■ FOOT AND ANKLE

Corrective supramalleolar osteotomy for malunited pronation-external rotation fractures of the ankle

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We undertook a prospective study to analyse the outcome of 48 malunited pronation-external rotation fractures of the ankle in 48 patients (25 females and 23 males) with a mean age of 45 years (21 to 69), treated by realignment osteotomies. The interval between the injury and reconstruction was a mean of 20.2 months (3 to 98).

In all patients, valgus malalignment of the distal tibia and malunion of the fibula were corrected. In some patients, additional osteotomies were performed. Patients were reviewed regularly, and the mean follow-up was 7.1 years (2 to 15).

Good or excellent results were obtained in 42 patients (87.5%) with the benefit being maintained over time. Congruent ankles without a tilted talus (Takakura stage 0 and 1) were obtained in all but five cases. One patient required total ankle replacement.

The outcome after a fracture of the ankle may be compromised by persistent cartilage and soft-tissue problems and residual incongruency after inadequate reduction.¹ It has been widely recognised that post-traumatic asymmetrical loading of the ankle joint may cause degenerative disease, as is particularly common in malunited pronation-external rotation fractures.²⁻⁵ In some reports of isolated corrective osteotomies of the fibula, the talus remained tilted in up to 37% of fractures,⁶ and up to 50% of these patients subsequently developed osteoarthritis.^{7,8} In contrast, Chao et al⁹ reported no progression at a mean of 34 months in 12 patients who underwent corrective fibular osteotomy.

It has been emphasised that the best outcome depends on anatomical restoration of the ankle mortise by adequate lengthening and correction of the angular and rotational deformities of the fibula.^{5,6,8-11} These studies all reported a much higher rate of pre-operative degenerative change in the patients with a poor or fair outcome than in those with a good outcome. Therefore, they concluded that early correction of malalignment is essential. However, no assessment of tibiotalar alignment or overall valgus malalignment of the hindfoot was performed.

Malunion after pronation-external rotation injuries of the ankle is often accompanied by fibular shortening and/or malrotation. In these ankles, we have also observed valgus tibiotalar malalignment with increased density of subchondral bone and a narrowing of lateral joint

space (Fig. 1a), and valgus malalignment of the hindfoot (Fig. 1b). In order to correct this malunion, we perform a supramalleolar osteotomy, followed by correction of the fibula. If valgus malalignment of the hindfoot persists, a calcaneal osteotomy is also performed.

The aim of this prospective study was to assess the outcome of distal tibial osteotomy, and corrective surgery of the fibula under these circumstances in a series of patients.

Patients and Methods

Between 1995 and 2008, 48 consecutive patients (25 women and 23 men) with a mean age of 45 years (21 to 69) were treated for malunion after pronation-external rotation fractures of the ankle with the use of a varus osteotomy of distal tibia and corrective osteotomy of fibula. Using Weber's classification,¹² 43 had type C fractures (eight of which were Maisonneuve type¹³), and five had type B fractures. The primary treatment was conservative in three patients and operative in 42. In three patients the fracture had been overlooked. The mean interval between the injury and reconstruction was 20.2 months (3 to 98). All patients were prospectively followed with clinical and radiological assessments. Based on a preliminary experience of supramalleolar osteotomies to realign a valgus malaligned osteo-arthritic ankle,¹⁴ we aimed for correction to a varus position of between 2° and 4°. When the tibial articular surface was preserved, the osteotomy was planned extra-articularly at approximately 3 cm above the

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Fig. 1a

Fig. 1b

Radiographs of a 46-year-old man with a malunion 2.6 years after fracture: a) anteroposterior view, showing the valgus tibiotalar tilt resulting from impaction of tibial plafond, typically with evidence of increased subchondral sclerosis and cyst formation, and b) the hindfoot alignment view, showing a valgus malalignment.

tibiotalar joint. If the tibial articular surface was impacted with $> 5^\circ$ of valgus of the lateral aspect of the joint, an intra-articular osteotomy was considered. Thereafter, a corrective fibular osteotomy was anticipated to lengthen and/or rotate the malunited fibula based on comparison with the contralateral unaffected ankle.⁸

Medial closing wedge osteotomy of distal tibia. The distal tibia was exposed through a 5 cm to 6 cm long medial incision. The osteotomy site was selected pre-operatively with regard to the centre of rotation of the deformity. In order to preserve enough bone for placement of the plate, the osteotomy was always undertaken at least 2.5 cm above the tibiotalar joint. Under fluoroscopic guidance, two 2 mm Kirschner (K)-wires were inserted as guide wires. The osteotomy was performed along the K-wires preserving the contralateral cortex. An anatomically shaped plate with interlocking screws (TIBIAXIS; Integra, Plainsboro, New Jersey) was first fixed distally with four locking screws. A compression device was introduced into a hole at the proximal end of the plate and secured by a screw. Once the desired position was achieved, the plate was proximally fixed using four locking screws.

Corrective osteotomy of fibula. The distal fibula was exposed through a 5 cm to 6 cm longitudinal incision. The anterior syndesmotic ligament was identified, and a small Hohmann retractor was placed just proximal to it. Another small retractor was placed approximately 3 cm more proximally at the posterior aspect of fibula. An oblique osteotomy was performed between the two retractors using an oscillating saw. A 2.5 mm K-wire was then introduced from an anterolateral direction (e.g. with an angulation of approximately 60° to the coronal plane) into the distal

fibula and another wire was placed parallel to it in the proximal fibula. A special distractor (Integra) was placed over these two wires and used to lengthen the fibula incrementally. Appropriate lengthening, as checked fluoroscopically, was defined by the following criteria: 1) appropriate closure of the medial clear space with restoration of the relationship of the medial malleolus and the medial surface of the talus, 2) an anatomical position of talus within the mortise with parallel articular surfaces of tibiotalar joint, and 3) restoration of anatomical landmarks as described by Weber and Simpson.¹⁵ A clamp was then used to compress the fibular fragments and fixation obtained using a six-hole plate with locking screws (TIBIAXIS, Integra).

Lateral opening wedge osteotomy of tibia. After exposure of the distal fibula as described above, fibular osteotomy was performed 6 cm to 8 cm above the tibiotalar joint. It was mobilised posteriorly to expose the lateral aspect of distal tibia. A 2 mm K-wire was introduced as a guide wire for the planned osteotomy. Two 1.2 mm K-wires were introduced into the distal tibia from the medial side parallel to and 2 mm to 3 mm above the tibiotalar joint. The osteotomy was performed along the first K-wire until it reached the two K-wires and a special distractor was placed over two additional K-wires distally and proximally to the osteotomy, and used to open the osteotomy incrementally until the lateral distal tibia was well aligned with the talus. After inserting a wedge shaped allograft (Tutoplast; Tutogen Medical GmbH, Neunkirchen am Brand, Germany), sized according to the width of the osteotomy, a 2.7 mm plate and screws (Synthes, Solothurn, Switzerland) was used for further stabilisation. The K-wires were then removed.

A malunited posterior malleolus was corrected prior to the medial closing tibial osteotomy by extending the medial approach through the sheath of the tendon of tibialis posterior. The site and plane of the original fracture was marked by two K-wires, and the osteotomy performed along the K-wires using an osteotome. The fragment was mobilised and then brought distally using the small distractor over the two K-wires. A one-third fibular plate (Synthes) was used to fix it distally to the planned medial closing wedge osteotomy of the distal tibia, with proximal fixation deferred until the corrective osteotomy of the distal tibia had been undertaken.

If there was a persistent valgus deformity of the heel, a sliding osteotomy of the calcaneum was undertaken through an additional approach.¹⁶ If there was persistent pronation and abduction of the forefoot, a lateral lengthening osteotomy of calcaneum was undertaken through a lateral approach.¹⁷

The wound was step-by-step closed and covered by a compressive dressing. A well-padded short leg splint held the foot in the neutral position. The wound was inspected two to four days after surgery, and if satisfactory the foot was placed in a VACOPed cast (OPED AG, Steinhausen, Switzerland) for eight to ten weeks and partial weight-

Table I. The classification of osteoarthritis according to Takakura et al³ before and after operation with a mean follow-up of 7.1 years (2 to 15)

	Pre-operative (n = 48) (%)	Latest follow-up (n = 47)* (%)
Stage 0	14 (29.2)	8 (17.0)
Stage 1	24 (50.0)	34 (72.3)
Stage 2	7 (14.6)	3 (6.4)
Stage 3	3 (6.2)	2 (4.3)
Stage 4	0 (0.0)	0 (0.0)

* one patient required total ankle replacement 26 months after corrective surgery (pre-operatively, classified as stage 3)

bearing was permitted. During this time, manual lymphatic drainage and continuous passive movement of ankle was also initiated. After the osteotomy had united, usually at 8 to 12 weeks, full weight-bearing was permitted and a rehabilitation programme was initiated, with gradual return to full activities.

Pre-operative data including level of function were collected prospectively by independent reviewers who were not subsequently involved in the operations. Post-operative follow-up included a clinical and radiological examination at two months, four months, one year, and annually thereafter. A separate clinical review of the patients was completed by an independent resident (AB), with data entered on our database. Two of the authors (BH and MK) evaluated the blinded radiographs, according to the criteria described below and judgements were based on consensus.

The clinical examination involved assessment of alignment with the patient standing, and the range of movement and stability of the ankle with the patient sitting and standing. The range of movement was measured with a goniometer.¹⁸ The patients rated their pain on a visual analogue scale (VAS) of 0 to 10 points (0 representing no pain, 10 representing maximum pain).¹⁹ The American Orthopaedic Foot and Ankle Society (AOFAS) hindfoot score was recorded.²⁰ The subjective and objective results were rated according to Reidsma et al.¹⁰ A good subjective result implied slight pain with excessive use, normal function in work-related activities, but restriction of strenuous activities. An objectively good result meant loss of ankle movement by no more than 10°, a slight decrease of subtalar movement compared with the contralateral side, and no progression of arthritis. A subjectively fair result implied less pain than before surgery, some improvement in walking, and unchanged activity. A fair objective result meant that joint function was the same or only slightly less than before the operation, with minimal progression of arthritis. A subjectively poor result was defined as more pain with less activity and walking than before the operation. Considerable limitation of movement and progression of arthritis denoted a poor objective result.

The patients also were asked to indicate the level of function in comparison to pre-operative function in activities of daily living and in specific activities such as sports and climbing stairs, as well as their satisfaction with the procedure.

Radiological measurements. Radiological evaluation included an anteroposterior (AP) radiographs of the ankle, an AP and lateral view of the foot and a Saltzman view²¹ while weight-bearing. The tibiotalar angle was measured on the AP view, as previously described.²² The perpendicular distance between the longitudinal axis of the tibia and the lowest point on the calcaneum was measured on the Saltzman view as previously described, with positive values if the weight-bearing axis fell medial to the most inferior point on the calcaneum (varus calcaneum), and negative values if the weight-bearing axis fell laterally (valgus calcaneum).²² Two authors (BH, MK) evaluated the serial radiographs of each patient. Any signs of arthritis, including formation of osteophytes, narrowing of the joint space and subchondral sclerosis, and any tilt and/or lateral shift of the talus on the AP weight-bearing radiographs were recorded. Grading was performed according to Takakura et al³ (Table I): Grade 0: no tibiotalar tilt, no signs of arthritis; Grade 1: no tibiotalar tilt but with some subchondral sclerosis or osteophyte formation; Grade 2: tibiotalar tilt with varus/valgus alignment without subchondral bone contact; Grade 3: tibiotalar tilt with varus/valgus alignment with subchondral bone contact; Grade 4: loss of tibiotalar joint space with total subchondral bone contact.

Bone healing and union were assessed radiologically at eight weeks follow-up. In cases where bone healing was not confirmed, additional radiographs were performed at 12 and 16 weeks follow-up. After 16 weeks a CT scan was performed in two patients with delayed union in this study. **Statistical analysis.** This was performed using SPSS version 16.0 (SPSS Inc., Chicago, Illinois). A Kolmogorov-Smirnov normality test was performed to verify whether the data met the assumptions of a parametric test. The intraclass correlation coefficients (ICC) and the 95% confidence interval (CI) of the ICC were used to quantify the inter- and intra-observer reliability. ICC values were interpreted as follows: 1, perfect agreement; 0.81 to 0.99, excellent agreement; and 0.61 to 0.80, substantial agreement.²³ A Bland-Altman plot, including 95% confidence intervals (estimated as 1.96 times the standard deviation (SD) of the differences), was generated to quantify agreement between tibiotalar angle measurements by two observers.²⁴⁻²⁶ A paired samples *t*-test was used for continuous variables. The relationship between continuous variables was investigated by Pearson correlation. The level of significance was set up at *p* < 0.05.

Results

Corrective distal tibial osteotomy was undertaken with a medial closing wedge in 45 patients (Fig. 2), and with a lateral opening wedge in combination with an intra-articular osteotomy in three patients (Fig. 3). In order to align the hindfoot appropriately, an additional osteotomy of the calcaneum was undertaken in 19 patients (16 medial sliding osteotomies, three lateral column lengthening

Fig. 2a

Fig. 2b

Fig. 2c

Fig. 2d

Figures 2a and 2b – radiographs of a 48-year-old man with malunion eight months after fracture, in a) anteroposterior (AP) view showing fibular malunion with shortening and external rotation and a valgus tibiotalar angle, and b) lateral view showing the talus well-centralised without incorporation of the posterior malleolus. Figures 2c and 2d – AP (c) and lateral (d) radiographs at six years showing correct alignment with parallel tibiotalar surfaces.

osteotomies). In three patients a corrective osteotomy of the posterior malleolus was also performed. In two patients with a segmental defect at the un-united fibular site, bone graft from the ipsilateral iliac crest was added. Tibiofibular screws were not required in any cases.

The mean follow-up was 7.1 years (2 to 15). A well aligned stable ankle was obtained in all cases, and it remained stable at the final review.

The mean supramalleolar correction was 5.2° (4° to 8°), achieving a mean tibiotalar angle of 92.8° (90° to 95°). The intraobserver reliability found excellent agreement with an ICC of 0.944 (95% CI 0.896 to 0.970, $p < 0.001$) and ICC of 0.924 (95% CI 0.859 to 0.959, $p < 0.001$). The interobserver reliability was similarly excellent with ICC of 0.848 (95% CI 0.717 to 0.918, $p < 0.001$). The Bland-Altman analysis demonstrated that most differences between both observers were inside of 95% limits of agreement (-1.6° to 1.8°). The range of measurement error of 3.4° was lower than the mean correction measured in this study.

The mean perpendicular distance from the most inferior point on the calcaneum and the longitudinal tibial axis was -3.1 mm (SD 1.7; -7 to 0) pre-operatively and 3.0 mm (SD 2.6; -5 to 6) at final follow-up (t -test, $p < 0.001$).

In all but two patients (4.2%), the supramalleolar osteotomy of tibia united after a mean of 2.4 months (2 to 4) and full weight-bearing of the ankle was achieved after a mean of 2.6 months (2 to 4.5). In the two patients with delayed union, union occurred after six and seven months, respectively. Delayed wound healing was observed in three patients (6.3%), and persistent valgus malalignment due to undercorrection in two patients (4.2%). In these two

patients the overall hindfoot was still valgus because of valgus heel position which represents an inframalleolar problem. In four patients (8.4%), the plates were removed after 12 months because of local discomfort. One patient (one ankle, 2.1%) had increasing symptoms due to osteoarthritis and underwent total ankle replacement after 26 months. A total of 42 patients (87.5%) were satisfied or very satisfied with the outcome. The mean AOFAS hindfoot score improved significantly from 48 (36 to 66) to 86 (64 to 100) points (t -test, $p < 0.001$).

Of the 47 patients who did not undergo ankle replacement, 41 (87.2%) were pain free and six (12.8%) reported moderate pain with a mean VAS of 2.1 points (1 to 4). The localisation of pain was peri-articular in four ankles (8.5%), posterior, around the tendo Achillis in two (4.3%), lateral in one (2.1%), and above the ankle at the level of the osteotomy in one ankle (2.1%).

The mean pre-operative and post-operative range of movement was 41.2° (30° to 50°) and 40.1° (30° to 50°), respectively. A strong correlation was found between pre- and post-operative ranges ($r = 0.872$, $p < 0.001$).

While 42 patients (89.4%) had a subjectively good or excellent result, objectively good or excellent results were seen in 44 patients (93.6%). A total of five patients (10.6%) had a fair subjective result and three patients (6.4%) a fair or poor objective result. The two features that were found to be associated with a poor result were a final range of movement $< 30^\circ$, and the existence of arthritic changes prior to operation. Of the two patients with persistent valgus malalignment, one had a poor result, and one had a fair result.

In all 43 patients (89.6%) returned to their former professional activity, and 34 (70.8%) returned to their former

Fig. 3a

Fig. 3b

Fig. 3c

Fig. 3d

Radiographs of a 43-year-old woman for whom an ankle arthrodesis had been proposed, in a) anteroposterior (AP) view showing impaction of the lateral aspect of tibial plafond and subchondral cyst formation and b) lateral view showing a defect at anterior aspect of tibia. Figures 3c and 3d – intra-operative lateral (c) and AP (d) view radiographs after fibular osteotomy, reconstruction of lateral tibial plafond, and lateral opening wedge osteotomy of the distal tibia.

sport. However, 11 patients did not participate in sport prior to the fracture; of these, only one had commenced a sporting activity at latest follow-up. A total of four patients including that patient who was revised to total ankle replacement were not able to return to their former sporting activities.

The pre- and post-operative radiological evidence of arthritis was compared. There was no evidence of progression in 30 patients (62.5%), six of whom had no arthritic change; whereas, 14 (29.2%) showed slight progression, and three (6.3%) who had incongruence of the ankle mortise at the final follow-up showed considerable progression. According to Takakura et al's³ classification, ten ankles deteriorated by one stage (six ankles, stage 0 to stage 1; three ankles, stage 1 to stage 2; one ankle, stage 2 to stage 3) and 11 ankles improved by one stage (nine ankles, stage 2 to stage 1; two ankles, stage 3 to stage 2), while 26 remained at the same stage (Table I). In all 30 patients (63.8%) had anatomical restoration of the ankle.

Discussion

In our study of 48 consecutive patients with a malunited pronation-external rotation fracture of the ankle, all but one ankle were successfully corrected with preservation of the ankle joint at a mean follow-up of 7.1 years. The benefit in terms of function and pain relief of a reconstructive osteotomy of the fibula with, if necessary, medial malleolar osteotomy after malunion of a fracture of the ankle has been reported.¹⁰ *In vitro* evaluation of the individual and combined effects of fibular shortening, lateral displacement, and external rotation revealed significant increases in the contact pressures in the mid-lateral and posterolateral quadrants of the talar dome associated with most of the dis-

placement conditions.⁴ Hvid et al²⁷ found that the antero-lateral part of distal tibial metaphysis was less resistant than all other areas. This may explain why these fractures tend to depress the lateral aspect of distal tibial metaphysis allowing valgus tilting of the talus. This, in turn, may cause persistent overloading of the syndesmosis, with residual pain.

Based on these findings, we started performing supramalleolar osteotomies to normalise the forces at tibiotalar joint. As some articular cartilage was generally absent laterally, we overcorrected the tibial plafond to 2° to 3° of varus. In our preliminary series of 35 patients with a mean follow-up of five years we found that supramalleolar osteotomy was effective reconstructive surgery under these conditions.¹⁴ These realignment osteotomy should decrease the load on the damaged area of the tibiotalar joint and return the transmission of force through the ankle to normal.

We therefore have found that malunited ankles after fracture can be successfully realigned using a supramalleolar osteotomy, with a minimal rate of complications. In all cases, appropriate alignment and sufficient stability was obtained, and no recurrence of deformity was observed. However, in 19 ankles (39.6%), an additional corrective osteotomy below the ankle was necessary.

We felt that restoring the transmission forces at the ankle to normal would unload the syndesmotic ligaments. Therefore, unlike others,^{9,10,28} we did not stabilise the syndesmosis in any case with no subsequent instability. A varus osteotomy of distal tibia also allowed the talus to be correctly positioned thereby allowing appropriate fibular reduction. Finally, lengthening of distal fibula may have tightened the syndesmotic ligaments and thereby stabilised the fibula in the incisura.

The limit of malalignment which can be successfully reconstructed is debatable, but from our experience, preservation of $> 30^\circ$ of movement and pain on loading but not at rest seem important predictors for a good outcome.

A medial closing distal tibial wedge osteotomy was sufficient in most patients. However, one of the limitations is the presence of lateral impaction of distal tibial plafond. We considered an angulation of $> 5^\circ$ as an indication for the lateral reconstruction, despite being a more extensive procedure. The three patients requiring a lateral osteotomy did no worse than those undergoing a medial osteotomy. In particular, none developed subsequent avascular necrosis in the lateral tibial plafond. As reported elsewhere,^{28,29} we continue to use this approach for these difficult cases.

In conclusion, osseous balancing is crucial in salvaging a malunited ankle after fracture, in order to protect it from further degenerative change. Reconstructive osteotomies of the fibula combined with realignment of the distal tibia may postpone the development of osteoarthritis.

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