Isolated Subtalar Arthrodesis*

BY MARK E. EASLEY, M.D.†, HANS-JÖRG TRNKA, M.D.‡, LEW C. SCHON, M.D.§, AND MARK S. MYERSON, M.D.§

Investigation performed at the Department of Orthopaedic Surgery, The Union Memorial Hospital, Baltimore, Maryland

Abstract

Background: **The purposes of this retrospective study were to review the results of isolated subtalar arthrodesis in adults and to identify factors influencing the union rate. The hypotheses were that (1) the overall outcome is acceptable but is not as favorable as previously reported, (2) complication rates, especially the nonunion rate, are higher than previously reported, and (3) factors contributing to a less favorable union rate can be identified.**

Methods: **Between January 1988 and July 1995, 184 consecutive isolated subtalar arthrodeses were performed in 174 adults (115 men and fifty-nine women) whose average age was forty-three years (range, eighteen to seventy-nine years). Eighty patients (46 percent) were smokers. The indications for the procedure included posttraumatic arthritis after a fracture of the calcaneus (109 feet), a fracture of the talus (thirteen feet), or a subtalar dislocation (thirteen feet); primary subtalar arthritis (thirteen feet); failure of a previous subtalar arthrodesis (twenty-eight feet); and residual congenital deformity (eight feet). Rigid internal fixation with one or two screws was used for all feet. Bone graft was used in 145 feet; the types of graft material included cancellous autograft (ninety-four feet), structural autograft (twenty-nine feet), cancellous allograft (seventeen feet), and structural allograft (five feet). Bone graft was not used in the remaining thirty-nine feet.**

Results: **Clinical and radiographic follow-up examinations were performed for 148 (80 percent) of the 184 feet at an average of fifty-one months (range, twenty-four to 130 months) postoperatively. The average ankle-hindfoot score according to the modified scale of the American Orthopaedic Foot and Ankle Society (maximum possible score, 94 points) improved from 24 points preoperatively to 70 points at follow-up. Thirty feet had clinical evidence of nonunion. The union rate was 84 percent (154 of 184) overall, 86 percent (134 of 156) after primary arthrodesis, and 71 percent (twenty of twenty-eight) after revision arthrodesis. The union rate was 92 percent (ninety-three of 101 feet) for nonsmokers and 73 percent (sixty-one of eighty-three feet) for smokers ($p < 0.05$). Intraoperative inspection revealed that 42 percent (seventy-eight) of the 184 feet had evidence of more than two millimeters of avascular bone at the subtalar joint; all thirty nonunions occurred in this group ($p < 0.05$). A nonunion occurred in three of the five feet that had been treated with structural allograft and in two of the six feet in which the subtalar arthrodesis had been performed adjacent to the site of a previous ankle arthrodesis. After elimination of the subgroups of feet in patients who smoked, those that had had a failure of a previous subtalar arthrodesis, those that had been treated with a structural graft, and those that had had the subtalar arthrodesis adjacent to the site of a previous ankle arthrodesis, the union rate improved to 96 percent (seventy-three of seventy-six). Complications other than nonunion included prominent hardware requiring screw removal (thirty-six of 184 feet; 20 percent), lateral impingement (fifteen of 148 feet; 10 percent), symptomatic valgus malalignment (five of 148 feet; 3 percent), symptomatic varus malalignment (four of 148 feet; 3 percent), and infection (five of 184 feet; 3 percent).**

Conclusions: **To the best of our knowledge, the present study includes the largest reported series of isolated subtalar arthrodeses in adults. Our results suggest that the outcome following isolated subtalar arthrodesis is not as favorable as has been reported in previous studies. The rate of union was significantly diminished by smoking, the presence of more than two millimeters of avascular bone at the arthrodesis site, and the failure of a previous subtalar arthrodesis ($p < 0.05$ for all). Other factors that probably affect the union rate include the use of structural allograft and performance of the arthrodesis adjacent to the site of a previous ankle arthrodesis.**

Isolated subtalar arthrodesis has been used for the treatment of numerous hindfoot problems in adults, including posttraumatic talocalcaneal arthritis[1,5,6,8,10,12,20,22-26], complex acute calcaneal fracture[3,10], primary talocalcaneal arthritis[16-18], symptomatic residual congenital deformity (such as talocalcaneal coalition)[9,16-18], posterior tibial tendon dysfunction[15], and (rarely) inflammatory arthritis isolated to the subtalar joint[24]. Although triple arthrodesis traditionally has been favored for the treatment of talocalcaneal problems that are not amenable to nonoperative measures, advocates of isolated subtalar arthrodesis cite the advantages of preserved hind-

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†Division of Orthopaedic Surgery, Box 2950, Duke University Medical Center, Durham, North Carolina 27710.

‡Orthopaedic Hospital Gersthof, Wielemangasse 28, Vienna 1180, Austria.

§Union Memorial Orthopaedics, The Johnston Professional Building, 3333 North Calvert Street, Suite 400, Baltimore, Maryland 21218. Please address requests for reprints to Dr. Myerson, c/o Elaine P. Bulson, Editor. E-mail address: elaineb@helix.org.

foot motion, a lower risk of arthritis of adjacent joints, a less complex operative procedure, and elimination of the risk of nonunion or malunion of the transverse tarsal joint[17,18].

The outcome after isolated subtalar arthrodesis generally has been reported to be favorable, provided that the primary pathological findings are limited to the subtalar joint[17,18,24]. Previous authors[12,17,18,23,24,26] typically have reported high rates of patient satisfaction, low rates of complications, and low rates of nonunion, regardless of either the pathological findings in the hindfoot leading to subtalar symptoms or the operative technique used for subtalar arthrodesis. Other investigators[4,5,8,10,16,20] have demonstrated satisfactory but less favorable outcomes as well as higher complication rates. The purposes of the current retrospective study were to evaluate the results of a consecutive series of subtalar arthrodeses performed at our institution and to identify factors influencing the union rate. Our hypotheses were that (1) the overall outcome of subtalar arthrodesis is acceptable but is not as favorable as previously reported, (2) complication rates, especially the nonunion rate, are higher than previously reported, and (3) factors contributing to a less favorable union rate can be identified.

Materials and Methods

Between January 1988 and July 1995, 184 consecutive isolated subtalar arthrodeses were performed in 174 adults (115 men and fifty-nine women) who had an average age of forty-three years (range, eighteen to seventy-nine years) at the time of the procedure. The pathological findings leading to subtalar arthrodesis included posttraumatic arthritis following a fracture of the calcaneus (109 feet), a fracture of the talus (thirteen feet) (Figs. 1-A and 1-B), or a subtalar dislocation (thirteen feet); primary subtalar arthritis (thirteen feet); and residual talocalcaneal coalition (eight feet). In addition, twenty-eight revision subtalar arthrodeses were performed because of the failure of a previous subtalar arthrodesis. None of the procedures in the current study were performed because of dysfunction of the posterior tibial tendon. Our treatment of adult acquired flatfoot secondary to posterior tibial tendon dysfunction does not include isolated subtalar arthrodesis; instead, flexible flatfoot deformities are treated with medial displacement calcaneal osteotomy and either medial soft-tissue reconstruction or talonavicular arthrodesis, and fixed flatfoot deformities are treated with triple arthrodesis[21]. All patients had had a failure of nonoperative treatment, which consisted of modification of activities or occupational status, use of nonsteroidal anti-inflammatory medications, use of an orthosis or brace, physical therapy, and injection of steroids into the subtalar joint. When clinical and radiographic evaluation did not confirm that the pathological findings were isolated to the subtalar joint, selective injection into the subtalar joint helped to establish the diagnosis. A sterile mixture of Xylocaine (lidocaine), bupivacaine, and a corticosteroid was injected into twenty (11 percent) of the 184 feet that subsequently underwent subtalar arthrodesis. The injection indicated that symptoms were isolated to the subtalar joint and confirmed that treating the pathological findings in the subtalar joint with arthrodesis probably would be useful in resolving the symptoms in the hindfoot.

The average duration of symptoms related to the subtalar joint was seventeen months (range, four to 126 months). Each patient's height, weight, activity level,

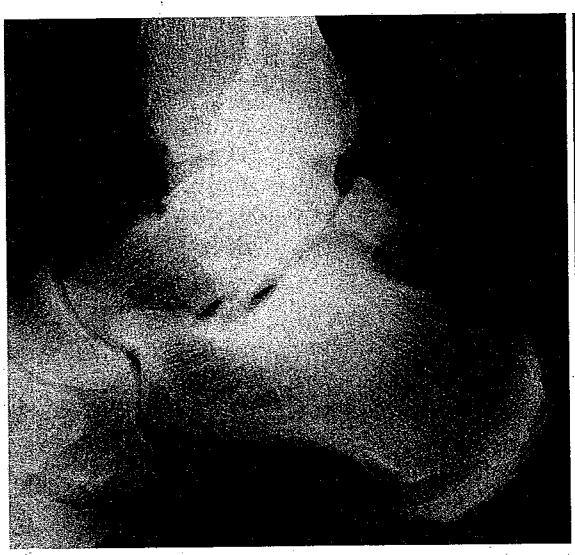

FIG. 1-A

FIG. 1-B

Figs. 1-A and 1-B: A man who was thirty-six years old at the time of the index operation had sustained a fracture of the talar neck ten years previously. The fracture was treated nonoperatively. Mild avascular necrosis of the talar body, loss of talar height, and progressive painful subtalar arthritis subsequently developed. After the failure of nonoperative treatment, the patient was managed with subtalar arthrodesis.

Fig. 1-A: Lateral radiograph made two years before the operation.

Fig. 1-B: Lateral radiograph, made one year after the operation, showing subtalar fusion. The calcaneotalar screw has been removed.

occupation, history of systemic illness, and smoking status were determined in order to identify factors influencing the union rate. A standard preoperative clinical assessment was performed, but without the use of the ankle-hindfoot scale of the American Orthopaedic Foot and Ankle Society[14], which had not yet been published at the time of the preoperative assessment for most patients. (A preoperative score according to the scale of the American Orthopaedic Foot and Ankle Society was assigned retrospectively for patients who had the arthrodesis before 1994 and prospectively for those who had the procedure in 1994 or 1995.) All patients had preoperative radiographs of the foot and ankle.

Operative Technique

All procedures were performed with use of intravenous sedation and a regional ankle block[19] unless an iliac-crest bone graft was to be used (fifty-four feet), in which case general anesthesia was used. Each patient received a prophylactic dose of intravenous antibiotics preoperatively. When necessary (in fewer than 10 percent [seventeen] of the 184 procedures), an ankle tourniquet was temporarily applied in order to improve visualization during the operative approach. The tourniquet was always released at the time that the subchondral surfaces were assessed for vascularity, and in no case was it reinflated.

The operative technique for isolated subtalar arthrodesis was not standardized but instead was tailored to each patient's particular pathological findings. A lateral approach through a horizontal incision was used for 150 feet that were treated with *in situ* arthrodesis, and a posterolateral approach through a vertical incision was used for thirty-four feet that were treated with subtalar distraction arthrodesis. In all patients, the operative procedure involved removal of all residual cartilage from both surfaces of the subtalar joint and rigid internal fixation with either one or two screws. Bone graft was used in 145 feet; the types of graft material included cancellous autograft (ninety-four feet), structural autograft (twenty-nine feet), cancellous allograft (seventeen feet), and structural allograft (five feet). Bone graft was not used in the remaining thirty-nine feet.

In Situ *Subtalar Arthrodesis* (Figs. 2-A and 2-B)

In situ subtalar arthrodesis[20] is performed with the patient in the lateral decubitus position. A straight lateral incision is made over the extensor digitorum brevis muscle from the anterior aspect of the distal part of the fibula to the cuboid, in line with the fourth ray. In patients who have had previous open reduction and internal fixation of a calcaneal fracture, the same approach to the lateral aspect of the calcaneus is used again. The extensor digitorum brevis fascia is divided along its plantar border, immediately dorsal to the peroneal tendons, and the extensor digitorum brevis is elevated dorsally to expose the sinus tarsi. The soft tissues, including fat and capsular tissue, are removed to expose the subtalar joint. When there is evidence of subfibular impingement (symptomatic compression of the peroneal tendons between the lateral aspect of the calcaneus and the distal aspect of the fibula), adequate lateral-wall decompression is performed with use of an osteotome or chisel.

Next, a lamina spreader is used to improve visualization of the subtalar joint. An osteotome or chisel is used to remove residual cartilage and to expose the subchondral bone of the posterior facet of the calcaneus, the inferior articular surface of the talus, and the middle and anterior facets of the subtalar joint. Care is taken to avoid damage to the medial soft-tissue structures. The subchondral surfaces are denuded adequately to create a vascularized surface. To increase the surface area of the arthrodesis site, fish-scaling is performed on the subchondral surface of both the talus and the calcaneus.

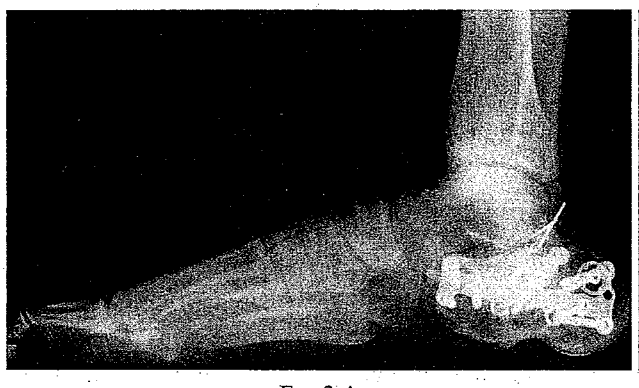

FIG. 2-A

FIG. 2-B

Figs. 2-A and 2-B: A man who was thirty-eight years old at the time of the index operation had a calcaneal fracture that initially had been treated with open reduction and internal fixation. The patient also had been managed with the insertion of two Kirschner wires in the tip of the fibula to secure a distal fibular fracture with an associated peroneal tendon dislocation. The patient subsequently had subsidence of the posterior facet of the talus into the body of the calcaneus with loss of calcaneal height and was managed with *in situ* subtalar arthrodesis and removal of the hardware that had been used to treat the calcaneal and fibular fractures.

Fig. 2-A: Lateral radiograph, made at the time of the index operation, demonstrating subtalar arthritis with mild loss of calcaneal height.

Fig. 2-B: Lateral radiograph, made five years after the arthrodesis, showing successful subtalar fusion with no evidence of ankle arthritis, a solid calcaneotalar fusion, and an anatomically healed fibular fracture.

The wound is irrigated. If bone-grafting is indicated, local bone graft (from the site of the lateral-wall decompression or the anterior process of the calcaneus), iliac-crest graft, or cancellous allograft is packed into the entire subtalar joint space, including the spaces between the inferior aspect of the talus and the middle and anterior facets of the calcaneus.

The subtalar joint is reduced. A partially threaded cannulated screw is placed from the calcaneus to the talus under fluoroscopic guidance. A second screw is inserted from the calcaneus into the talus (again under fluoroscopic guidance) when there is clinical or radiographic evidence (on intraoperative stress radiographs) that the first screw has failed to provide adequate stabilization of the structural graft for bone-block arthrodesis. The wound is closed in layers; after reapproximation of the extensor digitorum brevis fascia, the skin is closed.

Bone-Block Distraction Arthrodesis (Figs. 3-A and 3-B)

Bone-block distraction arthrodesis was used when there was a decreased talar inclination angle that resulted in anterior ankle impingement (limited dorsiflexion due to contact between the dorsal aspect of the talar neck and the anterior aspect of the distal part of the tibia). With bone-block distraction under the body of the talus, near-anatomical talar inclination is restored. Structural autograft or allograft[2,4,5,20] was used in all thirty-four feet that were treated with bone-block distraction arthrodesis.

The procedure is performed with the patient in either the lateral decubitus or the prone position. A vertical posterolateral incision is used, similar to the vertical limb of a standard L-shaped incision for open reduction and internal fixation of a calcaneal fracture. The sural nerve is identified, and its main trunk and branches are protected. The periosteum of the lateral aspect of the calcaneus is elevated while the peroneal tendons are protected, and a lateral-wall decompression is then performed with an osteotome.

The subtalar joint is exposed, and a lamina spreader is used to improve visualization. Rarely, a femoral distractor (Synthes, Paoli, Pennsylvania) is placed medially, spanning both the ankle and the subtalar joint, to improve distraction and, thus, exposure. (The patient typically is placed in the prone position when the distractor is used.) The joint distractor was used in only nine (26 percent) of the thirty-four bone-block distraction procedures performed at our institution. Most of these procedures were performed in the early part of the series. The decision to use the distractor was made preoperatively, and thus the patient was in the prone position from the beginning of the procedure. As our technique improved, we performed more bone-block distraction procedures with the patient in the lateral decubitus position and used the lamina spreader exclusively to gain exposure.

The residual cartilage is denuded from the subtalar joint with an osteotome, and the surfaces are assessed for adequate vascularity. The subchondral surfaces are then fish-scaled to increase the surface area. The lamina spreader is left in place for provisional distraction. Intraoperative fluoroscopy is used to ensure that adequate distraction has been achieved. The wound is irrigated. A structural bone graft is contoured and wedged into the subtalar joint as the lamina spreader is removed. The size of the structural bone graft is determined by the amount of distraction required to correct the talar inclination angle. With the lamina spreader in place, intraoperative radiography or fluoroscopy is used to document the proper position of the talus. Next, the posterior height of the subtalar space is measured with a ruler. The structural graft is fashioned to match this height at its tricortical base. Intraoperative fluoroscopy is used to confirm that the graft is in a satisfactory position and that adequate correction has been achieved.

Under fluoroscopic visualization, a guide-pin is then placed from the calcaneus through the graft into the talus. The guide-pin can be inserted to the level of the subtalar joint before insertion of the graft in order to visually confirm that the screw will penetrate the center of the graft. The graft is then placed, the guide-pin is advanced through the graft into the talus, and a fully

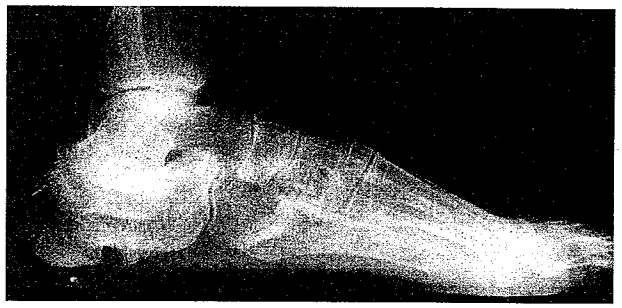

FIG. 3-A

Figs. 3-A and 3-B: A woman who was sixty-eight years old at the time of the index operation had a joint-depression fracture of the calcaneus that initially had been treated nonoperatively.

Fig. 3-A: Preoperative lateral radiograph, made three years after the injury, showing a negative Böhler angle and malunion of the calcaneus with a loss of talar declination.

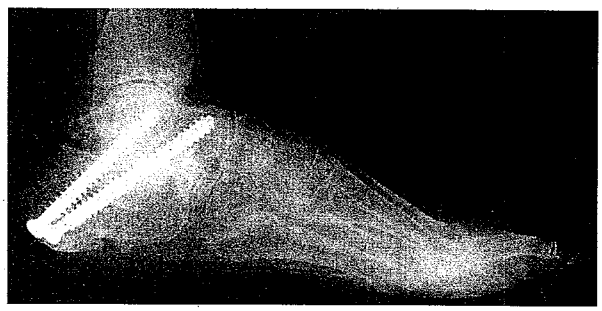

FIG. 3-B

Lateral radiograph, made five months after bone-block distraction arthrodesis with insertion of fully threaded cannulated screws, showing successful subtalar fusion and improvement of the talar declination angle.

threaded cannulated screw is advanced over the guide-pin, across the graft, and into the talus. Compression is not achieved; instead, the goal is to restore hindfoot height. The stability of the fixation obtained with a single screw is assessed intraoperatively. If necessary, a second screw is inserted with use of the same technique, typically anterior to the first screw, from the calcaneus into the neck of the talus. The wound is then closed in layers.

Assessment of Avascularity

Although the present study is retrospective, the senior authors (L. C. S. and M. S. M.) prospectively maintained a subjective record of the quality of the bone in the region of the subtalar joint at the time of subtalar arthrodesis. This independent record served to identify patients who had clinically important avascularity of the subchondral bone at the posterior facet of the calcaneus or the inferior articular surface of the talus. Clinically important avascularity was arbitrarily defined as at least two millimeters of nonbleeding subchondral bone noted intraoperatively at the time of subtalar arthrodesis. The amount of avascular bone was measured from the level of superficial subchondral bone to the level of bleeding subchondral bone during preparation of the surfaces for the arthrodesis. Although radiographs were retrospectively reviewed, the amount of avascular bone could not be consistently assessed on preoperative radiographs.

Postoperative Management

The procedure was performed on an outpatient basis unless iliac-crest bone was harvested (fifty-four feet), in which case the patient was observed overnight for pain control. All patients were discharged to home wearing a postoperative splint, and all wore a below-the-knee, prefabricated, removable, fixed-ankle, weight-bearing boot with a rocker-bottom sole after the wound had healed (typically within ten to fourteen days after the procedure). Weight-bearing was restricted for six weeks for patients who had had *in situ* arthrodesis and for eight to ten weeks for patients who had had distraction arthrodesis; thereafter, weight-bearing was permitted as tolerated.

The patients were evaluated both clinically and radiographically at regular intervals of two, six, and ten weeks and then (if necessary) at intervals of fourteen, eighteen, twenty-two, twenty-six, and thirty weeks. Clinical evaluation focused on wound-healing, evidence of infection, evidence of healing at the arthrodesis site (with stress applied to the subtalar joint to determine if pain had resolved), and sural nerve symptoms. Radiographic evaluation consisted of a lateral radiograph of the foot and one or two Broden subtalar radiographs to assess healing. Patients with clinical stability and radiographic evidence of healing (bridging callus or trabeculation) at the union site were routinely discharged from care at the ten-week interval. Patients without adequate confirmation of clinical and radiographic healing were followed at monthly intervals until healing occurred or delayed union or nonunion was established. Delayed union or nonunion was indicated by continued clinical symptoms with stress applied to the former subtalar joint and by lack of bridging callus or trabeculation at the arthrodesis site as seen on radiographs. In patients who demonstrated clinical and radiographic evidence of union, the time to fusion was recorded as the follow-up interval in which union was determined to have occurred. Although use of the below-the-knee, prefabricated, removable, fixed-ankle, weight-bearing boot was discontinued when there was clinical and radiographic evidence of union, the patient had the option of continuing to use the boot until he or she felt comfortable enough to wear regular shoes.

TABLE I

MODIFIED AOFAS* SCORE ACCORDING TO INDICATION FOR SUBTALAR ARTHRODESIS†

Indication for Subtalar Arthrodesis	Score‡ *(points)*
Residual talocalcaneal coalition	86 (82-92)
Nontraumatic arthritis	76 (62-94)
Subtalar dislocation	76 (66-82)
Calcaneal fracture	70 (12-54)
Talar fracture	68 (38-88)
Failure of previous subtalar arthrodesis	58 (26-94)

*AOFAS = American Orthopaedic Foot and Ankle Society.

†We found no significant difference between any two groups.

‡The values are expressed as the average, with the range in parentheses.

Follow-up Assessment

The investigation was approved by the internal review board, and informed consent was obtained from all patients. Three investigators who were not directly involved in the operative procedures, including two of the authors (M. E. E. and H.-J. T.), conducted this retrospective review. The patients completed a standardized questionnaire at the time of follow-up to determine (1) the pathological findings that led to subtalar arthrodesis, (2) the patient's height, weight, smoking status, and history of systemic illness at the time of subtalar arthrodesis, and (3) the patient's subjective satisfaction with the procedure. The questionnaire also was used to identify the patient's occupational status before the subtalar arthrodesis and at the time of follow-up.

The clinical evaluation involved a careful history and physical examination. The history consisted of a review of the questionnaire with the patient by one of the investigators. The physical examination was used to assess alignment, pain with stress at the site of the subtalar arthrodesis, subfibular impingement, the range of motion of the ankle, pain at the ankle or the transverse tarsal joint, prominent hardware, and sural nerve symptoms. Finally, a modification of the ankle-hindfoot scale of the American Orthopaedic Foot and Ankle Society[14] was

TABLE II

RATE OF UNION AND TIME TO UNION ACCORDING TO INDICATION FOR SUBTALAR ARTHRODESIS*

Indication for Subtalar Arthrodesis	Rate of Union†	Time to Union‡ (wks.)
Talar fracture	12 of 13 (92%)	12 (10-24)
Calcaneal fracture	96 of 109 (88%)	13 (8-30)
Nontraumatic arthritis	10 of 13 (77%)	12 (10-18)
Subtalar dislocation	10 of 13 (77%)	10 (8-12)
Residual talocalcaneal coalition	6 of 8 (75%)	10 (8-10)
Failure of previous subtalar arthrodesis	20 of 28 (71%)	15 (10-30)

*We found no significant difference between any two groups.
†The values are expressed as the number of feet, with the percentage in parentheses.
‡The values are expressed as the average, with the range in parentheses.

used to assess functional outcome. The maximum postoperative score was reduced from 100 to 94 points by elimination of the 6 points assigned to subtalar motion.

The radiographic assessment included an evaluation of lateral and anteroposterior radiographs of the foot, two Broden radiographs of the hindfoot, and an anteroposterior radiograph of the ankle. Radiographic union was determined on the basis of the lateral radiograph and the two Broden radiographs (as assessed at postoperative visits). Progressive arthritis of adjacent joints was determined on the basis of all five views.

Complications were categorized as delayed union or nonunion, lateral impingement, prominent hardware, sural neuralgia, symptomatic valgus or varus malalignment of the hindfoot (defined as more than 10 degrees of valgus or more than 5 degrees of varus relative to anatomical alignment), and infection.

Statistical analysis was performed to determine the impact of several variables (height, weight, pathological findings leading to subtalar arthrodesis, smoking status, systemic illness, the failure of a previous subtalar arthrodesis, the type of bone graft, the use of one versus two screws for internal fixation, and the presence of avascular bone at the arthrodesis site) on the time to union and the rate of union. The methods of analysis included the unpaired Student t-test, chi-square analysis, one-way analysis of variance with a Scheffé ranges test, two-way analysis of variance, and a forward stepwise multiple-regression analysis. The level of significance was set at $p < 0.05$.

The final clinical and radiographic results were determined only for the 139 patients (148 feet) who were seen at the time of follow-up. However, data regarding nonunion, infection, and prominent hardware was available from a review of the charts of all 174 patients (184 feet).

Results

Study Group

Of the 174 patients (184 feet), thirty-one patients (thirty-two feet) were lost to follow-up: three patients (three feet) died, four patients (four feet) were contacted but declined to participate, and twenty-four patients (twenty-five feet) had moved from the area or could not be located, or both. Of the remaining 143 patients (152 feet), four patients (four feet) were evaluated with use of a telephone interview and a follow-up questionnaire without physical or radiographic examination and 139 patients (148 feet) had a clinical and radiographic examination at an average of fifty-one months (range, twenty-four to 130 months) postoperatively. Of these 148 feet, 142 were seen at our institution and six were seen by orthopaedic surgeons at other institutions closer to the patients' residences. Although these latter patients did not return to our institution, independent follow-up (with completion of the standardized questionnaire as well as a physical examination to determine the ankle-hindfoot score[14]) was possible with the assistance of the local orthopaedic surgeons. Radiographs for these patients were forwarded to our office for review.

Clinical Outcome

In the group of 139 patients (148 feet) who were evaluated both clinically and radiographically at the time of the present study, the average score according to the modified system of the American Orthopaedic Foot and Ankle Society[14] (maximum, 94 points) improved from 24 points (range, 0 to 54 points) preoperatively to 70 points (range, 12 to 94 points) at follow-up. The average pain score (maximum, 40 points) improved from 2 to 27 points, whereas the average functional score (maximum, 45 points) improved from 20 to 35 points. Eighty-four percent (117) of the 139 patients had returned to a level of activity and a work status that were equal to those before the onset of their hindfoot symptoms, whereas 16 percent (twenty-two) had had no improvement in their level of activity or work status.

Influence of Pathological Findings on the Results

With the numbers available for study, we found no significant relationship between the clinical outcome and the pathological findings that led to subtalar arthrodesis. However, the outcome was most favorable for patients who had had the procedure because of residual talocalcaneal coalition and least favorable for those who had had the procedure because of the failure of a previous subtalar arthrodesis (Table I). Similarly, we

TABLE III
MODIFIED AOFAS* SCORE ACCORDING TO TYPE OF BONE GRAFT†

Type of Bone Graft	Number of Feet	Score‡ *(points)*
None	39	70 (30-94)
Cancellous autograft	94	73 (25-94)
Cancellous allograft	17	68 (46-90)
Structural autograft	29	64 (46-90)
Structural allograft	5	NA§

*AOFAS = American Orthopaedic Foot and Ankle Society.
†We found no significant difference between any two groups.
‡The values are expressed as the average, with the range in parentheses.
§NA = Not applicable. (The numbers were too small for analysis.)

could detect no significant relationship between the rate of union or the time to union and the pathological findings that led to subtalar arthrodesis (Table II).

Influence of the Method of Bone-Grafting on the Results

With the numbers available, we could detect no significant relationship between the type of bone graft that had been used and the average ankle-hindfoot score[14] (Table III). Similarly, we could detect no significant relationship between the type of bone graft and the rate of union or the time to union (Table IV). Although a nonunion occurred in three of the five feet that had been treated with structural allograft, the limited number of feet in that group precluded statistical analysis.

Union

Overall Union Rate

The overall union rate was 84 percent (154 of 184). The union rate was significantly influenced by smoking, evidence of more than two millimeters of avascular bone at the subtalar joint, and the failure of a previous subtalar arthrodesis ($p < 0.05$ for all). The nonunion rates that were determined according to clinical and radiographic criteria differed: thirty feet had clinical evidence of nonunion, whereas forty-two had radiographic evidence of nonunion. All thirty feet with clinical evidence of nonunion also had radiographic evidence of nonunion; thus, twelve feet had radiographic evidence of nonunion without corresponding clinical evidence.

A forward stepwise multiple-regression analysis was performed to examine the relationship between nonunion and six potential explanatory variables: age, gender, type of bone graft, smoking status, avascular necrosis, and number of screws. The occurrence of nonunion was best predicted with use of a model using avascular necrosis and type of bone graft ($r^2 = 0.366$, indicating that 36.6 percent of the occurrence was predicted). None of the other variables contributed significantly to the model.

It should be noted that although the use of fully threaded screws is generally recommended[5], the use of partially threaded screws is not contraindicated. Although partially threaded screws were associated with collapse of the graft in one patient (Figs. 4-A through 4-D), the collapse did not cause a clinical problem.

Influence of Smoking on the Union Rate

Eighty (46 percent) of the 174 patients were smokers at the time of the subtalar arthrodesis. Twenty-two (73 percent) of the thirty nonunions occurred in smokers (Figs. 4-A through 4-D). The union rate for smokers (73 percent; sixty-one of eighty-three feet) was significantly lower than that for nonsmokers (92 percent; ninety-three of 101 feet) ($p < 0.01$).

Influence of Avascular Bone on the Union Rate

A review of intraoperative findings recorded by the senior authors revealed that seventy-eight (42 percent) of the 184 feet had more than two millimeters of avascular subchondral bone at the subtalar joint. All thirty nonunions occurred in this group, resulting in a 62 percent rate of union (forty-eight of seventy-eight) for feet that had evidence of avascular bone according to our arbitrary criteria. Because all nonunions occurred in feet with more than two millimeters of avascular bone at the subtalar joint, the rate of nonunion was significantly higher among patients with avascular bone at the site of

TABLE IV
RATE OF UNION AND TIME TO UNION ACCORDING TO TYPE OF BONE GRAFT*

Type of Bone Graft	Rate of Union†	Time to Union‡ *(wks.)*
None	34 of 39 (87%)	11 (8-24)
Cancellous autograft	80 of 94 (85%)	11 (8-20)
Cancellous allograft	14 of 17 (82%)	13 (10-24)
Structural autograft	24 of 29 (83%)	16 (10-30)
Structural allograft	2 of 5 (40%)	16 and 20

*We found no significant difference between any two groups.
†The values are expressed as the number of feet, with the percentage in parentheses.
‡The values are expressed as the average, with the range in parentheses, for the groups that had been treated with no graft, cancellous autograft, cancellous allograft, and structural autograft. For the group that had been treated with structural allograft, the individual values are given for the two feet that had union.

TABLE V
ASSOCIATION BETWEEN AVASCULAR BONE AT SUBTALAR JOINT AND INDICATION FOR SUBTALAR ARTHRODESIS

Indication for Subtalar Arthrodesis	Avascular Bone at Subtalar Joint*
Failure of previous subtalar arthrodesis	21 of 28 (75%)
Calcaneal fracture	45 of 109 (41%)
Nontraumatic arthritis	4 of 13 (31%)
Residual talocalcaneal coalition	2 of 8 (25%)
Talar fracture	3 of 13 (23%)
Subtalar dislocation	3 of 13 (23%)

*The values are expressed as the number of feet, with the percentage in parentheses.

the arthrodesis ($p < 0.05$, chi-square analysis). As anticipated, the presence of at least two millimeters of avascular bone usually was observed in association with traumatic etiologies and with the failure of a previous subtalar arthrodesis. Surprisingly, however, such bone also was observed in association with nontraumatic etiologies (Table V).

Influence of Failed Previous Subtalar Arthrodesis on the Union Rate

The union rate was 86 percent (134 of 156) after primary arthrodesis and 71 percent (twenty of twenty-eight) after revision arthrodesis; this difference was significant ($p < 0.05$). The nonunion rate was 14 percent (twenty-two of 156) after primary arthrodesis and 29 percent (eight of twenty-eight) after revision arthrodesis. Of the twenty-eight feet that had a revision arthrodesis, twenty-three had been referred from other institutions and five had undergone previous operative procedures at our institution.

Influence of Other Factors on the Union Rate

Height, weight, the height-to-weight ratio, and systemic illness did not influence the union rate. Although the number of feet that had an attempted subtalar arthrodesis adjacent to the site of a previous ankle arthrodesis was too small for statistical analysis, our findings suggest that such treatment may be associated with a diminished rate of union; specifically, two of the six feet that were so treated went on to nonunion.

With the numbers available for study, we could detect no significant relationship between the union rate and the number of screws used for fixation: the union rate was 84 percent (129 of 153) when one screw had been used and 81 percent (twenty-five of thirty-one) when two screws had been used.

Analysis of Uncomplicated Subtalar Arthrodeses

To determine the union rate after subtalar arthrodeses that were uncomplicated by factors that might diminish the union rate, we eliminated various subgroups and reanalyzed the data. After eliminating the feet that had been treated with revision arthrodesis, structural bone graft (including allograft), and subtalar arthrodesis adjacent to the site of a previous ankle arthrodesis, the union rate improved by only 6 percent, from 84 percent (154 of 184) for the overall group to 90 percent (104

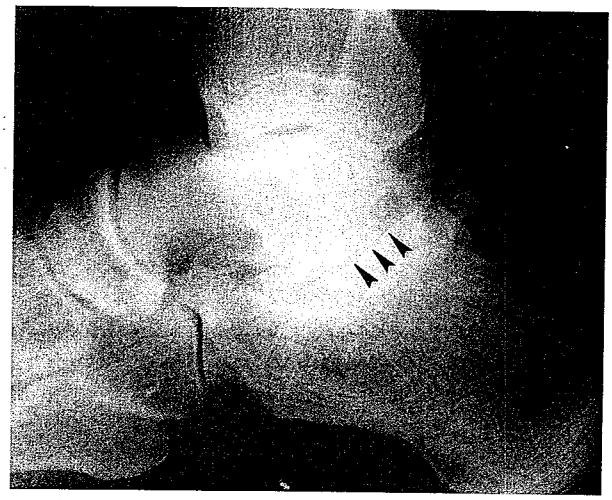

FIG. 4-A

Figs. 4-A through 4-D: A man who was fifty-six years old at the time of the index operation and had a history of smoking two packs of cigarettes a day. Symptomatic and recalcitrant subtalar arthritis developed after a dislocation of the subtalar joint.

Fig. 4-A: Lateral radiograph, made at the time of the index operation, showing erosion of the subtalar joint (arrowheads), a posterior fragment from the talus on the dorsal aspect of the posterior facet, anterior translation of the talus on the calcaneus, and loss of normal talar declination.

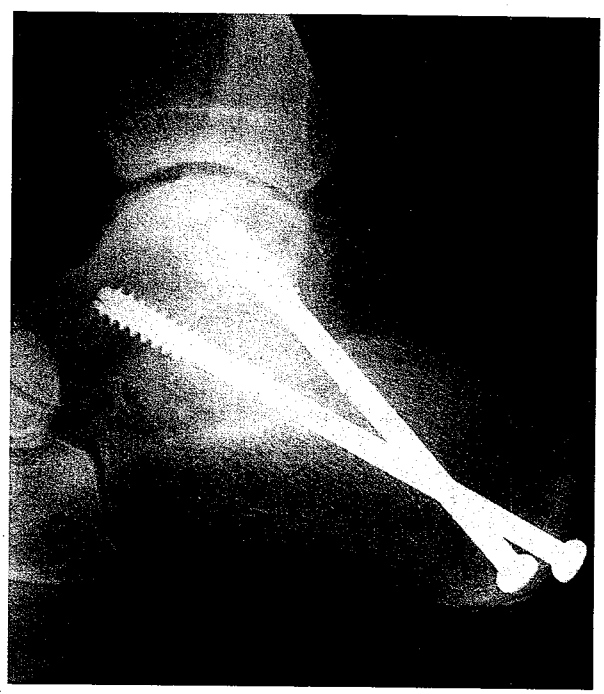

FIG. 4-B

Lateral radiograph made after subtalar bone-block arthrodesis and removal of the os trigonum.

of 116). However, when the patients who smoked were also eliminated, the union rate improved to 96 percent (seventy-three of seventy-six).

Radiographic Results

Preoperative and follow-up radiographs were available for 148 (80 percent) of the 184 feet. Preoperative radiographs revealed that fifty-one (34 percent) of the 148 feet were in patients who had evidence of degenerative changes in the ankle (twenty-five feet) or the transverse tarsal joint (twenty-six feet). Follow-up radiographs revealed that twenty (14 percent) of the 148 feet were in patients who had evidence of new or progressive degenerative changes in the ankle (five feet) or the transverse tarsal joint (fifteen feet). The discrepancy between radiographic and clinical evidence of nonunion was described earlier.

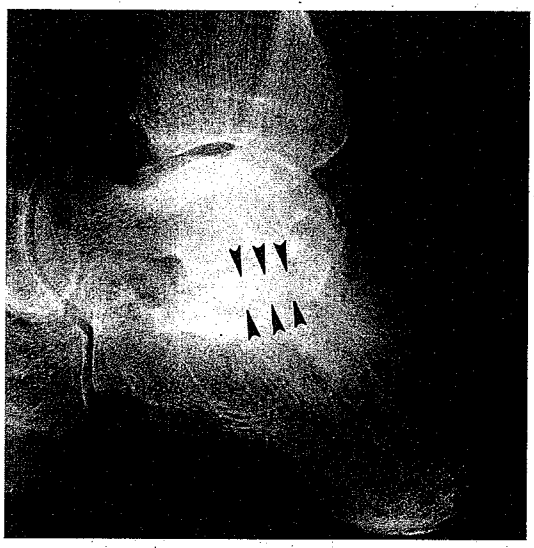

FIG. 4-C

Lateral radiograph, made nine months after the operation, showing collapse of the bone block (top arrowheads) and radiolucency (bottom arrowheads) between the bone block and the calcaneus. The partially threaded screws, which became prominent plantarly as the construct collapsed, have been removed.

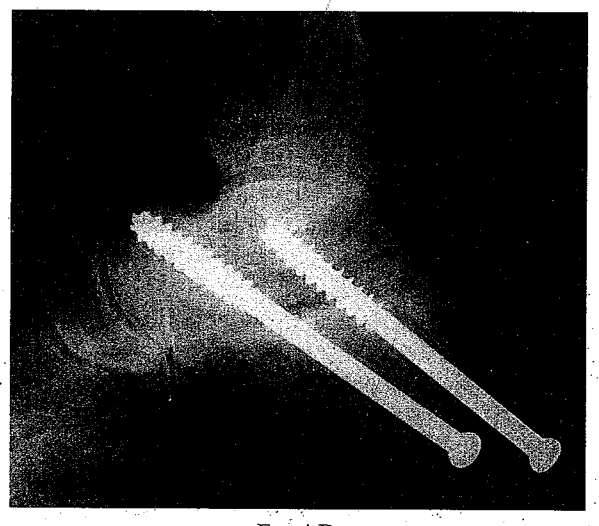

FIG. 4-D

Lateral radiograph, made sixteen months after the index operation, showing successful posterior fusion after revision subtalar arthrodesis, insertion of two screws, and placement of additional bone graft. The patient was asymptomatic at the time of the most recent follow-up.

Complications Other Than Nonunion

Complications other than nonunion included prominent hardware necessitating screw removal, infection, symptomatic malalignment of the hindfoot, lateral impingement, and sural neuralgia. Prominent hardware requiring screw removal was observed in thirty-six (20 percent) of the 184 feet, including thirty (20 percent) of the 150 feet treated with *in situ* subtalar arthrodesis and six (18 percent) of the thirty-four feet treated with distraction arthrodesis. With the numbers that were available for study, we could detect no significant difference in the prevalence of screw removal between the feet treated with *in situ* arthrodesis (in which compression is achieved) and those treated with distraction arthrodesis (in which compression is not achieved).

Infection occurred in five (3 percent) of the 184 feet. Two deep infections were treated with irrigation and débridement and intravenous administration of antibiotics. One of these deep infections resolved, and the hindfoot went on to union. The second deep infection occurred in a patient with a history of an open calcaneal fracture. Chronic osteomyelitis developed despite extensive débridements and long-term antibiotic therapy, and the patient ultimately had a below-the-knee amputation. The three superficial infections resolved uneventfully with administration of cephalexin (250 milligrams orally four times a day for five days) and dressing changes.

Symptomatic malalignment of the hindfoot was observed in nine (6 percent) of 148 feet. Four feet had excessive varus angulation (more than 5 degrees of varus relative to anatomical alignment) that was associated with overloading of the lateral part of the foot, which remained symptomatic despite orthotic treatment and shoe modifications. Five feet had excessive valgus angulation (more than 10 degrees of valgus relative to anatomical ligament) that was associated with clinical and radiographic evidence of subfibular impingement.

Lateral impingement was noted in fifteen (10 percent) of 148 feet. Eleven feet (including the five feet with symptomatic valgus malalignment of the hindfoot) had subfibular impingement, and the other four had impingement at the lateral shoulder of the talus that was symptomatic during forced dorsiflexion of the ankle or at the end of the stance phase of gait.

Sural nerve injury was noted in seventeen (9 percent) of the 184 feet. Three of the injuries could be directly related to the subtalar arthrodesis because they occurred in patients who had not had previous operative management. All three of these patients had been managed with distraction arthrodesis through a vertical posterolateral approach. The other fourteen nerve injuries occurred in patients who had had previous operative procedures on

the hindfoot: twelve of these injuries occurred in feet that had had open reduction and internal fixation of a calcaneal fracture either at our institution (three feet) or at another institution (nine feet), and two occurred in feet that had had failure of a previous subtalar arthrodesis that had been performed at another institution.

Discussion

To the best of our knowledge, our investigation represents the largest reported series of isolated subtalar arthrodeses in adult patients. This consecutive series comprised all subtalar arthrodeses that were performed in a high-volume foot-and-ankle practice during a seven-year period, regardless of the etiology that prompted the procedure or the operative technique that was used. Although the inclusion of a variety of diagnoses and operative methods creates a heterogeneous study group, it allows for the investigation of factors influencing the outcome. Furthermore, our study included the largest reported series of bone-block distraction arthrodeses and the only reported series of revision subtalar arthrodeses of which we are aware.

The results of the present study supported our hypothesis that subtalar arthrodesis is associated with a less favorable outcome and a higher rate of complications (including nonunion) than has been previously reported. Traditionally, isolated subtalar arthrodesis has been associated with high rates of patient satisfaction, low rates of complications, and an essentially negligible rate of nonunion[17,18,24]. We have identified several explanations for our finding that isolated subtalar arthrodesis has a less favorable outcome than has been suggested in the literature.

First, many of the investigators who have reported the results of isolated subtalar arthrodesis lacked the objective, accepted assessment tools now available. Although the ankle-hindfoot scoring system of the American Orthopaedic Foot and Ankle Society[14] combines objective and subjective criteria, it has been deemed a valid assessment tool and has gained universal acceptance among most foot and ankle surgeons[2-4,10,16,18]. With the loss of hindfoot motion after subtalar arthrodesis, the maximum possible score is 94 points rather than 100 points as originally described[14]. Mangone et al.[16] demonstrated that this modification of the system represents an accurate and objective means of determining the outcome of subtalar arthrodesis, despite the elimination of the 6 points normally assigned to subtalar motion. Most previous studies on subtalar arthrodesis, like the current study, have included this modified version of the scoring system in which the maximum possible score is reduced to 94 points[2-4,10,16]; one exception was the report by Mann et al.[18], in which the 6 points for subtalar motion were reassigned to transverse tarsal motion. The average follow-up score in the present study (70 points) was consistent with those reported in several recent investigations: Flemister et al.[10], in a large series of isolated subtalar arthrodeses that were performed for posttraumatic degenerative joint disease, reported an average score of 74 points; Mangone et al.[16], in a series of subtalar arthrodeses that were performed for a variety of pathological findings, reported an average score of 77 points; and Bednarz et al.[2] and Burton et al.[4], in series of subtalar bone-block distraction arthrodeses, reported average scores of 75 and 76 points, respectively.

Second, we investigated all types of subtalar arthrodeses in this consecutive series of patients, including revision arthrodeses, arthrodeses performed with use of allograft, and arthrodeses performed adjacent to the site of a previous ankle arthrodesis. Although these cases represented only a minority of the procedures in our series, they appear to have had an influence on the outcome for the entire group: a nonunion occurred in eight (29 percent) of the twenty-eight feet that had had a failure of a previous arthrodesis, in three of the five feet that were treated with structural allograft, and in two of the six feet in which the subtalar arthrodesis was performed adjacent to the site of a previous ankle arthrodesis.

Third, smoking has been shown to have a negative influence on the rate of union[7]. Eighty (46 percent) of the 174 patients in the present study were smokers, and twenty-two (73 percent) of the thirty nonunions occurred in smokers. The rate of union among smokers was significantly lower than that among nonsmokers ($p < 0.01$). Bednarz et al.[2], in their study of bone-block distraction arthrodeses, reported a nonunion rate of 14 percent (four of twenty-eight patients) and noted a strong association between smoking and nonunion. The rate of nonunion in that study is similar to the overall rate in our study (16 percent; thirty of 184 feet) as well as the rate in our subgroup of patients who were managed with bone-block distraction arthrodesis with use of structural autograft (17 percent; five of twenty-nine feet).

Fourth, we believe that the presence of avascular bone at the subtalar joint has a negative influence on the results, particularly the rate of union. We acknowledge that our assessment of avascular bone at the subtalar joint is arbitrary. The designation of two millimeters of avascular subchondral bone is not based on any previously established classification system, and it is not intended as a proposed classification system; this arbitrary designation of avascularity simply served as a means to objectively and quantitatively identify feet with a substantial amount of avascular subchondral bone at the site of the subtalar arthrodesis. We recognize that the factors influencing the rate of fusion at the ankle are not identical to those influencing the rate of fusion at the subtalar joint; however, in our opinion, the effect of avascular subchondral bone at the subtalar joint is analogous to the effect of avascular subchondral bone at the ankle joint as described by Holt et al.[13] and Frey et al.[11].

With the numbers available for study, we could detect no significant relationship between height, weight, the height-to-weight ratio, or systemic illness and the

outcome or the rate of union. Except for the failure of a previous subtalar arthrodesis, the pathological findings that prompted the index procedure had an unremarkable influence on the outcome or the time to union. Aside from the poor results observed when structural allograft was used, the method of bone-grafting had no influence on the outcome or the rate of union. The limited number of structural allografts did not permit statistical analysis; however, because a nonunion occurred in three of the five feet that had been treated with a structural allograft, we cannot advocate the use of structural allograft at this time. With the numbers available, we could detect no significant relationship between the rate of union and the number of screws used for fixation: the rate of union was 84 percent (129 of 153) when one screw had been used and 81 percent (twenty-five of thirty-one) when two screws had been used.

Complications other than nonunion included prominent hardware, infection, lateral impingement, symptomatic malalignment, and sural neuralgia. Prominent hardware was not more prevalent among feet that had been treated with bone-block distraction arthrodesis, and the rate of screw removal was not different from that associated with *in situ* arthrodesis. Despite the lack of intraoperative clinical and radiographic evidence of hardware prominence, 20 percent (thirty-six) of the 184 feet required screw removal. An infection occurred in 3 percent (five) of the 184 feet: all three superficial infections resolved uneventfully, and one deep infection improved after débridement and intravenous administration of antibiotics. The fifth infection, which developed in a patient who had a history of an open calcaneal fracture, ultimately necessitated a below-the-knee amputation. Lateral impingement occurred in 10 percent (fifteen) of 148 feet, either in the subfibular region or at the lateral shoulder of the talus. Although five of these cases of impingement were attributable to symptomatic valgus malalignment of the hindfoot, the other ten occurred despite neutral alignment and lateral-wall decompression. Symptomatic varus malalignment was noted in four patients, all of whom had overloading of the lateral aspect of the foot at the time of follow-up. The malalignment failed to respond to nonoperative treatment, and the patients were considered candidates for hindfoot osteotomy. Our results indicate that sural neuralgia typically is related to previous operative intervention (such as open reduction and internal fixation of a calcaneal fracture), but we also noted an increased prevalence among feet that had been treated with bone-block distraction arthrodesis through a vertical posterolateral approach, which places the sural nerve at risk.

Mann et al.[18] reported that the prevalence of mild or moderate progression of degenerative changes in the adjacent joints was 36 percent (twelve of thirty-three) for the ankle and 41 percent (thirteen of thirty-two) for the transverse tarsal joint. Those authors reported that the motion of the transverse tarsal joint was reduced according to objective clinical criteria. Our radiographic findings support those of Mann et al. In the present study, the prevalence of progression of degenerative changes in the adjacent joints was 14 percent (twenty of 148). We surmise that the prevalence of progression in our study was lower because the prevalence of degenerative changes on preoperative radiographs was substantial (34 percent; fifty-one of 148), which makes the determination of mild radiographic progression less obvious.

It stands to reason that there is an inverse relationship between the technical complexity of subtalar arthrodesis and the rate of union. However, even after elimination of what we considered to be the most complex procedures (those performed after the failure of a previous subtalar arthrodesis, those performed with use of structural grafts, and those attempted adjacent to the site of a previous ankle arthrodesis), the union rate improved by only 6 percent (from 84 percent [154 of 184] to 90 percent [104 of 116]). When the group was limited to nonsmokers, the union rate improved to 96 percent (seventy-three of seventy-six), which is consistent with the findings of several other large studies of isolated subtalar arthrodesis[8,10,18,24]. Therefore, our experience indicates that smoking has a negative influence on the rate of union following subtalar arthrodesis. Because all thirty nonunions occurred in feet that had had more than two millimeters of avascular subchondral bone at the subtalar joint, elimination of that group would have increased the rate of union to 100 percent (106 of 106). We therefore believe that it is important to inform the patient that the intraoperative detection of substantial avascular bone may diminish the chance for successful fusion. However, the etiology of the nonunions was multifactorial because 62 percent (forty-eight) of seventy-eight feet with more than two millimeters of avascular bone went on to have a successful fusion.

In conclusion, the results of isolated subtalar arthrodesis in adults are satisfactory, but, based on the recently introduced ankle-hindfoot scoring system of the American Orthopaedic Foot and Ankle Society[14], they are not as favorable as those reported by previous authors who used a variety of less objective assessment methods. Factors that had a significant influence on the union rate included smoking, the presence of avascular subchondral bone at the arthrodesis site, and the failure of a previous subtalar arthrodesis. Other factors that probably affect the union rate include the use of structural allograft and the performance of the arthrodesis adjacent to the site of a previous ankle arthrodesis. The rate of nonunion following subtalar arthrodesis probably is determined not by a single factor but, rather, by a combination of these and other factors.

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