, were considered type-I fractures. Type-II fractures were defined as two-part fractures of the posterior facet and were similar in appearance to a split fracture of the tibial plateau; three subtypes, IIA, IIB, and IIC, were based on the location of the primary fracture line. Type-III fractures consisted of three-part fractures characterized by a centrally depressed fragment, similar to a split depressed fracture of the tibial plateau or a die-punch fracture of the distal part of the radius; subtypes included IIIAB, IIIAC, and IIIBC. Type-IV fractures, or four-part articular fractures, were highly comminuted and often had more than four articular fragments.

Clinical Examination

The amounts of displacement and soft-tissue disruption associated with an intra-articular fracture of the calcaneus are proportional to the force generated to produce the injury. In injuries caused by minimum force, swelling and ecchymosis are mild. Severe soft-tissue disruption occurs with higher-energy injuries and may be associated with open fractures. Open fractures may present with a slight puncture wound medially, where a spike of the medial wall of the calcaneus protrudes, or they may be substantial, with extensive soft-tissue disruption, usually laterally. With these severe high-energy wounds, talonavicular disruptions may occur, with the talar head traveling through the anterior aspect of the calcaneus. In the most severe of these fractures, the talar head protrudes through the plantar skin.

Pain is usually severe and is related to the amount of bleeding into a tightly enveloped fascia of the heel. If the patient is seen more than six hours after the injury, the lateral skin is usually so swollen that the skin creases have disappeared. Careful evaluation by palpation of the fibular malleolus should be performed to discern whether the peroneal tendons have dislocated.

Compartment Syndromes

Care must be taken to ensure that the severe pain associated with the fracture is not related to a compartment syndrome of the foot, especially in the calcaneal compartment[40,89]. A compartment syndrome develops when pressure increases in a closed soft-tissue space, ultimately affecting pulse pressure to the point where arterial flow is influenced. The long-term sequelae of a compartment syndrome of the foot include clawfoot deformity with permanent loss of function, contracture, weakness, and sensory disturbances[40]. There are four compartments — medial, lateral, central, and interosseous — within the foot. The central compartment is divided into two separate compartments by a transverse septum in the hindfoot; the superficial compartment contains the flexor digitorum brevis muscle, and

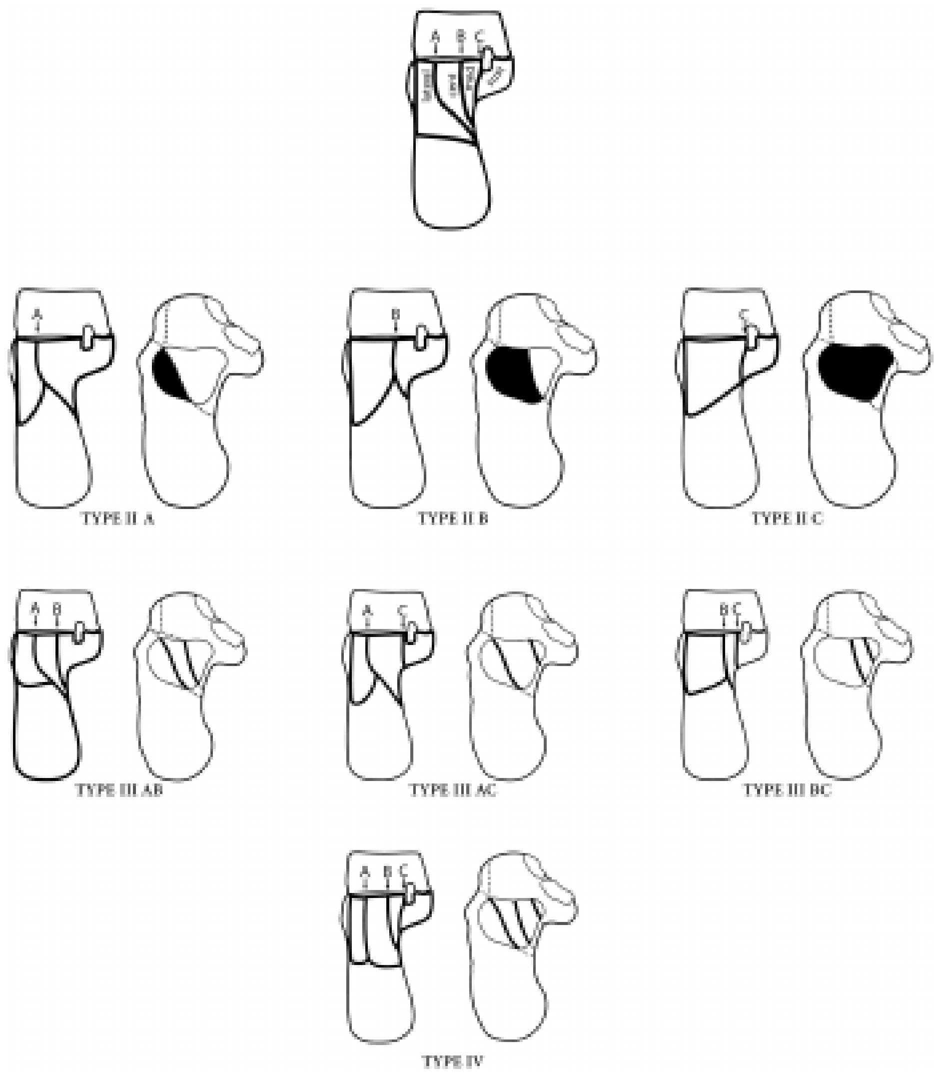

FIG. 8-B

Classification of intra-articular calcaneal fractures according to Sanders et al.[105,106]. Type I = nondisplaced fractures, type II = displaced fractures, and type III = comminuted fractures. (Reprinted, with permission, from: Sanders, R: Intra-articular fractures of the calcaneus: present state of the art. J. Orthop. Trauma, 6: 254, 1992.)

the deep compartment contains the quadratus plantae muscle and the lateral plantar nerve[40]. The latter compartment is known as the calcaneal compartment. In addition, there is a communication between the calcaneal compartment and the deep posterior compartment of the leg[89]. A self-contained needle manometer system (Quikstik; Stryker, Kalamazoo, Michigan) is most commonly used to measure compartment pressures. Most authors have recommended that fasciotomy be performed when the compartment pressure rises to within ten to thirty millimeters of mercury (1.33 to 4.00 kilopascals) of the diastolic pressure[40,89].

During operative treatment of a compartment syndrome of the foot, the calcaneal compartment can best be released by a separate hindfoot incision similar to that used for release of the plantar fascia[40,89]. The incision begins four centimeters anterior to the posterior portion of the heel and three centimeters from the plantar surface, and it is approximately six centimeters long, paralleling the sole of the foot. It may be extended proximally to decompress the entire tibial neurovascular bundle. The fascia overlying the abductor hallucis muscle is seen, directly in line with the incision. As the fascia is opened, the medial compartment is released. The abductor hallucis muscle is stripped from its overlying fascia and is retracted superiorly, revealing the dense white fascia of the medial intermuscular septum. Incision of this fascia releases the calcaneal compartment, but care must be taken to avoid the lateral and medial plantar nerves and vessels just beneath the septum. When this incision is used for release, the two dorsal incisions should be employed to release the other compartments of the foot as needed[40,89].

Blisters

Blisters may appear when substantial swelling is present. They can occur anywhere about the foot, and the vesicles can be filled with either clear fluid or blood[47-49,131]. The blister is the result of a cleavage at the dermal-epidermal junction, and the fluid represents sterile transudate[47-49,131]. If the dermis retains some epidermal cells, then the fluid remains clear. If the dermis is completely devoid of epidermal cells, then the transudate becomes bloody[47]. In a prospective study of fifty-three feet, Giordano and Koval evaluated methods for the treatment of blisters, including aspiration, deroofing with subsequent application of Silvadene (silver sulfadiazine) cream or coverage with a nonadherent dressing, and leaving the blister intact and covered by loose gauze or exposed to the air[48]. Although there was no major difference in outcome among the different techniques, two patients in whom the incision had passed through a blood-filled blister had complications related to wound-healing. Varela et al. reviewed the cases of fifty-three patients retrospectively and found that two had a major wound infection secondary to an incision through the blister[131]. In that study, microbial evaluation of eleven ruptured vesicles demonstrated colonization with skin pathogens soon after rupture of the blister and until re-epithelialization.

On the basis of these data, incisions should be modified to avoid blistered skin.

Treatment Options

The treatment of displaced intra-articular calcaneal fractures can be divided into three categories: nonoperative, open reduction and internal fixation, and primary arthrodesis.

Nonoperative Treatment

Nonoperative treatment consists of early range-of-motion exercises and non-weight-bearing for approximately three months. The foot is placed in a boot, which is locked in neutral flexion in order to prevent an equinus contracture, and an elastic compression stocking is used to minimize dependent edema. Nonoperative treatment is best reserved for nondisplaced (Sanders type-I) fractures[33,103]. For patients who have displaced intra-articular fracture fragments, nonoperative treatment offers little chance of a return to normal function because a calcaneal malunion will develop. Of concern is the fact that a reduction of the articular surface never is obtained, the heel remains shortened and widened, the talus remains dorsiflexed in the ankle mortise, and the lateral wall causes impingement and binding of the peroneal tendons. Specific indications for nonoperative treatment include a nondisplaced fracture[30,103], severe peripheral vascular disease or insulin-dependent diabetes, and other medical problems that contraindicate an operation. Specific situations in which nonoperative treatment may be required because an injury precludes early operative intervention include a severe open fracture; a life-threatening injury; and soft-tissue compromise, such as blistering and massive, prolonged edema, which may substantially delay operative treatment.

Operative Treatment with Use of a Lateral Approach

When operative treatment is elected, it should be performed within the first three weeks after the injury, before early consolidation of the fracture. Once the fracture has consolidated, it is difficult to separate the fracture fragments to obtain an adequate reduction. An operation should not be attempted until after swelling in the foot and ankle has markedly decreased. Because this may take seven to fourteen days, a variety of methods must be used to reduce edema. If the patient is seen in the emergency room, immediate elevation and application of a Jones dressing with a posterior splint is employed. Several days later, if the swelling has begun to decrease, a boot locked in neutral flexion and an elastic compression stocking can be used. Many authors have reported good results with use of a foot pump[43,88,127].

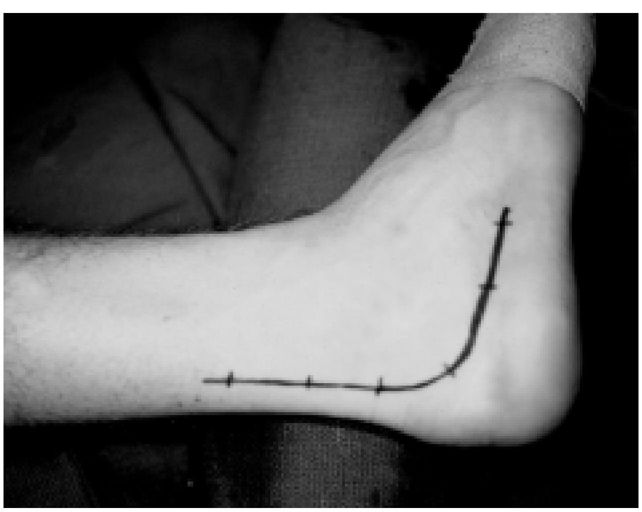

FIG. 9-A

FIG. 9-B

Fig. 9-A: Photograph showing Seligson's lateral extensile approach to the calcaneus, as described by Gould[52].
Fig. 9-B: The sural nerve and the peroneal tendons are protected within the full-thickness anterior flap.

The patient can be evaluated with computed tomographic scans and conventional radiographs one week after the injury. If operative intervention is indicated at that time, it may be performed as soon as the wrinkle test is positive[105]. This test is best performed by direct palpation of the skin over the lateral aspect of the calcaneus and by visual evaluation of this area when the patient dorsiflexes and everts the foot. If skin-wrinkling is seen and no pitting edema is evident, operative intervention may be undertaken.

The operation can be performed by placing the patient in either lateral decubitus or the prone position on a translucent table or a cardiac pacemaker insertion board (pacer board) so that fluoroscopy may be used intraoperatively. After exsanguination of the lower extremity, the tourniquet is inflated to 350 millimeters of mercury (46.66 kilopascals). The calcaneus is approached through an extensile right-angled lateral incision[52,137] (Fig. 9-A). This approach minimizes the sequelae of peroneal tendinitis and devascularization of the anterior skin flap and preserves the sural nerve (Fig. 9-B).

The fracture line at the level of the angle of Gissane is identified, and the thin lateral wall is lifted gently and retracted inferiorly to expose the articular fracture fragments buried within the body of the calcaneus. The superolateral fragment of the posterior facet is evaluated and rotated out from within the body, immediately decompressing the remaining fracture. Attention then is turned to restoration of the height of the calcaneus, which is accomplished by repositioning the posterior tuberosity under the sustentaculum. This is done by placing a periosteal elevator into the fracture line in the medial wall and levering the tuberosity down and shifting it medially[37].

If the superolateral fragment is in two or more pieces, it can be reconstructed anatomically with use of resorbable pins (SmartPin, self-reinforced poly levolactic acid; Bionx Implants, Blue Bell, Pennsylvania). The anterolateral corner of the superolateral fragment should line up with the posterolateral corner of the anterolateral fragment so that the angle of Gissane, at the anterior edge of the posterior facet, lines up. Brodén's views are made, and the reduction of the joint is accepted or is rejected and repositioned until the surgeon is satisfied that the articular surface is anatomically reduced. Then, 3.5-millimeter cortical-bone lag screws are placed from the lateral cortex toward the sustentaculum. Attention next should be turned to the calcaneal body. The anterolateral fragment and the posterior tuberosity are realigned to ensure that the body is anatomically reduced. This may require manipulation with a Schanz pin[109]. A low-profile lateral plate is applied to stabilize the posterior facet, the anterior process, and the posterior tuberosity. The reduction is again verified under fluoroscopy and, if it is found to be satisfactory, a layered closure is performed (Figs. 10-A through 10-I).

While postoperative treatment may vary from surgeon to surgeon, I recommend the following regimen. The patient is kept in the hospital overnight, and a below-the-knee non-weight-bearing cast is applied before the patient is discharged. The patient returns three weeks later, at which time the cast and stitches are removed and the foot is placed back in the stocking and walking boot, which is locked at 90 degrees. The patient may begin range-of-motion exercises out of the boot at this time, but weight-bearing is not permitted for another six weeks. Additionally, the patient should wear the boot while sleeping, for approximately three weeks (six weeks postoperatively), to prevent the development of an equinus contracture. At nine weeks postoperatively, the patient may begin progressive weight-bearing while wearing the boot. The patient should be able to return to a reasonably active job by four and one-half months postoperatively (Figs. 10-J and 10-K).

Primary Arthrodesis

At the present time, a primary arthrodesis is advocated only for patients who have a Sanders type-IV highly comminuted intra-articular fracture (Figs. 11-A, 11-B, and 11-C)[15,105,106]. After restoration of the calcaneal body and the joint surface according to the method described earlier, the remaining cartilage is removed from both surfaces of the posterior facet and an autologous bone graft is used to perform an arthrodesis. Typically, a 6.5 to 8.0-millimeter cannulated cancellous-bone lag screw is placed from the posterior tuberosity into the talar dome to stabilize the fusion. This may require removal of isolated 3.5-millimeter screws from either the side-plate or the articular reduction. The limb is placed in a non-weight-bearing below-the-knee cast for three months, after which time the patient may begin to walk, following the same regimen as described for patients who have been operated on with a lateral approach.

Results of Treatment

Treatment Before the Advent of Computed Tomographic Scanning

Closed treatment of calcaneal fractures was evaluated in at least eight large studies, which demonstrated varying rates of success and in which different methods of treatment, classification, and outcome measurement were used[39,54,65,66,73,96,100,101]. Simpson et al. compared the sixty-two largest studies that were performed before 1983 and cautioned against drawing conclusions on the basis of the existing literature[112]. Giachino and Uhthoff came to the same conclusion[45]. Therefore, the results of studies published before computed tomographic scanning became available are ambiguous and should be evaluated in a historical context.

Many studies using more modern methods of analysis subsequently were published. These studies can be categorized as those involving nonoperative treatment,

FIG. 10-A FIG. 10-B FIG. 10-C

Figs. 10-A through 10-K: A foot that had a Sanders type-IIIBC displaced intra-articular calcaneal fracture.
Fig. 10-A: Lateral radiograph showing the displaced intra-articular calcaneal fracture.
Figs. 10-B and 10-C: Coronal and transverse computed tomographic scans indicating a Sanders type-IIIBC fracture.

those involving operative treatment, and those comparing operative with nonoperative methods.

Nonoperative Treatment

Crosby and Fitzgibbons utilized a computed tomographic scanning classification based on a fracture pattern involving the posterior facet in order to evaluate the results of closed treatment[30]. They classified small or nondisplaced fractures as type I, displaced fractures as type II, and comminuted fractures as type III. Their series included thirteen type-I, ten type-II, and seven type-III fractures. All fractures were treated with closed methods. Those authors concluded that all patients who had a type-I fracture had a good result but that most who had a type-II fracture and all who had a type-III fracture had a poor result with closed treatment, and they suggested operative treatment for these fractures.

Kitaoka et al. reviewed a series of sixteen calcaneal fractures that had been treated nonoperatively between 1980 and 1987[65]. Unique to this study was the use of gait analysis to evaluate outcomes. Most patients had an altered gait pattern, especially when they walked on uneven ground, confirming that there was at least some persistent functional impairment.

Operative Treatment

Medial Compared with Lateral Approach

Previously, most authors focused more on restoration of the overall shape of the calcaneus and correction of Böhler's angle than on reduction of the joint[39,81,82,93,126,128,133]; thus, McReynolds[75,76] and others[17-19] stressed the importance of a medial approach for reconstruction of the shape of the extra-articular portion of the calcaneus. This approach resulted in an indirect and often incomplete reduction of the joint surface; as a result, Stephenson used a medial approach for reduction of the body and a lateral approach for reduction of the joint[123-125].

Recently, Burdeaux reported on his twenty-one-year experience with reduction from the medial side[20]. Computed tomographic scans were not used, and the classifi-

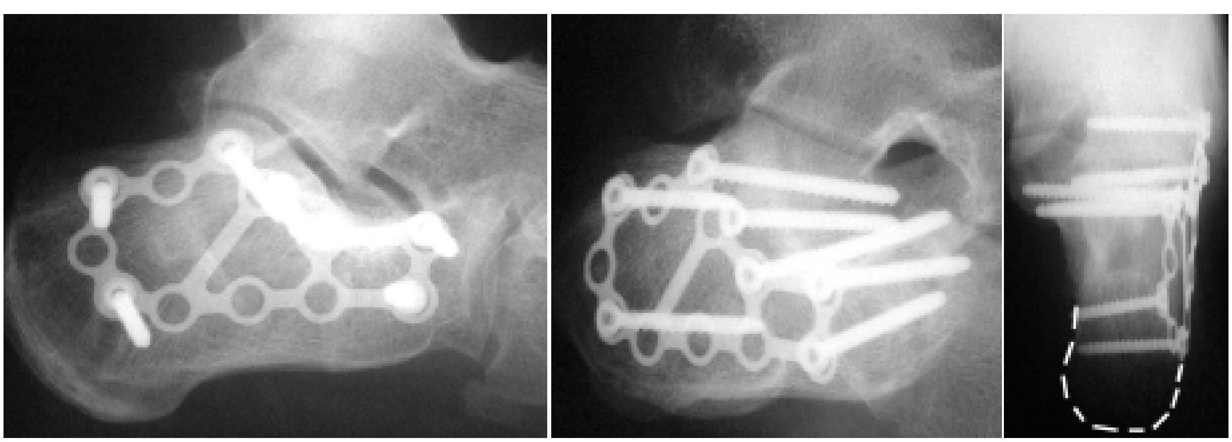

FIG. 10-D FIG. 10-E FIG. 10-F

Postoperative lateral, Brodén, and axial radiographs.

FIG. 10-G

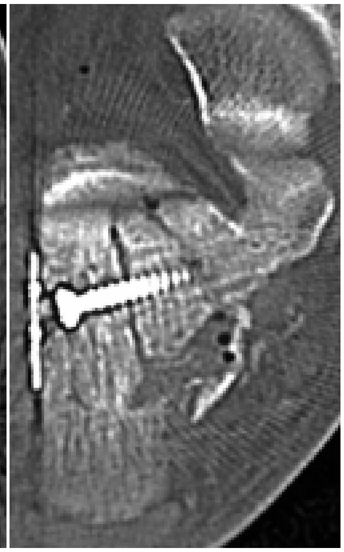

FIG. 10-H

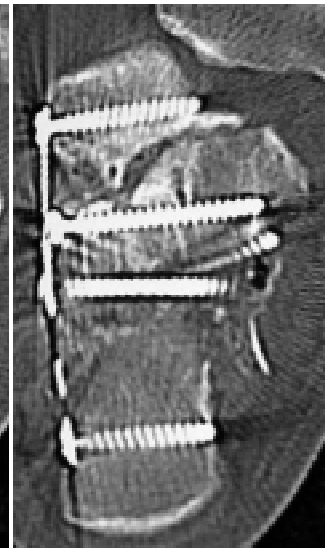

FIG. 10-I

Postoperative coronal, oblique, and transverse computed tomographic scans showing both the articular and the extra-articular reduction.

cation system of Essex-Lopresti[39] was employed. Sixty-one fractures (an average of three per year) were treated according to a protocol that required a small medial incision to reduce the posterior tuberosity to the sustentaculum with use of a threaded Steinmann pin. The superolateral fragment then was decompressed with use of manual compression. Fourteen fractures (23 percent) necessitated a second, lateral incision before the joint could be reduced. The average duration of follow-up was 4.4 years. The average score according to the American Orthopaedic Foot and Ankle Society[64] was 94.7 points, and the patients returned to work at an average of 4.9 months. The advantages of this approach included full weight-bearing while wearing a shoe by eight weeks and few wound complications. The principal disadvantage was that approximately one of every five fractures necessitated an additional, lateral incision. In addition, because computed tomographic scans were not used for evaluation of the severity of the fractures, these data cannot be used for purposes of comparison[20].

A lateral approach was used in the most recent operative series[8-10,16,36,37,41,59,68,71,83,84,105-107,127,134,136,137]. Reduction of the calcaneal body with reconstitution of the height, width, and length is consistently reproducible, irrespective of the amount of comminution. Reduction of the joint, when technically possible, is attainable with the lateral approach as well. In these series, a medial approach was only rarely needed[62].

Results with a Lateral Approach

Good results were reported in four separate large series of operatively treated displaced intra-articular

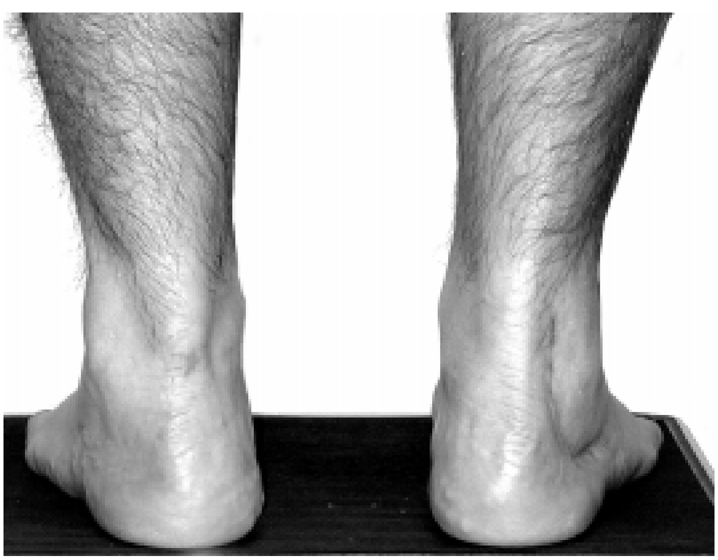

FIG. 10-J

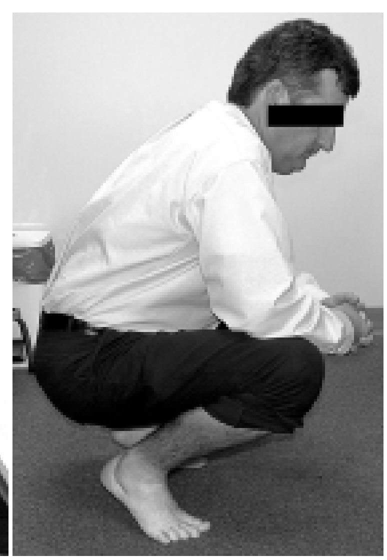

FIG. 10-K

Clinical photographs made one year postoperatively. The patient had resumed all activities, including tennis.

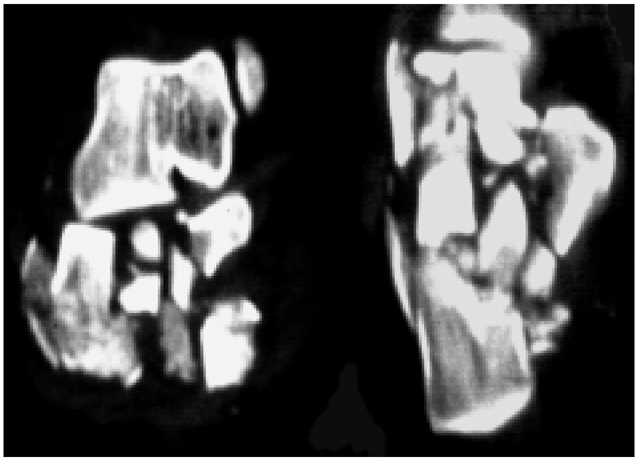

FIG. 11-A

Figs. 11-A, 11-B, and 11-C: A foot that had a Sanders type-IV comminuted calcaneal fracture that was treated with a primary arthrodesis. Fig. 11-A: Preoperative computed tomographic scans.

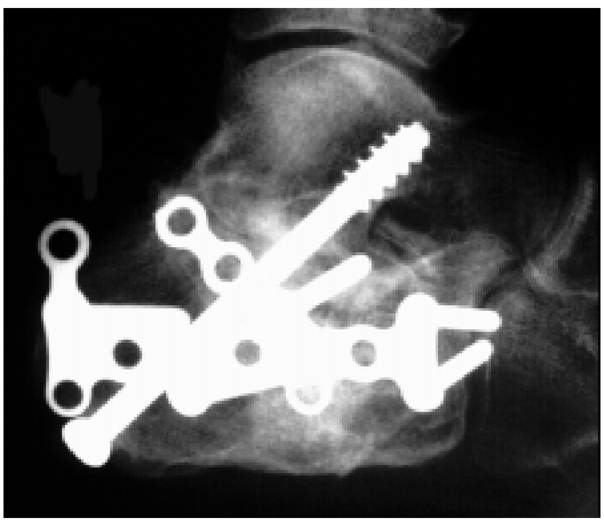

FIG. 11-B

Postoperative lateral radiograph.

calcaneal fractures. Bèzes et al. reported on 205 fractures[10]; Letournel, ninety-nine fractures[69]; Sanders et al., 120 fractures[106]; and Zwipp et al., 123 fractures[137]. All operations within each series were performed by the same surgeon with use of the same operative technique, and all fractures were classified with use of a consistent method. All of the fractures in the four series were treated with a similar operative approach. Because the methods of assessment varied, no real comparison among series can be made. However, these data clearly show that operative intervention can lead to an excellent functional outcome.

Sanders et al. classified 132 displaced intra-articular calcaneal fractures (types II, III, and IV) with their computed tomographic scanning-based system, and 120 were followed for an average of twenty-nine months[106]. All fractures were treated with a lateral approach, lag-screw fixation of the posterior facet, and fixation of the calcaneal body with an anterior cervical AO plate ("H-plate") without bone-grafting. Computed tomographic scans were made for all patients preoperatively, postoperatively, and at the one-year follow-up evaluation. Classification of the clinical outcome was based on the Maryland Foot Score[106], with feet that needed a subsequent subtalar arthrodesis because of posttraumatic arthritis considered as having had failure of treatment. The height, length, and width of the heel were 98, 100, and 110 percent of normal, regardless of the fracture type. Böhler's and Gissane's angles were reduced to within 5 degrees of normal in all but three feet. In sixty-eight (86 percent) of the seventy-nine feet that had a type-II fracture, the articular surface was anatomically reduced as verified on computed tomographic scanning. Ten of the articular reductions were nearly anatomical (within two to three millimeters), and one was approximate (within four to five millimeters). The clinical outcome for fifty-eight (73 percent) of the seventy-nine feet was good or excellent. Eight feet (10 percent) had a fair result, and thirteen were considered to have had failure of treatment; of these twenty-one feet, ten

FIG. 11-C

Postoperative axial radiograph.

needed a subtalar arthrodesis. In those cases, arthrograms, computed tomographic scans, and inspection of the joint at the time of the isolated subtalar arthrodesis verified an anatomically reduced articular surface with damaged cartilage.

Of the thirty feet that had a type-III fracture, eighteen (60 percent) had an anatomical reduction of the posterior facet, eight had a nearly anatomical reduction, and four had an approximate reduction. Clinically, there were twenty-one good-to-excellent results, three fair results, and six failures of treatment. Seven feet ultimately needed a subtalar arthrodesis, including four that had had an anatomical reduction.

Of the eleven feet that had a type-IV fracture, none had an anatomical reduction, three had a nearly anatomical reduction, two had an approximate reduction, and six had a complete failure (a greater than five-millimeter stepoff). Clinically, one result was good-to-excellent, two were fair, and eight were complete failures. The good-to-excellent result and the fair results were in patients who had a nearly anatomical reduction[106].

When the results were compared according to the year of the operation, an operator-dependent improvement in the outcome was noted[106]. Worse results occurred at the start of the series, while the number of good-to-excellent results improved in each successive year. When these data were further analyzed with respect to fracture type and year, it appeared that type-II fractures were easier to fix than were type-III fractures; however, the results of treatment of type-III fractures improved over time as well. In contrast, the results of operative treatment of type-IV fractures did not improve even after four years of experience[106].

Sanders et al. concluded that (1) an anatomical articular reduction is needed to obtain an excellent or good result, (2) an anatomical articular reduction cannot ensure a good-to-excellent result, probably because of injury to the cartilage at the time of impact, (3) a reproducible operative technique is surgeon-dependent and between thirty-five to fifty operations, or roughly two years of operative experience, are necessary before the results can become fairly predictable for type-II and III fractures, (4) type-IV fractures are so severe that a primary arthrodesis is indicated after reconstitution of the calcaneal shape, and (5) the results deteriorate over time as the number of articular fracture fragments increases[106].

The remainder of the more recently published reports consist of smaller series of operatively treated fractures[32,33,59,67,71,87,119,127,129]. The nine studies are divided with respect to whether the classification system of Crosby and Fitzgibbons[30] (four series) or that of Sanders et al.[105,106] (five series) was used. The Crosby and Fitzgibbons type-II classification can be further divided into types II and III according to the system of Sanders et al., making the latter classification more specific and allowing the two systems to be used interchangeably when generalized data from different studies are reviewed. Similarly, most authors used either the Maryland Foot Score[106] or the Creighton-Nebraska Assessment tool[30], which also facilitates comparisons between studies. As a result of the similarities between the studies of Crosby and Fitzgibbons[32], Sanders et al.[106], Song et al.[119], Thordarson and Krieger[127], Laughlin et al.[67], and Tornetta[129], certain general conclusions may be reached. These include: (1) correct operative intervention can achieve good outcomes and (2) classifications based on computed tomographic scanning appear to be prognostic. These findings are similar to those of Sanders et al., who found that the more comminuted the articular surface, the worse the prognosis[106].

Use of Bone Graft

Bone-grafting for the treatment of calcaneal fractures originally was described by Palmer, who was dissatisfied with the use of contemporary internal fixation techniques alone and employed bone graft to support the reduction of the articular surface[93]. Letournel suggested that bone graft was not needed because lag screws were able to stabilize the reduction of the articular surface[68,69]. Stephenson used no bone graft and reported only one late collapse[123-125], whereas Leung et al. used bone graft in all of their patients and thought that it was needed[70,71]. O'Farrell et al. did not use bone graft and noted no instance of collapse of the posterior facet[91]. Sanders et al. did not use bone-grafting in their series of 120 fractures, and no patient had a subsequent loss of articular reduction[106]. Consequently, I believe that there is little need for bone graft when internal fixation is employed.

Operative Compared with Nonoperative Treatment

Over the last decade, only a few studies comparing operative treatment with nonoperative treatment have been published[16,61,71,91,95,127]. Järvholm et al. compared the results for twenty patients who had been managed operatively over a twelve-year period with those for a historical control group that had been managed nonoperatively during the same period by other surgeons and found that the problems associated with internal fixation did not justify operative treatment[61]. However, few operative procedures were performed each year. In addition, the surgeons did not consistently use lag screws, and they never fixed the body of the calcaneus with a plate or staples. Fluoroscopy was not available, and the authors stated that they were never able to obtain a perfect reduction. That study[61] had many of the flaws seen in the literature on calcaneal fractures, which prevent the reader from reaching meaningful conclusions.

Buckley and Meek reported on thirty-four calcaneal fractures; seventeen were treated operatively, and seventeen were treated nonoperatively[16]. The patient groups were matched cohorts with respect to age, gender, type of work, and duration of follow-up. The best

FIG. 12

Photograph showing a foot that had apical wound necrosis with minor dehiscence after an extensile approach.

results were in patients who had a perfect anatomical reduction of the posterior facet. When such a reduction was not possible, there appeared to be no difference between the two types of treatment. However, classification based on computed tomographic scanning was not performed, so the fractures were not consistently classified. More importantly, the seventeen operations were performed by twelve different surgeons, all of whom used different techniques.

Three studies comparing operative with nonoperative treatment were published in 1993[71,91,95]. Parmar et al. compared the results of nonoperative treatment of thirty-one displaced fractures with those of operative treatment of twenty-five displaced fractures[95]. They used their own computed tomographic scanning classification, and they fixed the fractures with Kirschner wires through a Kocher approach. No attempt was made to reduce the fracture of the tuberosity, and the surgeons had difficulty evaluating the postoperative computed tomographic scans. Evaluation with use of their own scoring system revealed no real difference between the two groups. Poor operative fixation and a lack of postoperative assessment of the reduction with computed tomographic scans severely limited the usefulness of that study.

O'Farrell et al. managed twelve patients operatively and twelve nonoperatively[91]. Computed tomographic scanning was performed without classification of the fractures. A Kocher incision and lag-screw and plate fixation were used. Computed tomographic scanning

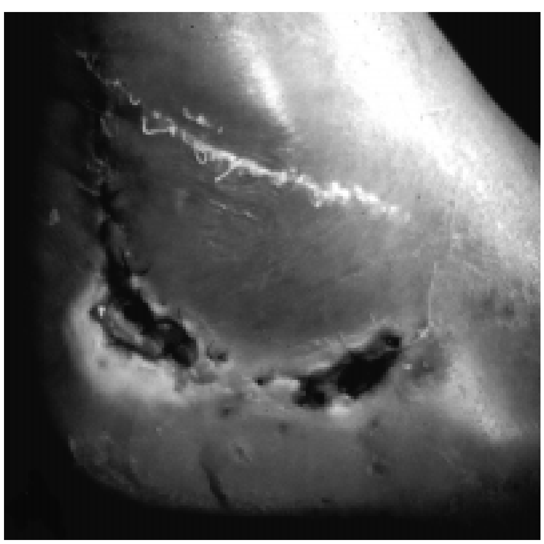

FIG. 13-A

FIG. 13-B

Fig. 13-A: Severe calcaneal osteomyelitis.
Fig. 13-B: The patient was managed with débridement, antibiotic-impregnated beads, and intravenous administration of antibiotics, followed by insertion of a free-tissue-transfer iliac-crest bone graft and a subtalar arthrodesis.

was not performed postoperatively. The outcome was judged on the basis of walking distance, subtalar motion, return to work, and shoe size. The authors concluded that the results of operative treatment were superior, but their patient population was too small for their findings to reach significance.

Leung et al., in a nonrandomized, retrospective study, compared the results for forty-four patients who had been managed operatively with those for nineteen who had been managed nonoperatively[71]. They used the computed tomographic scanning classification system of Crosby and Fitzgibbons[30] and a lateral extensile approach; the reduction was held with lag-screw and plate fixation. The duration of follow-up averaged three years. The results were better, with respect to pain, activity, range of motion, return to work, and swelling of the hindfoot, in the group that had been treated operatively.

Thordarson and Krieger performed a randomized, prospective trial comparing operative with nonoperative treatment[127]. They carefully classified the fractures with use of computed tomographic scans and included only Sanders type-II and III (displaced) fractures. Nonoperative treatment consisted of non-weight-bearing and early range of motion. Operative treatment was performed by a single surgeon and consisted of an extensile lateral approach with lag-screw and plate fixation. Follow-up assessment was consistent and, with use of the 100-point scoring system of the American Orthopaedic Foot and Ankle Society, it was possible at seventeen months for all fifteen feet that had been treated operatively and at fourteen months for eleven of fifteen that had been treated nonoperatively. The functional score averaged 86.7 percent for the group that had been treated operatively compared with 55.0 percent for the group that had been treated nonoperatively ($p < 0.0001$). In the group that had been treated operatively the clinical result was excellent for seven feet, good for five, fair for two, and poor for one, whereas in the group that had been treated nonoperatively it was excellent for one, good for three, fair for one, and poor for six ($p < 0.01$). Although this series was small and the follow-up period was short, it is the first randomized, prospective study, to my knowledge, in which many of the variables were held constant. On the basis of this small series, it appears that operative intervention may indeed offer superior results.

In a long-term study reported by Crosby and Fitzgibbons, all fractures originally were treated nonoperatively[32]. However, because of poor outcomes with displaced and comminuted fractures, those authors began to treat displaced (type-II) fractures operatively[30,32]. With use of the same assessment instrument, the results for the patients who had been managed operatively then were compared with those for the patients who had been managed nonoperatively. The outcomes were found to be significantly superior in the group that had been treated operatively ($p < 0.0001$). Crosby and Fitzgibbons recommended operative intervention for displaced fractures.

Operative and Nonoperative Complications

Neurological Complications

Cutaneous Nerve Injury

The most common neural problem associated with operative treatment is damage to a sensory cutaneous nerve. The sural nerve is most commonly injured because of the frequency of use of the lateral approach; however, nerve injury also may occur after a medial approach, with the calcaneal branch of the posterior tibial nerve most commonly affected[92]. A neuroma or complete loss of sensation in the affected region may develop. Nonoperative treatment is advised. When a

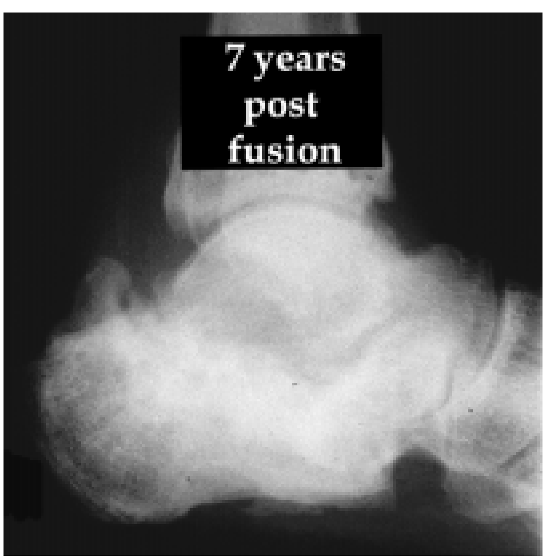

FIG. 13-C

FIG. 13-D

Radiograph and photograph, made seven years postoperatively. The patient was still infection-free and wore a modified shoe.

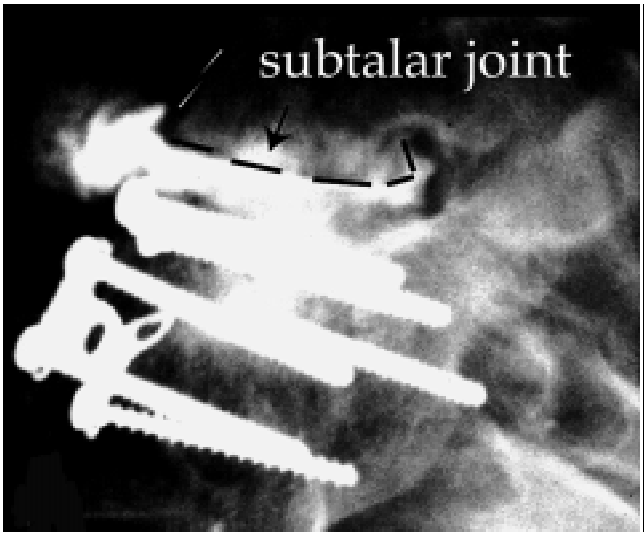

FIG. 14-A

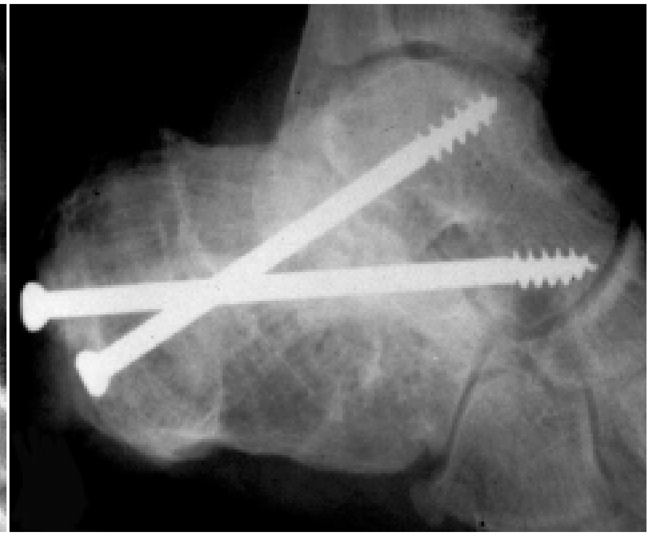

FIG. 14-B

Fig. 14-A: Intraoperative arthrogram showing anatomical alignment of the joint. Direct visualization revealed an absence of articular cartilage on the posterior facet.
Fig. 14-B: Lateral radiograph made after the subsequent *in situ* subtalar arthrodesis.

neuroma is painful, I recommend resection with burial of the stump into deep tissue.

Nerve Entrapment

Entrapment or compression of the posterior tibial nerve, more commonly seen after nonoperative treatment, can occur secondary to a malunited fracture[38,65,90]. Patients report pain in the medial aspect of the heel and paresthesias in the distribution of the posterior tibial nerve. The pain is frequently worse at night or with walking or standing. A trial injection of a local anesthetic into the tarsal tunnel can assist in making the diagnosis. If the diagnosis remains in doubt, electrodiagnostic studies are indicated. When clinical and diagnostic tests show nerve entrapment, operative decompression of the posterior tibial nerve and its branches may provide relief.

Reflex Sympathetic Dystrophy

Reflex sympathetic dystrophy may occur regardless of the method of treatment, and it may result in long-term and possibly permanent functional impairment. The clinical diagnosis is made when the patient has pain that is disproportionate to the extent of the injury; cold, clammy skin; purplish discoloration; an inability to tolerate anyone touching the foot; and difficulty wearing socks and shoes. Myerson and Quill confirmed the diagnosis when a tibial nerve block did not relieve the symptoms[90]. Alternatively, a lumbar sympathetic block, thermogram, or bone scan may be performed to obtain a diagnosis.

The symptoms of early reflex sympathetic dystrophy may be reversed with use of intensive therapy such as massage, motion and manipulation, or weight-bearing if the fracture has healed. More protracted cases necessitate multiple lumbar sympathetic nerve blocks and counseling. Unless a specific stimulus (for example, a prominent screw or a neuroma) is found to be causing the underlying pain, additional operative treatment should be avoided[90].

Wound Dehiscence and Calcaneal Osteomyelitis

The most common overall problem after operative treatment of a calcaneal fracture is wound dehiscence[8,72,105]. If the wound cannot be closed at the time of the operation, a delayed primary closure may be attempted several days later. More commonly, the incision closes fairly easily but then dehisces, as late as four weeks postoperatively and usually at the angle of the incision (Fig. 12). All motion should be stopped to prevent additional dehiscence. Daily whirlpools or wet-to-dry dressing changes should be coupled with oral administration of antibiotics. When the necrosis is partial-thickness in nature, this regimen is usually successful. If it is unsuccessful, a low-profile fasciocutaneous flap such as a lateral arm flap may be needed[72].

If purulence is encountered, repeat débridements must be performed. Most patients do not have diffuse osteomyelitis but rather have the superficial type, which is due to direct extension from an adjacent source[25]. If the infection is superficial, the plate and screws may be retained. After the wound bed is deemed clean, treatment should consist of a free tissue transfer and six weeks of intravenous administration of antibiotics. If there is diffuse osteomyelitis, the fixation must be removed together with all necrotic and infected bone (Figs. 13-A through 13-D). After repeat débridements and six weeks of administration of culture-specific antibiotics, a salvage procedure, an arthrodesis, or an amputation can be performed, depending on the amount of calcaneus remaining.

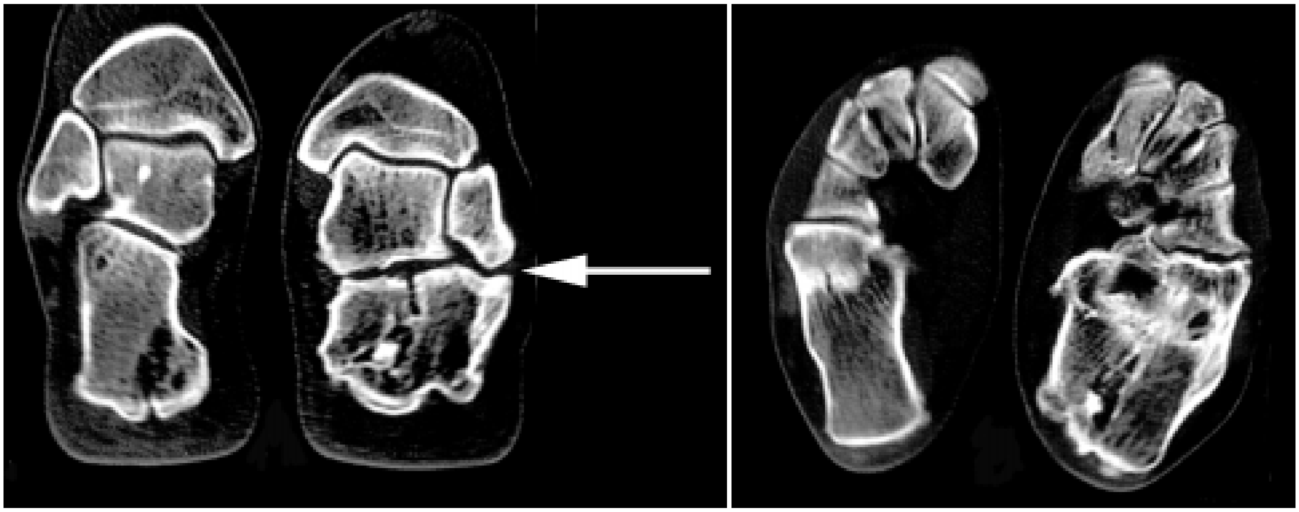

FIG. 15-A FIG. 15-B

Coronal (Fig. 15-A) and transverse (Fig. 15-B) computed tomographic scans showing a calcaneal malunion. Note the arthrosis of the subtalar joint; the dislocation of the peroneal tendons; the short, wide heel; and the fibular tip abutment (arrow).

Arthritis

Arthritis of the Subtalar Joint

One of the goals of internal fixation is an anatomical reconstruction of the joint surface of the posterior facet. The joint will deteriorate rapidly, and severe pain and disability will certainly result, if the reduction is inadequate, if screws protrude into the joint, or if the articular cartilage has been extensively damaged at the time of the injury[90,92,106] (Fig. 14-A). Even in patients who have a truly anatomical reduction, arthritis of the subtalar joint may develop as a result of damage to the cartilage at the time of the injury[105]. This was demonstrated in an experimental model by Borrelli et al., who found that profound and possibly irreversible damage to the articular cartilage occurred after a single high-energy-impact load[12].

If posttraumatic arthritis is present clinically and radiographically, it should be verified as the cause of the pain[92]. This can be accomplished by injecting a local anesthetic into the subtalar joint. If the pain is relieved, then nonoperative measures, such as modifications of shoewear, a University of California Berkeley Laboratory orthosis, walking aids, and nonsteroidal anti-inflammatory agents, can be tried before operative treatment is contemplated. If these measures fail, the hardware should be removed and an *in situ* subtalar arthrodesis with use of bone graft and large cannulated lag screws should be performed[104] (Fig. 14-B).

Arthritis of the Calcaneocuboid Joint

Arthritis of the calcaneocuboid joint is a sequela of operative intervention, most commonly if the anterolateral fragment is not perfectly repositioned, as well as of nonoperative treatment. If this joint appears to be painful, an injection of local anesthetic can be performed to differentiate the pain from peroneal pain. If the calcaneocuboid joint is identified as the site of the pain, nonoperative treatment should be offered, followed by an arthrodesis if all other methods fail[107].

Malposition

Malreduction of the Tuberosity

Malposition can occur after both operative and nonoperative treatment. The most common deformity is residual varus angulation of the hindfoot due to an incomplete reduction of the tuberosity[85,90,92]. Clinically, the lateral edge of the shoe is worn away and the lateral counter is deformed. The heel may show obvious varus malalignment from behind, with a fibular prominence, but it will become pronounced when the patient stands on the toes. If use of lateral shoe wedges is unsuccessful, a correctional osteotomy may be needed[78].

Malreduction of the Superolateral Fragment

Occasionally, there may be varus malalignment that is caused by overreduction of the superolateral fragment. If this occurs, the patient will be unable to evert the subtalar joint despite the fact that the body of the calcaneus is not in varus malalignment. The best treatment is prevention, and the utmost care must be taken intraoperatively to prevent this complication. I have found that nonoperative treatment is rarely successful and that, if it fails, the only remaining option is subtalar arthrodesis.

Problems Related to the Peroneal Tendons

Tendinitis

This problem is generally seen after nonoperative treatment and is due to lateral abutment — that is, it occurs when the lateral wall has subluxated the peroneal tendons against the distal tip of the fibula or has dislocated the tendons. Entrapment may also occur after operative treatment[120], but it is more common after a standard Kocher approach because the tendons are released from their sheath in order to allow access to the subtalar joint. The use of the extensile approach has largely circumvented these problems[52,137]. However, care must be taken, when the operation is performed near the fibula, to subluxate and not to dislocate the tendons.

Postoperatively, adhesions and scarring of the tendons may develop as a result of either the operative approach or prominent hardware. Differential injections of local anesthetic can document that the pain is peroneal in nature; however, Mizel et al. recently pointed out that this method may not be completely accurate[86]. They noted communication with the ankle and subtalar joints as well as failure of the contrast material to fill the distal part of the tendon in three of twenty patients. Those authors suggested that an injection of contrast material be performed simultaneously with injection of the anesthetic to alert the clinician to any lack of specificity of the anesthetic test. If the diagnosis is peroneal scarring or impingement, an operative release or removal of the hardware will be needed after nonoperative methods such as massage and stretching have failed.

Dislocation

Occasionally, surgeons make the diagnosis of dislocation of the peroneal tendons preoperatively, usually by palpation. Although the dislocation often is reducible after the lateral wall abutment has been removed, sometimes the tendons continue to dislocate as the surgeon manipulates the subtalar joint after completing the reduction and fixation of the calcaneus. In these instances, the surgeon should attempt to reconstruct the soft-tissue envelope to correct this problem[80,113,115,121].

Ankle Pain

When the subtalar joint becomes stiff, the patient loses the ability to evert and invert the joint properly. Because the ankle and subtalar joints are coupled, when the subtalar joint is locked the lateral motion is borne by the ankle[110]. However, the ankle joint is not designed to move in this manner and lateral ankle pain becomes noticeable to the patient, usually in the form of a chronic sprain. Nonoperative management is the rule, with nonsteroidal inflammatory agents, injections, application of a cast, and use of a brace all offered as palliation. Patients with recalcitrant pain may need a magnetic resonance imaging scan to rule out other abnormalities of the ankle.

Heel Exostoses

Painful osseous prominences may develop on the plantar surface of the heel after a calcaneal fracture. These exostoses can be readily removed operatively if nonoperative methods such as the use of heel pads are unsuccessful. The technique for operative removal originally was described in 1921 by Cotton, who specifically avoided a plantar incision as this was associated with painful scarring[29].

Heel-Pad Pain

Chronic pain in the heel pad may occur as a result of damage to the unique septated architecture of the heel pad. Sallick and Blum recommended sensory denervation for this problem, but their ability to distinguish various causes of pain was limited and they performed this procedure indiscriminately[102]. Barnard and Odegard[6] as well as Lance et al.[66] noted that plantar pain secondary to a damaged heel pad is not alleviated by operative treatment. At the present time, there is still no effective treatment for this problem.

Calcaneal Malunions

Many surgeons still treat calcaneal fractures nonoperatively, either because of a lack of familiarity with the operative techniques or because they fear the operative complications[73,96]. However, complications of nonoperative treatment may be equally troublesome. They include impingement, subluxation, or dislocation of the peroneal tendons, resulting in pain and instability; posttraumatic arthritis of the subtalar joint or the calcaneocuboid joint, or both; malalignment of the hindfoot, resulting in altered patterns of shoe-wear and gait; and posterior tibial or sural neuritis[13,21,28,29,42,63,77,85,90,98,106,120]. These problems all are due to the development of a calcaneal malunion, and they result in pain and functional disability in a surprisingly large number of patients (Figs. 15-A and 15-B). In order to improve the outcome in these patients, treatment must focus on correction of the specific anatomical problems that are encountered.

As early as 1921, Cotton addressed residual problems in the heel after fracture[29]. He noted a mass of bone on the lateral side of the heel that prevented the subtalar joint from moving and caused substantial fibular and peroneal impingement. Cotton recognized this abutment as a source of pain and suggested that resection would relieve the pain. He stated that, in many patients, “one must do far more than at first seems reasonable” and, in fact, “cut ruthlessly across the joint line often leaving what seems not half the joint.”[29] He also performed an extra-articular osteotomy to correct malposition of the heel, resection of symptomatic plantar heel spurs, and intensive manipulation of the subtalar joint[29,51]. Weight-bearing was begun at six weeks. The results were impressive, with eight of nine patients returning to work. Magnuson reported good results with use of this technique coupled with use of a large bone wrench to pry open the subtalar joint[77].

St C. Ibister advocated resection of the tip of the lateral malleolus; however, this technique never gained much favor[120]. Kalamchi and Evans[63] combined the technique of Conn[26] with the Gallie arthrodesis[42] and used the lateral exostosis as graft. They stated that the trapezoidal slot for the graft allowed for correction of

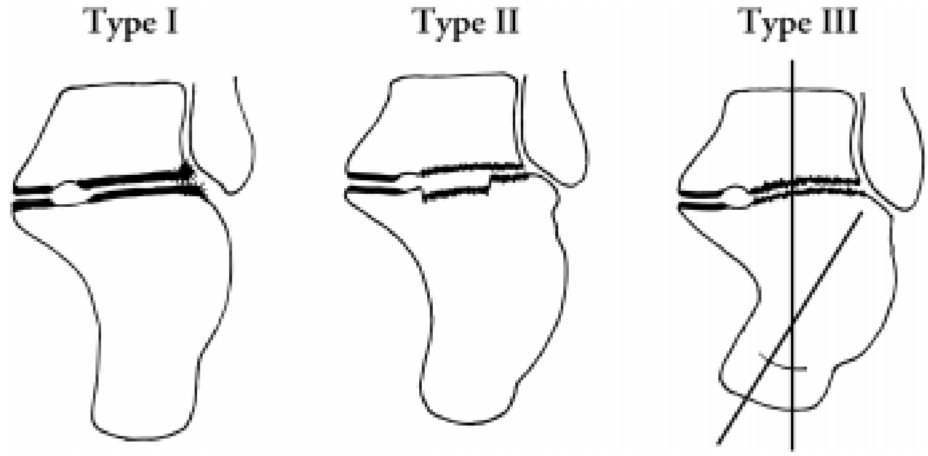

FIG. 16

Illustration of the computed tomographic scanning classification of calcaneal malunions described by Stephens and Sanders[122]. Type-I malunions are characterized by a large lateral exostosis, with or without extremely lateral arthrosis of the subtalar joint; type-II, by a lateral exostosis combined with major arthrosis across the width of the subtalar joint; and type-III, by a lateral exostosis, severe arthrosis of the subtalar joint, and a malunion of the calcaneal body with the hindfoot in varus (as shown) or valgus angulation.

valgus of the heel, thereby fusing the heel in a neutral position. Those authors reported a good result in six patients[63]. Braly et al. performed a lateral decompression coupled with a peroneal tenolysis for patients who had an old calcaneal fracture with lateral pain[13]. Nine of eleven patients who were managed with this technique instead of an arthrodesis had a good result compared with six of eight who had the procedure after a failed subtalar arthrodesis.

Carr et al. reported preliminary results with use of a modified version of the Gallie arthrodesis[42] known as the subtalar distraction bone block arthrodesis[21]. The modification included the use of a medial femoral distractor and a differentially wedged tricortical iliac-crest bone graft to distract the collapsed calcaneus and restore the talocalcaneal angle, thereby correcting the horizontal talus as well as the subluxation of the talonavicular joint. The graft was held with fully threaded 6.5-millimeter cancellous-bone screws that were not placed in lag mode to prevent compression. The talocalcaneal angle was corrected, and the result was good in six of the eight patients; however, complications included two broken screws, one nonunion, and three prominent screw heads that produced pain. In addition, there were five superficial wound sloughs. Other authors who have used this technique have reported varus malunion in a number of patients[15,104]. Buch et al. reported a good result in only seven of fourteen patients who had been managed with this technique; two patients had a varus malunion necessitating reoperation[15]. Sanders et al. reported on seventeen patients who were managed with this technique; four had a varus malunion, and two needed a reoperation[104].

Bednarz et al. recently reported on twenty-nine feet that had been followed for an average of thirty-three months after a subtalar distraction bone block arthrodesis[7]. All patients were managed by a single surgeon at one institution, and the outcomes were evaluated with use of the American Orthopaedic Foot and Ankle Society scoring system. Although all but one patient was satisfied with the outcome, four had a painful nonunion and two of the four subsequently had a varus malunion. Those authors noted a relationship between smoking and nonunion: all four nonunions were in smokers. They concluded that a satisfactory result could be achieved if complications were avoided.

An osteotomy for the treatment of calcaneal malunions was described by Romash[97]. The osteotomy recreated the primary fracture line, and, with use of an external frame, the anatomy was restored. The tuberosity fragment was translated beneath the sustentacular fragment medially, and residual varus angulation was corrected. His clinical series comprised ten feet that were followed for an average of fourteen months. Two procedures were revisions of previous triple arthrodeses. Nine feet had a satisfactory result.

Stephens and Sanders recently developed a prognostic and reproducible treatment algorithm, based on a computed tomographic scanning classification of calcaneal malunions, to plan operative intervention[122] (Fig. 16). According to the algorithm, type-I malunions included a large lateral exostosis, with or without extremely lateral arthrosis of the subtalar joint; type-II, a lateral exostosis combined with arthrosis across the width of the subtalar joint; and type-III, a lateral exostosis, severe arthrosis of the subtalar joint, and a malunion of the calcaneal body with the hindfoot in varus or valgus angulation. In addition to these computed tomographic findings, the calcaneocuboid and ankle joints as well as any abnormalities of the peroneal tendons or other bones were clearly seen. Treatment was based on the type of malunion. Type-I malunions were treated with a peroneal tenolysis and lateral exostectomy coupled with a very lateral joint resection and early motion as described by Cotton[29] and by Magnuson[77]. For type-II malunions without substantial loss of heel height, a peroneal tenolysis, a lateral wall exostectomy, and an *in situ* subtalar arthrodesis were performed with use of the local bone as graft as described by Kalamchi and Evans[63]. Type-III malunions were treated with a peroneal tenolysis, a lateral calcaneal exostectomy, a subtalar arthrodesis, and a calcaneal osteotomy to correct malalignment or shortening of the hindfoot. Although the osteotomy could be performed through the original fracture line as described by Romash[97], the one-stage lengthening did not always allow for closure of the wound. As a result, if complete restoration of length was needed, an osteotomy through the fracture line was performed followed by the application of an Ilizarov frame. In all other instances, the principal problem was varus or valgus of the heel, and a calcaneal osteotomy was performed[81].

Twenty-six patients (twenty-six malunions) were evaluated at an average of thirty-two months (range, twelve to fifty-seven months) after treatment with use of the protocol just described[122]. There were seven type-I, fifteen type-II, and four type-III malunions. Of the seven patients who had a type-I malunion, six had an excellent result and one had a good result, with restoration of approximately 50 percent of subtalar motion. Pain due to lateral impingement was eliminated in all but one patient, who continued to have persistent pain in the sinus tarsi. Of the fifteen patients who had a type-II malunion, eleven had an excellent result, three had a good result, and one had a fair result. All fifteen patients were limited in their ability to walk on uneven surfaces secondary to the subtalar arthrodesis, but none needed assistive devices. Three of the fifteen patients had mild pain, which limited certain activities of daily living. Women's shoewear was limited to less than a one-inch (2.54-centimeter) heel. Most patients preferred a lace-up walking shoe, and one needed orthotic devices. There were no problems with the heel-counter impinging on the malleoli or with symptomatic limitation of dorsiflexion of the ankle in these fifteen patients. Of the four patients who had a type-III malunion, two had an excellent result, one had a good result, and one had a poor result. These patients had shoewear requirements similar to those of the patients who had a type-II malunion. All four patients who had a type-III malunion had pain that limited certain activities of daily living. One patient walked with a moderate limp and needed an orthosis.

There were no wound complications or infections in this series, and all arthrodesis sites eventually united[122]. No patient who had a type-II malunion had a varus malunion necessitating revision. One patient had a superficial wound infection, which resolved after a course of oral administration of antibiotics, and one had peroneal instability, which was corrected at the time of the operation. Although there was calcaneocuboid involvement in association with a number of the original fractures, only one patient was symptomatic enough to warrant arthrodesis of this joint. No patient needed a triple arthrodesis.

Conclusions

Distinct advances have been made in the understanding and treatment of displaced intra-articular calcaneal fractures. Computed tomographic scanning has allowed an understanding of the pathological anatomy of these fractures, and two-dimensional computed tomographic scans in both the coronal and the transverse plane are recommended. Classifications based on computed tomographic scanning are prognostic with respect to outcome, and the classification system of Sanders[103] or of Crosby and Fitzgibbons[30] can be applied.

The focus of current treatment is on operative methods, with the goal of restoring not only articular congruency but also the shape and alignment of the calcaneus. Operative treatment should be delayed until swelling has subsided. A lateral approach with use of an extensile incision appears to be associated with the fewest soft-tissue complications. The operative treatment of choice consists of lag-screw fixation of the joint and plate fixation of the calcaneal body, without the use of bone graft. Intraoperative fluoroscopy to obtain Brodén's[14], lateral, and axial radiographs is strongly recommended to ensure an anatomical reduction. Patients who have a highly comminuted Sanders type-IV fracture should be managed with an anatomical reconstruction of the calcaneus coupled with a primary subtalar arthrodesis. Patients who have had failure of operative treatment of a calcaneal fracture secondary to subtalar arthrosis will benefit from a simple subtalar arthrodesis, as the shape and alignment already have been restored. Finally, patients who have had nonoperative treatment and have a symptomatic calcaneal malunion and subtalar arthrosis will benefit from restoration of shape, a subtalar arthrodesis, and a lateral decompression of the fibular and peroneal tendons.

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