Combined medial malleoplasty and Taylor Spatial Frame after a supramalleolar osteotomy in the treatment of ankle deformity in skeletally immature patients: A prospective study of a novel technique and the short-term results

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ABSTRACT

Background: This study examined the effectiveness of the Taylor Spatial Frame (TSF) in the treatment of deformity and limb shortening caused by distal tibial physeal arrest and the effectiveness in maintaining alignment and stability by reconstruction of the medial malleolus and the medial collateral ligament using an autogenous iliac crest graft and attached sartorius muscle-tendon.

Methods: Thirteen pediatric patients with angular deformity of the distal tibia were enrolled in this prospective study. The mean age was 8.3 yr (range, 6 to 12 yr). All patients had open fractures with skin loss. Ten patients had Salter-Harris type IV physeal fractures, while three had Salter-Harris type V physeal injury. All patients had a varus ankle deformity (range, 15 to 33 degrees) and limb shortening (range, 1.9-cm to 3.3-cm). All patients were treated by a supramalleolar osteotomy and TSF for deformity correction for limb-length equalization. The absent medial malleolus was treated by medial malleoplasty with a graft from the ipsilateral iliac crest.

Results: The mean follow-up period was 30 mo. The mean preoperative shortening of the tibia in relation to the fibula was 2.6 cm (range, 1.9 cm to 3.3 cm). The length of the short tibia was restored in all patients, and correction of the ankle deformity and stability were restored with a satisfactory outcome.

Conclusions: TSF is highly effective in the treatment of distal tibial deformity in pediatric patients due to traumatic physeal arrest. Reconstruction of the medial malleolus and its ligamentous attachment is crucial for ankle joint stability.

Level of Evidence: Level IV.

Key Words
physeal injury, Taylor Spatial Frame, malleoplasty

INTRODUCTION

Pediatric ankle fractures represent about 6% of tibial fractures in children.\textsuperscript{1,2} Resulting complications include bony bar formation, limb-length discrepancy, angular deformity, abnormal gait, and ankle arthrosis due to partial or complete growth arrest of the distal tibial physeal plate.\textsuperscript{1,3}

Several alternatives have been described for the treatment of the angular deformity of the distal tibia caused by traumatic physeal arrest such as open wedge osteotomy, hemiepiphyseodesis, distraction chondrogenesis, and distraction osteogenesis by Ilizarov.\textsuperscript{4–6} Free grafting of the fibular head, composite tendon flaps, and autogenous iliac crest grafts also were described to reconstruct the absent medial malleolus.\textsuperscript{5,7,8}

This study examined the effectiveness of the Taylor Spatial Frame (TSF) in the treatment of the deformity and limb shortening caused by distal tibial physeal arrest as well as the effectiveness in maintaining alignment and stability by reconstructing the medial malleolus and the medial collateral ligament of the ankle joint using autogenous iliac crest graft with its attached sartorius muscle and tendon. We hypothesized that TSF is highly effective in deformity correction, especially rotational deformity, around the ankle joint in pediatric patients and that reconstruction of the absent medial malleolus and the collateral ligament with an iliac graft with its sartorius tendon is crucial in maintaining ankle joint alignment and stability.

MATERIALS AND METHODS

Ethical Review and Study Design

This prospective study was approved by the ethical committee of Benha University (IRB# Ortho.22/2014) and was in...
accordance with the ethical standards of the institutional and national research committee and the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. Informed consent was obtained from all individual participants included in the study.

**Patient Enrollment and Injury Characteristics**

Between May 2014 and June 2017, 13 pediatric patients with angular deformity of the distal tibia were enrolled in this prospective study. The mean age of the patients at the time of surgery was 8.3 yr (range, 6 to 12 yr, SD 1.83) (Table 1). There were six girls and seven boys.

The initial injuries were high-energy traumas. All patients had open fractures with skin loss. Ten had Salter-Harris type IV physeal fractures, while three patients had Salter-Harris type V physeal fractures. All patients were treated initially by Kirschner-wire fixation and a back slab until the wounds were healed.

Skin scars were present on the medial sides of the ankles in eight patients. The medial malleolus was absent in all patients at the time of presentation. There was a varus ankle deformity in all patients (range, 15 to 33 degrees), and the mean limb shortening was 2.62 cm (range, 1.9 to 3.3 cm, SD 0.49).

**Imaging and Deformity**

Plain anteroposterior and lateral radiographs and CT scans were obtained to determine the status of the physes. Six patients had complete growth arrest of the distal tibial physis, and seven had partial growth arrest of about 50% to 60% in comparison to the other distal tibial physis.

The deformity was described in relation to the terms published by Paley et al.10: mechanical axis deviation (MAD) and joint orientation angle (deformity angle). Both MAD and the deformity angle were measured preoperatively and postoperatively; the mean preoperative joint orientation angle deformity in the coronal plane was 23.8 degrees (range, 15 to 33 degrees) varus, while the mean preoperative deformity of the distal tibia in the sagittal plane was 5.9 degrees (range, 0 to 15 degrees) posteriorly (apex anterior). A rotational deformity was found in three patients; clinical assessment discovered the mean preoperative rotational angular deformity (internal) was 3.46 degrees (range, 0 to 30 degrees). The rotational deformity was assessed clinically by thigh-foot angle in comparison to the other limb.

**Treatment**

All patients were treated by a supramalleolar osteotomy and TSF. After correction and fixator removal, the absent medial malleolus was treated by medial malleoplasty using a graft from the ipsilateral iliac crest with its growing apophysis, perichondrium, and sartorius tendon. Functional outcome was assessed by the ankle and hindfoot scale (American Orthopaedic Foot and Ankle Society).11

**Surgical Technique**

Under general anesthesia, the patient was placed supine with the affected limb draped. Using the guidance of image intensifiers, the distal ring of the TSF (Smith and Nephew, Memphis, TN, USA) was applied at the distal tibia with
1.8-mm wires inserted from lateral to medial above the level of physeal plate at different angles with a drop 4-mm half pin to increase the ring stability.

Medium-sized fast fix struts were connected to the distal ring. The proximal ring was inserted at the proximal tibia, and then the struts were connected. The proximal ring was fixed to the proximal tibia perpendicular to the bone in all planes with 1.8-mm wires and drop 4-mm half pins.

The struts were disconnected from the distal ring, and a small incision was made at the anterior border of the tibia. A 2.5-mm drill bit was used to make holes in the talus in the supramalleolar region. The osteotomy was performed with a fine osteotome. The skin was closed, and the struts were reconnected.

Plain anteroposterior and lateral radiographic views were performed at a distance of 90 cm. It was necessary for the radiographs to include the whole proximal ring in both views and the site of the osteotomy.

The proximal ring was considered as the reference ring; all offsets and deformity parameters were calculated preoperatively and rechecked postoperatively.

The distal tibial articular surface and the fibular physeal plate were considered the two corresponding points; the correction started 5 days postoperatively after obtaining the web site prescription. The patients were discharged from the hospital 7 days postoperatively after training.

Follow-up was done in the outpatient clinic weekly after discharge and included checking the strut length, pin site care, wound care, as well as obtaining plain radiographs to evaluate the correction progress.

Undercorrection of the varus deformity was present in one patient after finishing the prescribed treatment, so a new prescription was obtained. When the deformity and shortening were corrected, the apparatus was left static until consolidation of the regenerate. The fixator was removed, and a below-knee walking cast was applied for 4 wk to allow for more consolidation of bone regeneration and for pin track healing (Figure 1).

Patients then underwent another surgical procedure called a medial malleoplasty. The iliac crest was approached and the anterior superior iliac spine (ASIS) and the sartorius muscle were identified. With a fine osteotome, the ASIS was osteotomized with the sartorius muscle attached. The size of iliac crest was roughly determined from preoperative lateral radiographs, and the length of the sartorius muscle tendon was adjusted to be 5 to 10 cm long to allow for suturing of the tendon to the talus.

The anterior approach to the distal tibia was done away from the poor skin. The distal tibia and the talus were exposed. The medial surface of the distal tibia above the remnant physeal plate was roughened with a fine rasp. The graft was positioned and fixed by partially serrated screws and Kirschner wires, with the wide base upward while the tip of the graft was pointed downward supporting the medial surface of the talus.

The sartorius tendon was implanted into the talus through a drill hole as a medial collateral ligament. The tendon was sutured to the medial surface of the talus by nonabsorbable sutures. The wound was closed, and the below-knee cast was applied. Patients stayed nonweight bearing for 3 mo. After the graft had incorporated, the cast was removed, and patients were allowed to walk with foot-ankle support for 2 mo, after which they were allowed to move freely (Figure 1).

Statistical Analysis
A sample size calculation and statistical comparisons were performed using SPSS (version 13.0; SPSS Inc., Chicago, IL). Clinical data were statistically analyzed using the Mann-Whitney U-test for quantitative data of the term of union time, leg-length discrepancy and angular deformity.

RESULTS
The mean follow-up period was 30 mo (range, 24 to 40 mo, SD 5.41). The mean preoperative shortening of the tibia in relation to the fibula was 2.6 cm (range, 1.9 to 3.3 cm). Postoperative results showed that varus deformity and posterior inclination were corrected in all except four patients who had residual varus deformity of 2 to 7 degrees. While two patients had residual posterior angular deformity of 2 to 3 degrees, no rotational deformity was found. The mean preoperative MAD was 45.9 mm (range, 40 to 55 mm, SD 5.87), while the mean postoperative MAD was 6.07 mm (range, 5 to 8 mm, SD 1.12).

The mean time needed for correction and lengthening was 29.08 days (range, 22 to 35 days, SD 4.25), the mean time for fixator removal was 16.5 wk, (range, 13.5 to 19 wk). Graft incorporation was evident at a mean of 15.69 wk, (range, 12 to 19 wk). Pin-track infections were found in nine patients who were treated with oral antibiotics for 10 days during the infection flare up. Four patients had superficial wound infections, which were treated by antibiotics and daily dressing until the infection subsided. One patient had a fracture at the tip of the graft 3 mo after allowing the patient to move freely; the patient was treated with a below-knee cast for 2 mo. Clinically the mean ankle hindfoot scale score improved from 51.8 preoperatively (SD 10.16) to 89.9 postoperatively (SD 7.6) (Figure 2). At the end of the procedure and during the follow-up period, the deformity was corrected, and limb-length discrepancy was restored in all patients; ankle joint stability was confirmed after medial malleoplasty (Table 2).

DISCUSSION
Treatment of ankle fractures in pediatric patients should achieve two goals: satisfactory anatomical reduction and avoidance of growth arrest. Partial growth arrest in growing children leads to progressive angular deformity and limb shortening.1–3,12–14 Dabash et al.4 concluded that physeal bar resection in traumatic physeal growth arrest is suitable in early stages provided that the deformity has not developed, and corrective osteotomy should be considered if the deformity angle was between 10 and 25 degrees. Scheffer et al.6 treated 14 distal tibial deformities in 13 pediatric patients with an open wedge osteotomy. The etiology was traumatic in all patients with Salter-Harris type IV physeal fracture. They concluded that this technique is suitable for cases with mild deformity of less than 25 degrees and mild limb-length discrepancy of up to 25 mm. The current study...
represents 13 patients with distal tibial physeal arrest caused by trauma, types IV and V Salter-Harris, an absent medial malleolus, limb-length discrepancy of an average 2.6 cm, and deformity angles up to 33 degrees. The deformity correction and limb-length restoration were achieved in all except four patients. Residual varus ankle deformity was present (2 to 7

FIGURE 1. (A) Anteroposterior and lateral radiographic views showing a supramalleolar osteotomy of the distal tibia after application of Taylor Spatial Frame (TSF) with gradual correction of the deformity. Varus deformity was present with an absent medial malleolus. (B) Anteroposterior and lateral radiographic views after removal of TSF. (C) Clinical photograph showing the instability of the ankle joint before medial malleoplasty. (D) Clinical photographs showing the harvesting of autogenous anterior superior iliac spine with the sartorius muscle-tendon unit. (E) Clinical photographs showing preparation of the medial side of the distal tibia, fixation of the graft with the wide base upward, and medial collateral ligament reconstruction. (F) Follow-up radiograph 18 mo postoperatively. (G) Intraoperative radiographic image intensifier shows graft fixation by screws and smooth Kirschner wires.
degrees) and residual posterior angulation was present in two patients (2 to 3 degrees).

Scheffer et al.\(^6\) advocated that hemiepiphysiodesis in the treatment of such cases of partial growth arrest is not suitable. Horton et al.\(^15\) proposed a combination of ipsilateral hemiepiphysiodesis to prevent deformity progression and epiphysiodesis of the sound limb to prevent limb-length discrepancies, while Cain et al.\(^16\) and Ghanem et al.\(^17\) concluded that epiphysiodesis of a sound limb is suitable for patients with predicted limb-length discrepancy of 2 to 5 cm at maturity. If the predicted discrepancy is more than 5 cm, limb lengthening is the treatment of choice.

Chondrodiastasis either by uniplanar or circular fixator is another method of treatment of angular deformities due to physeal arrest. There were some reported complications, including pin-track infection, osteolysis, axial deviation, premature closure of physeal plate, and joint immobilization.\(^{18-21}\) Other authors\(^5\) reported distraction osteogenesis for the treatment of physeal growth arrest with a satisfactory outcome with a follow-up period of 1.6 to 5 yr.

Koren et al.\(^22\) concluded that the TSF allowed accurate correction of complex limb deformities in children and adolescents after treatment of two patients with supramalleolar osteotomy and TSF in a case series of 51 patients. Also, Rozbruch et al.\(^23\) retrospectively reviewed treatment of 102 patients with tibial deformities including 22 patients with distal tibial deformity, treated by osteotomy and TSF, with a satisfactory result. In the current study a homogenous group of pediatric patients with multiplaner ankle deformities treated with supramalleolar osteotomy and TSF had overall satisfactory results and few complications.

Shui-Pei,\(^8\) treated five adult males with an absent medial malleolus and soft-tissue and skin defect by a vascularized fibular head graft with tendon and skin free flap. The outcomes were satisfactory. However, the procedure was time-consuming, needed a well-equipped location, well-trained hands, and the rate of vascular anastomosis failure was high.

Mayr et al.\(^7\) treated a 10-year-old boy with compound fractures with a lost medial malleolus, a small metaphyseal fragment, and a soft-tissue defect on the medial malleolus with ipsilateral autogenous iliac graft and free scapular flap with microvascular anastomosis. In that patient they split the iliac crest graft with its perichondrium obliquely to place the iliac physeal plate in the middle of the graft to meet the site of the distal tibial physeal plate. The proximal bony part of the graft was fixed to the metaphysis by screws and the distal bony part used was to substitute for the medial malleolar defect. The screws were removed 14 mo postoperatively, and the overall result was satisfactory.

Nithyananth et al.\(^24\) reported a patient with an open ankle fracture with medial malleolar and overlying soft tissue defects treated with an autogenous iliac crest graft, with the wide base superiorly fixed with cancellous screws and the soft-tissue defect reconstructed using a reverse-flow sural artery flap. In the current study, the iliac crest graft was fixed to the distal tibia by screws and Kirschner wires, with the growing end directed downward to support the talus and allow for further normal growth of the substituted medial malleolus.

In this study, we present a novel technique to treat such cases of traumatic physeal growth arrest, absent medial malleolus, and an ankle joint deformity. The TSF is effective in correction of angular and rotational deformities in all planes and

![FIGURE 2.](A) Clinical photograph of the deformed ankle before surgical intervention. (B and C) Clinical photographs of the corrected ankle 24 mo after surgical intervention. (D and E) Radiographs 24 mo postoperatively.)

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### Table 2. Patient outcomes (preoperative and postoperative deformity values, functional score)

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**TABLE 2.** Patient outcomes (preoperative and postoperative deformity values, functional score)

- **AHFS:** ankle hindfoot scale
- **MAD:** mechanical axis deviation
- **Preop:** preoperative
- **Postop:** postoperative

AHFS, ankle hindfoot scale; MAD, mechanical axis deviation.

### CONCLUSIONS

The Taylor Spatial Frame (TSF) is highly effective in the treatment of pediatric patients with distal tibial deformity due to traumatic physeal arrest. In addition, the reconstruction of the medial malleolus and its ligamentous attachment is crucial for ankle joint stability.

### REFERENCES


