Supramalleolar osteotomy for treatment of post-traumatic angular tibial deformities affecting the ankle joint

Ahmed Shawkat Rizk, Mahmoud Ibrahim Kandil

Orthopaedics and Traumatology Department, Faculty of Medicine, Benha University, Banha, Egypt

Correspondence to Ahmed Sh Rizk, MD, Orthopaedics and Traumatology, Faculty of Medicine, Benha University, Benha University, El-Shaheed Farid Nada Street, Benha, Qalyubia, Egypt. Tel: +20 122 188 0770/ +20 132 721 162; e-mail: drahmadshawkat@gmail.com

Received 1 April 2019
Accepted 17 April 2019

The Egyptian Orthopaedic Journal 2019, 54:1–14

Background
Angular deformities of the leg resulting from malunion of distal tibial fractures or physeal arrest in skeletally immature patients are usually associated with ankle and foot pain secondary to disturbed mechanics and joint overload and could inevitably lead – if uncorrected – to degenerative arthritis. This prospective, case series study aims to evaluate the functional and radiological outcomes of supramalleolar corrective osteotomies for treating symptomatic angular deformities of the tibia and to assess its role in preventing or postponing degenerative arthritis of the ankle joint.

Patients and methods
This study included 18 patients presented with symptomatic angular tibial deformities secondary to malunion of previous distal tibial fractures or post-traumatic physeal arrest. Twelve patients had varus deformities of the ankle, while six patients had valgus deformities. Partial fibulectomy proximal to the level of the planned osteotomy was initially done in all patients; varus deformities were corrected with medial opening-wedge osteotomy and bone grafting with or without tibial fixation, while valgus deformities were corrected with medial closing-wedge osteotomy fixed by plates and screws. The ankle–hindfoot scale of the American Orthopaedic Foot and Ankle Society was used for evaluating the functional results preoperatively and postoperatively.

Results
The mean age of the patients at presentation was 17.6±5.9 years (ranged from 10 to 44 years). All the osteotomies united in an average duration of 10±4.8 weeks (ranged from 7 to 15 weeks) with no reported surgery-related complications apart from delayed wound healing in two cases. The deformity was clinically improved in all the 18 patients, while the radiological parameters were satisfactory in 16 patients with statistically significant improvement ($P<0.001$) in mean postoperative tibial articular surface, talar tilt, tibiocrural, and the malalignment angles in the last follow-up compared with the mean preoperative values while two cases showed incomplete correction with residual deformity in the last follow-up. The mean (American Orthopaedic Foot and Ankle Society) ankle–hindfoot score was markedly improved from 43.8±7.5 preoperatively to 75.6±9.4 in the last follow-up indicating a statistically significant improvement ($P<0.001$). No progressive joint narrowing was detected in any of the studied cases throughout the follow-up period that extended for with a mean duration of 5.5±2.8 years.

Conclusion
Supramalleolar osteotomy is an effective procedure for treating symptomatic angular deformities of the tibia. Supramalleolar osteotomies – not only – correct the deformity and improve the functional outcome, but also represent a joint-preserving surgery protecting the articular cartilage through correcting the mechanics and equally redistributing the joint loads thus preventing progressive degenerative arthritis.

Keywords:
angular deformities of the tibia, joint-preserving procedure with satisfactory functional results, preliminary partial fibulectomy above the syndesmosis, supramalleolar corrective osteotomy, symptomatic malaligned ankle

Egypt Orthop J 54:1–14

1110-1148

Introduction

Unlike osteoarthritis of the hip and knee joints which is predominantly degenerative, traumatic insult or its sequel represents the main cause of end-stage tibiotalar osteoarthritis in about 80% of patients [1]. Post-traumatic articular affection or angular deformities of the tibia with hindfoot varus/valgus deformity represent the most common causes of ankle arthrosis that is more prevalent in young and more active patients. Biomechanical studies have shown that varus or valgus hindfoot deformity – through altering the load distribution in the ankle – could result in medial (with varus deformity) or lateral (with valgus deformity) joint overload and degeneration of the ankle joint in the short-term or medium-term follow-up [2].

Supramalleolar osteotomies (SMOT) not only correct the deformity of the ankle with improved functional outcome, but also restore the disturbed mechanics and load distribution insuring more protection to the articular surface of the tibiotalar joint that is usually asymmetrically loaded with such angular deformities [3].

The main goal of this prospective, case series study was to evaluate the functional and radiological outcomes of supramalleolar corrective osteotomies for treating symptomatic angular deformities of the tibia and to assess their role in preventing or postponing degenerative arthritis of the ankle joint throughout the follow-up period.

Patients and methods

The procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1975, as revised in 2000 and 2008. This study was authorized by the institutional review board and all patients gave informed consent before inclusion in the study.

This prospective case series study was conducted in the Orthopedic Department, Benha University Hospital between January 2009 and November 2017. The study included 18 cases in 18 different patients (Table 1) with symptomatic, malaligned (MA) ankles secondary to post-traumatic angular tibial deformities. Sixteen patients were men and two patients were women. Twelve patients had varus deformity while six patients had valgus deformity of the ankle. Patients with post-traumatic, MA ankles with pain and/or restricted movements with/without early asymmetrical arthritic changes affecting either the medial or the lateral aspects of the tibiotalar articulation were included in this study. Patients with congenital or developmental anomalies resulting in angular deformities of the leg, patients with inframalleolar deformities with/without stiff or arthritic subtalar joints, patients with infected hardware and patients with peripheral vascular or neurological insults were excluded from this study.

Complete and detailed history of the previous injury (regarding its nature, initial management, and duration till presentation) was addressed. Physical assessment had been done to evaluate the gait, foot and ankle posture, and attitude – in relation to the leg and the ground – during weightbearing, limb length discrepancy (LLD), and the range of motion of the ankle and the hindfoot. Weightbearing plain radiographs [anteroposterior (AP) and lateral views] of the affected leg and ankle, computed tomography, and scanograms were done in all cases.

Methods of evaluation

All the patients were clinically and radiologically evaluated during the preoperative assessment and at the last follow-up visit. The American Orthopedic Foot and Ankle Society (AOFAS) ankle–hindfoot scale was used for clinical assessment. Radiological evaluation was based on certain parameters as the MA angle, tibial articular surface (TAS) angle, tibiocrural (TC) angle, the talar tilt (TT) angle, and the Takakura *et al.* [4] score. MA angle (the angle between the two lines that represent the mechanical axes of the proximal and distal segments) signifies the severity of the deformity and identifies the site of the CORA. TAS angle is formed by the mechanical axis of the tibia and the tangent of the distal TAS (tibial plafond) on an AP view and normally ranges between 86° and 92° (average 89°) on the medial side of the ankle. TT angle evaluates tibiotalar congruence; this angle is formed by the distal TAS and the articular surface of the talus on an AP radiograph and it is normally less than 4°. TC is formed by the mechanical axis of the tibia and the line tangent to the tip of both the lateral and medial malleoli and normally ranged from 79° to 87°. Preoperative arthritic changes were classified according to Takakura *et al.* [4] as follows:

(1) Stage 1: osteosclerosis and/or osteophytosis with no sign of narrowing of the joint space.
(2) Stage 2: incomplete medial or lateral narrowing of the joint space.
(3) Stage 3: obliteration of the medial or lateral joint space and contact between adjacent subchondral bone.
(4) Stage 4: complete obliteration of the entire joint space resulting in bone to bone contact.

Surgical techniques

The procedures were done in the operating theater under complete aseptic conditions with either general or spinal anesthesia, under C-arm guidance and a thigh

Table 1 Patients' characteristics

No	Age	Sex	Side	Deformity	Cause	Previous operation	Time till surgery (months)	Concomitant procedure	Follow-up (years)
1	12	Female	Right	Varus	Physeal injury	None	30	None	5
2	25	Male	Right	Varus	Malunited pilon	Tibial external fixation with fibular plating	9	None	6
3	11	Male	Right	Varus	Physeal injury	None	19	Fibular shortening Fibular epiphysiodesis	5
4	12	Male	Right	Varus	Physeal injury	None	35	None	1
5	13	Male	Right	Varus	Physeal injury	None	23	None	5
6	44	Male	Right	Varus	Malunited pilon	Tibial external fixation with fibular plating	22	None	6
7	12	Male	Right	Varus	Physeal injury	None	30	None	5
8	36	Male	Right	Varus	Malunited pilon	Tibial external fixation with fibular plating	18	Anterior ankle decompression	8
9	12	Male	Left	Varus	Physeal injury	None	10	None	6
10	20	Might	Right	Varus	Malunited pilon	External fixator	40	None	5
11	14	Male	Right	Varus	Physeal injury	None	12	None	6.5
12	12	Male	Right	Varus	Physeal injury	None	26	None	7.5
13	13	Female	Right	Valgus	Physeal injury	None	55	None	6
14	22	Male	Right	Valgus	Malunited pilon	None	30	None	5
15	10	Male	Right	Valgus	Physeal injury	Tibial external fixation with fibular wires	62	Syndesmotic fixation secondary tibial epiphysiodesis	7
16	26	Male	Left	Valgus	Malunited pilon	Tibial external fixation with fibular plating	29	None	5
17	12	Male	Right	Valgus	Physeal injury	None	20	None	3
18	11	Male	Right	Valgus	Physeal injury	None	34	None	7

tourniquet. SMOT was done in all cases showing abnormal TAS angle and an extra-articular CORA with either normal or abnormal TT angle. Varus deformities were planned to be corrected by a supramalleolar medial opening-wedge osteotomy with bone grafting; meanwhile, valgus deformities were planned to be corrected by supramalleolar medial closing-wedge osteotomy. Both opening and closing-wedge osteotomies were performed as close as possible to the level of the predetermined CORA (the point of intersection of the two lines that represent the mechanical axes of the proximal and distal segments) and internal fixation with plates and screws was used in all cases that underwent closing-wedge osteotomies, while tibial fixation after the medial opening-wedge osteotomy – that was done in most of cases – was dependent on many factors including the soft tissue condition on the medial side, the amount of the needed correction and the size of the graft and, finally, the stability of the osteotomy after opening the wedge and impaction of the graft.

Partial fibulectomy was performed as an initial, preliminary step in all cases before tackling the tibial deformity. It was done in a more proximal level above the level of the planned tibial osteotomy with an excision of 1–2 cm of the fibula to allow unrestricted deformity correction without affecting the distal tibiofibular articulation and syndesmosis or disturbing the ankle mechanics reported to occur after distal fibular osteotomies. Moreover, proximal fibular osteotomy avoids a previously exposed and internally fixed distal fibula in most cases with pilon fractures and allows easy and safe manipulation in the presence of post-traumatic distal tibiofibular bony synostosis detected in the axial and coronal

Figure 1

Correction of varus malalignment of the ankle through supramalleolar opening-wedge osteotomy after partial fibulectomy: (a) varus malalignment of the ankle following pilon fracture; (b) after proximal partial fibulectomy and anterior ankle decompression, the osteotomy was done using a power saw; (c) after cutting the bone, the osteotomy was opened until correction was achieved using a broad chisel. (d) Fixation of the proximal and distal fragments after opening the wedge and achieving the desired correction. (e) The osteotomy gap was filled and impacted with bone grafting.

computed tomography cuts, which is a common finding after MA, comminuted pilon fractures.

Supramalleolar medial opening-wedge osteotomy was done via a limited medial skin incision starting from the medial malleolus and extending upwards with minimal periosteal stripping. Using an oscillating saw, a horizontal cut – as close as possible to the level of the predetermined CORA – was made with marked attention to preserve the opposite lateral cortex to act as a fulcrum for correction and also to enhance stability. MA was corrected through opening the osteotomy using a broad osteotome to the extent achieving the clinically desired correction that was checked radiologically with a TAS angle of about 90°–92°; then fixation of the recently aligned tibia was secured to maintain the achieved correction and prevent any secondary displacement or collapse. The last step was filling or impacting the osteotomy site with an appropriate amount of bone grafting (Fig. 1).

Iliac bone graft was used in all the adult cases, while the excised part of the fibula was used in skeletally immature patients after longitudinally splitting the fibular fragment and drilling the cortex to facilitate and fasten graft intake.

For performing a medial closing-wedge, two k-wires were used guiding the appropriate wedge to be removed. The first wire is inserted parallel to the ankle joint line while the second wire was inserted at the calculated angle of correction in relation to the first wire, regardless of its position in relation to the mechanical axis of the tibia and is directed toward the first wire and the bone wedge was cut between the two intersected wires. Manipulating the distal tibial segment by closing the wedge achieves the desired correction (Fig. 2) that was checked clinically and radiologically and maintained through medial plate fixation without bone grafting.

Concomitant and secondary procedures

Associated procedures (Fig. 3) were done in some cases for special pathoanatomical abnormalities. These concomitant procedures included an anterior ankle decompression removing an anterolateral impinging bony hump, a second fibular shortening osteotomy with plate fixation and fibular epiphysiodesis. Prophylactic syndesmotic fixation prior to correction and a second intervention in the form of partial epiphysiodesis of the medial malleolar epiphysis was needed in one case when there was a differential growth within the epiphysis itself aiming at decreasing the chances for recurrence.

Postoperative care and follow-up

Patients were discharged with a protective splint till wound healing and suture removal and then a removable splint was used with encouraged active and passive range of motion (ROM) of ankle and subtalar joints. Full weightbearing was initiated

Figure 2

(a) (b)

Correction of valgus malalignment of the ankle through supramalleolar closing wedge osteotomy after partial fibulectomy: (a) valgus malalignment of the ankle with physeal closure of the distal fibula and partial scalloping of the tibial physis, (b) after partial fibulectomy and prophylactic syndesmotic fixation and correction after closing-wedge osteotomy.

Figure 3

(a) (a-) (b) (b-) (c)

Concomitant and secondary procedures that were done in special situations: (a, a-) anterior ankle decompression removing an anterior impinging bony hump, (b, b-) Fibular epiphysiodesis and fibular shortening osteotomy for correction of the talar tilt to reconstruct the ankle, (c) partial epiphysiodesis of the medial part of the distal tibial epiphysis.

Table 2 Functional and radiological outcome

Parameters	Preoperative	Last follow-up	*P* value
American Orthopaedic Foot and Ankle Society			
Varus (10 cases)			
Range	42–62	76–100	<0.001
Mean±SD	48.6±3.1	83.7±7.6	
Valgus (six cases)			
Range	44–64	76–90	<0.001
Mean±SD	51±3.6	80.5±8.5	
Total (16 cases)			
Range	42–64	76–100	<0.001
Mean±SD	49.5±7.5	82.5±9.4	
Tibial articular surface angle			
Varus (10 cases)			
Range	63°–75°	86°–92°	<0.001
Mean±SD	71°±4.2°	88.6°±2.2°	
Valgus (six cases)			
Range	102°–122°	88°–98°	<0.001
Mean±SD	107°±8.2°	93.6°±1.7°	
Healing time (weeks)			
Varus (10 cases)			
Range	7–15		0.18
Mean±SD	10.2±4.6		
Valgus (six cases)			
Range	7–13		–
Mean±SD	9.66±4.8		
Total (16 cases)			
Range	7–15		–
Mean±SD	10±4.8		

when there was evidence of radiographic healing and graft taking. Clinical assessment and scoring patients' conditions according to the AOFAS ankle–hindfoot score (pain level, limitations of activities, and walking ability) at 3 and 6 months and then yearly throughout the follow-up period were done.

Statistical analysis

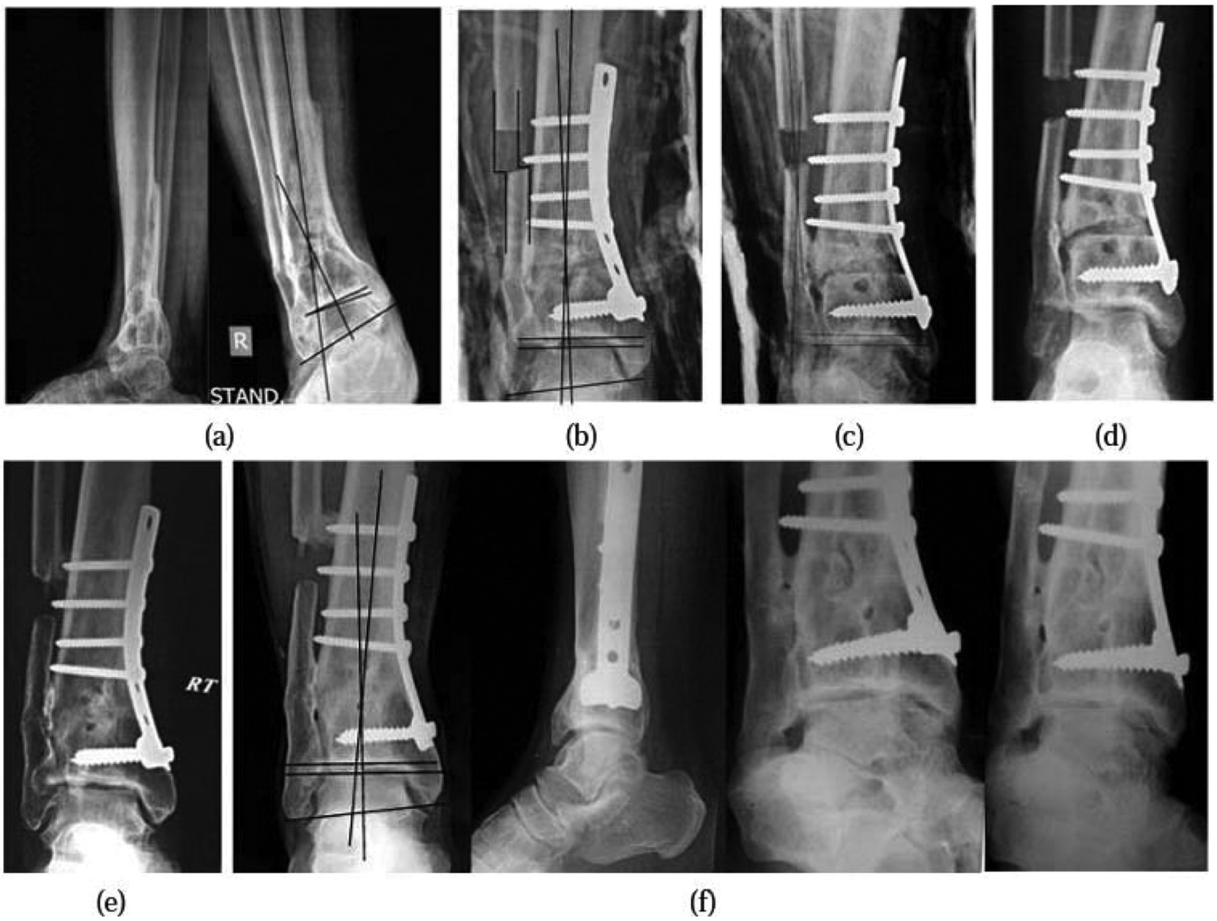
Statistical analysis was performed using SPSS, version 19.0 (SPSS Inc., Chicago, Illinois, USA). Statistical analysis was done using a two-tailed Student's *t*-test and a *P* value less than 0.05 was considered statistically significant.

Results

This study included 18 cases with post-traumatic MA ankles in 18 different patients (Tables 1 and 2); their ages ranged from 10 to 44 years with a mean age of 17.6 ±5.9 years. Among the 18 cases, there were 16 male (representing 88.9% of the studied cases) and two female cases (representing 11.1% of the studied cases). The right side was affected in 16 cases, while the left side was affected in two cases. Twelve cases (representing 66.67% of the studied cases) had varus deformity of the ankle, while the other six cases (representing 33.3% of the studied cases) had valgus deformity with the mean MA angle being 15°±3.8° and 21°±4.6°, respectively. Varus deformity was secondary to physeal insult in skeletally immature patients in eight cases while malunion of the distal tibial fractures (malunited pilon fractures) was the cause in the remaining four cases with post-traumatic distal tibiofibular bony synostosis in three out of these four cases. Valgus deformity was secondary to physeal arrest in skeletally immature patients in four cases while malunion of distal tibial fractures was the cause in the remaining two cases. Among the 18 studied cases, four cases had asymmetrical narrowing of the joint space (Takakura and colleagues, stage 2) with abnormal TT angle; three cases had lateral narrowing and joint overload secondary to varus MA and one case had medial narrowing and joint overload secondary to valgus MA. The first injury/presentation for osteotomy interval ranged from 9 to 62 months with a mean interval of 28±11.8 months. Twelve patients had no previous operative intervention for their initial injury, while five cases were managed by tibial external fixation with fibular plating, and one case had a temporary distal fibular epiphyseal fixation using k-wires combined with tibial external fixation. The patients were followed up for a mean duration of 5.5±2.8 years (ranged from 1 to 8 years).

All the osteotomies united – radiologically – in a mean duration of 10±4.8 weeks (ranged from 7 to 15 weeks) with no statistically significant difference in the mean healing time between the two types of osteotomies (either opening- or closing-wedge osteotomies) in the two groups of patients. There was a statistically significant improvement ($P<0.001$) in the mean last follow-up MA angle for both groups with either varus or valgus MA compared with the mean preoperative angle (Figs 4 and 5). The mean preoperative TAS angle in the 12 patients with varus deformity was 71°±4.2° (ranged from 63° to 75°), which was significantly improved postoperatively with the mean angle being 88.6°±2.2° (ranged from 86° to 92°) ($P<0.001$). The mean preoperative TAS angle in the six patients with valgus deformity was 107°±8.2° (ranged from 102° to 122°), which was improved postoperatively with the mean angle being 93.6°±1.7° (ranged from 88° to 98°), indicating a statistically significant improvement ($P<0.001$). Although, there was a statistically significant improvement ($P<0.001$) of both the MA angle and TAS angle, two patients of the 16 patients who completed their follow-up showed incomplete correction with residual radiographic deformity in the last follow-up with still uncorrected TC angle. Postoperatively, three of the four cases with

Figure 4



Very satisfactory radiological result after supramalleolar osteotomy and concomitant anterior ankle decompression: (a) standing preoperative radiograph showing varus deformity (abnormal TAS, TC, and MA angles) with asymmetrical joint space (abnormal TT angle) and impinging bony hump. (b) Immediate postoperative. Anteroposterior (AP) view radiograph (in cast) showing accepted correction with improved TAS, TC, TT, and MA angles with changed attitude of the distal segment of the fibula in relation to the proximal segment after partial fibulectomy and corrective medial opening-wedge osteotomy. (c) Immediate postoperative Mortis view radiograph (in cast) showing improved attitude after corrective osteotomy (done below the tibiofibular bony synostosis) with the graft keeping the osteotomy open. (d) 3 weeks postoperative Mortis view radiograph (after cast removal) showing good fixation, improved ankle attitude with symmetrical joint space, and the graft in place with no early collapse. (e) 3-year follow-up showing complete graft intake and remodeling with preserved, symmetrical joint space and very satisfactory alignment. (f) 8-year follow-up AP, lateral and different degrees of internal rotation views, radiographs showing very satisfactory radiological result (apart from small anterior hump) regarding alignment, joint preservation, and completely consolidated osteotomy site. MA, malalignment; TAS, tibial articular surface; TC, tibiocrural; TT, talar tilt.

asymmetrical narrowing of the joint space (Takakura and colleagues, stage 2) with abnormal TT angle were improved with corrected TT angle, while the last case still has an abnormal angle with asymmetrical joint space but showed no evidence of progression of the arthritic changes till the last follow-up.

The clinical results regarding pain, ROM, gait, and walking distance were very satisfactory with no surgery-related complications apart from delayed wound healing that occurred in two cases. The mean AOFAS ankle–hindfoot score was markedly improved from 43.8±7.5 (ranged from 40 to 57) preoperatively to 82.6±9.4 (ranged from 75 to 95) postoperatively in the last follow-up indicating a statistically significant improvement ($P<0.001$) with no statistically significant difference between the two groups of osteotomies, and all patients stated that they were satisfied with the procedure. The deformity was clinically improved (Figs 6 and 7) in all the 18 patients although the radiological results were not ideal in two cases with residual deformity still present after surgery. Preoperative LLD was reported in 14 cases with discrepancy that ranged from 0.5 to 2 cm. Among these 14 cases with LLD, 10 cases had varus deformity while the last four cases had valgus deformity. Postoperatively, LLD was corrected in the 10 cases with preoperative varus deformities while the remaining four cases with preoperative valgus deformity that were treated by a subtraction closing wedge osteotomy still had LLD, but to a lesser extent when compared with the

Figure 5

Incomplete correction with residual deformity over a 7-year follow-up. (a) Standing preoperative radiograph showing valgus deformity (abnormal TAS, TC, and MA angles) with symmetrical joint space (normal TT angle), scalloped lateral part of the distal tibial epiphysis and complete fibular physeal arrest. (b) Immediate postoperative AP view radiograph (in cast) showing accepted correction with improved TAS, TC, and MA angles with good coaptation of the osteotomy site with no translation or displacement or syndesmotic disruption (prophylactic syndesmotic screw fixation) after osteotomy. (c) 1-year follow-up radiograph showing early recurrence of the deformity (mostly due to crushed lateral part of the distal tibial physis with continued differential growth with the distal tibial physis itself) in spite of good fixation and completely united osteotomy. (d) 2-years follow-up radiograph after medial malleolar epiphysiodesis (performed as a secondary procedure) to decrease deformity progression. (e) 3-year follow-up radiograph showed improved alignment 1 year following medial malleolar epiphysiodesis. (f) 5-year postoperative radiograph showing preserved and symmetrical joint space with residual valgus deformity indicating that medial epiphysiodesis was not completely effective. (g) 7-years follow-up AP and Mortis view radiograph showing preserved and symmetrical joint space with incompletely corrected deformity. AP, anteroposterior; MA, malalignment; TAS, tibial articular surface; TC, tibiocrural; TT, talar tilt.

preoperative. LLD and they reported more satisfaction and improved gait. Such improvement could be – mostly – explained by the correction of the deformity and restoration of the normal relationship between the foot and the leg.

Discussion

Unlike the hip and knee joints, osteoarthritis of the ankle mostly result from trauma due to either severe articular cartilage injury or MA of the distal tibia that

Figure 6

(a) (b) (c) (d) (e)

Preoperative and postoperative clinical photographs (from the front and the back) of a case with varus ankle (corresponding to the radiograph presented in Fig. 4 and reporting the same patient) showing satisfactory deformity correction and near normal ankle range of motion: (a) varus deformity of the ankle with abnormal foot attitude in relation to leg. (b) Clinical photographs 3 weeks postoperatively showing accepted deformity correction. (c) Clinical follow-up 3 years postoperatively showing satisfactory deformity correction. (d) Clinical follow-up 5 years postoperatively showing satisfactory deformity correction with near normal ankle range of motion. (e) Clinical follow-up 8 years postoperatively showing satisfactory deformity correction.

Figure 7

(a) (b) (c) (d)

Preoperative and postoperative clinical photographs (from the front and the back) of a case with valgus ankle (corresponding to the radiograph presented in Fig. 5 and reporting the same patient) showing satisfactory deformity correction: (a) valgus deformity of the ankle (from the front and the back) with abnormal foot attitude in relation to the leg. (b) Clinical photographs 6 months postoperatively showing accepted deformity correction (from the front and the back). (c) Clinical follow-up 3 years postoperatively showing early recurrence of the deformity correction. (d) Clinical follow-up 7 years postoperatively showing improved foot attitude after partial (medial) distal tibial epiphysiodesis.

markedly affects the tibiotalar contact point as well as the contact area. MA actually affects the integrity and durability of the tibiotalar articulation as the ankle mortise is not an inherently congruent joint, and its stability is based mainly on the alignment of the mortise [5]. Cadaveric biomechanical work had reported up to 40% decrease in the contact surface area of the ankle joint in the presence of MA or deformity [6], but there is no consensus in the literature regarding the acceptable limits of angular deformity of the tibia and the potential for the development of pain in the ankle joint or radiographic evidence of arthritis [7]. Merchant and Dietz [8] reported a statistically nonsignificant difference in patients who had a combination of 5° angulations in the frontal plane and 10° or more in the sagittal plane when compared with patients who had less angulations regarding joint pain and function. Kristensen *et al.* [9] reported that angulations exceeding 10° were compatible with normal function and absence of pain, but Haskell and Mann [10] – in a more recent study – showed that 33–44% of patients presenting for ankle replacement have coronal plane deformities exceeding 10° of angulations.

In addition to cosmetic disfigurement, significant mechanical MA and disturbed mechanics of the ankle joint with subsequent altered load distribution leads to stress concentration, pain, and articular cartilage damage heralding joint degeneration; so realignment is imperative [7]. Simply, the easiest and most effective method for correction of supramalleolar deformities should be by performing SMOT in the juxta-articular region of the tibia, with great attention given for anatomical reconstruction of the ankle joint restoring the normal anatomical relationship between the distal tibia and fibula and tibiotalar congruency to improve the function of the foot and ankle [11].

Medial opening wedge osteotomy for varus deformity is the standard procedure for such MA while correction of valgus deformity either through a medial closing or lateral opening wedge osteotomy is a matter of debate and controversy [7]. In this study, the SMOT via a medial incision was used for the correction of both varus and valgus deformities in all cases. Apart from substantial shortening in some cases where large-sized wedges of bone must be removed, correction of valgus deformity through a medial closing-wedge osteotomy in the juxta-articular cancellous region of the tibia allows rapid healing and preserves the lateral cortex of the tibia which is strong and elastic and will remain intact when compression forces are applied medially to close the osteotomy abolishing the need for additional lateral fixation. In contrast, correction of valgus through a lateral opening-wedge osteotomy requires a bone graft with a longer healing time and may need an additional medial fixation to avoid overcorrection as the medial cortex of the distal tibia is usually weak [12]. In this study, the type of osteotomy (opening vs. closing wedge) does not influence the final functional outcome or the time of bone healing, although LLD was not corrected in any of the patients that were treated by closing-wedge osteotomy.

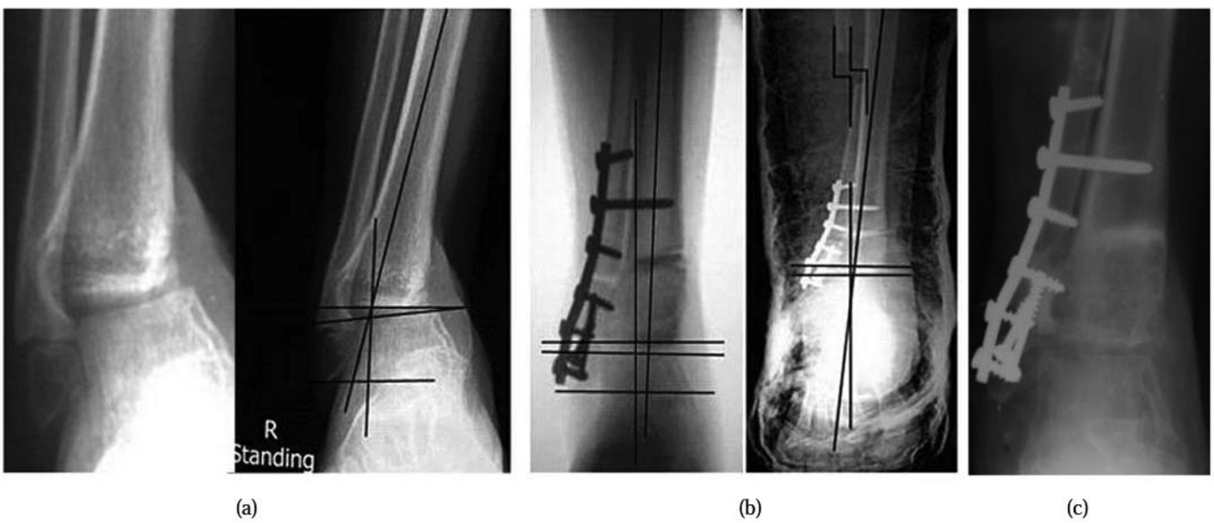
Several studies have clearly reported satisfactory clinical and radiographic results after corrective SMOT for both varus [13,14] and valgus [15,16] deformities. The functional and radiological results of this study are in agreement with the results of such studies [13–16] showed significant improvement in the radiological parameters and the functional outcome expressed by AOFAS ankle–hindfoot score of all the studied cases. Moreover, two of the six cases with preoperative asymmetrical narrowing of the joint space (Takakura and colleagues, stage 2) with either medial or lateral joint overload showed symmetrical improvement in the joint space while the remaining four cases showed no progressive joint narrowing or arthritic changes throughout the follow-up period that extended for a mean duration of 5.5±2.8 years (ranged from 1.5 to 8 years) indicating that this procedure could be also considered as a joint-preserving surgery protecting the articular cartilage through correcting the mechanics and equally redistributing the joint loads, thus preventing progressive degenerative arthritis.

Performing a fibular osteotomy in combination with SMOT is a matter of debate and controversy. Some authors have proposed combined fibular osteotomy for all SMOT patients [17,18]; some have suggested that the fibula should always be preserved [19–22], and some authors have performed fibular osteotomy depending on certain conditions [16,23,24]. Stufkens *et al.* [25] reported that the fibula may restrict the extent of correction afforded by SMOT, whereas distal fibular osteotomy could be a very difficult and critical task in such cases. They also reported that the tibiotalar contact force shifted in different directions with and without fibular osteotomy after SMOT. Different studies have reported adverse biomechanical changes affecting the contact area and pressure in the normal ankle joint with improperly performed fibular osteotomies [26,27]. When the distal fibula is osteotomized and translated by 1–2 mm, the tibiotalar contact area can decrease by up to 30% while manipulating the distal fibula into a varus or valgus position by 1° results in more than 50% reduction in contact area [26] and shortening of the fibula by 2 mm or more, or lateral rotation of 5° or more, significantly increases the contact pressure across the ankle joint [27]. So, avoiding distal fibular osteotomy (at the level of the ankle) could be beneficial with no risk of disturbing the contact area and pressure within the ankle joint [28] provided that unrestricted and satisfactory correction could be achieved. Zhao *et al.* [29] reported that no clinical study has directly compared the outcomes of SMOT with and without fibular osteotomy. In this study, the preliminary partial fibulectomy performed above the level of the syndesmosis – instead of the usually performed more distal fibular osteotomy – allowed unchanged ankle joint mechanics and unrestricted correction. Moreover, proximal fibular osteotomy avoids a previously exposed and plated distal fibula in most cases with pilon fractures and allows easy and safe manipulation in the presence of post-traumatic distal tibiofibular bony synostosis, which is a common finding after MA, comminuted pilon fractures.

The most challenging supramalleolar angular deformities were secondary to post-traumatic physeal arrest. Early intervention presents a real risk for deformity recurrence and a high incidence of second surgical intervention until complete physeal closure at 14–16 years of age, but delaying intervention produces much complex conditions with progressing deformity making earlier intervention better and easier. Angular deformities secondary to post-traumatic physeal arrest had presented 3–5 years after the initial injury and were associated with differential growth within the same physis (between different parts) resulting from scalloping or compression with high risk for recurrence or differential tibiofibular growth resulting in incongruent joint with abnormally tilted talus and a CORA lies within the joint or very close to it, resulting in severe deformities. In such cases, epiphysiodesis of the fibula is not enough, a second fibular shortening osteotomy is necessary and iatrogenic syndesmotic diastases could be mandatory for proximally migrating or elevating the epiphysiodesed and shortened fibula to the desired position with temporary syndesmotic fixation till soft tissue healing and osteotomy union (Fig. 8).

In this study, acute correction through a single surgical procedure was done in all cases and osteotomies were internally fixed using plates and screws in all – except two cases – in which the soft tissue condition on the medial side was questionable with a fear of soft tissue breakdown with a minimal needed correction and stable osteotomy after opening the wedge and impaction of the graft. Fixation using plates and screws allows rapid healing and early rehabilitation. This goes in hand with what was reported by many surgeons who prefer plate fixation over other methods of fixation [12]. All the osteotomies united in an average duration of 10±4.8 weeks (ranged

Figure 8



Varus deformity secondary to post-traumatic physeal arrest. (a) standing preoperative radiograph showing valgus deformity with marked differential growth between the tibia and fibula with fibular overlengthening, asymmetrical joint space with talar tilt (abnormal TT angle) and a CORA lies very close to the ankle joint. (b) Intraoperative assessment of the correction and immediate postoperative radiograph after proximal partial fibulectomy, epiphysiodesis of the fibula, and a second fibular shortening osteotomy for ankle reconstruction, and a medial opening wedge SMOT. (c) 26 weeks postoperatively showing satisfactory result regarding deformity correction with united both osteotomies. SMOT, supramalleolar osteotomies.

from 7 to 15 weeks) with no statistically significant difference in the healing time between the two groups of osteotomies. Stamatis *et al*. [18] also reported no significant difference in the healing time between their two groups of cases with either closing-wedge or opening-wedge SMOT with an average healing time of about 14 weeks. In another study by Zhao *et al*. [29], they reported that a mean duration of 3.8 months (range: 3–8) was needed for bony union and stated that union times longer than 6 months occurred in three patients for whom β-tricalcium phosphate was used to fill the osteotomy gaps. The relatively short time needed for union in patients who underwent opening-wedge osteotomies in this study was attributed to the use of cancellous and corticocancellous autologous bone graft with a marvelous osteogenic, osteoinductive and osteoconductive potentials compared with graft substitutes used in other studies.

In most of varus deformities following intra-articular or extra-articular distal tibial fractures, there was comminution and shortening resulting in LLD that should be addressed while correcting the deformity; in such conditions, an opening-wedge osteotomy and bone graft definitely adds length and corrects preoperative LLD. This makes opening-wedge osteotomy – in contrast to dome-shaped osteotomies that minimize the lengthening and shortening of the tibia – preferable in cases with LLD. In valgus deformities of the ankle, medial closing wedge osteotomy results in shortening but the corrected foot attitude in relation to the leg could – to some extent – compensate for this making postoperative LLD a benign and negligible issue.

None of the cases had inframalleolar deformity, and the subtalar joint was mobile in all cases. So, none of the studied cases needed any inframalleolar correction. A freely mobile and stable subtalar joint could compensate for incompletely corrected MA with residual deformity; this joint allows for movement in the frontal plane (inversion and eversion) and could therefore compensate for varus and valgus deformities of the lower extremity [30]. Residual valgus was much more tolerated than residual varus; this could be explained by the anatomical fact that the subtalar joint – normally – allows inversion (that could compensate for residual valgus deformity) more than eversion (that could compensate for residual valgus deformity) [31]. This could explain why the clinical and functional results were superior to the radiological results and patients with residual radiological valgus deformity and disturbed angles were clinically satisfied (Fig. 9). On the other hand, the alignment of the whole limb could be affected by angular deformities around the knee joint; minimal varus deformity of the knee could give a false impression of improper correction by a well-performed SMOT although the radiological parameters were markedly improved (Fig. 10). So, we recommend hip-to-calcaneus radiographs to

Figure 9

Although residual radiological valgus deformity is still present, the clinical results were very satisfactory, a well-functioning, stable, and freely mobile subtalar joint could compensate for incompletely corrected malalignment with residual deformity.

Figure 10

Although the radiological parameters were markedly improved by a well-performed SMOT, minimal varus deformity of the knee could give a false impression of residual deformity and improper correction. SMOT, supramalleolar osteotomies.

evaluate lower limb alignment in SMOT patients. This is in agreement with what was presented by Mann *et al.* [22] and Kim *et al.* [20], who reported that the clinical results were good, although the mean postoperative TT was 10° and that no radiological outcome seemed to have a significant influence on the clinical outcomes.

The satisfactory results of this study could be attributed to many factors. In all cases, the deformity was only in the coronal plane with no associated sagittal plane MA. In all cases, the deformity was only supramalleolar with no other hindfoot MA the preliminary partial fibulectomy performed in all cases allowed unrestricted extent of correction that could be achieved by the SMOT. Also, the partial fibulectomy was done in a more proximal level allowing undisturbed ankle joint mechanics. In most cases, the CORA was away from the ankle joint and the osteotomy was done very close to the CORA. Most of the cases had congruent deformity within the tibiotalar joint space with a mean TT angle of up to 4°of tilt while incongruent deformity within the tibiotalar joint space with a mean TT angle of more than 4° of tilt was found only in four cases caused by post-traumatic physeal arrest.

To the best of our knowledge, no studies addressed and presented proximal fibular osteotomy (partial proximal osteotomy) achieving the benefit of easy, unrestricted correction and avoiding the well-reported biomechanical hazards of performing the classic distal fibular osteotomies that usually needed with SMOT for correction of such deformities. On the other hand, the small number of cases and the heterogeneous sample of the included and studied cases including adolescents and adults, the pre- and postoperative radiological evaluations without weight-bearing full-length AP view (hip-to-calcaneus radiographs) which would be useful for the full leg alignment evaluation, the lack of alternatives (different types of osteotomies and different fixation methods) used as a control group, and the relatively short, mean follow-up periods – especially in adolescent patients with a high potential for recurrence – represent the limitations of this study; however, these limitations do not appear to undermine the results achieved in this study. Also, there were several studies that included adolescents and adults in their research claiming that heterogeneity did not affect their final outcome [18,32]. Further long-term studies are recommended to detect the risk factors for progression of ankle degeneration, and meticulous biomechanical work should be performed to address the effect of different types of SMOT fixed with different fixation methods on ankle biomechanics and kinematics.

Conclusion

SMOT is an effective procedure for treating symptomatic angular deformities of the tibia. SMOT – not only – correct the deformity and improve the functional outcome, but also represent a joint-preserving surgery protecting the articular cartilage through correcting the mechanics and equally redistributing the joint loads, thus preventing progressive degenerative arthritis. The preliminary performed proximal – above the level of the syndesmosis – partial fibulectomy allowed unrestricted correction without distorting the ankle mechanics. Moreover, it allows easy and safe manipulation in the presence of post-traumatic distal tibiofibular bony synostosis which is a common finding after comminuted, MA pilon fractures.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

References

1 Horisberger M, Valderrabano V, Hintermann B. Posttraumatic ankle osteoarthritis after ankle-related fractures. J Orthop Trauma 2009; 23:60–67.

2 Alexej B, Geert P, Monika H, Jochen P, Marcel G, Heath BH, Victor V. Supramalleolar osteotomies for degenerative joint disease of the ankle joint: indication, technique and results. Int Orthop 2013; 37:1683–1695.

3 Tanaka Y. The concept of ankle joint preserving surgery: why does supramalleolar osteotomy work and how to decide when to do an osteotomy or joint replacement. Foot Ankle Clin 2012; 17: 545–553.

4 Takakura Y, Takaoka T, Tanaka Y, Yajima H, Tamai S. Results of opening-wedge osteotomy for the treatment of a post-traumatic varus deformity of the ankle. J Bone Joint Surg 1998; 80-A:213–218.

5 Cancelliere P. Supra malleolar osteotomies for neglected tibial deformity affecting the ankle and foot. Clin Res Foot Ankle 2016; 4:192.

6 Tarr RR, Resnick CT, Wagner KS, Sarmiento A. Changes in tibiotalar joint contact areas following experimentally induced tibial angular deformities. Clin Orthop 1985; 199:72–80.

7 Emmanouil DS, Paul SC, Mark SM. Supramalleolar osteotomy for the treatment of distal tibial angular deformities and arthritis of the ankle joint. Foot Ankle Int 2003; 24:754–764.

8 Merchant TC, Dietz FR. Long-term follow-up after fractures of the tibial and fibular shafts. J Bone Joint Surg 1989; 71:599–606.

9 Kristensen KD, Kiaer T, Blicher J. No arthrosis of the ankle 20 years after malaligned tibial-shaft fracture. Acta Orthop Scand 1989; 60:208–209.

10 Haskell A, Mann RA. Ankle arthroplasty with preoperative coronal plane deformity. Clin Orthop Relat Res 2004; 424:98–103.

11 Di-Domenico LA, Gatalyak N. End-stage ankle arthritis, arthrodiastasis, supramalleolar osteotomy, or arthrodesis? Clin Podiatr Med Surg 2012; 29:391–412.

12 Hintermann B, Knupp M, Barg A. Supramalleolar osteotomies for the treatment of ankle arthritis. J Am Acad Orthop Surg 2016; 24:424–432.

13 Lee KB, Cho YJ. Oblique supramalleolar opening wedge osteotomy without fibular osteotomy for varus deformity of the ankle. Foot Ankle Int 2009; 30:565–567.

14 Lee WC, Moon JS, Lee K, Byun WJ, Lee SH. Indications for supramalleolar osteotomy in patients with ankle osteoarthritis and varus deformity. J Bone Joint Surg Am 2011; 93:1243–1248.

15 Hintermann B, Barg A, Knupp M. Corrective supramalleolar osteotomy for malunited pronation-external rotation fractures of the ankle. J Bone Joint Surg Br 2011; 93:1367–1372.

16 Knupp M, Stufkens S, Bolliger L, Barg A, Hintermann B. Classification and treatment of supramalleolar deformities. Foot Ankle Int 2011; 32:1023–1031.

17 Tanaka Y, Takakura Y, Hayashi K, Taniguchi A, Kumai T, Sugimoto K. Low tibial osteotomy for varus-type osteoarthritis of the ankle. J Bone Joint Surg Br 2006; 88:909–913.

18 Stamatis ED, Cooper PS, Myerson MS. Supramalleolar osteotomy for the treatment of distal tibial angular deformities and arthritis of the ankle joint. Foot Ankle Int 2003; 24:754–764.

19 Ahn TK, Yi Y, Cho JH, Lee WC. A cohort study of patients undergoing distal tibial osteotomy without fibular osteotomy for medial ankle arthritis with mortise widening. J Bone Joint Surg Am 2015; 97:381–388.

20 Kim YS, Park EH, Koh YG, Lee JW. Supramalleolar osteotomy with bone marrow stimulation for varus ankle osteoarthritis: clinical results and secondlook arthroscopic evaluation. Am J Sports Med 2014; 42:1558–1566.

21 Kobayashi H, Kageyama Y, Shido Y. Treatment of varus ankle osteoarthritis and Instability with a novel mortise-plasty osteotomy procedure. J Foot Ankle Surg 2016; 55:60–67.

22 Mann HA, Filippi J, Myerson MS. Intra-articular opening medial tibial wedge osteotomy (plafond-plasty) for the treatment of intra-articular varus ankle arthritis and instability. Foot Ankle Int 2012; 33:255–261.

23 Pagenstert G, Leumarm A, Hintermann B, Valderrabano V. Sports and recreation activity of varus and valgus ankle osteoarthritis before and after realignment surgery. Foot Ankle Int 2008; 29:985–993.

24 Colin F, Bolliger L, Horn Lang T, Knupp M, Hintermann B. Effect of supramalleolar osteotomy and total ankle replacement on talar position in the varus osteoarthritic ankle: a comparative study. Foot Ankle Int 2014; 35:445–452.

25 Stufkens SA, van Bergen CJ, Blankevoort L, van Dijk CN, Hintermann B, Knupp M. The role of the fibula in varus and valgus deformity of the tibia: a biomechanical study. J Bone Joint Surg Br 2011; 93:1232–1239.

26 Ramsey PL, Hamilton W. Changes in tibiotalar area of contact caused by lateral talar shift. J Bone Joint Surg Am 1976; 58-A:356–357.

27 Thordarson DB, Motamed S, Hedman T, Ebramzadeh E, Bakshian S. The effect of fibular mal-reduction on contact pressures in an ankle fracture malunion model. J Bone Joint Surg Am 1997; 79:1809–1815.

28 Driscoll HL, Christensen JC, Tencer AF. Contact characteristics of the ankle joint. Part 1: the normal joint. J Am Podiatr Med Assoc 1994; 84:491–498.

29 Zhao H, Liang X, Li Y, Yu G, Niu W, Zhang Y. The role of fibular osteotomy for supramalleolar osteotomy in treatment of varus ankle arthritis: a biomechanical and clinical study. J Orthop Surg 2016; 11:127.

30 Knupp M. The use of osteotomies in the treatment of asymmetric ankle joint arthritis. Foot Ankle Int 2017; 38:220–229.

31 Hayashi K, Tanaka Y, Kumai T, Sugimoto K, Takakura Y. Correlation of compensatory alignment of the subtalar joint to the progression of primary osteoarthritis of the ankle. Foot Ankle Int 2008; 29:400–406.

32 Sen C, Kocaoglu M, Eralp L, Cinar M. Correction of ankle and hindfoot deformities by supramalleolar osteotomy. Foot Ankle Int 2003; 24:22–28.