Limb Reconstruction

ORIGINAL

K. Mader · C.C. Verheyen · T. Gausepohl · D. Pennig

Minimally invasive ankle arthrodesis with a retrograde locking nail after failed fusion

Abstract A retrograde nail with posterior-to-anterior (PA) locking into os calcis, talus and tibia was used to correct deformity and achieve fusion after failed fusion. A variety of methods have been published to achieve union of the ankle and subtalar joint in a failed fusion situation. We have studied a retrograde locking nail technique through a 2.5-cm incision in the non-weightbearing part of the sole of the foot. Remaining cartilage in the ankle joint, where necessary, was percutaneously removed through an anterior approach and the locking nail was inserted after reaming of os calcis, talus and tibia. Locking screw insertion was in the sagittal plane (p.a. direction), in talus os calcis and tibial diaphysis using a nail mounted jig. Ten patients were entered in the study (age 27–60 years). The initial aetiology for attempted fusion was post-traumatic in nine cases and rheumatic in one case. There were 25 previous operations in the cohort not leading to fusion. An additional temporary external fixator was used in four cases to reach and maintain the optimum position for the procedure. The intervention time was 30–75 min. Dynamisation of the nail was performed after four months under local anaesthesia. The mean duration of follow-up was 4 years (3–5.5 years). Radiologically and clinically, fusion was achieved in 16 weeks (range, 12–20 weeks). There was no loosening of the implant or implant failure. A leg length discrepancy was avoided using this technique. There was one complication with varus malunion in a heavy smoker which united after corrective osteotomy, revision nailing and bone grafting. Patient satisfaction was measured on a scale (not visual analogue) of 0 (not satisfied) to 10 (completely satisfied); overall satisfaction averaged 9.5 points (range, 6–10 points). The postoperative ankle-hindfoot score of the American Orthopedic Foot and Ankle Society averaged 73.5 points (range, 61–81 points). Retrograde locked nailing with locking in the sagittal plane is a reliable minimally invasive procedure to achieve fusion of the ankle and the subtalar joint after failed fusion.

Key words Ankle arthrodesis · Failed fusion · Retrograde nail · Calcaneotalotibial arthrodesis

K. Mader (✉) · D. Pennig
Department of Trauma and Orthopaedic Surgery, Hand and Reconstructive Surgery
St. Vinzenz-Hospital
Merheimer Straße 221–223, D-50733 Cologne, Germany
e-mail: k.mader@ndh.net

T. Gausepohl
Department of Trauma Surgery, Hand and Reconstructive Surgery
Paracelsus-Kliniken
Marl, Germany

C.C. Verheyen
Department of Orthopedic Surgery
Isala Clinic
Zwolle, The Netherlands

Introduction

Several treatment options are available for pain and disability due to post-traumatic arthritis and deformity of the ankle. In cases in which a tibiotalar arthrodesis is sufficient, this is usually performed by open or arthroscopic means, with bone graft when required [1, 2]. However, when severe deformity is present, or the subtalar joint is affected as well, either a calcaneotalotibial arthrodesis or a talectomy and calcaneotibial arthrodesis are to be considered [3]. Calcaneotalotibial arthrodesis has been described with the use of bonegrafting and cast, plating, screws and external fixation [4–6]. The combination of blade plate fixation and morcellised bone is the preferred method for

some foot and ankle surgeons due to the ability to provide rigid fixation, avoid a plantar foot incision and provide good clinical results [7–9]. Excision of the talus has been reported to yield unsatisfactory results, and has the major drawback of resultant shortening [3]. Screw fixation may be prone to implant migration and was demonstrated to have a low union rate [10]. External fixation is uncomfortable for the patient and has demonstrated a high rate of non-union and infection [5, 6].

Intramedullary fixation for ankle arthrodesis was first reported by Adams in 1948 and introduced by Carrier in 1991 for patients with rheumatoid arthritis using Steinmann pins, whereas retrograde locked nailing systems have been employed for post-traumatic arthritis by Kile and Moore, and for Charcot ankle joints by Pinzur and Stone [1, 11–14].

A retrograde nailing system locked in the posterior-to-anterior (PA) plane for performing tibiotalocalcaneal arthrodesis has been introduced by the senior author (D.P.) in order to increase rotational stability and bony purchase [15]. Using a prospective protocol, the efficacy of this minimally invasive method in achieving union in cases of failed fusion after attempted ankle arthrodesis with existing subtalar joint pathology after multiple interventions has been evaluated.

Materials and methods

Between 1996 and 1998 a total of ten patients with failed fusion after ankle arthrodesis were prospectively treated by arthrodesis using the retrograde nailing system: nine patients had post-traumatic ankle deformities, one had severe rheumatic arthritis. All but one patient had previous severe trauma to the ankle or distal tibia. All patients were available for follow-up (Table 1).

Eight patients were women, two were men. The mean age was 55 (range, 27–60 years). The mean height was 1.75 m (range, 1.55–1.90 m), and the mean weight was 74.6 kg (range, 60–95 kg). The mean interval between the injury and the index operation in the cases of post-traumatic arthritis was 24 months (range 10–500). In all cases, severe arthritis of the subtalar joints was confirmed by radiological and clinical examination, and existing pain in the subtalar joint was evaluated using injection of a local anaesthetic agent. In two patients there was an equinus deformity. A total of 25 previous operations had been performed for arthrodesis in the cohort (mean 3.0 operations per patient). These included attempted ankle arthrodesis (12), one patient suffered from diabetes mellitus, one had a history of renal failure, six were smokers and three had a history of infection. There were two neurogenic and two post-traumatic equinus deformities.

Plain radiographs in two planes were used to assess the extent of joint destruction and for pre-operative planning. A standard operative technique was used in all patients [15, 16]. In three patients equinus correction was effected by temporary application of a hinged external fixator with straight clamps and screw insertion from the medial side into the mid shaft of the tibia and the os calcis or tarsal bones.

Operative technique

The operation was performed either under general (five patients) or spinal anaesthesia (five patients). The patient was placed in a supine position on a radiolucent operation table and the leg was draped to enable fluoroscopic control during surgery. A tourniquet was used in all cases. The fusion goal was a neutral position in all patients, with 5° valgus and 10°–15° external rotation. In patients with preserved articular surface of the ankle joint percutaneous debridement was performed using a 6-mm drill bit via small arthroscopy-like portals under fluoroscopy control. The subtalar joint was not debrided as the subsequent drilling up to 12 mm for the 10/12 nail destroyed most of the subtalar joint. A fibula segment of 1.5 cm was excised 10–12 cm proximal to the fibula tip through a lateral incision. A 2.5-cm incision was made in the non-weightbearing part of the sole of the foot (Fig. 1) and with blunt plantar dissection extended to the distal surface of the os calcis, the neurovascular bundle being protected with Langenbeck retractors. The ankle was brought into the fusion position, and a sharp-tipped 5-mm Steinmann pin driven through the os calcis and talus into the distal tibia, and its position confirmed radiologically in both planes (Fig. 2). The 5-mm Steinmann pin was then replaced with a 3-mm guide wire and reaming was performed. In all cases a 12/10-mm diameter nail was used (Orthofix Srl, Bussolengo, Italy). The nail with the best suited length (140, 160 or 180 mm) was inserted into the handle and locked (Fig. 3). The nail was then inserted by hand over the guide wire, which was subsequently removed. With the nail holes in the frontal plane, a lateral view was taken with the image intensifier to confirm that the position of the most proximal of the distal holes was at the level of the posterior process of the talus. After turning the handle 90° to allow locking in the sagittal plane, the guide bar was mounted and PA locking carried out first in the talus and then in the os calcis using the appropriate drill and screw guides through stab incisions in the tendo Achilles (Figs. 4, 5). The direction of locking was aimed at the 2nd metatarsal, taking care not to penetrate the Chopart joints. The guide bar was then advanced to the corresponding nail length and tibial locking performed after manual impaction of the nail, after careful blunt dissection through the gastrocnemius muscle, by drilling in a PA direction using the guide and then inserting the screw through a stab incision from the front. After placement of the nail end cap the incisions were closed.

Postoperatively a plaster cast was applied; this was changed to a partial weightbearing cast (15 kg) after two weeks depending on the condition of the soft tissues. The period of immobilisation was 6 weeks in total for all patients. In four patients the temporary external fixator was left in place for 4 weeks and no cast was applied. After this full weightbearing was allowed in a shoe with a stiff sole. Dynamisation of the nail was performed routinely at a mean of 3.5 months (range 3–14 months) by removal of the proximal locking screw under local anaesthesia. Two additional corrective osteotomies were performed in patients with post-traumatic equinus deformity during the index operation.

Follow-up

The patients attended for regular clinical examinations and at a mean final follow-up of four years (minimum three years) filled out a standardised, self-reported questionnaire (the Foot Function

Table 1 Data on the ten patients

Case	Gender, age (years)	Involved side	Weight (kg)	Type of injury/fracture	Initial treatment	Previous operations	Type of arthrodesis	Additional procedures	Duration that cast was worn (weeks)	Complications	Follow-up (months)	Ankle-Hindfoot Scale (94 pointstotal)*
1	F, 60	R	75	Severe arthrosis, rheumatoid arthritis	No	Two failed fusions (ex. fix.)	Retrograde arthrodesis nail, fibula resection	Dynamisation (after 3 mths)	6	No	48	66
2	M, 30	R	80	Trimalleolar fracture dislocation	Open reduction, internal fixation	Two failed fusions (ex. fix., screw fix.)	Retrograde arthrodesis nail, fibula resection, percutaneous removal of cartilage	Dynamisation (after 3 mths), corrective osteotomy and revision nailing	6	Varus malunion	42	58
3	F, 59	R	95	Trimalleolar fracture dislocation	Open reduction, internal fixation	Ankle arthrodesis	Retrograde arthrodesis nail, fibula resection	Dynamisation (after 3 mths), bone graft	6	No	40	77
4	F, 59	R	76	Third-grade open trimalleolar fracture, arthrosis deformans after osteomyelitis	Retrograde arthrodesis nail, fibula resection	Several operations for osteomyelitis right distal tibia, failed attempt arthrodesis cast	Retrograde arthrodesis nail, fibula resection	Dynamisation (after 3 mths)	6	No	47	77
5	F, 62	L	83	Ankle fracture, osteomyelitis, diabetes	Open reduction, internal fixation	Removal of implants, articular lavages, attempted screw arthrodesis	Retrograde arthrodesis nail, fibula resection	Dynamisation (after 3 mths)	6	No	36	65

Cont. Table 1

Case	Gender, age (years)	Involved side	Weight (kg)	Type of injury/fracture	Initial treatment	Previous operations	Type of arthrodesis	Additional procedures	Duration that cast was worn (weeks)	Complications	Follow-up (months)	Ankle-Hindfoot Scale (94 points total)*
6	M, 29	L	100	Tibial pilon fracture, pes equinus, posttraumatic	Open reduction, internal fixation	Three failed fusions	Retrograde arthrodesis nail, fibula resection	Dynamisation of nail (after 3 mths)	6	No	66	84
7	F, 62	L	62	Ankle fracture, osteomyelitis	Open reduction, internal fixation	Arthroscopic and open revision and attempted screw arthrodesis, antibiotic beads	Percutaneous removal of cartilage; retrograde arthrodesis nail, fibula resection	Dynamisation (after 3 mths)			40	61
8	F, 40	R	88	Bimalleolar fracture	Open reduction, internal fixation	Four attempts for ankle arthrodesis (screws ex-fix)	Retrograde arthrodesis nail, fibula resection	Dynamisation (after 3 mths)	6	No	49	74
9	F, 51	R	70	Trimalleolar fracture dislocation	Open reduction, internal fixation	Three failed fusions	Retrograde arthrodesis nail, fibula resection, percutaneous removal of cartilage	Dynamisation (3 mths), resection fibula	6	No	45	81
10	M, 40	L	65	Compound tibial fracture left, post-traumatic pes equinus, post-traumatic arthritis	Open reduction, internal fixation	Two failed fusions	Correction of foot position with external fixation; retrograde arthrodesis nail, fibula resection	Dynamisation (after 3 mths)	No (ex. fix.)	No	60	77

*Modified Ankle-Hindfoot Score of the American Orthopedic Foot and Ankle Society [17]

Fig. 1 Intraoperative photograph of the plantar aspect of the foot showing the incision for insertion of the arthrodesis nail
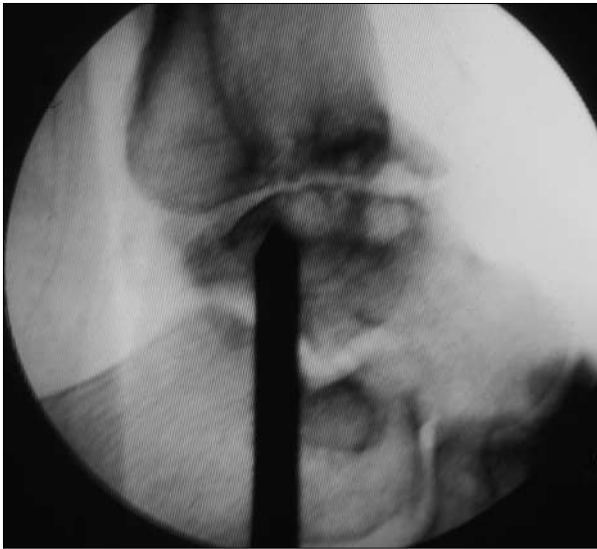

Fig. 2 Intraoperative photograph of the image intensifier of the lateral ankle showing introduction of a Steinmann nail into the talus via the os calcis

Fig. 3 Intraoperative photograph after insertion of the arthrodesis nail: mounted jig for posterior–anterior locking of the talus and os calcis
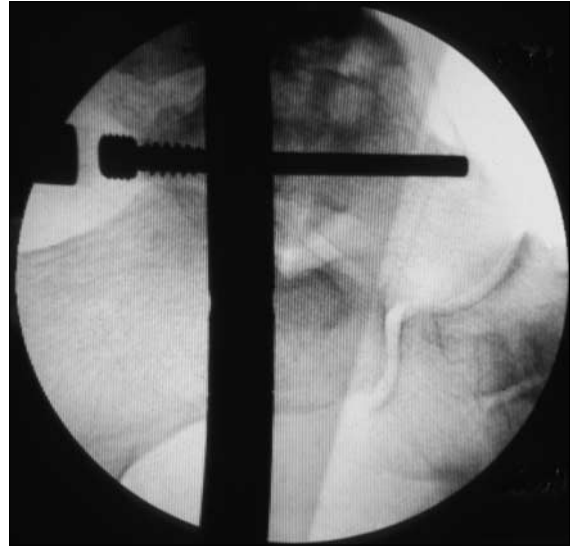

Fig. 4 Intraoperative photograph of the image intensifier of the lateral ankle showing posterior–anterior locking of the talus
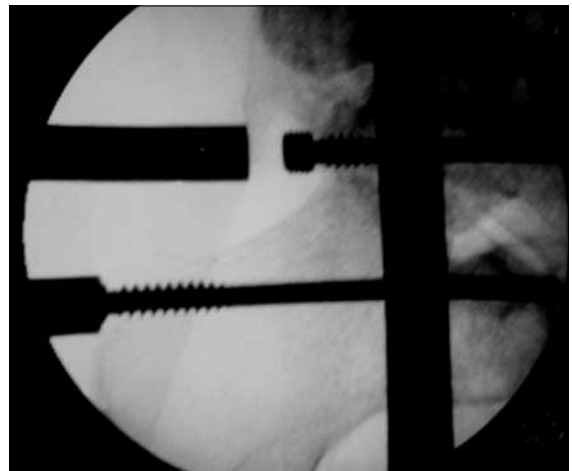

Fig. 5 Intraoperative photograph of the image intensifier of the lateral ankle showing posterior–anterior locking of the os calcis

Index) [17]. Additionally, patients were asked to rate their satisfaction with the procedure on a scale (not a visual analogue) of 0 (not satisfied) to 10 (completely satisfied without reservation) and to state whether they would have the operation again under similar circumstances. The clinical results were evaluated according to a modified ankle-hindfoot score of the American Orthopaedic Foot and Ankle Society [18]. This 100-point score was modified to a maximum possible score of 94 points by subtracting the 6 points assigned to subtalar motion, which was expected to be absent in this study population [18]. A score of 94 points was achieved by patients with no pain, full range of sagittal motion in the Chopart joints, no ankle or hindfoot instability, good alignment, ability to walk more than six blocks, ability to ambulate on any walking surface, no discernible limp, no limitation of daily or recreational activities, and no assisting devices needed for ambulation. Union and foot alignment was assessed radiologically on standard antero-posterior and lateral radiographs of the ankle and foot. Two reviewers measured the position of the fusion and status of union, and graded the osteoarthritic changes in the talonavicular, calcaneocuboid, naviculocuneiform,

tarsometatarsal and first metatarsophalangeal joints according to the system of Kellgren and Moore [19].

Analyses

The chi-square test was used to evaluate comparative results. The level of significance was defined as $p \leq 0.05$.

Results

Complications

Complications such as damage to neurovascular structures, non-union and infection were not seen. There was one varus malunion in a heavy smoker, which healed after corrective osteotomy with exchange reamed nailing and bone grafting.

Subjective assessment

Overall, patient satisfaction averaged 9.5 points (range 5–10 points) on the 0 to 10-point grading scale, and 9 (90%) of the 10 patients stated that they would have the operation in a comparable situation. All but two patients (80%) stated that they would recommend this treatment modality to a friend who had the same clinical situation and pain as they had had prior to the operation.

At the time of the latest follow-up, Foot Function Index evaluation revealed a mean of 12 points for the subsegment pain (range, 10–15 points). Self-reported responses to direct queries from the examiner about pain in the midfoot region revealed moderate pain in two patients and no pain in 8 patients.

Disability subscale

All but four patients had no difficulty in walking four blocks. Overall foot disability was rated with a mean of 14 points (range, 12–43 points). Overall activity limitation was moderate, with a mean of 10 points (range, 8–15 points).

Clinical assessment

The mean duration of follow-up was 4 years (3–5.5 years). The average ankle-hindfoot score for all 10 feet was 69.7 points (range, 57–94 points). At the time of the latest follow-up, 8 patients had no pain and seven had mild pain. Six patients had no limitation in recreational or daily activities,
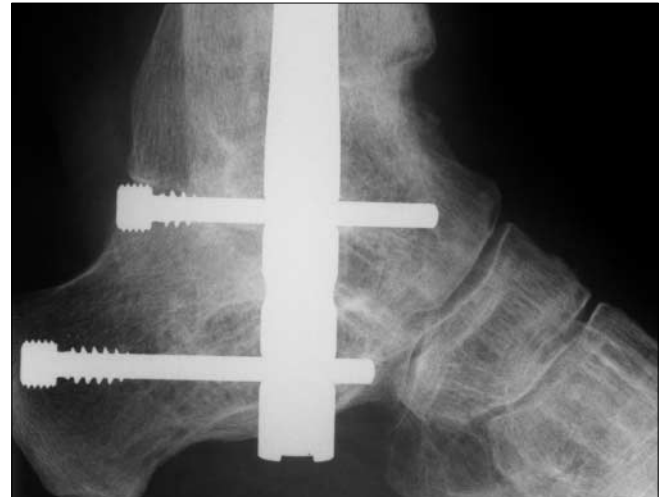

Fig. 6 Lateral radiograph of the ankle 8 months after retrograde arthrodesis demonstrating trabecular union

four patients had limitation in recreational but not daily activities. Six patients had no difficulty walking on any surface, and four had some difficulty on uneven terrain and stairs. All but one patient showed an obvious limp. Sagittal motion was moderately restricted in all patients. No patient had an ankle-hindfoot instability. Clinically, ankle-hindfoot alignment was good, with pre-planned foot position in all patients (slight equinus in female and plantigrade in male).

Radiographic assessment

Fusion
Fusion was determined clinically and radiographically. All arthrodeses but one united in the correct position within 16 weeks (range, 12–20 weeks) of the index operation (Fig. 6).

Position and alignment
The position of the foot was satisfactory within 5° of the planned fusion angle in all patients. There was a significant association between position and alignment of the foot and patient satisfaction ($p=0.01$).

Arthritic changes
Two patients had a painful degenerative arthritis (Grade 4 according to Kellgren and Moore) of the midtarsal joints preoperatively, and three a Grade 4 at the final follow-up. In this one patient with newly developed arthritic changes the Chopart joints were fused in an additional operation.

Discussion

Tibiotalocalcaneal arthrodesis has been reported infrequently until recently and generally shows reasonable

results [5, 11, 13, 20]. Chou et al. recently published a multicentre retrospective study of 55 patients (56 ankles) who underwent simultaneous tibiotalocalcaneal arthrodesis with severe disease involving the ankle and subtalar joints [21]. Fusion was achieved in 48 ankles, with an average time to fusion of 19 weeks. Their results are in conjunction with our findings with one major difference: the high complication rate, with the most common complications being nonunion (8 ankles) and wound infection (6 ankles). While demonstrating that tibiotalocalcaneal arthrodesis is an effective salvage procedure for patients with disease both involving the ankle and subtalar joints, a serious complication rate was tolerated. We will focus on three topics in the discussion: (1) anatomic structures at risk in retrograde nailing, (2) lack of nonunions in our series and (3) high patient satisfaction rate.

When using a retrograde nail for combined subtalar and ankle arthrodesis, several anatomical structures are at risk during dissection onto the os calcis, reaming and nail insertion; these are the skin, heel pad, plantar aponeurosis, plantar muscles, tendons and neurovascular structures. Pochatko and colleagues demonstrated on cadaver specimens six zones with a gradually increasing risk of damaging these plantar structures during the retrograde insertion of Alta femoral nails [22]. Structures grossly damaged by the procedure were the plantar fascia, flexor digitorum brevis muscle, abductor hallucis muscle, lateral plantar artery and the adjacent small plantar muscles. If the nail entered the os calcis at the junction of the sustentaculum tali and the body of the os calcis, the position in the talus and distal tibia was central. The placement of locking screws from lateral to medial was considered unsafe because of a lack of adequate bony purchase. The authors concluded that several structures on the plantar aspect are at grave risk of being damaged by the procedure, and recommended open insertion of the nail [22]. Using a short straight incision in the sole of the foot, with blunt dissection to the inferior surface of the os calcis, and Langenbeck retractors throughout the procedure, damage to these structures was avoided in all cases [15, 16].

The high union rate (10 arthrodeses out of 10) in our series may be explained by the locking plane used and the protocol of reamed nailing. For an adequate bony purchase, and to control and neutralise sagittal forces in calcaneotalotibial arthrodesis, PA locking was used (Figs. 7–11). Mann et al. recently analysed the impact of a PA calcaneal interlocking screw on rotational stability secondary to increased bone purchase compared with the standard lateral-to-medial (transverse) screw [23]. The PA screw construct was significantly stiffer than the transverse screw construct: 1.96 and 1.41 Nm/E, respectively ($p<0.036$). In the series reported by Chou et al., in 37 procedures in which a nail was used there were five nonunions (22%) [21]. In their series a revision nail locked in the lateral-medial plane was used. The use of a PA lock-

Fig. 7 Lateral preoperative radiograph of the left ankle of a 40-year-old male with post-traumatic arthritis and post-traumatic pes equinus

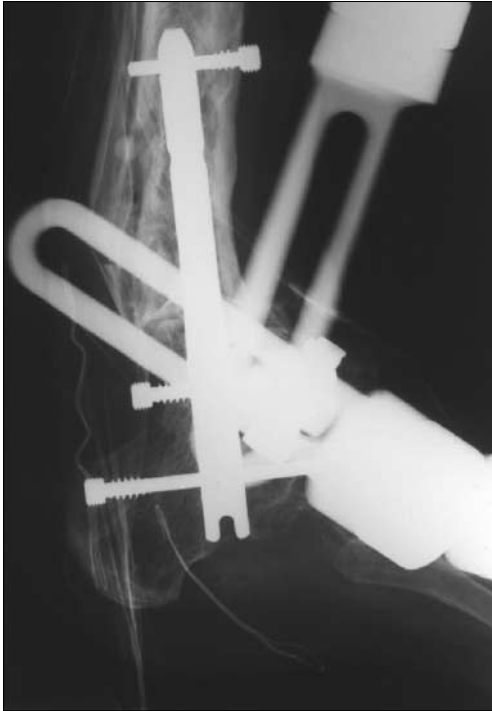**Fig. 8** Anterior–posterior preoperative radiograph of the same patient

Fig. 9 Postoperative lateral radiograph of the same patient with retrograde nail and external fixator maintaining foot position after corrective osteotomy of the talus

Fig. 10 Lateral radiograph of that patient 8 months after the index operation demonstrating solid union of the arthrodesis in the ankle and subtalar joint

ing plane may constitute one decisive difference explaining the high union rate in our series. Reamed nailing is not only accepted as standard treatment for healing of long bone fractures, but has traditionally yielded superior

Fig. 11 Anterior–posterior radiograph 8 months after the index operation demonstrating solid union

results in the treatment of non-union and the salvage of failed fusion in arthrodesis [24, 25]. The effect of the reaming debris is demonstrated by the solid clinical and radiologic union of the subtalar joint in all patients in our series without additional procedures such as removal of cartilage. All cases in this series were revision cases with a mean of 2.5 previous operations. As far as these revision cases are concerned, our results compare favourably with those obtained by external fixation and bone grafting. While Kitaoka et al. reported an overall union rate of 77% after revision arthrodesis using an external fixator and bone graft [5], which corresponds to the union rates reported by other authors, in our series there was one delayed union in the revision cases and an overall union rate in correct position of 90%.

The only complication encountered was one case of malunion in a heavy smoker. Smoking alone as a risk factor increases the risk of non-union by 16 times when no other medical risk factor for non-union is present [26]. In addition to PA locking and the use of a stable steel implant with 4-mm locking bolts, the reaming process may contribute significantly to achieve such a high union rate.

Patient satisfaction is one major goal to reach in patients with severe pathology in the ankle and foot. Procedures with a high complication rate with inflammation and infection as in screw and plate arthrodesis and external fixation or nonunion after failed fusion not only endanger the final result but also trouble an already suffering patient [5, 10, 20]. Additional surgical procedures,

such as revision nailing, bone grafting or resiting of external fixation pins or wires, persisting or evolving pain, disability and limitation of overall activity and poor clinical outcome will all influence patient satisfaction. The union rate was high, with a low rate of additional procedures, and a high patient satisfaction rate was achieved compared to other methods such as external fixation and plate and screw arthrodesis [5, 9, 10, 20].

One disadvantage of calcaneotalotibial arthrodesis is that rigidity of the hind foot may predispose to secondary degenerative changes in the naviculocuneiform and tarsometatarsal joints, as was also shown to be the case after ankle and triple arthrodesis [9, 10, 15, 16, 27]. Although this is a potential hazard, we believe that prospective patients should be made aware of it as part of their informed consent.

Whether the subtalar joint should be included in an ankle fusion is a matter of individual judgement of clinical and radiological signs [6, 8, 15, 16, 21]. Talar changes such as cyst formation and partial talar necrosis indicate degeneration of the subtalar joint. A local anaesthetic injection may be of value to determine subtalar pain [15, 16]. In cases of severe equinovarus deformity, especially of neurogenic origin, fusion of the subtalar joint is an essential step in achieving and maintaining correction.

Calcaneotalotibial arthrodesis would seem to be indicated as a salvage procedure for severe deformity and/or painful arthritis, in the hind part of the foot and the ankle [15, 16, 21]. Using a retrograde locking nail, the accepted goals of calcaneotalotibial arthrodesis, which are union, maintenance of hindfoot alignment, limitation of complications and overall patient satisfaction, have been achieved.

References

1. Adams, JC (1948) Arthrodesis of the ankle joint: experiences with the transfibular approach. J Bone Joint Surg Br 30:506–511
2. Baciu CC (1986) A simple technique for arthrodesis of the ankle. J Bone Joint Surg Br 68:266–267
3. Reckling FW (1972) Early tibiocalcaneal fusion in the treatment of severe injuries of the talus. J Trauma 12:390–396
4. Kirkpatrick JS, Goldner JL, Goldner RD (1991) Revision arthrodesis for tibiotalar pseudarthrosis with fibular onlay–inlay graft and internal screw fixation. Clin Orthop Relat Res 268:29–36
5. Kitaoka HB, Anderson PJ, Morrey BF (1992) Revision of ankle arthrodesis with external fixation for non-union. J Bone Joint Surg Am 74:1191–1200
6. Rickman M, Kreibich DN, Saleh M (2001) Fine wire arthrodesis of severe ankle pathology. Injury 32:231–247
7. Papa JA, Myeerson MS (1992) Pantalar and tibiocalcaneal arthrodesis for post-traumatic osteoarthrosis of the ankle and hindfoot. J Bone Joint Surg Am 74:1042–1049
8. Pell RF, Myerson MS, Schon LC (2000) Clinical outcome after triple arthrodesis. J Bone Joint Surg Am 82:47–57
9. Saltzmann CL, Fehrle MJ, Cooper RR et al (1999) Triple arthrodesis: twenty-five and forty-four year average follow-up of the same patients. J Bone Joint Surg Am 81:1391–1402
10. Morrey BF, Wiedemann GP (1980) Complications and long term results of ankle arthrodeses following trauma. J Bone Joint Surg Am 62:777–784
11. Carrier D, Harries C (1991) Ankle arthrodesis with vertical Steinmann pins in rheumatic arthritis. Clin Orthop Relat Res 268:10–14
12. Kile TA, Donnely RE, Gehrke JC et al (1994) Tibiotalocalcaneal arthrodesis with an intramedullary device. Foot Ankle Int 15:669–673
13. Pinzur MS, Kelikian A (1997) Charcot ankle fusion with a retrograde locked intramedullary nail. Foot Ankle Int 18:699–704
14. Stone K, Helal B (1991) A method of ankle stabilization. Clin Orthop Relat Res 268:102–106
15. Mader K, Pennig D, Gausepohl T, Patsalis T (2003) Calcaneotalotibial arthrodesis with a retrograde posterior-to-anterior locked nail as a salvage procedure for severe ankle pathology. J Bone Joint Surg Am 85[Suppl 4]:123–128
16. Boer R, Mader K, Pennig D, Veheyen CCPM (2007) Tibiotalcalcaneal arthrodesis with a reamed retrograde locking nail: results of the first 50 patients. Clin Orthop Relat Res (in press)
17. Badiman-Mak, E, Conrad, KJ, Roach, KE (1991) The Foot Function Index: a measure of foot pain and disability. J Clin Epidemiol 44:561–570
18. Kitaoka HB, Alexander IJ, Adelaar RS et al (1994) Clinical rating systems for the ankle-hindfoot, midfoot, hallux, and lesser toes. Foot Ankle Int 15:349–353
19. Kellgren JH, Moore R (1952) Generalized osteoarthrosis and Heberden's nodes. Br Med J 1:181–187
20. Acosta R, Ushiba J, Cracchiolo A (2000) The results of a primary and staged arthrodesis and tibiotalocalcaneal arthrodesis in adult patients. Foot Ankle Int 21:182–194
21. Chou LB, Mann RA, Yaszay B et al (2000) Tibiotalocalcaneal arthrodesis. Foot Ankle Int 21:804–808
22. Pochatko DJ, Smith JW, Phillips RA et al (1995) Anatomic structures at risk: combined subtalar and ankle arthrodesis with a retrograde intramedullary rod. Foot Ankle Int 16:542–547
23. Mann MR, Parks BG, Pak SS, Miller SD (2001) Tibiocalcaneal arthrodesis: a biomechanical analysis of rotational stability of the Biomet ankle arthrodesis nail. Foot Ankle Int 22:731–733
24. Bhandari M, Guyat GH, Tong D et al (2000) Reamed versus nonreamed intramedullary nailing of lower extremity long bone fractures: a systematic overview and metaanalysis. J Orthop Trauma 14:2–9
25. Hak DJ, Lee SS, Goulet JA (2000) Success of exchange reamed intramedullary nailing for femoral shaft nonunion or delayed union. J Orthop Trauma 14:178–182
26. Cobb TK, Gabrielson TA, Campbell DC 2nd et al (1994) Cigarette smoking and nonunion after ankle arthrodesis. Foot Ankle Int 15:64–67
27. Conti RJ, Walter JH Jr (1990) Effects of ankle arthrodesis on the subtalar and midtarsal joints. J Foot Surg 29:334–336