The calcaneus is the most common tarsal bone fractured. Calcaneal fractures can be subdivided into intra-articular and extra-articular fractures of the subtalar joints. Intra-articular fractures make up 70 to 75 percent of all calcaneal fractures, whereas extra-articular fractures make up 25 to 30 percent.\textsuperscript{12, 22} Intra-articular fractures are the fractures that usually come to mind when calcaneal fractures are being discussed, and they are the most controversial fractures to treat.\textsuperscript{15} These fractures are known for their significant socioeconomic impact on a patient’s ability to work and for their effect on long-term disability. On the other hand, extra-articular fractures are usually much more benign and treatable and lead to far less disability.

**EXTRA-ARTICULAR FRACTURES**

Extra-articular fractures (Fig. 29-1) have been grouped into five different types: (1) anterior process, (2) tuberosity, (3) medial process, (4) sustentaculum, and (5) body. The sustentacular and body fractures are probably not truly separate entities and have the same mechanism of injury as intra-articular fractures.

**Anterior Process Fractures**

Anterior process fractures have been reported to make up 15 percent of fractures in a large series of calcaneal fractures.\textsuperscript{3} The two reported types of anterior process fractures are (1) avulsion and (2) compression. The avulsion type is the most common. This fracture is usually small and extra-articular. The mechanism of injury is thought to be an avulsion by either the bifurcate ligament or the extensor digitorum brevis following an inversion stress to an adducted planatarflexed foot.\textsuperscript{42} This injury is most common in women wearing high heels. The compression fracture was reported by Hunt to be a larger fragment that is usually displaced superiorly and posteriorly, with significant calcaneocuboid joint involvement and incongruity.\textsuperscript{25} It is thought to result from a forced abduction injury, which causes an impact of the calcaneocuboid joint and thus a compression fracture of the anterior process.

Treatment for the avulsion type is usually a cast for immobilization if no displacement is present and the fragment is small. When the fragment is larger and there is displacement, open reduction and internal fixation should be considered to reduce the calcaneocuboid joint incongruity. Degan and colleagues reported on seven patients who required late excision.\textsuperscript{9} Six of them had an ununited fragment and secondary pain. The investigators reported that although not all of these fractures healed, not all nonunions are painful. Late excision relieved symptoms in five of the seven patients.

**Tuberosity Fractures**

Tuberosity fractures were previously subdivided into beak or avulsion fractures.\textsuperscript{34, 53} These two types are now considered to be the same entity. Tuberosity fractures result from avulsion of the superior tuberosity of the calcaneus by the tendo Achillis. They are most common in osteoporotic older women.
If the fracture is minimally displaced or undisplaced, it can be treated by a cast in equinus. On the other hand, if it is displaced, an attempted closed reduction can be tried but is usually unsuccessful. Open reduction with fixation using a tension band technique over Kirschner wires (K-wires) is the preferred method of treatment.

**Medial Calcaneal Process Fractures**

Fractures of the medial calcaneal process are rare. Watson-Jones attributed these to shear injuries from a direct blow. Bohler believed that they were avulsion injuries of the plantar fascia. The medial calcaneal process is also the site of origin of the abductor hallucis longus and part of the flexor digitorum longus.

Treatment is not required if the fracture is minimally displaced or undisplaced. In significantly displaced fractures, closed reduction may be attempted. Open treatment should be considered only if the fracture cannot be reduced manually and threatens to create a bothersome exostosis.

**INTRA-ARTICULAR FRACTURES**

Intra-articular fractures make up the majority of calcaneal fractures, as noted earlier. Eighty to 90 percent of these fractures are secondary to a fall, and an increasing number seem to be due to high-energy motor vehicle accidents. Five to 9 percent are bilateral. Ten percent have associated compression fractures in the lumbar spine. Other associated injuries are reported in 60 percent of cases by Lance and colleagues and in 70 percent of cases by Slatis and colleagues. Although some controversy exists about modalities of treatment, there is generalized agreement on the pathoanatomy and pathomechanics of injury. Knowledge of both is essential to understanding the pathology of this fracture and options for treatment.

**Pathoanatomy and Pathomechanics**

Intra-articular calcaneal fractures occur following eccentric axial loading of the talus on the calcaneus (Fig. 29–2). This produces a primary shear fracture line that is parallel to the posterolateral edge of the talus and passes through the posterior calcaneal facet. The primary fracture line separates the calcaneus into two parts: (1) body (posterolateral) and (2) sustentaculum (anteromedial) (see Fig. 29–2). Each part contains a portion of the posterior facet. The amount of posterior facet belonging to each fragment depends on how medial or lateral the split occurs. This, in turn, is related to the position of the foot at the time of impact (inversion or eversion position). The more medial the split, the larger the articular component on the body fragment, and vice versa. The body fragment displaces laterally and proximally toward the fibula while the sustentacular fragment stays home, anatomically fixed to the undersurface of the talus by the capsule and ligaments of the middle facet (Fig. 29–3).

If the injurious force continues to be applied, secondary fracture lines develop off the primary shear line. The posterior secondary fracture line creates the "thalamic fragment" (also known as semilunar, comet, or suprolateral fragment), which is the depressed portion of the posterior subtalar facet (see Fig. 29–3). The size of the thalamic fragment depends on the posterior exit point of the secondary fracture line. When the line exits superiorly, this fracture is called a central depression type, and when the line exits posteriorly, the fracture is called a tongue type. As the body of the talus drives the thalamic fragment into the spongy, cancellous bone of the calcaneal body fragment, it usually shears the attachment of the thalamic fragment from the lateral wall and causes a blow-out fracture, leading to the well-recognized lateral bulge. Together with the lateral displacement of the body fragment, the lateral bulge impinges on the fibulocalcaneal space, predisposing the patient to fibulocalcaneal impingement and peroneal tendon entrapment. The eccentric loading causes the thalamic fragment's articular facet to rotate medially as it is impacted into the calcaneal body fragment.

The fracture lines on the medial side are therefore sharp, well defined, and relatively uncomminuted because they were produced by a shearing force. In contrast, the fracture lines on the lateral side are comminuted and poorly defined because they were produced secondary to the axial impaction and lateral expansion (see Fig. 29–2). The body fragment, having been released from its attachment anteriorly,
FIGURE 29–2. (A), The midaxial lines of the tibia and calcaneus are shown to be parallel but laterally displaced with respect to each other.

(B), As the primary fracture line develops, the body of the calcaneus displaces laterally and proximally. This impacts the lateral portion of the posterior facet against the posterior lateral edge of the talus, leading to the shearing off of the lateral wall and the development of the posterior secondary fracture line.

(C), As the body of the calcaneus progresses proximally and laterally, it causes the thalamic fragment to rotate medially and to impact into its cancellous bone. This explodes out the sheared-off lateral wall fragment and results in several comminuted fragments impinging into the peroneal tendon space against the fibula. A bone defect is left above the thalamic fragment and adjacent to the lateral wall fragment from the depression.

FIGURE 29–3. Multiple views of the calcaneus demonstrating the primary and secondary fracture lines.

(A), Superior view of the calcaneus demonstrating the primary fracture line dividing the calcaneus into anteromedial and posterolateral segments, also known as the sustentacular and body fragments, respectively. The posterior secondary fracture line parallels the posterolateral rim of the subtalar joint. The anterior secondary fracture line extends into the calcaneocuboid joint.

(B), A view of the calcaneus from its plantar (inferior) aspect demonstrates the primary fracture line across the waist of the calcaneus and the anterior secondary fracture line, which splits the calcaneus in a transverse plane and may enter the calcaneocuboid joint. The posterior secondary fracture line cannot be seen from this view.

(C), From the lateral view, the secondary fracture lines are clearly seen to emanate off the primary fracture line. The posterior secondary fracture line can extend even more posteriorly, becoming a tongue-type fracture instead of the central depression-type fracture illustrated. The anterior secondary fracture line may extend into the plantar aspect of the calcaneus or may enter into the calcaneocuboid joint, as illustrated.

(D), Medial view of the calcaneus demonstrates the medial extension of the posterior secondary fracture line along the posterior rim of the posterior facet. The anterior secondary fracture line goes under the sustentaculum.

(E), An axial view of the calcaneus shows how the primary fracture line splits the medial wall. The level of this split is important in deciding on the operative approach. The posterior secondary fracture line can be seen to shear away the lateral wall of the calcaneus and to have a compression front to it on its inferior aspect. An anterior secondary fracture line is not appreciated from this view.
FIGURE 29–4. Classification of intra-articular fractures of the calcaneus. (A), Shear. (B), Tongue type. (C), Central depression type. (D), B or C with comminution. (E), Comminuted. (From Paley D, Hall H: Calcaneal fracture controversies: Can we put Humpty Dumpty together again? Orthop Clin North Am 20:667, 1989.)

loses its alignment and pitch as it tilts into varus and is plantarflexed proximally by the tendo Achillis. As the calcaneal pitch collapses, the calcaneal length and tendo Achillis fulcrum shorten. At the same time, secondary fracture lines extend anteriorly, entering into the plantar aspect of the calcaneus anteriorly or penetrating into the calcaneocuboid joint. This fracture line extension allows the arch to further collapse.

The shearing compression and angular forces take their toll on the surrounding soft tissues, leading to a stretch, shearing injury on the medial side and a compression injury on the plantar aspect. The lateral soft tissues suffer impingement from the expanding lateral wall and translation of the calcaneal body, but they are relatively spared compared with the plantar and medial sides. For this reason, fracture blisters are more commonly seen on the medial side, and hemorrhage is more commonly seen on the plantar aspect, indicating the maximal areas of tissue disruption.

The pathoanatomy of the calcaneus and foot

FIGURE 29–5. These undisplaced intra-articular calcaneal fractures demonstrate the primary and secondary fracture lines. The primary line (left) is a shear line extending from the lateral process of the talus plantarward. The secondary lines develop off this primary line anteriorly and posteriorly. The extension is either tongue type (left) or central depression type (right). The anterior extension is either "calcaneocuboid" or "plantar." (From Paley D, Hall H: Calcaneal fracture controversies: Can we put Humpty Dumpty together again? Orthop Clin North Am 20:667, 1989.)
has measurable and predictable changes. Böhler's angle becomes flattened. The talocalcaneal angle, which indicates varus or valgus malalignment of the heel, decreases in magnitude, indicating varus malalignment. The bony longitudinal arch formed by the base of the calcaneus and the first metatarsal is decreased. The length of the calcaneus shortens posterior to the lateral talar process. This portion of the calcaneal length is called the tendo Achilles fulcrum. The heel height decreases, and the fat pad height slightly increases. The width of the calcaneus increases at the level of the blow-out, encroaching into the fibulocalcaneal space. The subtalar joint becomes incongruous, and extension into the calcaneocuboid joint may also lead to incongruity of the calcaneocuboid joint. This constellation of displacement is fairly constant, and the variability seen between fractures is related more to degree than to variations in pathoanatomy.

**Classification (Figs. 29-4 to 29-6)**

The classic categorization of intra-articular calcaneal fractures was described by Essex-Lopresti in 1952. He divided intra-articular fractures into two main groups: tongue and central depression types. Stephenson incorporated the Essex-Lopresti classification with a consideration for the number of fracture parts, subdividing fractures into two- and three-part types. Soeur and Remy included a comminuted group in their classification. Rowe and colleagues categorized tongue-type and central depression–type fractures into those with and those without comminution.

Based on the examination of more than 100 calcaneal radiographs, I have noted that just as consistently as a posterior secondary fracture line occurs, there is also an anterior secondary fracture line, which extends forward off the primary shear line. As noted in the
description of the pathomechanics, the anterior secondary fracture line may extend into the plantar aspect of the calcaneus, just posterior to the calcaneocuboid joint, or into the calcaneocuboid joint itself. I have called these lines plantar and calcaneocuboid types. In order to grade the degree of comminution of calcaneal fractures from plain radiographs, these anterior secondary fracture lines are useful. Comminution can be defined as the presence of more than one posterior and one anterior secondary fracture line. Therefore, central depression and tongue-type fractures can be subdivided into those with and those without comminution.

When comminution and displacement are so significant that the fracture pattern cannot be readily classified into a central depression or tongue type, the fracture is subclassified as comminuted. Displaced intra-articular calcaneal fractures can therefore be subclassified into the following four groups: (1) shear fracture (two-part fracture); (2) tongue-type fracture (A, no comminution; B, with comminution); (3) central depression fracture (A, no comminution; B, with comminution); and (4) comminuted fracture.

Certainly, comminution is best defined using computed tomography (CT). Unfortunately, CT is not always readily available, especially at night. Therefore, a classification based on plain radiographs remains useful.

Recently, CT classifications have been reported. These provide more objective criteria on which to define comminution and the size of the joint fragments. Crosby and Fitzgibbons divided fractures by displacement and comminution: type I, undisplaced; type II, displaced; type III, displaced and comminuted. Although this is a simple system to follow, there is no definition of location or amount of comminution. Eastwood and colleagues divided fractures according to the lateral wall of the calcaneus because this is the first part seen on lateral exposure and thereby affects treatment. In type I, the lateral wall is formed by the lateral joint fragment; in type II, the lateral wall is formed by both the lateral joint proximally and the lateral wall distally. In type III, the body fragment makes up the entire lateral wall.

**TABLE 29-1. LONG-TERM RESULTS OF TREATMENT OF CALCANEAL FRACTURES**

<table>
<thead>
<tr>
<th>TREATMENT</th>
<th>SATISFACTORY RESULTS (%)</th>
<th>UNSATISFACTORY RESULTS (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Reduction</td>
<td>67</td>
<td>33</td>
</tr>
<tr>
<td>Pozo et al16</td>
<td>58</td>
<td>42</td>
</tr>
<tr>
<td>Rowe et al16</td>
<td>50</td>
<td>30</td>
</tr>
<tr>
<td>Lance et al20</td>
<td>63</td>
<td>37</td>
</tr>
<tr>
<td>Essex-Lopresti12</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Closed Reduction</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>Coton et al17</td>
<td>73</td>
<td>27</td>
</tr>
<tr>
<td>Hermann12</td>
<td>47</td>
<td>53</td>
</tr>
<tr>
<td>Rowe et al16</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Primary Arthrodesis</td>
<td>60</td>
<td>40</td>
</tr>
<tr>
<td>Lindsay et al21</td>
<td>75</td>
<td>25</td>
</tr>
<tr>
<td>Hall et al18</td>
<td>46</td>
<td>54</td>
</tr>
<tr>
<td>Zayer46</td>
<td>84</td>
<td>16</td>
</tr>
<tr>
<td>Thompson et al44</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Percutaneous Reduction</td>
<td>60</td>
<td>40</td>
</tr>
<tr>
<td>Essex-Lopresti12</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Open Reduction</td>
<td>59</td>
<td>41</td>
</tr>
<tr>
<td>Essex-Lopresti12</td>
<td>56</td>
<td>44</td>
</tr>
<tr>
<td>Rowe et al16</td>
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<td>Maxfield et al15</td>
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<td>14</td>
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<td>Hazlett22</td>
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<td>McReynolds46</td>
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<td>Letournel31</td>
<td>77</td>
<td>23</td>
</tr>
<tr>
<td>Stephenson43</td>
<td>75</td>
<td>25</td>
</tr>
<tr>
<td>Harding et al20</td>
<td></td>
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</tr>
</tbody>
</table>
Sanders proposed what appears to be the most useful classification using CT criteria (Fig. 29–7). Based on the coronal cuts, fractures are classified by the number and location of intra-articular fracture lines. The posterior subtalar joint facet is divided into three columns: lateral, central, and medial. The sustentaculum is a separate entity. This classification correlated with the results after operative treatment.

Natural History of Operative and Nonoperative Treatment of Calcaneal Fractures

The results of nonoperative and operative treatment of intra-articular calcaneal fractures are listed in Table 29–1. In general, nonoperative treatment results reported in the literature were unsatisfactory in 30 to 50 percent of cases. In comparison, operative treatment results were reportedly unsatisfactory in 25 to 40 percent of cases.

Following calcaneal fracture, usually a gradual improvement in painful symptomatology occurs over a 2- to 6-year period (Table 29–2). More than half of patients reach a plateau in their symptomatology within the first 2 years, with more than 75 percent having a plateau within 4 years. Only a very small percentage (usually between 5 and 10 percent) actually show worsening symptoms. Therefore, recorded results in the literature with only short-term follow-up of 2 to 4 years actually underestimate rather than overestimate successful results. This is fortunate because few long-term studies of calcaneal fractures are available.

The major shortcoming of all of the studies noted in Tables 29–1 and 29–2 is that the clinical evaluation of results was based on completely different criteria and evaluation protocols from author to author. This lack of standardization makes it difficult to compare results. In addition, the fracture classification used varied from author to author.

| TABLE 29–2. SYMPTOM STABILIZATION AFTER FRACTURE |
|-----------------------------------|---------|-----------|
| STUDY        | CHANGE IN SYMPTOMS | PATIENTS (%) | PERIOD |
| Essex-Lopresti | Plateau  | 88        | 18 mo   |
|              | Worst     | 0         | 6 mo–7 yr|
| Lindsay et al  | Plateau  | 57        | 1 yr    |
|              | Improving | 15        | 3–8 yr  |
|              | Worse     | 7         | 10 yr   |
|              | Temporarily worse | 6 | 8.8 yr |
| Pozo et al    | Plateau  | 66        | 2–3 yr  |
|              | Worst     | 24        | 3–6 yr  |
|              |           | 0         | >6 yr   |
| Paley et al   | Plateau  | 60        | 2 yr    |
|              | Worst     | 20        | 2–4 yr  |
|              |           | 10        | 4–5 yr  |
|              |           | 10        | >6 yr   |
factors that were significantly related to patient outcome. Similar to a previously published ankle fracture score, we developed a calcaneal fracture score. A result was determined for each patient and for each heel using this score. In the 44 patients with unilateral fractures, the opposite, uninjured foot was radiographed, and 11 measurable parameters of calcaneal anatomy or pathoanatomy were determined, and compared between sides. Not only was the absolute value of each measured parameter compared, but the ratio and the difference between sides were statistically analyzed.

According to this critical study, the factors found to be significantly associated with an unsatisfactory result were (1) increased patient weight; (2) decreased patient height; (3) increased time off work; (4) heavy labor occupation; (5) increased heel width; (6) decreased fibulocalcaneal space; (7) subtalar and calcaneocuboid joint incongruity; (8) subtalar and calcaneocuboid joint arthrosis; (9) ankle arthrosis; (10) fracture type (comminuted was worst, central depression was second worst, and tongue type was best); (11) fracture comminution; and (12) decreased Böhler's angle ratio of the injured to the normal side. The factors that were not associated with an unsatisfactory result included (1) height of the fall, (2) workmen's compensation status, (3) heel height, (4) heel alignment, (5) arch angle, (6) tendo Achilles fulcrum length, and (7) calcaneal length.

No significant age difference was found between result groups. However, patients older than 50 years of age did have a more unsatisfactory outcome. Similarly, there was no difference in the proportion of female patients in each result group, but four of six female patients sustained a satisfactory result. Thus, age and sex are probably related to prognosis. The
TABLE 29-3. FACTORS ASSOCIATED WITH POORER OUTCOME

<table>
<thead>
<tr>
<th>FACTOR</th>
<th>STUDY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age &gt;50</td>
<td>Lindsay et al^12^</td>
</tr>
<tr>
<td>Lateral impingement</td>
<td>Slatis et al^10^</td>
</tr>
<tr>
<td>Peroneal entrapment</td>
<td>Pozo et al^13^</td>
</tr>
<tr>
<td>Heel pad pathology</td>
<td>Lindsay et al^12^</td>
</tr>
<tr>
<td>Subtalar arthritis</td>
<td>Pridie^12^</td>
</tr>
<tr>
<td>Subtalar incongruity</td>
<td>Essex-Lopresti^12^</td>
</tr>
<tr>
<td>Subtalar stiffness</td>
<td>Lance et al^10^</td>
</tr>
<tr>
<td>Decreased Böhler’s angle</td>
<td>Slatis^10^</td>
</tr>
</tbody>
</table>

anatomic factors in this analysis that proved most significant were increase in calcaneal width, decrease in fibulocalcaneal space, subtalar incongruity, and subtalar arthrosis. The first two factors are measurable manifestations of clinical problems frequently seen following malunion of calcaneal fractures. Increase in calcaneal width and decrease in fibulocalcaneal distance lead to fibulocalcaneal impingement and peroneal tendon space encroachment. These are some of the more common sources of pain following calcaneal fracture. Subtalar joint incongruity leads to subtalar arthrosis, another important cause of pain and of an unsatisfactory outcome.

The most common primary clinical problems were heel pad pain and fibulocalcaneal impingement pain, which were equally frequent. The difference between the patients who suffered from fibulocalcaneal pain and those who suffered from heel pad pain was that the majority of heels with the fibulocalcaneal area as the primary painful area had a satisfactory outcome, whereas the majority of heels with the heel pad as the primary painful area had an unsatisfactory outcome. The most common secondary painful area was the subtalar joint; for patients with pain at this site, results were equally divided between satisfactory and unsatisfactory outcomes. All patients who had no painful area had a satisfactory result. Similarly, the majority of patients who had no secondary painful area also had a satisfactory result. Thus, pain seems to be the primary determin-
patient in the nonoperatively treated group (two versus seven).\textsuperscript{45}

**Radiographic Assessment**

Radiographic evaluation of the fractured os calcis should include plain radiography and, whenever possible, CT. Plain radiography should include four standard views of the fractured side and the same views of the uninjured side.

The lateral view of the foot allows evaluation of Böhler's angle and is useful in classifying the type of fracture (joint depression versus tongue). It also shows anterior fracture lines extending into the calcaneocuboid or plantar aspect of the foot. The lateral radiograph can be used to assess the decrease in the calcaneal pitch and arch angle; the shortening of the tendo Achillis fulcrum; the talocalcaneal angle, which is a measure of heel alignment; the loss of heel height; and the protrusion of bony fragments, which may act as exostoses, into the soft tissues. The lateral view in a weight-bearing position gives a good evaluation of the fat pad.

The anteroposterior view of the ankle is useful in assessing the fibulocalcaneal space. This space is usually greater than 15 mm. Extrusion of bone fragments into this space can easily be seen. Normally, it should be possible to place a dime between the shadow of the fibula and the calcaneus (dime sign).

The axial view shows the lateral displacement of the body of the calcaneus toward the fibula, as well as the step at the medial cortex. It should show the posterior facet with the depression in its articular surface. Widening of the heel can be appreciated, and varus malalignment can be noted. To improve the assessment of the malalignment, the standard 45-degree axial radiograph should be taken with a long tibial x-ray plate under both the heel and the tibia. The alignment of the tibia should normally be parallel to that of the calcaneus, although the midaxial line of the calcaneus lies lateral to that of the tibia. Any angulation on the midaxial line of these two bones demonstrates a malalignment. This view has been termed the long axial view.

Finally, an anteroposterior external oblique view of the foot shows the calcaneocuboid joint and any fracture line extension into it. These same radiographs should be taken of the uninjured side for reference. For purposes of reconstruction, the uninjured side can serve as a template. In addition to these standard views, a medial oblique axial projection gives an excellent view of the middle and posterior facets of the subtalar joint and often shows the fracture line in its best projection. The interval between the lateral malleolus and the calcaneus is also best evaluated on this view.

CT has greatly improved our understanding of the pathoanatomy of each individual fracture. Positioning of the foot is important when this technique is being used.\textsuperscript{16} The patient lies supine in the scanner, with both ankles in 30 degrees of plantar flexion, the knees and hips flexed, and the feet 30 degrees off the flat surface of the table. The gantry should be oriented to provide semicoronal sections at 90-degree orientation to the table, 60-degree orientation to the sole of the foot, and 90-degree orientation to the posterior facet plantar aspect of the foot.\textsuperscript{59} This gives axial CT cuts of the calcaneus and its posterior facet. The orientation can be checked on the scout view. A second angle of tomographic cut should be parallel to the sole of the foot to assess the calcaneocuboid joint.

**Nonoperative Treatment**

The foot should be examined for its neurovascular status, and the degree of swelling should be assessed. Attention should be paid to the possibility of a tarsal tunnel or compartment syndrome. The clinical signs and symptoms include pain above and beyond that expected from the injury, severe degrees of swelling, and decreased sensation in the distribution of the plantar nerves, with intact sensation in the distribution of the calcaneal branch of the posterior tibial nerve and in the adjacent sural and saphenous nerves. Stretch pain on passive abduction or adduction of the toes may be elicited. In the face of these signs or symptoms, compartment pressure may be measured in the interosseous compartments, or fasciotomies may be performed on a prophylactic basis, without any further objective evidence. These fasciotomies are performed thorough two dorsal intermetatarsal longitudinal incisions, either with or without a medial incision in the region of the abductor hallucis muscle. If a tarsal tunnel syndrome is present, the tarsal tunnel should be exposed from the posterior to the medial malleolus, to the point
where the nerve enters the abductor hallucis muscle. The treatment of compartment syndrome in the foot is independent of the surgeon's choice of operative or nonoperative treatment.

Fortunately, in the majority of cases, especially those due to a fall from a height, there is no compartment syndrome. Treatment begins in the emergency room with immediate elevation of the foot and packing of the foot in ice, with sufficient protection to prevent an ice burn of the skin. The icing should be performed for 15 minutes on and 10 minutes off routinely for the first several hours and should then be performed intermittently over the next 24 hours. The foot should be wrapped in an elastic bandage. Many surgeons prefer to wrap the foot in a thick cotton wad dressing with a posterior plaster slab. I see no advantage to this because it prevents the ice from working through all of the layers and provides no significant additional compression over that provided by a simple tensor bandage. The foot should be kept strictly elevated for several days.

At this point, a plaster cast can be applied and the patient can start walking with crutches, with full weight bearing as tolerated. Because the foot will tend to swell, walking should be performed for short periods only (20 minutes), followed by elevation for 1 to 2 hours. The cast should be changed after 1 week to accommodate for the decreased amount of swelling. The skin needs to be inspected, and fracture blisters must be kept sterile. Walking should be encouraged, mixed with appropriate periods of elevation, until the vasomotor edema period is over (approximately 2 to 3 weeks). The patient should be encouraged to bear weight to desensitize the heel and thus decrease the chance of late pain. The patient must be made aware that modified shoe wear may become necessary because of the widened heel and the flattened arch. After 6 weeks, the cast can usually be discontinued in favor of shoe wear. Physical therapy can be started for ankle and subtalar range of motion.

Operative Treatment

Several operative techniques have been used to treat displaced intra-articular calcaneal fractures. These include percutaneous elevation of the tongue fragment, and open reduction and internal fixation and primary arthrodesis.

Percutaneous elevation is primarily used in the treatment of tongue-type fractures. A Steinmann pin or Gissane spike is inserted into the posterior aspect of the tongue fragment and then levered distally to improve Böhler's angle and reduce the tongue fragment. The Steinmann pin is then driven across into the rest of the calcaneus to immobilize this fragment. A slipper cast may be incorporated around the protruding Steinmann pin. This procedure does not address anatomic joint congruity or the problems of heel width or heel alignment. Recently, indirect dynamic and closed reduction methods have been described.40, 44

Open Reduction

Several different open reduction techniques have been popularized: the medial approach, the lateral approach, and the combined medial and lateral approach.

The medial approach described by McReynolds has the advantages of using a very small incision and exposing the side of the fracture where the fracture lines are best delineated because the least amount of comminution is present.36 This makes reduction of the body fragment to the sustentacular fragment relatively accurate. It is also easier to judge heel alignment medially. This side has good bone available for fixation in the arch under the sustentaculum. The disadvantages of this approach are its proximity to the neurovascular bundle, which limits the extensibility of the incision. Furthermore, with this approach, the reduction of the subtalar joint is performed in a blind fashion. This approach offers very limited room for hardware, and for this reason, the staple has been chosen as the simplest device for the limited exposure. There is poor access for bone grafting and no accessibility to the calcaneocuboid joint. The medial approach is contraindicated when the sustentacular fragment is very small.

The lateral approach described by Palmer gives excellent access to the subtalar joint and is an extensile approach.49 There is no proximity to a significant neurovascular bundle, with the exception of the sural nerve. Ample

*See references 19, 31, 36, 46, 61, and 63.
room is present for bone grafting and for fixation. In addition, the lateral bulge and fibulocalcaneal space can be decompressed easily. This incision may be extended to include exposure of the calcaneocuboid joint if necessary. The disadvantages of this approach are that it exposes the more comminuted side and thus makes judging the alignment and reduction of the body fragment more difficult, with the most common error being that of nonreduction of the lateral shift of the body. Laterally, there is poor bone for fixation. This approach involves greater soft tissue dissection, and closure of the incision may be difficult.\textsuperscript{17}

**Medial Approach (Figs. 29–8, 29–9)**

An incision is made two fingerbreadths below the medial malleolus, starting at the posterior aspect of the calcaneus and continuing anteriorly. The neurovascular bundle is palpated; it is usually located within one fingerbreadth behind the medial malleolus. The incision may be extended just to that point, avoiding exposure of the structure, but is preferably extended anterior to this point, with careful dissection and identification of these structures for their protection. Care should be taken to identify the calcaneal branch of the posterior tibial nerve. It is sometimes necessary to sacrifice one of the branches of this calcaneal nerve because it crosses the middle of the operative field. However, the main branch should be spared at all costs, both because of its important innervation of the heel pad and because of the risk of a painful neuroma if it is injured. Decompression of the tarsal tunnel may be considered prophylactically in association with this procedure.

**FIGURE 29–8.** Operative treatment using a medial approach. The medial displacement, overriding, and rotation are drawn from the roentgenogram of this tongue-type fracture (arrows). The approximate location of the incision, fascia, and vascular plexus is shown. (© 1976 Baylor College of Medicine.)
The dissection is carried through the abductor hallucis longus muscle down to bone. The primary shear fracture line is easily identified; it lies posterior to the sustentaculum fragment. Dissection can be extended proximally to identify the sustentaculum. The extensor hallucis longus tendon is easily identified in this location and may on occasion be caught in the fracture line. A blunt-tipped elevator is inserted into the fracture line and used to elevate the depressed posterior facet fragment or fragments. The surgeon performs this maneuver in a completely blind fashion, guided only by touch. On decompression of this fragment, a loud cracking sound may be heard. This does not represent formation of a new fracture but simply disimpaction of the depressed fragment from the body of the calcaneus. As this fragment is elevated from the medial approach, it spontaneously rotates laterally. This assists in its reduction because it is rotated medially when it is depressed. This fact is important to recognize and can be seen on a CT scan. The articular surface of the depressed fragment usually faces the sustentacular fragment. After this fragment is elevated, it needs to be pushed up as high as possible against the overlying talar portion of the posterior subtalar joint. The articular surface of the talus acts as a template for the reduction of this fragment.

After this fragment has been elevated, the elevator is turned around and is used to lever the body fragment medially. To assist in this reduction, it is worthwhile to insert one Steinmann pin axially and one transversely into the body fragment of the calcaneus. While the surgeon performs the levering maneuver, an assistant can use these two pins to correct the equinus position of the calcaneus, thus restoring Böhler's angle, and to assist in shifting the calcaneus medially and out of varus. The fracture line on the medial side is usually quite crisp and sharp, and an accurate reduction of the body fragment to the medial wall of the sustentacular fragment can easily be achieved. An anterior extension fracture is often seen also, and this fracture may need to be reduced as well as possible from the medial side. The reduction of the body fragment should not be attempted before elevation of the posterior facet because this facet would block the medial repositioning.
Once the body fragment has been reduced, an assistant should keep it in place using the two Steinmann pins. Two small drill holes are made at a distance apart equal to that of the prongs of a staple. The staple is then driven into the calcaneus, with one prong in the sustentacular fragment and one prong in the body fragment. If a third split is easily seen and reachable, a three-prong staple can be inserted, as described by McReynolds. This fixes part of the anterior extension of the fracture line. The lateral wall of the calcaneus is then pushed in manually to reduce the lateral bulge.

Additional fixation can be provided by insertion of one or two axial pins from the posteroinferior surface of the calcaneus, just above the weight-bearing surface and in the direction of the posterior facet. The pins should not extend across the joint. Another pin can be inserted in line with the calcaneocuboid joint to give longitudinal support to the calcaneus.

*Lateral Approach (Figs. 29–10 to 29–13)*

The lateral approach to the calcaneus should extend from the base of the fifth metatarsal to the superior posterior corner of the tuberosity of the calcaneus. This incision can be extended more proximally by a longitudinal incision parallel to the tendon Achillis. This incision is made at the junction between the smooth and the rough skin felt just anterior to the tendon Achillis.

After incision of the skin and subcutaneous tissues, the sural nerve should be identified and retracted proximally. The dissection should continue perpendicular to the os calcis, with care taken not to skive the anterior proximal flap. The peroneal tendons are identified, and the incision is carried down distal to them straight to bone. The fibulocalcaneal ligament is incised at its attachment to the bone and is elevated together with the periosteum on the surface of the calcaneus, the periosteum under the peroneal tendons, and the rest of the soft tissues anterior to the incision and elevated flap. This prevents skin vascularity problems because the skin is not dissected off of this flap. The flap is retracted proximally and anteriorly and is held in the retracted position by two small Steinmann pins drilled into the talus and fibula and bent back to support the flap. The body of the calcaneus is thus exposed, and the dissection is carried out in the direction of the fibula to expose the posterior subtalar joint.

Distally, the exposure is carried out to the calcaneocuboid joint if necessary. During the dissection, it may become evident that there is a sheared off fragment of lateral wall that will be completely stripped and devoid of its vascularity if the periosteum is removed. A decision must be made whether to remove the periosteum off this fragment or whether to elevate this fragment with the periosteum as a flap. The latter may be performed as long as it does not interfere with the more important exposure of the subtalar joint. In either case, this fragment will need to be deroofed in order to expose the underlying depressed facet of the calcaneus.

On initial inspection, the location of the depressed facet is often unclear because no articular cartilage is seen. Because of the crushed cancellous bone, a bone defect is evident. An elevator may be inserted to search for the depressed fragment. This fragment is not evident because its articular surface has been rotated medially and is facing away from the lateral exposure.

Once this fragment has been identified, first by irrigating and removing all of the surrounding clot and then by probing with a blunt instrument, the fragment is elevated and reoriented so that it can be reduced into place. Not infrequently, this fragment is noted to be completely devoid of soft tissue attachments and must therefore be avascular. The depressed articular fragment can be elevated and left in place or can actually be removed temporarily from the wound and placed in a dish. I remove the fragment from the os calcis and put it safely into a bone dish covered with a blood clot to keep it well nourished and moist. Usually, the fragment is left within the wound. A headlamp may be useful to see into the cavity to inspect the undersurface of the talus and the remaining impacted posterior facet of the os calcis.

The amount of intact, undisplaced os calcis posterior facet will depend on how medially or laterally the primary fracture line occurred. In some cases, the primary fracture line is very medial, leaving no articular facet connected to the sustentaculum. In all cases, however, the exposed lateral aspect of the sustentacular fragment can be seen, and a sharp vertical fracture line can be identified below the un-
FIGURE 29-10. (A), Lateral approach to the os calcis. The incision is made between the base of the fifth metatarsal and the posterosuperior corner of the calcaneus.

(B), The incision can be extended proximally just anterior to the tendo Achillis at the junction between the rough and smooth skin. The sural nerve should be identified and kept with the anterior flap.

(C), The incision should be carried down perpendicular to bone without skiving. The peroneal tendons should be elevated with the subperiosteal flap, exposing them as little as possible. The calcaneofibular ligament may or may not be identified before it is cut and is elevated with the subperiosteal dissection. A flap of sheared-off lateral cortex may be identified and can be elevated or simply stripped and excised. The bony defect beneath the subtalar joint is identified after this lateral cortex is elevated. The depressed facet fragment is difficult to identify because it is medially rotated. Its articular surface is facing away from the incision. A cortical margin of bone may be noted facing up. This is the lateral cortex of the depressed facet fragment. The incision can be used to expose the calcaneocuboid joint. The incision should be extended proximally or distally, as needed, for additional exposure.
FIGURE 29–11. (A), The calcaneus with its primary and secondary fracture lines. The primary fracture line is line ah; the posterior secondary fracture line is line de; the anterior secondary fracture line is line lk; the posterior facet is identified between the points b, c, and g; the middle facet is identified as j; and the anterior facet is identified as i. The primary fracture line component running through the posterior facet is ab. The extension of the primary fracture line on the medial aspect of the calcaneus is af. The extension of the secondary fracture line component on the medial aspect of the calcaneus is ef. The undersurface of the thalamic fragment and the direction to which it will displace is along line df. The thalamic fragment is a wedge-shaped piece with the following sides to it: a superior aspect consisting of the lateral part of the posterior facet abc; a lateral aspect consisting of the lateral cortex cancellous surface bcedb; a purely cancellous surface facing inferiorly, deid; another cancellous surface facing inferomedially, abfa; and finally, an articular and cortical surface facing medially, aced.

(B), With displacement, the thalamic fragment is depressed into the calcaneus, as shown. The thalamic fragment has been removed and is shown in a 90-degree medially rotated position (B1). The body fragment has plantarflexed and shifted laterally into varus. The anterior secondary fracture line, which extends into the calcaneocuboid joint, remains undisplaced.

(C), After exposure of the fracture region, a 2-mm Kirschner wire (K-wire) is inserted into the center of the sustentaculum immediately beneath the subchondral bone of the subtalar joint.

(D), The wire is withdrawn from the medial side until only the tip of the wire is seen protruding from the lateral side of the sustentacular fragment.

(E), The depressed fragment is elevated, rotated, and reduced anatomically to the sustentacular fragment. The K-wire is then advanced from the medial side to fix the thalamic fragment in place. A second K-wire is inserted to hold the reduction.
FIGURE 29-11 Continued (F). The first K-wire is removed and replaced by an appropriate-length 4-mm screw. If the cannulated screw system is being used, a screw is introduced under the K-wire. In this manner, both K-wires are replaced with 4-mm cancellous screws. A Steinmann pin is inserted transversely into the body of the calcaneus, and the second one is inserted axially into the body fragment.

(C). These two heavy pins are used to manipulate the body fragment back into position. The transverse pin is used to restore the calcaneal length and to shift the calcaneus medially, whereas the axial pin is used to dorsiflex the calcaneus and restore its pitch and Böhler's angle. With the reduction being maintained by means of these two pins, two K-wires can be inserted, one longitudinally and the other axially, to stabilize the reduction of the body fragment. The surgeon must ensure that the calcaneal body has been shifted medially far enough and dorsiflexes far enough. A common error is to reduce the body fragment insufficiently in these two directions. Radiographs can be taken or the image intensifier can be used to obtain a spot check of the reduction on the lateral and axial views.

(H). The split in the calcaneocuboid joint can be fixed by a figure-of-eight technique. A K-wire is inserted from the plantar to the dorsal aspect. A figure-of-eight wire is placed around the K-wire and tightened to close the split and maintain the reduction.

(I). A 3.5 reconstruction plate is molded to the lateral side of the calcaneus. The topmost hole is bent at about 60 to 90 degrees to go over the top of the calcaneus posteriorly. A screw is drilled and fixed into the body of the calcaneus at this point. The posterior half of the plate should parallel the subtalar posterior facet to the level of the primary split. At this point, the plate is bent in line with the longitudinal axis of the anterior calcaneus to end just proximal to the calcaneocuboid joint, and 4-mm cancellous screws are inserted along the whole length of the plate, except in the region of the subchondral bone defect. The plate acts as a buttress for the calcaneus.
FIGURE 29-12. (A), After bone defect described above is exposed by elevation of the sheared-off lateral wall and by retraction of the superior flap that contains the peroneal tendons, a K-wire is inserted into the sustentacular fragment subchondrally, as shown. (B), The K-wire is backed out the medial side until only its tip is seen within the bone defect. The thalamic fragment is elevated and reduced to the sustentacular fragment, and the K-wire is advanced to fix it in place. A Steinmann pin is introduced transversely and axially into the body fragment to facilitate the reduction. (C), The body fragment is reduced by dorsiflexing it and medially translating it so that its medial wall is now in line with the medial wall of the sustentacular fragment. Two K-wires are used to maintain this alignment, one axial and one longitudinal. (D), The K-wires fixing the thalamic fragment have been replaced by lag screws. A reconstruction plate has been applied along the lateral side of the calcaneus.

FIGURE 29-13. (A), The lateral approach to the calcaneus with fixation using lag screws and a 3.5 reconstruction plate. (B), The radiograph shows the plate to run parallel to the subtalar joint and curve distally to reach the calcaneocuboid joint and proximally over the tuberosity. (From Paley D, Hall H: Calcaneal fracture controversies: Can we put Humpty Dumpty together again? Orthop Clin North Am 20:673, 1989.)
dersurface of the talus. A thin blunt elevator should be used to probe into the remaining posterior subtalar facet of the sustentacular fragment and the talus. The surgeon can also probe in the direction of the middle facet between the sustentaculum and the talus. To allow for this inspection, the depressed fragment must either be removed or redepressed. The moment this fragment is elevated, it obliterates the view of the sustentacular fragment. It is therefore preferable to first drill a subchondral 2-mm K-wire under the posterior facet in the direction of the sustentaculum for fixation. This is a safe direction to exit medially because the neurovascular bundle runs posterior and inferior to the sustentaculum. After the wire exits through the bone, it should be tapped out the medial side to minimize the amount of spinning that it must do in the soft tissues, thus decreasing the risk of wrapping up any important structures.

A second wire is inserted in a similar manner from the lateral side in another portion of the sustentacular fragment. Both wires are then backed up until only their tips are protruding from the lateral aspect of the sustentacular fragment. The depressed joint fragment can now be re-elevated and carefully reduced into place so that it is congruent with the overlying talar articular surface and with the sustentacular fragment fracture line. The latter can be better appreciated by reinserting the thin elevator to ensure that there is no step-off across this fracture line. The K-wire is then drilled from the medial side back into the sustentacular fragment to hold it in place. The same is done with the second K-wire. One of the K-wires can be backed out medially and replaced with a 4-mm AO cancellous screw. The length of the screw is first determined using a depth gauge. A washer is used under the head of the screw, and the screw is inserted to gain interfragmentary compression into the sustentacular fragment. This procedure is repeated for the second K-wire. This provides stable fixation of the depressed fragment in its anatomic position. If cannulated screws are available, the appropriately sized K-wire for the screw is used instead of the 2-mm wire.

The next step is to reduce the body fragment. This is perhaps the most difficult step. Again, I prefer to use one Steinmann pin across the body of the calcaneus and one axially into the body of the calcaneus. Traction is placed on the transverse Steinmann pin. The calcaneus is then shifted medially. An elevator may be inserted from lateral to medial into the primary fracture line to help lever the body fragment medially. It is often quite difficult to get the calcaneal body out to length and height despite the Steinmann pin maneuver. The use of a femoral distractor or even an external fixator can facilitate this maneuver. Once the body is sufficiently medial, the axial pin is used to dorsiflex the body of the calcaneus out of its equinus position. This Steinmann pin should be pushed distally as hard as possible because in my experience it is not possible to correct. Once the body reduction has been achieved, a second axial Steinmann pin can be inserted, and a longitudinal Steinmann pin can be inserted toward the calcaneocuboid joint. These pins provide temporary stability but can also be left in place throughout the duration of treatment.

Next, attention should be given to the anterior lateral aspect of the calcaneus, including the calcaneocuboid joint. Any displaced fracture in this region should be reduced. If a displaced fracture line extends into the calcaneocuboid joint, the dissection should be carried out to expose this joint and reduce the displacement. Because the split into the joint is usually in a transverse plane, fixation should be from dorsal to plantar. Two forms of fixation may be used. If it does not involve too much increased dissection and if the bone stock allows, an interfragmentary screw with a washer should be inserted from dorsal to plantar. Most of the time, however, there is too much comminution and not enough bone for fixation for this screw to be effective. I find tension band wiring to be the best way to fix this fracture. A K-wire is inserted from dorsal to plantar. A figure-of-eight wire is then placed around the K-wire where it exits dorsally and where it exits on the plantar surface. Twisting this wire leads to interfragmentary compression, which maintains the reduction of the calcaneocuboid joint split.

Once the entire calcaneus has been reduced as well as possible, a reconstruction plate extending from the body fragment all the way to the anterior portion of the calcaneus can be attached. This step is carried out by first shaping the plate. The proximal-most hole should be bent around the top of the calcaneus. The next three holes are usually parallel to the posterior facet of the subtalar joint. The plate is then bent again to follow the lateral contour of the anterior half of the calcaneus distal to the joint. A screw needs to be placed through
the proximal-most hole into the body fragment and into the distal fragment. Fixation into the comminuted portion between these fragments is not essential. One or two screws may be added for support in this region. If a sheared-off lateral wall fragment is present, it should be put back into place before plating. Furthermore, if bone grafting of the bone defect is planned, it should be performed before the plate is applied because the lateral wall fragment will close off the opening and make it difficult to insert a bone graft. A Y-plate can also be used, with the upper arm of the Y following the direction described for the reconstruction plate and the lower arm of the Y gaining fixation to the body of the calcaneus.

If bone grafting is chosen, the graft should be taken from the iliac crest. Only cancellous bone should be used. The use of allograft or bone from a bone bank should be avoided if possible because of the risk of infection. When the bone graft is inserted, the pieces should be kept to a maximum of 5 mm in diameter. The bone should be packed in, but care should be taken not to pack it too tightly and to avoid extrusion of this bone into the plantar aspect of the foot. There is disruption and often bone loss on the cortical surface of the plantar aspect of the foot, and packing in too much bone will lead to extrusion into the heel pad. The tourniquet times should be limited to a total of 2 hours in one session or two 1 1/2-hour periods separated by a 15-minute interval.

The last maneuver, which must not be forgotten, is to feel under the fibula in the peroneal tendon space. Small bone fragments may have been extruded into this region and are often attached to soft tissues in that region. This will lead to exostosis with calcaneofibular impingement or peroneal tendon tenosynovitis. These fragments should be excised and used as bone grafts. The skin flap is closed over a suction drain in two layers. Repair of the calcaneofibular ligament is unnecessary. The ligament can usually be left to heal on its own. A sterile dressing is applied with a bulky wrap. The foot should be supported in a neutral position using a posterior slab. If this adds undue tension to the incision, the foot is best left alone to lie in equinus.

**Combined Medial and Lateral Approach**

For the combined medial and lateral approach, the patient is best positioned prone. Again, one Steinmann pin is introduced axially into the heel and one is introduced transversely across the body of the heel posteriorly and in its midportion. It is easiest to approach the heel through the lateral incision described earlier, and after the depressed fragment is reduced, a small medial incision is made to assist in the reduction and to ensure the accuracy of reduction of the body fragments. The Steinmann pins in the heel are used to assist in the reduction, as described previously. With the patient in the prone position, there is less difficulty with the management of the axial pin because it does not get in the way. It may take some reorientation to get used to the upside-down appearance of the anatomy because of the prone position. One of the big advantages is that if any bleeding occurs, the blood does not accumulate; thus, the operative field is kept relatively dry. Fixation is with a plate and screws on the lateral side and a staple on the medial side.

**Open Reduction and External Fixation** (Fig. 29–14)

For open reduction and external fixation, the circular external fixator of Ilizarov is applied as the first step. Application of this device includes certain reduction maneuvers using the wires of the apparatus. Once the maximum possible reduction by ligamentotaxis has been achieved, a limited lateral incision is made, directly over the subtalar joint, and open reduction with internal fixation is carried out. A preconstructed two-ring frame with an anterior and a posterior threaded rod is applied to two wires on the tibia. The rings are parallel to each other. They are connected to these two wires, which are perpendicular to the tibia. They are fixed to the wires with wire fixation bolts. The rings are centered around the soft tissues of the leg to ensure at least a fingerbreadth of space circumferentially. The threaded rod anteriorly should be parallel to the crest of the tibia on both anteroposterior and lateral inspection of the tibia. The wires are then fixed and tensioned to 130 kg. With the rings used as guides, two olive wires are then inserted from anteromedial to posterolateral on the tibia in the direction of the fibula or two half-pins are added perpendicular to the wires. Two additional threaded rods are added medially and laterally to complete the tibial fixation.
Using the image intensifier, the surgeon inserts a smooth wire into the cuboid and across into the cuneiforms. This wire should not cross into the metatarsals or into the navicular. Insertion of this wire should start on the dorsal aspect of the cuboid so that the wire is not at too great an inclination. A half-ring is fixed onto this wire, roughly centered on the foot. This half-ring is then connected to the distal tibial ring, with the forefoot placed in a plantigrade position at a 90-degree angle to the tibia. This locks the position of the foot. The reduction maneuver of the heel can now be performed because any downward shift on the calcaneus will result in movement of the body of the heel, not the foot. If the forefoot were not fixed, any downward push on the calcaneus would result only in dorsiflexion of the ankle.

A smooth wire is inserted into the body of the calcaneus so that it is situated posteriorly and proximally in the body. This wire should be inclined from distally on the lateral side to proximally on the medial side to help correct the varus deformity. A half-ring is connected to the distal tibial ring with three threaded rods, one at each end of the half-ring and one in the middle. The half-ring is connected to the wire in the heel. The wire in the heel is arched posteriorly by one hole to aid in lengthening of the heel. Two tensioners are placed

**FIGURE 29-14.** Circular external fixation and open reduction technique.

(A) A two-ring fixator is applied to the tibia with anterior, posterior, medial, and lateral threaded rods. These are applied from the midtibia-down, with a separation of approximately 10 cm between the upper and lower rings. The wires are inserted perpendicularly to the tibia. First, one wire is inserted proximally and one is inserted distally in the tibia, spaced apart the distance of the rings. The frame is then centered on these wires, and the rings are fixed and tensioned to these wires. The other two wires are then inserted. The first wire is an olive wire inserted from the lateral side, aiming for the wires. The other two wires are inserted. The proximal ring, a wire goes through the tibia at an angle of approximately 60 degrees to the first wire, and on the second ring, a wire with an olive goes posteriorly in the same direction as the medial face of the tibia, posteromedial to anterolateral. These two are fixed and tensioned to 130 kg. The direction as the medial face of the tibia, posteromedial to anterolateral. These two are fixed and tensioned to 130 kg. The direction is brought to 90 degrees, and a wire is inserted across from the cuboid through the cuneiforms. This is connected to a half-ring, as shown. The half-ring is then connected to the tibial rings to maintain the foot at 90 degrees.

Illustration continued on following page
FIGURE 29-14 Continued

(H), The final position on the axial view is shown with the forces that are acting on the body fragment. On the olive wires, there is a lateral-to-medial force holding the reduction of the primary fracture line. On the smooth wire, there is a force pulling distal and out of varus, maintaining alignment of the body fragment.  

(I), The position of this wire on the cross-sectional view of the calcaneus is shown.

(J), After reduction of the body fragment, the olive wire is fixed and tensioned with wire fixation bolts.

(K), The final maneuver is to connect the posterior heel half-ring to the anterior half-ring in the midfoot by medial and lateral threaded rods. This can be facilitated by preapplying connection points to the threaded rods on the anterior ends of the half ring. The calcaneus is shown in its reduced position maintained by the triangle of fixation. This triangle consists of fixation points in the tibia, midfoot, and hindfoot. The crushed zone in between is thus prevented from collapse. In fact, both the ankle and subtalar joints can be distracted and thus prevented from experiencing any pressure during treatment. This fixation, therefore, allows for full weight bearing, as tolerated, by the patient without fear of loss of reduction. The counterbalanced forces are shown: the force of the tendo Achillis pulling upwards is balanced by the strut between the tibia and the calcaneus. The force of collapse of the arch through the plantar fascia is counterbalanced by the strut between the midfoot and the hindfoot, and the force of the hindfoot distraction between the tibia and calcaneus is balanced by the solid strut between the midfoot and the tibia.
onto this wire and tensioned simultaneously from either side. This assists in the reduction of the heel. Once this wire is fixed and tensioned, the half-ring is pulled distally while the nuts in the threaded rod are loosened. The half-ring is then fixed in place by tightening of all of its nuts, which thus holds the heel in the reduced position. The position should now be checked with an image intensifier, and as the heel height has been reduced, no more distal traction should be applied. A No. 11 blade should be used to release the skin distal to the heel wire. This step is extremely important, and if it is not performed, the skin tension will lead to necrosis proximal to the wire.

The next step must be to reduce the depressed subtalar facet. This must be achieved before the heel can be shifted medially. First, a small incision is made on the lateral side. The peroneal tendons are not in the way much because the height of the heel has been restored. The incision is parallel to the subtalar joint just below the fibula. Operating through the fracture lines, the surgeon elevates the posterior facet. It can be fixed into place using a 4-mm cancellous screw. Reduction and fixation with the temporary K-wires are done in the same manner as that described for the lateral approach.

Next, an olive wire with a small fragment washer is applied from the lateral side. It is used to pull the heel medially. When this wire is pulled on from the medial side, the entire body of the calcaneus is shifted over medially. The first wire in the heel does not impede this shift because it is a smooth wire. This reduction should be carried out under image intensifier control. The image intensifier is placed in an axial position so that it is at a 45-degree angle to the heel. The surgeon can then determine if the medial side has been sufficiently reduced.

Once the medial translation has been completed, the open reduction is treated in the same manner as described previously. This includes addressing the calcaneocuboid joint and bone grafting if needed. The fragments in the fibulocalcaneal space should be excised, and those in the lateral wall should be reduced or removed. The wound is then closed. If there is any significant tension on the wound, the one advantage of this system is that longitudinal traction on the heel wires, and thus the tension on the wound, can be decreased. The height of the heel can be relengthened gradually, starting 7 to 10 days later at 1 mm/day.

In some cases, it may be advisable to insert one wire into the depressed subtalar fragment in its reduced position, instead of adding a second screw. This will support the fragment from potential collapse during weight bearing.

The frame is completed by connecting the anterior half-ring to the posterior half-ring. This is performed medially and laterally. Once this has been completed, sterile sponges are applied to the pin sites, together with clips that hold the sponges in place. Lateral and axial radiographic views of the heel should be used to confirm reduction. It should be noted that reduction in this case is much easier than in all of the above-described approaches because it is not necessary to fight the pull of the soft tissues, which tends to collapse the body fragment in. The fixator holds the reduction while the surgeon is free to work. The frame is usually not found to be in the way. Because of the wire's flexibility with distraction, the half-ring on the heel lies distal to the wire insertion site and is thus out of the way.

Postoperative Management

Whether operative or nonoperative treatment is chosen, one principle of management has been early range of motion. Early range of motion of the subtalar joint adheres to the principles of treatment of intra-articular fractures. Non-weight bearing for 8 to 12 weeks is recommended to prevent collapse of the surgically fixed and reduced calcaneus and subtalar joint. Current methods of internal fixation are not strong enough to allow earlier weight bearing. On the other hand, some nonoperative treatment methods allow early weight bearing. 24, 37, 50 Does early weight bearing desensitize the heel pad? The magnitude of injury to the heel pad cannot be underestimated, and its tendency toward fibrosis and dystrophic changes of the soft tissues around the heel is well recognized. 37 Would the stimulation from partial or complete early weight bearing reduce this soft tissue dystrophy? This important question remains to be answered.

I have begun treating calcaneal fractures by first applying the Ilizarov external fixator and achieving as anatomic a ligamentotaxis reduction as possible. 1, 13, 48 This is followed by a lateral approach to the fracture and anatomic open reduction of the remaining displacement and deformity. I fix the depressed thalamic
fragment in its anatomically reduced position using a screw. The rest of the fixation is carried out with the external fixator. The base of fixation is the apparatus on the tibia, extending to the midfoot and hindfoot to bypass the crushed midpoint of the calcaneus. This non-collapsible triangle of fixation allows the patient to begin weight bearing within 24 hours of the surgery. This resulted in a painless heel and foot in seven of eight patients treated in this manner with more than 2 years of follow-up. These preliminary results of early weight-bearing treatment of anatomically reduced calcaneal fractures are encouraging. I do not believe that immobilization of the subtalar joint with early weight bearing interferes with the prognosis for this joint. In the case illustrated (Fig. 29–15), there is a 75 percent return of subtalar function; the patient returned to work as a roofer. These early results remain anecdotal but promising and add to the existing questions about calcaneal controversies.

Results of Open Reduction and Internal Fixation of Intra-Articular Calcaneal Fractures

A summary of the long-term results of numerous studies of calcaneal fractures treated by a variety of operative and nonoperative means is given in Table 29–1. It is worth highlighting the published results and complications of some studies reporting on open reduction and internal fixation by different approaches.

We reported on 52 calcaneal fractures, all of which were treated by the medial approach by one surgeon (H. Hall). The results were excellent in 19, good in 13, fair in 13, and poor in seven. There were 17 complications: superficial wound infection in one, bone graft donor site infection in one, calcaneal nerve hyposthesia in 11, calcaneal nerve neuroma in one, exostosis requiring removal in two, and a protuberant staple requiring removal in one.

Letournel reported on 83 cases; all patients were treated by the lateral approach using his multiple-H plate. He reported eight wound necroses and three wound infections. His results were normal in 27 percent, good in 31 percent, fair in 33 percent, and poor in 9 percent. The normal-, and good-result groups were considered to have no functional disability. Subtalar motion was normal in only three cases. It was greater than 50 percent normal in 47 percent of cases. In the rest, it was less than 50 percent normal.

Harding and Waddell reported on 52 fractures, all of which were treated by the lateral approach. They used an external fixator to aid in the reduction and then fixed the fragments using minimal internal fixation with a threaded pin or screw. Fifty percent of heels had greater than 50 percent subtalar range of motion. Complications included three pin track infections from the Roger Anderson device, two superficial infections, and one deep infection, which required a ring sequestrectomy. One patient developed a nonunion of the calcaneus. Thirty-nine of the patients were considered to have a satisfactory result.

Stephenson reported on 22 feet treated by a combined medial and lateral approach. He had six cases of superficial skin necrosis but no deep infections. Twenty of 22 feet had normal restoration of the medial border. Nineteen of 22 had congruent subtalar reduction. The average subtalar motion was 75 percent normal (range, 30 to 100 percent). Based on these criteria, the final result was rated as good in 77 percent, fair in 4 percent, and poor in 19 percent.

Sanders and associates reported on 120 fractures using their CT classification and with a follow-up averaging 29 months. All fractures were treated using a lateral approach, lag screw and H-plate fixation, and no bone grafting. Postoperative reduction of heel height, length, and width were 98 percent, 100 percent, and 110 percent of normal, respectively, irrespective of fracture type. A radiographic anatomic reduction was achieved in 86 percent of type II, 60 percent of type III, and 0 percent of type IV fractures. The clinical outcome in the 79 type II fractures was 73 percent good or excellent, 14 percent fair, and 17 percent poor. The clinical outcome in the 30 type III fractures was 70 percent good or excellent, 10 percent fair, and 20 percent poor. Seven of these fractures required later fusion. The clinical outcome in the 11 type IV fractures was 9 percent excellent or good, 18 percent fair, and 73 percent poor. Sanders identified a learning curve in which the number of good or excellent results improved with each year of experience of the surgeon for types II and III fractures but not for type IV fractures, even after 4 years of experience.

Leung and colleagues compared operative with nonoperative treatment in 44 operated and 19 nonoperated intra-articular calcaneal
FIGURE 29–15. (A and B), Preoperative lateral radiograph (A) and CT scan (B) of an intra-articular calcaneal fracture, central depression type. Note the depression and medial rotation of the posterior facet. The facet faces away from a lateral incision. (C), The Ilizarov apparatus was applied and the heel height restored. The Seligson modification of the lateral incision was then made. One can see the cartilaginous edge of the medially rotated facet. The underside of the talus is also seen. Between the two is seen the cartilage of the undepressed portion of the posterior facet on the sustentacular fragment. The thalamic fragment was elevated and fixed with screws and suspended with an Ilizarov wire. (D), After anatomic restoration of the calcaneus, the patient is seen ambulating, with full weight bearing as tolerated 2 days after surgery. The fixator was removed after 8 weeks. (E), The 1-year follow-up lateral radiograph. (F), CT scan of the subtalar joint after 1 year shows anatomic restoration and normal heel height and width. The result is a painless heel with 75 percent normal range of motion. (From Paley D, Hall H: Calcaneal fracture controversies: Can we put Humpty Dumpty together again! Orthop Clin North Am 20:674, 1989.)
fractures. All surgery was through a lateral approach. There were 17 excellent, 23 good, four fair, and zero poor results in the operative group compared with zero excellent, 10 good, six fair, and three poor results in the nonoperative group. There was more pain, more limited walking distance, less subarticular range of motion, and a lower rate of return to work in the nonoperative group. The only complications of surgery were irritation of the peroneal tendons by hardware in two patients.

Buckley and Meek also compared open reduction with closed treatment. They used a cohort matched for fracture type, age, occupation, and year of injury. Seventeen patients were operated on by the lateral approach, and 17 were treated nonoperatively. There was no significant difference in heel pain, subtalar motion, and return to work between the two groups. However, in those fractures treated operatively, the overall clinical result was better when an anatomic reduction was achieved. Conversely, when the reduction was less than perfect, the overall clinical score was the same as that with no operation. This study highlights the persistent unsolved controversy. 38

The most severe fractures (Sanders type IV) remain an unsolved problem. These may be best treated by combined internal and external fixation. The role and need for bone grafting remain controversial. Palmer recommended its use as a means of fixation. 49 Letournel believed it was unnecessary because lag screws were sufficient to hold the articular surface together. 31 Stephenson, using no bone graft, had only one late collapse. 63 Leung used bone graft in all cases. 32 Sanders does not recommend bone grafting and believes it can block articular reduction. 38 Hall used bone graft in 10 cases and had a 67 percent satisfactory result. In the other 42 cases, in which bone grafting was not used, a 62 percent satisfactory result was achieved. There is no significant difference between these results. 47 The literature does not support the need for bone grafting even in the presence of a large bone defect. The only late collapse in my most recent series was the only patient in the group who had had bone grafting. 48

In the majority of cases, there is not just one source of pain. There has been distortion of the calcaneal anatomy, subtalar joint, foot biomechanics, and pericalcaneal soft tissues. It is no wonder that simply excising the protuberant bone on the lateral side of the foot or fusing the arthritic subtalar joint frequently does not relieve the patient's chronic pain. 1, 52 Braly and colleagues reported only a 46 percent satisfactory result rate after late subtalar fusion for calcaneal malunion. 3 When combined with lateral wall excision, the results were 75 percent satisfactory. 3 Johansson and colleagues reported a 95.6 percent satisfactory result rate after in situ modified Grice fusion for malunited calcaneal fractures. 28 However, 15 of 23 patients continued to have problems with shoe wear, and 18 of 23 had heel widening, valgus, and loss of heel height.

These approaches might be more successful in the previously operated foot in which a restoration of part of the anatomy was carried out, leaving only one or two painful problem areas. In less fortunate patients with multifactorial sources of chronic pain refractory to all other modes of therapy, amputation was the occasional final solution. 26 Even then, only 62 percent of patients had relief after the ablative procedure.

In 1988 Carr and colleagues described a new salvage procedure for calcaneal fracture malunion (Fig. 29–16). 6 This procedure was first described in 1977 by Koshkarev and Zhitsitski in the Soviet Union. 29 This is the first procedure that addresses the majority of the painful calcaneal problem areas simultaneously, with one operation. Through a posterior operative approach to the subtalar joint, the calcaneus is distracted away from the overlying talus hinging on the anterior talocalcaneal articulations. A triquetral iliac crest bone graft is inserted between the calcaneus and the talus. This simultaneously increases the calcaneal height, eliminates the limb length discrepancy, fuses the subtalar joint, decompresses the fibulocalcaneal impingement and peroneal tendon space entrapment, corrects the heel malalignment, restores the longitudinal foot arch, and decompresses tibiotalar impingement. Carr and colleagues reported satisfactory results in 13 of 16 patients with chronic pain.

Myerson and Quill reported on the salvage of 43 painful calcaneal fractures that had been previously treated by open or closed techniques to union. 38 They tried to identify the focus of pain and treat such foci selectively.
FIGURE 29-16. (A). The normal alignment of the hindfoot in relation to the midfoot and forefoot is shown on the lateral view. Note the declination of the anterior talus: a straight line can be drawn through the midline of the body, through the midfoot, and into the midline of the first metatarsal. Viewed from behind, the varus-valgus alignment of the heel is neutral midfoot, and into the midline of the first metatarsal. This is a normal situation following a comminuted intra-articular fracture of the os calcis. (B). This composite and the mid-weight bearing line from the tibia lies slightly toward the medial wall of the os calcis. (B). This composite picture of an old os calcis fracture demonstrates that the talus is crushed down into the body of the os calcis and has lost its normal anterior declination. This is a common situation following a comminuted intra-articular fracture of the os calcis. (C). Leg length, hindfoot height, and malleolar position are corrected in an old os calcis fracture using the distraction bone block technique. In addition, the heel is narrowed by removing the lateral wall. The peroneals can now be replaced under the decompressed end of the fibula. Two fully threaded screws prevent rotation and maintain exact position and height without further compressing the heel. Proper talocalcaneal angles in both the sagittal and the transverse planes must be achieved before the screws are inserted so that the hindfoot does not end up in varus. Although this correction results in loss of subtalar motion, cosmetic appearance and function are markedly improved and pain is significantly reduced.

Note that although the heel is tilted into varus in the sagittal plane, it may be laterally displaced in relation to the leg. The inset shows fragments of iliac crest and the block graft that resolves much of this anatomic distortion.
The subtalar distraction bone block arthrodesis was used in patients with subtalar osteoarthritis, with a decreased talar declination angle indicating loss of heel height. In situ fusion was used when there was no loss of heel height. Lateral ostectomy was part of both procedures as needed. Lateral ostectomy on its own was used when there was no evidence of subtalar joint arthritis or pain on selective injections of local anesthetic. Subtalar distraction bone block arthrodesis yielded seven good, three fair, and four poor results. The results of in situ arthrodesis were good in 11, fair in two, and poor in two cases. Triple arthrodesis produced fair results in two cases and poor results in three. Ostectomy alone yielded results that were good in one, fair in two, and poor in four. In addition to these bony procedures, Myerson and Quill identified and treated a group of patients with tarsal tunnel decompression, reflex sympathetic dystrophy blocks, and neuroma exploration and excision. Tibial nerve decompression yielded two good results, two fair results, and one poor result. Sural nerve resection relieved symptoms in six of seven patients. They concluded that distraction bone block arthrodesis is the most useful salvage procedure. Ostectomy alone yielded poor results despite patient selection owing to osteoarthritis that was not detected preoperatively.38

CONCLUSIONS

Numerous controversies surround our understanding of the treatment of intra-articular calcaneal fractures. These controversies include the basic issue of operative versus nonoperative treatment, prognostic factors, the surgical approach, the use of bone graft, and the method of fixation. In attempting to resolve some of these issues, I have tried to clarify the question of prognostic factors while adding to the existing list of controversies by questioning the role of early subtalar range of motion versus early weight bearing. The solution to many of these controversial issues lies in better standardization of classification and evaluation methods so that better comparisons can be made, and in better understanding of the pathoanatomy so that anatomic reconstruction can be better carried out.

References