Foot function after subtalar distraction bone-block arthrodesis

A PROSPECTIVE STUDY

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Subtalar distraction bone-block arthrodesis for malunited calcaneal fractures was performed in 31 patients (26 men, five women), with a mean age of 38.5 years. The mean time from injury to arthrodesis was 36 months. There were no cases of nonunion.

One patient had an early dislocation of the bone block requiring a repeat arthrodesis, and one had a soft-tissue infection. The mean AOFAS hindfoot score improved significantly from 23.5 before operation to 73.2 at a mean follow-up of 33 months ($p > 0.001$). Compared with the unaffected side, the talocalcaneal height was corrected by 61.8%, the talus-first metatarsal axis by 46.5%, the talar declination angle by 38.5% and the talocalcaneal angle by 35.4%. Dynamic pedobarography revealed a return to normal of the pressure distribution during roll-over and a more energetic gait. The distribution of local transfer of load correlated well with the AOFAS score. The amount of correction of the heel height correlated with a normal pattern of pressure transfer on the heel ($p < 0.05$).

Displaced intra-articular fractures of the calcaneum when treated conservatively or reduced inadequately may cause serious malalignment of the hindfoot. The most common problems include painful subtalar arthritis, loss of calcaneal height with subsequent tibiotalar impingement and flattening of the longitudinal arch, increased calcaneal width causing fibulocalcaneal abutment and impingement of the peroneal tendons, as well as axial malalignment of the hindfoot.¹⁻⁵ These features are responsible for the alteration of the distribution of pressure in the adjacent joints and the transfer of load to the mid- and forefoot which results in a pathological gait.³ Subtalar arthrodesis eliminates the pain which occurs as a result of residual movement with severe joint incongruity.⁵⁻⁷ Decompression of the lateral wall of the calcaneum may relieve impingement of the peroneal tendons and fibulocalcaneal abutment. Decreased heel height with tibiotalar impingement and axial malalignment of the hindfoot can be corrected by re-orientation of the hindfoot.^{2,5,8-10}

Subtalar distraction bone-block arthrodesis was first described by Carr et al.⁸ It has been reported to be effective in correcting malalignment of the hindfoot due to various causes and to improve the functional outcome.¹⁰⁻¹⁵ So far there has been no prospective study of the evaluation of gait. In this study we prospectively assessed the function of the foot both clinically

and by dynamic pedobarography before and after subtalar arthrodesis. We were particularly concerned with the improved geometry of the hindfoot and function in a series of patients who had had a unilateral arthrodesis after a fracture of the calcaneum.

Patients and Methods

Between October 1994 and November 1998 a total of 31 patients (26 men, five women) underwent unilateral subtalar distraction bone-block arthrodesis for post-traumatic subtalar arthritis (Table I). Exclusion criteria were bilateral arthrodesis, *in situ* arthrodesis for degenerative subtalar arthritis and refusal to consent to participation in the trial. All patients had a malunited calcaneal fracture. It was combined with a fracture of the talus in two patients and a fracture of the navicular or cuboid in one each. Two of these patients had nonunion after attempted subtalar arthrodesis carried out elsewhere, one with partial avascular necrosis of the talus. Twenty of the patients had been treated conservatively and 11 operatively. All presented with severe subfibular pain which was not relieved by conservative measures such as insoles, orthoses, change of activities, analgaesics or physiotherapy. The predominant clinical findings were deformity of the hindfoot (loss of longitudinal arch and calcaneal height with anterior ankle impingement, varus/valgus deformity and broadening

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Table I. Details of the 31 patients

Case	Gender	Age (yrs)	Mechanism of injury	Type of fracture, side*	Time to surgery (mths)	Follow-up (mths)	Concomitant injuries	Initial treatment†	Special remarks	AOFAS score	
										Pre-op	Post-op
1	M	36	Fall	Calc # R	36	42		Op		38	84
2	M	26	MVA‡	Calc # R	33	44	Polytrauma	Op	Screw removal	14	73
3	M	23	MVA	Navicular # + Calc # R	7	24	Pelvis #	Op		16	74
4	M	29	MVA	Calc + Cuboid # R	38	48	Femur # R	Op	Additional femoral derotation	19	74
5	M	27	MVA	Calc # L	120	30		Cons		46	92
6	M	60	Crush	Calc # R	20	45		Op		16	66
7	M	35	Fall	Calc # L	8	68		Cons		32	76
8	M	46	Fall	Calc # + Talus	15	27	Bilateral malleolar #	Cons	Screw removal	22	75
9	M	45	Fall	Calc # R	25	30		Op		17	61
10	M	29	Fall	Calc # L	21	32		Cons		30	94
11	F	49	Fall	Calc # L	15	24		Cons		22	74
12	M	58	Fall	Calc # R	354	33		Cons	Screw removal	26	76
13	M	35	Fall	Calc # R	11	32	Polytrauma	Cons		16	52
14	M	40	Fall	Calc # L	15	27		Cons		22	69
15	M	54	Fall	Calc # R	108	26		Cons		15	72
16	F	41	MVA	Calc # R	12	40	Rib # L	Op	Screw removal	22	89
17	M	44	Fall	Calc # L	13	44		Cons		20	63
18	M	40	Fall	Calc # L	16	32		Cons		29	74
19	F	48	MVA	Calc # R	15	32	Scapho-lunate dissociations	Cons	Previous failed arthrodesis, calcaneocuboid arthrodesis, screw removal	23	78
20	F	28	Fall	Calc # L	19	48		Cons		26	79
21	M	45	Fall	Calc # L	31	25		Op		36	64
22	M	47	Fall	Calc # R	11	47		Cons		26	79
23	M	25	Fall	Calc # R	48	24		Cons	Tenotomy for claw toes	49	79
24	M	33	MVA	Calc # R	18	31		Cons	Tenotomy for claw toes	24	74
25	F	26	MVA	Calc + Talus # R	12	24	Dislocation of first toe L	Op	Tenotomy for claw toes	17	60
26	M	48	Direct crush	Calc # R	37	34		Op	Previous failed arthrodesis	21	61
27	M	20	MVA	Calc # L	7	33		Cons		21	71
28	M	56	Fall	Calc # R	25	34		Cons		18	79
29	M	52	Fall	Calc # L	14	32		Cons		10	57
30	M	38	Fall	Calc # R	18	24		Op		19	88
31	M	48	Fall	Calc # L	19	48	Pilon # R	Cons		18	61

* # = fracture; L, left; R, right

† op, operative; cons, conservative

‡ motor-vehicle accident

of the heel) combined with a considerably restricted range of movement in the ankle and subtalar joints. The mean age of the patients at the time of arthrodesis was 38.5 years (20 to 60). The mean time interval from injury to subtalar arthrodesis was 35.7 months (7 to 345). All patients were prospectively evaluated with respect to the clinical and radiological findings, functional scoring and pedobarography. There was an identical protocol for follow-up (see below).

Operative technique. Surgery was carried out by two authors (RG, HZ). All patients had general anaesthesia and received a single injection of a prophylactic antibiotic. In those who had been treated conservatively at the time of the original accident, a posterolateral approach (Gallie incision) was used. Patients were placed prone, a tourniquet was applied to the thigh and the posterior iliac crest was

draped free. A vertical skin incision 4 to 8 cm long was placed halfway between tendo Achillis and the lateral malleolus. Care was taken not to injure the sural nerve and the lesser saphenous vein at the proximal end of the incision. After dissecting the crural fascia, the subtalar joint was approached between flexor hallucis longus and the peroneal tendons. In patients who had been treated by open reduction and internal fixation as a primary procedure, the previous extended lateral approach was used and the implant removed. These patients were placed in a lateral position on the unaffected side and tourniquet applied to the thigh. The ipsilateral anterior iliac crest was draped free.

In cases of severe lateral bulging with subfibular impingement, lateral decompression of the calcaneal wall was carried out with an osteotome while protecting the peroneal

Fig. 1a

Fig. 1b

Fig. 1c

Fig. 1d

Diagrams and radiograph of the operative technique. The calcaneal height and talus-first metatarsal axis a) are corrected with the interposition of tricortical iliac bone grafts b) which are tailored according to the pre-operative planning. Figure 1c – Realignment is checked fluoroscopically or by an intra-operative radiograph and d) fusion is achieved with one or two cancellous (cannulated) bone screws. (Figures 1a, 1b and 1d reprinted with permission from *Operat Orthop Traumatol*).⁹

tendons and preserving their sheaths. Extensive fibrous tissue was removed from the joint and a laminar spreader was introduced into the subtalar joint. The talar and calcaneal joint surfaces were freed from all residual cartilage and sclerotic subchondral bone, which was best accomplished with an osteotome. Care was taken not to injure the posterior tibial neurovascular bundle running posteromedially. Under fluoroscopy the talus and calcaneus were realigned as had been planned before the operation. They were distracted and transfixed temporarily with two Kirschner wires (Fig. 1). In cases of marked soft-tissue scarring a medial half-pin distracter was applied to the tibia and calcaneus and the correct position of the talus and calcaneus was obtained. Fluoroscopically, the height of the heel which had been achieved was checked on a lateral view and axial talocalcaneal alignment on a 40° Brodén view.⁴ In cases of doubt, intra-operative standard radiographs were obtained. Two tricortical bone blocks from the ipsilateral iliac crest were tailored to the resulting subtalar joint space

and introduced as a press fit with the heel in slight valgus (approximately 5°). No allografts were used. One or two 6.5 mm cancellous screws were introduced through stab incisions over the heel from the posterior calcaneal tuberosity into the talar body. Alternatively, a 7.3 mm cannulated screw was used (Fig. 1). The decision to use a second screw was based on the surgeon's assessment of the stability of the hindfoot after placing the first one. If only one screw was inserted from the tuberosity, an additional 3.5 mm cancellous screw was passed through the anterior calcaneal process into the talar head to avoid rotation around the cancellous screw in the calcaneus. The wound was closed in layers and a suction drain was retained for two days. The result achieved was recorded by standard radiographs.

After operation a below-knee cast was applied and the leg was elevated. Isometric exercises were begun on the first post-operative day and patients were mobilised non-weight-bearing on crutches. At four to six days a flexible arthrodesis boot (Variostabil; Adidas Inc, Herzogenaurach,

Fig. 2

Lateral radiograph showing the measurement on a normal foot (adapted from Buch et al).¹⁷ The distances are depicted in white with double arrows (TCH, talocalcaneal height; CFD, cuboid-to-floor distance; NFD, navicular to floor distance). The angular measurements are depicted in black (TFMA, talus first metatarsal angle; TCA, talocalcaneal angle; TDA, talus declination angle; CP, calcaneal pitch angle).

Fig. 3a

Fig. 3b

Fig. 3c

Fig. 3d

Lateral (a) and axial (b) weight-bearing radiographs of a patient before and after arthrodesis. There is correction of the TCH and TFMA in the lateral view (c) and post-traumatic varus malalignment in the axial view (d).

Germany) was fitted and the patients were allowed to walk with partial weight-bearing (20 kg) for ten weeks. At that stage, fusion was assessed radiologically and then full weight-bearing was allowed in the patients' own shoe. Removal of internal fixation was necessary in seven patients who had either a prominent screw head or plantar callosities.

Follow-up. All the patients were examined at six and 12 weeks after operation. The pre- and post-operative assessments were by two authors (SR and TZ) and followed the same protocol. The results were documented in a questionnaire with respect to overall patient satisfaction, subjective complaints and performance of activities of daily life, work and sports. The patients' height, weight and smoking status

Fig. 4

Diagram showing the regions of interest for pedobarographic analysis according to Sharma et al.²⁰ (RF, rearfoot; MF, midfoot; MT, metatarsals; and D, toes).

Table II. Clinical findings on examination, by number and percentage

	Before correction	After correction
Chronic ankle oedema	25 (80.6)	5 (16.1)
Peroneal impingement	27 (87.1)	2 (6.4)
Hypoaesthesia lateral hindfoot	3 (9.6)	4 (12.9)
Restriction of toe extension	4 (12.9)	4 (12.9)
Painful tendo Achillis	-	1 (3.2)

were recorded as well as the presence of systemic illness, focusing on diabetes, peripheral vascular disease and immunological disorders. Clinical examination included assessment of the scar, swelling, symptoms related to the sural nerve, alignment of the hindfoot, the ability to walk on heel or tiptoe, muscular and tendinous problems, stability of the hindfoot and pain with lateral/medial stress. The range of movement in the ankle and midtarsal joints was measured with a goniometer and compared with that of the unaffected side.

The functional results were evaluated using the AOFAS ankle hindfoot scale.¹⁶ The six points for the range of hindfoot movement (eversion plus inversion) could not be assigned, so that the maximum score was 94 points. Weight-bearing lateral, anteroposterior and axial radiographs were obtained for all patients. The following parameters were assessed from the lateral radiographs: the talocalcaneal height (TCH), the cuboid-to-floor distance (CFD), the navicular-to-floor distance (NFD), the talus first metatarsal angle (TFMA), the talocalcaneal angle (TCA), the talus declination angle (TDA), and the calcaneal pitch angle (CP) (Fig. 2).¹⁷ Tibiocalcaneal alignment was evaluated on the axial weight-bearing radiographs (Fig. 3). Arthritic changes in the ankle and mid-tarsal joints were recorded by a modified Bargon scale¹⁸ in which grade 1 indicated the absence of arthritic changes, grade 2 mild arthritis (subchondral sclerosis, lateral osteophytes) and grade 3 severe arthritis (subchondral cysts, narrowing of the joint space, uneven joint surfaces). Bony union was assessed on the lateral radiographs (Fig. 3).

Dynamic pedobarography was carried out using a capacitive EMED S platform (Novel Inc, Munich, Germany) of 40 x 25 cm with a resolution of 4 sensors/cm². This allowed

assessment of the vertical ground reaction force during the whole gait cycle.¹⁹ The platform was included in a 4 m walkway on which patients walked freely at their normal speed. Five consecutive measurements were obtained for both feet. Eight regions of interest of the footprint were defined according to Sharma et al.,²⁰ namely rearfoot, midfoot, first metatarsal head, second metatarsal head, third to fifth metatarsal head, first toe, second toe, and lesser toes (Fig. 4). Data were recorded using the Novelwin software (Novel Inc). The following parameters were calculated for each region of interest and the foot as a whole, namely, pressure-time integral, maximum pressure, contact time and contact area. The gait line (centre of pressure line) was measured for the whole foot and lateral and medial gait line integrals were calculated.

Statistical analysis. This was performed using SPSS software for Windows (SPSS Inc, Chicago, Illinois) with the paired two-tailed *t*-test to compare pre-operative with post-operative parameters. A normal distribution was assured by the chi-squared test. We examined the correlation between the AOFAS score and the radiological and the pedobarographic results. Significance was assumed at *p* < 0.05.

Results

Complications. There were post-operative complications in four of the 31 patients (12.9%), which required surgical intervention in two (6.4%). One patient had dislocation of the bone block after two months following early weight-bearing with resultant varus malposition of the hindfoot. A Dwyer osteotomy and a secondary correction (valgus) osteotomy of the calcaneum with bone grafting from the iliac crest were carried out which restored normal alignment of the hindfoot. The further course was uneventful with sound fusion. Another patient with pre-existing varicosities of both legs developed a persistent soft-tissue infection which resolved over a protracted course with local wound care and antibiotics, but with residual impairment of function. One patient developed a painful plantar exostosis three months after surgery. The symptoms resolved completely after removal of the internal fixation and the exostosis. One patient had an allergic local skin reaction which settled uneventfully.

Clinical findings. Follow-up assessment was carried out after a minimum of two years. The mean follow-up period was 32.7 months (24 to 68). Subjectively, nine patients (29.0%) rated the result as excellent, 18 (58.1%) as good, eight (25.8%) as fair and two (6.5%) as poor. Before operation, all patients had rated the result of the treatment of the fracture as poor. Overall, 29 of the 31 patients (93.6%) were satisfied with the result and stated that under the same circumstances they would undergo the procedure again. All 31 patients had a stable hindfoot subjectively and clinically. On clinical inspection no gross deformities of the foot were seen. The surgical scars were sound. Two patients had mild dysaesthesia along the course of the sural nerve. Some

Table III. Mean (range) AOFAS scores before and after correction

	Before correction	After correction	p value
Pain	3.9 (0 to 20)	29.0 (20 to 40)	<0.001
Function	17.3 (10 to 29)	35.2 (26 to 44)	<0.001
Aspect	2.3 (0 to 5)	9.0 (5 to 10)	<0.001
Overall	23.5 (10 to 49)	73.2 (52 to 92)	<0.001

Table IV. Mean (range) radiological measurements before and after correction

	Before correction	After correction	Unaffected side
TCH (mm)	76.7 (67 to 89)	81.2 (70 to 93)*	84.0 (72 to 98)*
CFD (mm)	13.5 (6 to 20)	13.2 (6 to 19)	17.8 (11 to 26)
NFD (mm)	33.2 (19 to 45)	36.2 (23 to 45)*	32.9 (23 to 40)
TFMA (°)	9.7 (0 to 25)	5.7 (-10 to 19)*	1.1 (-8 to 12)*
TDA (°)	10.8 (-2 to 25)	14.5 (4 to 22)*	20.4 (13 to 26)*
TCA (°)	19.7 (0 to 38)	23.7 (11 to 34)*	31.0 (18 to 37)*
CP (°)	17.4 (7 to 24)	17.1 (8 to 22)	21.2 (12 to 28)*

* p < 0.001

important clinical parameters are summarised in Table II. One patient had undercorrection of the valgus malalignment and had painful restricted movement of the ankle after a pilon fracture. Another had disuse osteopenia and stiffness of the ankle after a protracted course of soft-tissue infection. Of 28 patients who had been employed before the accident 17 (60.7%) were still working in their previous occupations. Five patients (17.9%) had changed their occupation, but were working full-time. Three (10.7%) were working part-time and another three did not resume work.

The mean AOFAS hindfoot score improved significantly from 23.5 (10 to 49, SD 9.0) before to 73.2 (52 to 94, SD 10.2) after operation ($p > 0.001$). The individual scores are listed in Table I and the score sections are summarised in Table III. Active ankle dorsiflexion improved slightly from a mean of 7° (0 to 30) before to a mean of 8° (-20 to +20) after operation, while active ankle plantar flexion de-

creased significantly from a mean of 37° (20 to 50) before to a mean of 30° (10 to 40) after operation ($p < 0.001$).

Radiological findings. All patients achieved solid union of the arthrodesis. Varus malalignment of the hindfoot of more than 5° as noted on the axial views of eight patients before arthrodesis was corrected in six, and valgus malalignment of more than 10° as seen in three patients before correction was corrected in all three. There was no loss of correction noted at the time of follow-up. Broadening or shortening of the calcaneum of more than 20% compared with the unaffected side in the axial radiographs was seen in 21 patients before arthrodesis and was corrected in 15.

The mean pre-operative and post-operative radiological measurements are given in Table IV. While the TCH, TFMA, TDA and TCA improved significantly after the arthrodesis ($p < 0.001$), the measurements still fell short of reaching those of the unaffected contralateral side. Compared with the unaffected side, the loss of the TCH was corrected by 61.8%, the TFMA by 46.5%, the TDA by 38.5% and the TCA by 35.4%. The CFD and the CP did not change significantly after arthrodesis.

Mild arthritic changes in the ankle (grade 2) were seen in four patients before and in six patients after correction. In the talonavicular joint grade-2 arthritic changes were noted in eight patients and grade-3 changes in three before correction. The arthritis changed from grade 2 to 3 in two patients after subtalar arthrodesis. The number of patients with grade-2 arthritic changes in the calcaneocuboid joint increased from 4 to 5 and with grade-3 arthritis from 11 to 13 after correction. Overall arthritic changes increased in two of the 31 patients (6.5%) in the ankle and talonavicular joints and in three (9.7%) in the calcaneocuboid joint.

Pedobarographic findings. The mean pressure-time integral as a global measure of loading of the foot increased for the whole foot from 36.1 ± 15.0 N/cm² to 39.6 ± 15.1 N/cm² on the affected side and from 41.7 ± 16.2 N/cm² to 44.3 ± 15.9 N/cm² on the unaffected side. The values for the dif-

Fig. 5

The pressure-time integral over the regions of interest (see Fig. 4) before and after arthrodesis. The unaffected side served as a control (first and second columns).

Pedobarograph a) before and b) after correctional subtalar arthrodesis of the patient in Figure 3. There is unloading of the heel and improved push-off at the metatarsal region after correction. The load is increased over the lateral midfoot and the gait line shifted laterally as compared with the pre-operative state and with the unaffected side (c).

ferent regions are shown in Figure 5. The mean loading of the heel decreased significantly with correction, reaching the values of the unaffected side, while the mean values increased significantly for the second to fifth metatarsal and lesser toes towards the normal values. The pressure-time integral for the midfoot region increased beyond normal values of the unaffected side after correction (Fig. 5). Similar results were obtained for the maximum pressure values. The maximum pressure values for the whole foot increased significantly from $70.7 \pm 25.2 \text{ N/cm}^2$ before correction to $81.6 \pm 28.7 \text{ N/cm}^2$ after correction ($p < 0.03$), which did not differ from the normal values of the unaffected side ($80.3 \pm 29.7 \text{ N/cm}^2$). The gait line moved laterally with subtalar distraction bone-block arthrodesis (Fig. 6) as measured by an increased lateral gait line integral (A_L , area between gait line and foot axis, Fig. 7). Accordingly, the medial gait line integral (A_M) decreased significantly ($p < 0.001$) after arthrodesis (Fig. 7), but the gait line moved significantly from lateral to medial on the uninjured side.

The mean contact time of the heel decreased significantly from $663 \pm 183 \text{ ms}$ before correction to a mean of $520 \pm 149 \text{ ms}$ after correction ($p < 0.003$), similar to that of the unaffected side ($529 \pm 186 \text{ ms}$). The mean contact times for the other regions of the foot and the whole foot did not change significantly with arthrodesis. No significant changes were found except for the lesser toes in which the contact area approached the values of the contralateral side.

A higher pressure-time integral for the whole foot correlated significantly with a higher AOFAS score at the time of follow-up ($p < 0.05$). Patients with a post-operative AOFAS

Fig. 7

Depiction of the medial (A_M) and lateral (A_L) gait line integral before and after arthrodesis (same patient as in Figs 3 and 6). There is considerable load shift from medial to lateral after correction which is reflected by a significant ($p < 0.001$) increase in the lateral gait line integral.

hindfoot score >75 had a greater pressure-time integral at the toes and lateral forefoot while those with scores <75 had a greater pressure-time integral at the hindfoot and midfoot ($p < 0.05$). The amount of correction of heel height

Table V. Summary of the main results from the literature

Author/s	Number of cases	Time from injury (mths)	Follow-up (mths)	Comp with the unaffected side	Union rate (%)	Correction of TCH (mm)	Satisfaction (%)*	AOFAS score	
								Before AD†	After AD
Carr et al ⁸	10	20	19	-	90	6	(80)	-	-
Myerson and Quill ²	14	23	32	-	100	7	(50)	-	-
Amendola and Lammens ¹¹	15	48	-	15	100	6	73	38.3	70.3
Chan and Alexander ¹³	9	-	74	-	100	-	77	<50	76.5
Bednarz et al ¹²	28	34	33	-	86	8	96	25	75
Burton et al ¹⁵	13	21	47	-	100	5	85	-	76.1
Chen et al ¹⁴	32	16	71	24	91	11	(81)	47.8	80.1
Marti et al ²⁶	23	-	108	23	96	6	78	-	-
Trnka et al ¹⁰	37	17	70	-	86	5	81	21.1	68.9
Our series	31	36	33	31	100	5	93	23.5	73.2

* if satisfaction rate was not explicitly given, the rate of good to excellent results was put in parentheses

† arthrodesis

(TCH) correlated significantly with the decrease of pressure over the heel ($p < 0.05$).

Discussion

Although the optimal treatment of calcaneal fractures is still somewhat controversial, the sequelae of malunited calcaneal fractures are well recognised.^{1,2,4,9,13,21} Besides painful subtalar arthritis secondary to joint incongruity, displaced calcaneal fractures may result in substantial hindfoot malalignment. While in situ arthrodesis has been reported to be successful in cases of isolated subtalar arthritis,^{2,6,7,22-25} gross depression and/or axial deviation of the calcaneum requires correction of calcaneal height and width as well as restoration of malalignment of the axial hindfoot.^{2,5,8,10,25} Subtalar distraction bone-block arthrodesis was first described by Carr et al⁸ and has been reported in several retrospective series since.^{2,10-15,26} To the best of our knowledge, no prospective and homogeneous study evaluated gait function before and after unilateral correctional subtalar arthrodesis for pure posttraumatic hindfoot deformity and its correlation with the clinical and radiographic results. There were few complications. The rate of union was 100%, which has been reached in some of the previous studies on subtalar bone-block distraction fusion (Table V). Trnka et al¹⁰ noted that in four of five cases of nonunion, an allograft had been used and concluded that the routine use of allograft for bone-block arthrodesis should not be recommended. Chen et al¹⁴ suggested inadequate decortication was responsible for one case of nonunion in 32 arthrodeses. There is consensus that viable bone must be present at the interfaces of the site of arthrodesis after resection, and all sclerotic, non-viable bone should be removed to achieve solid union.^{6,9,10,14}

Neuralgia of the sural nerve is a commonly reported complication after distraction arthrodesis of the subtalar joint, the incidence varying between 0% and 17%.^{2,8,10,15} In our study two patients (6.5%) reported dysaesthesia along the lateral side of the foot. While careful dissection and limited approaches may minimise direct damage to the nerve, slight traction is difficult to avoid and may lead to neuralgia.¹⁰ Only one patient complained on a painful

tendo Achillis after correction. No routine lengthening of tendo Achillis was performed. With the posterolateral (Gallie) approach²⁷ no wound complications were seen. We therefore agree with other authors who favour this approach.^{8,10,15} A curved incision appears to be more prone to dehiscence and is difficult to close distally.^{8,11} In our series an extended lateral approach to the calcaneum and subtalar joint was used in only nine patients in whom the internal fixation had to be removed after open reduction. The horizontal part of the incision was closed immediately after removal of the internal fixation.

The problem of plantar heel pain because of prominent screw heads is well recognised.^{10,11,14,15} However, the reported rates of removal of screws vary considerably from 0% to 50%.^{2,8,12,15} In the present series seven patients (22.6%) reported occasional heel pain which resolved when the screws were removed. Chan and Alexander¹³ noted no pain when the screw had been passed through the dorsal aspect of the talus. This approach, puts the neurovascular structures at risk and may lead to anterior tibiotalar impingement at the head of the screw.²³ Since the eversion/inversion movement of the subtalar joint allows adaptation of the foot on uneven ground, the loss of shock absorption after subtalar fusion could have provoked pain beneath the screw heads in some of the patients although the heads were not prominent.

Results of follow-up. Subjective patient satisfaction was 93.6%. This confirms the favourable results of subtalar distraction bone-block arthrodesis found in previous studies (Table V). The consistent outcome throughout the studies despite different follow-up periods suggests that the functional results do not deteriorate with time.

The radiological variables showed that despite statistically significant improvement of the TCH, TFMA, TDA and TCA, they fell short of the normal measurements (Table IV). Since the anatomical shape of the calcaneum was not altered by the arthrodesis except for decompression of the lateral wall, no changes were seen in the calcaneal pitch angle and cuboid-to-floor distance. Böhler's tuberosity joint angle^{11,28} is not useful for evaluation of the results of subtalar arthrodesis since the joint is fused with

bone blocks and the superior border of the calcaneum decorticated and thus not clearly delineated. At follow-up, the TCH was increased by a mean of 5 mm and TFMA corrected by a mean of 4°. The total amount of correction is comparable with that of other reports.^{8,10-14,26} Some of the previous studies achieved greater correction of single parameters (Table V). One reason may be the mean time from injury to arthrodesis of three years which was longer than in all previous series except for that of Amendola and Lammens.¹¹

Only three of the previous studies on subtalar distraction bone-block fusion compared some of the radiological results of correction with the unaffected contralateral side (Table III). Amendola and Lammens¹¹ noted complete restoration of the TCH but undercorrection of the TDA. Burton et al¹⁵ noted undercorrection of the TCH. Chen et al¹⁴ achieved correction of the TCH of 80.1% in patients with good functional results and of 47.6% in those with fair results. They noted also that the latter group had greater pre-operative deformity. By contrast, Marti et al²⁶ did not find any correlation between radiological parameters and functional results. The total amount of distraction is limited by soft-tissue shrinkage, muscular contracture and stiffness of tendo Achillis, which takes place over time with malalignment of the calcaneum after displaced fractures. Further distraction would possibly increase the risk of skin necrosis, pain in tendo Achillis, traction neuralgia to the sural nerve and compromise the tibial nerve.^{10,11} Some authors caution against the development of a central regional pain syndrome (CRPS).^{10,11} In our series with moderate correction no CRPS was seen. It can be concluded from the increase in the functional scores and patient satisfaction that, despite incomplete restoration of hindfoot geometry, subtalar distraction bone-block arthrodesis is effective in improving the function of the foot and reducing pain. In agreement with earlier studies, the TCH and TFMA which could be corrected substantially, appear to be the most important parameters for restoring the geometry of the hindfoot. With severe deformities an additional calcaneal osteotomy should be contemplated.^{8,29,30}

Pedobarographic analysis. The subtalar joint acts in close coupling with the ankle joint and strongly influences the performance of the distal foot.³¹ We wished to investigate the impact of subtalar arthrodesis on the function of the foot as measured by dynamic pedobarography. The main findings after arthrodesis were unloading of the heel and increased loading of the midfoot, lateral hindfoot and first two toes. A lateral shift of the gait line was observed after operation. The overall increased pressure-time integral and peak pressures over the whole foot were consistent with a more vigorous gait pattern because of the restored geometry of the hindfoot and reduced pain. Kitaoka et al³ observed a more energetic gait in patients with a good result after conservatively treated fractures compared with those who had a poor result. In our study patients with an overall score of more than 75 had a greater pressure-time

integral over the whole foot ($p < 0.05$). As the overall loading of the unaffected side was also increased, this indicated improved function and increased symmetry.

With an intact subtalar joint, the calcaneum goes into rapid eversion during heel strike and the longitudinal foot arch flattens. The reason for the pathological increase in heel pressures before arthrodesis presumably lies in the restriction of effective load transfer to the midfoot secondary to varus or valgus malposition of the heel and pain during eversion of the heel.^{19,32-34} This is further reflected by a significantly increased contact time over the affected heel before arthrodesis. After subtalar arthrodesis with correction of heel alignment and reduction of pain, heel loading and contact time were reduced to the normal values of the unaffected side. Consequently, patients with inferior functional results (AOFAS score < 75) and undercorrection of the TCH had persisting higher pressures beneath the heel.

With the foot flat the intact subtalar joint exercises progressive inversion.³¹ This movement is restricted with subtalar fusion and only minimal inversion can take place at the mid-tarsal (Chopart) joint. With a rigid subtalar joint more load is brought to the lateral column and leads to increased pressure on the lateral mid- and forefoot with lateral shift of the gait line (Fig. 7). Patients with inferior functional results (< 75) had greater pressure values beneath the midfoot. The increased transfer of load through the lateral column may be reflected by the increase in arthritic changes at the calcaneocuboid joint as found in other series.^{15,25,26} The progression of osteoarthritic changes at the calcaneocuboid joint did not produce symptoms or adversely affect the functional results. In order to unload the lateral column, especially at the midfoot level, fusion is recommended in a slight valgus position (approximately 5°).^{10,14} Alternatively, a calcaneal osteotomy may be added to the arthrodesis as we do in cases of severe malalignment.³⁰

By contrast, push-off at the first and second toes was increased substantially to normal values after arthrodesis which shows the value of movement in the Chopart and Lisfranc joints.

Despite considerable increase in talar declination, dorsiflexion of the ankle could not be improved. This agrees with earlier observations and reflects the fact that the subtalar joint complex also makes some contribution to plantar flexion and dorsiflexion of the hindfoot complex, which is eliminated by subtalar fusion.^{3,11,14} However, as in other series, no progression of arthritic changes in the ankle was observed.^{14,26}

Correctional versus *in situ* arthrodesis. Few studies have compared *in situ* arthrodesis with distraction arthrodesis. Flemister et al⁷ found a higher incidence of malunion and nonunion after subtalar bone-block distraction arthrodesis as compared with *in situ* arthrodesis. However, bone-block arthrodesis was performed in cases of severe shortening of the hindfoot and loss of talar inclination with an overall high rate of satisfaction. Myerson and Quill² found the

results of bone-block arthrodesis to be inferior to simple *in situ* arthrodesis. Again, the latter was reserved for cases of severe deformity. Huang et al³⁵ found significantly improved patient satisfaction after sliding corrective osteotomy with mild distraction compared with *in situ* arthrodesis for malunited fractures of the calcaneus. The failure to demonstrate significant differences in functional outcome was attributed to the fact that insufficient improvement of the TDA could be achieved with a sliding calcaneal osteotomy alone. Therefore, correctional distraction arthrodesis was advocated for patients with signs of tibiotalar impingement. Given the good correlation between the radiological and functional results in our study, subtalar distraction bone block arthrodesis should be preferred to *in situ* arthrodesis, with decompression of the lateral wall, in cases of marked loss of heel height and symptomatic tibiotalar impingement.

While some progression of degenerative changes in the ankle was seen after *in situ* arthrodesis,^{6,24} we did not observe any such progression. This suggests that the relief of tibiotalar impingement may halt further degenerative changes at the ankle although movement of the ankle could not be improved. The question of what degree of malalignment has to be corrected remains to be answered. Myerson and Quill² suggested that distraction arthrodesis be performed where there is loss of TCH >8 mm. It appears from the available material that a minimum correction of 5 mm can be reproducibly achieved, and even more correction may be possible if the time from the injury to arthrodesis is not more than two years.

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