Supramalleolar Osteotomy for Treatment Of Post Traumatic Angular Tibial Deformities Affecting The Ankle Joint.

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Abstract

Background: Angular deformities of the leg resulting from mal-union 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 mal-union of previous distal tibial fractures or post-traumatic physeal arrest. 12 patients had varus deformities of the ankle while 6 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 (AOFAS) was used for evaluating the functional results pre- and post-operatively.

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 2 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 post-operative tibial articular surface (TAS), talar tilt (TT), tibiocrural (TC) and the mal-alignment (MA) angles in the last follow-up compared to the mean pre-operative values while 2 cases showed incomplete correction with residual deformity in the last follow-up. The mean (AOFAS) ankle-hind foot score was markedly improved from 43.8 ± 7.5 pre-operatively 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.

Conclusions: 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 re-distributing the joint loads thus, preventing progressive degenerative arthritis. The preliminary performed proximal partial fibulectomy - above the level of the syndesmosis - allowed easy, safe and unrestricted correction in the presence of post-traumatic distal tibio-fibular bony synostosis which is a common finding after comminuted, mal-aligned pilon fractures without distorting the ankle mechanics.

Keywords: Angular deformities of the tibia, Symptomatic mal-aligned ankle, Supramalleolar corrective osteotomy, preliminary partial fibulectomy above the syndesmosis, Joint-preserving procedure with satisfactory functional results.

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 showed 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 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 a 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 I) with symptomatic, mal-aligned ankles secondary to post traumatic angular tibial deformities. 16 patients were males and 2 patients were females. 12 patients had varus deformity while 6 patients had valgus deformity of the ankle. Patients with post traumatic, mal-aligned 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 infra-malleolar deformities with/without stiff or arthritic sub-talar 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 weight bearing, limb length discrepancy (LLD) and the range of motion of the ankle and hindfoot. Weight bearing plain X-rays (AP and lateral views) of the affected leg and ankle, C.T 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-Hind foot scale was used for clinical assessment. Radiological evaluation was based on certain parameters as the mal-alignment (MA) angle, tibial articular surface (TAS) angle, tibiocrural (TC) angle, the talar tilt (TT) angle and Takakura et al. score (4). 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 tibial articular surface (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 tibial articular surface and the articular surface of the talus on an AP X-ray 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°. Pre-operative arthritic changes were classified according to Takakura et al. (4) as follows:

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

Surgical techniques:
The procedures were done in the operating theatre under complete aseptic conditions with either general or spinal anesthesia, under c-arm guidance and a thigh tourniquet. Supramalleolar osteotomy 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 a supramalleolar medial closing wedge osteotomy. Both opening and closing wedge osteotomies were performed as near 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 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 excision of 1 to 2 cm of the fibula to allow unrestricted deformity correction without affecting the distal tibio-fibular 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 tibio-fibular bony synostosis detected in the axial and coronal CT cuts which is a common finding after mal-aligned, 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 perioseal stripping. Using an oscillating saw, a horizontal cut - as near 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. Mal-alignment was corrected through opening the osteotomy using a broad osteotome to the extent achieving the clinically desired correction that checked radiologically with a TAS angle of about 90° to 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 to 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 inserted parallel to the ankle joint line while the second wire 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 directed towards the first wire and the bone wedge was cut between the 2 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.

**Fig 1:** correction of varus mal-alignment of the ankle through supramalleolar opening wedge osteotomy after partial fibulectomy: (a) varus mal-alignment of the ankle following pilon fracture. (b) after a 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.

**Fig 2:** correction of valgus mal-alignment of the ankle through supramalleolar closing wedge osteotomy after partial fibulectomy: (a) valgus mal-alignment 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, correction after closing wedge osteotomy.

**Concomitant and secondary Procedures:**

Associated procedures (Fig 3) were done in some cases for special patho-anatomical abnormalities. These concomitant procedures included an anterior ankle decompression removing an antero-lateral 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 for decreasing chances for recurrence.
Postoperative care and follow-up:
Patients discharged with a protective splint till wound healing and suture removal then a removable splint was used with encouraged active and passive ROM of ankle and subtalar joints. Full weight bearing was initiated when there was evidence of radiographic healing and graft taking. Clinical assessment and scoring patients' conditions according to the AOFAS ankle-hind foot score (pain level, limitations of activities and walking ability) at 3 and 6months then yearly throughout the follow-up period was done.

Statistical analysis:
Statistical analysis was performed using SPSS ver. 19.0 (SPSS Inc., Chicago, IL, USA). Statistical analysis was done using a two-tailed Student t test and p < 0.05 was considered statistically significant.

Results:
This study included 18 cases with post traumatic mal-aligned ankles in 18 different patients (Table I & II), 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 males (representing 88.9% of the studied cases) and 2 female cases (representing 11.1% of the studied cases). The right side was effected in 16 cases while the left side was affected in 2 cases.12 cases (representing 66.67 % of the studied cases) had valgus deformity of the ankle while the other 6 cases (representing 33.3 % of the studied cases) had varus deformity with the mean mal-alignment(MA) angle was 15°± 3.8° and 21°± 4.6° respectively. Varus deformity was secondary to physeal insult in skeletally immature patients in 8 cases while mal-union of distal tibial fractures (mal-united Pilon fractures) was the cause in the remaining 4 cases.12 cases with post-traumatic distal tibio-fibular bony synostosis in 3 out of these 4 cases. Valgus deformity was secondary to physeal arrest in skeletally immature patients in 4 cases while mal-union of distal tibial fractures was the cause in the remaining 2 cases. Among the 18 studied cases, 4 cases had asymmetrical narrowing of the joint space (Takakura et al. stage 2) with abnormal TT angle; 3 cases had lateral narrowing and joint overload secondary to varus mal-alignment and 1 case had medial narrowing and joint overload secondary to valgus mal-alignment. The first injury/presentation for osteotomy interval ranged from 9 to 62 months with a mean interval of 28 ± 11.8 months. 12 patients had no previous operative intervention for their initial injury while 5 cases were managed by tibial external fixation with fibular plating, and 1 case had a temporary distal fibular epiphyseal fixation using k-wires combined with tibial external fixation. 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 mal-alignment compared to the mean pre-operative angle (Figs 4 & 5). The mean preoperative TAS angle in the 12 patients with varus deformity was 71°± 4.2° (ranged from 63 ° to 75°), that was significantly improved post-operatively with the mean angle was 88.6°± 2.2° (ranged from 86° to 92°) (P < 0.001). The mean preoperative TAS angle in the 6 patients with valgus deformity was 107 °± 8.2° (ranged from 102° to 122°), that was improved post-operatively with the mean angle was 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, 2 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 tibiocrural (TC) angle. Post-operatively, 3 of the 4 cases with asymmetrical narrowing of the joint space (Takakura et al. stage 2) with abnormal TT angle were improved with corrected TT angle while the last case still have abnormal angle with asymmetrical joint space but showed no evidence of progression of the arthritic changes till the last follow-up.
Table 1: The patients' characteristics.

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<th>Side</th>
<th>Deformity</th>
<th>Cause</th>
<th>Previous operation</th>
<th>Time till surgery (months)</th>
<th>Concomitant procedure</th>
<th>F. up (years)</th>
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<td>Malunited Pilon</td>
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<td>M</td>
<td>RT</td>
<td>Valgus</td>
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<td>Syndesmotic fixation 2ry tibial epiphysiodesis</td>
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<td>Valgus</td>
<td>Physeal injury</td>
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(No= number, F= female, M= male, RT= right, LT= left)

Table 2: Functional & Radiological Outcome.

<table>
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<th>Parameter</th>
<th>Pre-operative</th>
<th>last follow up</th>
<th>P value</th>
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<td><strong>AOFAS</strong></td>
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</tr>
<tr>
<td>Varus (10 cases)</td>
<td>42-62</td>
<td>76-100</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Range mean±sd</td>
<td>48.6±3.1</td>
<td>83.7±7.6</td>
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</tr>
<tr>
<td>Valgus (6 cases)</td>
<td>44-64</td>
<td>76-90</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Range mean±sd</td>
<td>51±3.6</td>
<td>80.5±8.5</td>
<td></td>
</tr>
<tr>
<td>Total (16 cases)</td>
<td>42 - 64</td>
<td>76 - 100</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Range mean±sd</td>
<td>49.5±7.5</td>
<td>82.5±9.4</td>
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<tr>
<td><strong>TAS Angle</strong></td>
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<tr>
<td>Varus (10 cases)</td>
<td>63° -75°</td>
<td>86° - 92°</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Range mean±sd</td>
<td>71°±4.2°</td>
<td>88.6±± 2.2°</td>
<td></td>
</tr>
<tr>
<td>Valgus (6 cases)</td>
<td>102° - 122°</td>
<td>88° - 98°</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Range mean±sd</td>
<td>107°±8.2°</td>
<td>93.6±1.7°</td>
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</tr>
<tr>
<td><strong>Healing Time</strong></td>
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<td></td>
<td></td>
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<tr>
<td>(weeks) Varus (10 cases)</td>
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<td>=0.18</td>
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<tr>
<td>Range mean±sd</td>
<td>10.2±4.6</td>
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<tr>
<td>Valgus (6 cases)</td>
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<tr>
<td>Range mean±sd</td>
<td>9.66±4.8</td>
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<tr>
<td>Total (16 cases)</td>
<td>7-15</td>
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<tr>
<td>Range mean±sd</td>
<td>10±4.8</td>
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Fig 4: very satisfactory radiological result after supramalleolar osteotomy and concomitant anterior ankle decompression: (a) standing pre-op. X-ray showing varus deformity (abnormal TAS, TC and MA angles) with asymmetrical joint space (abnormal TT angle) and impinging bony hump. (b) immediate post-op. A.P view X-ray (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 post-op. Mortis view X-ray (in cast) showing improved attitude after corrective osteotomy (done below the tibio-fibular bony synostosis) with the graft keeping the osteotomy open. (d) 3 weeks post-op. Mortis view X-ray (after cast removal) showing good fixation, improved ankle attitude with symmetrical joint space and the graft in place with no early collapse. (e) 3 years follow-up showing complete graft intake and remodeling with preserved, symmetrical joint space and very satisfactory alignment. (f) 8 years follow-up A.P, lateral and different degrees internal rotation views X-rays showing very satisfactory radiological result (apart from small anterior hump) regarding alignment, joint preservation and completely consolidated osteotomy site.

Fig 5: incomplete correction with residual deformity over 7 years follow-up. (a) standing pre-op. X-ray 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 post-op. A.P view X-ray (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 X-ray 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 X-ray after medial malleolar epiphysiodesis (performed as a secondary procedure) to decrease deformity progression. (e) 3 years follow-up X-ray showed improved alignment 1 year following medial malleolar epiphysiodesis. (f) 5 years post-op. X-ray showing preserved and symmetrical joint space with residual valgus deformity indicating that medial epiphysiodesis was not completely effective. (g) 7 years follow-up A.P and Mortis view X-rays showing preserved and symmetrical joint space with incompletely corrected deformity.
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 2 cases. The mean AOFAS ankle-hind foot score was markedly improved from 43.8 ± 7.5 (ranged from 40 to 57 ) pre-operatively to 82.6 ± 9.4 (ranged from 75 to 95 ) post-operatively 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 & 7) in all the 18 patients although the radiological results were not ideal in 2 cases with residual deformity still present after surgery.

Pre-operative limb length discrepancy (LLD) was reported in 14 cases with discrepancy ranged from 0.5 cm to 2 cm. Among these 14 cases with LLD, 10 cases had varus deformity while the last 4 cases had valgus deformity. Post-operatively, LLD was corrected in the 10 cases with pre-op. varus deformities while the remaining 4 cases with pre-op. valgus deformity that were treated by a subtraction closing wedge osteotomy still had LLD but to a lesser extent when compared to the pre-op. 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.

![Fig 6: Pre- and post-operative clinical photos (from the front and the back) of a case with varus ankle (corresponding to the x-rays 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 photos 3 weeks post-op, showing accepted deformity correction. (c) clinical follow-up 3 years post-op, showing satisfactory deformity correction. (d) clinical follow-up 5 years post-op. showing satisfactory deformity correction with near normal ankle range of motion. (e) clinical follow-up 8 years post-op. showing satisfactory deformity correction.](image)

![Fig 7: Pre- and post-operative clinical photos (from the front and the back) of a case with valgus ankle (corresponding to the x-rays presented in fig 5 and reporting the same patient) showing satisfactory deformity correction: (a) varus deformity of the ankle (from the front and the back) with abnormal foot attitude in relation to leg. (b) clinical photos 6 months post-op, showing accepted deformity correction (from the front and the back). (c) clinical follow-up 3 years post-op. showing early recurrence of the deformity correction. (d) clinical follow-up 7 years post-op. showing improved foot attitude after partial (medial) distal tibial epiphysiodesis.](image)
Discussion:
Unlike the hip and knee joints, osteoarthritis of the ankle mostly resulting from trauma due to either severe articular cartilage injury or mal-alignment of the distal tibia that markedly affect the tibiotaral contact point as well as the contact area. Mal-alignment actually affects the integrity and durability of the tibiotaral 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 mal-alignment 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 development of pain in the ankle joint or radiographic evidence of arthritis (7). Merchant and Dietz (8) reported a statistically non-significant difference in patients who had a combination of 5° angulations in the frontal plane and 10° or more in the sagittal plane when compared to 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 - in a more recent study - showed that 33- 44% of patients presenting for ankle replacement have coronal plane deformities exceeding 10° of angulations (10).

In addition to cosmetic disfigurement, significant mechanical mal-alignment 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 supramalleolar osteotomies 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 tibiotaral congruency to improve the function of the foot and ankle (11).

Medial opening wedge osteotomy for varus deformity is the standard procedure for such mal-alignment while correction of valgus deformity through either a medial closing or lateral opening wedge osteotomy is a matter of debate and controversy (7). In this study, the supramalleolar osteotomy via a medial incision was used for correction of both varus and valgus deformities in all cases. Apart from substantial shortening in some cases where large sized wedge 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 our study, the type of osteotomy (opening versus 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 supramalleolar osteotomy for both varus (13,14) and valgus (15,16) deformities. The functional and radiological results of the current 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 of the studied cases. Moreover, 2 of the 6 cases with pre-op. asymmetrical narrowing of the joint space (Takakura et al. stage 2) with either medial or lateral joint overload showed symmetrical improvement in the joint space while the remaining 4 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 (19,20,21,22), 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 supramalleolar osteotomies whereas distal fibular osteotomy could be a very difficult and critical task in such cases, they also reported that the tibiotaral contact force shifted in different directions with and without fibular osteotomy after supramalleolar osteotomies. Different studies reported the 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 to 2 mm, the tibiotaral contact area can decrease up to 30% while manipulating the distal fibula into a varus or valgus position by 1° results in more than 50% reduction in the 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 the current study, the preliminary performed partial fibulpectomy 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 tibio-fibular bony synostosis which is a common finding after mal-aligned, 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 to 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 to 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 tibio-fibular 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 tissues 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 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 2 groups of cases with either closing-wedge or opening-wedge supramalleolar osteotomies with an average healing time of about 14 weeks. In another study by Zhao et al. (29), they reported a mean duration of 3.8 months (range 3–8) 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 underwent open wedge osteotomies in this study was attributed to the use of cancellous and cortico-cancellous autologous bone graft with a marvelous osteogenic, osteoinductive and osteoconductive potentials compared to graft substitutes used in other studies.

In most of varus deformities following intra- 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 open wedge osteotomy and bone graft definitely adds length and corrects pre-operative LLD. This makes open 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 post-operative 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 mal-alignment 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 varus 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 a hip-to-calcanue radiographs to 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.  

Fig 9 : Although residual radiological valgus deformity still present, the clinical results were very satisfactory, a well functioning, stable and freely mobile subtalar joint could compensate for incompletely corrected mal-alignment with residual deformity.

Fig 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.

The satisfactory results of the current study could be attributed to many factors. In all cases, the deformity was only in the coronal plane with no associated sagittal plane mal-alignment. In all cases, the deformity was only supramalleolar with no other hind foot mal-alignment the preliminary partial fibulectomy performed in all cases allowed unrestricted extent of correction that could be achieved by the supramalleolar osteotomy. Also the partial fibulectomy was done in a more proximal level allowing undisturbed ankle joint mechanics. In most of cases, the CORA was away from the ankle joint and the osteotomy was done very close to the CORA. Most of cases had congruent deformity within the tibiotalar joint space with the mean talar tilt (TT) angle ≤ 4° of tilt while incongruent deformity within the tibiotalar joint space with the mean talar tilt (TT) angle > 4° of tilt was found only in 4 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 anterior-posterior view (hip-to-calcanue 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 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 risk factors for progression of ankle degeneration, and meticulous biomechanical work should be performed to address the effect of different types of supramalleolar osteotomies fixed with different fixation methods on ankle biomechanics and kinematics.

Conclusions:
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 re-distributing the joint loads thus, preventing progressive degenerative arthritis. The preliminary performed proximal - above the level of the syndesmosis - partial fibulectomy allowed unrestricted correction without disturbing the ankle mechanics. Moreover, it allows easy and safe manipulation in the presence of post-traumatic distal tibio-fibular bony synostosis which is a common finding after comminuted, mal-aligned pilon fractures.
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