FOOT & ANKLE INTERNATIONAL

DOI: 10.3113/FAI.2011.0986

Supramalleolar Osteotomy Using Circular External Fixation with Six-Axis Deformity Correction of the Distal Tibia

Daniel M. Horn, MD[1]; Austin T. Fragomen, MD[2]; S. Robert Rozbruch, MD[3]
Boston, MA; New York, NY

ABSTRACT

Background: **Supramalleolar osteotomy using circular external fixation with six-axis deformity correction is a rarely reported treatment method particularly well-suited for complex multi-dimensional deformities of the adult ankle. The purpose of this study was to assess the accuracy of deformity correction and change in functional status using this technique.** ***Methods:*** **We present a retrospective review of 52 patients who underwent supramalleolar osteotomy with application of the Taylor Spatial Frame (Smith & Nephew, Memphis, TN). Mean age was 44 (range, 18 to 79) years. The primary outcome was change in preoperative to postoperative distal tibial joint orientation angles. Coronal and sagittal plane joint orientation angles were measured for all 52 enrolled patients. The secondary outcome was change in AOFAS scores which were available for 31 patients.** ***Results:*** **Twenty-two patients had oblique plane deformities. The mean time in frame was 4 (range, 2 to 11) months, and patients were followed for a mean of 14 months after frame removal. All aggregate postoperative distal tibial angles underwent a significant improvement ($p < 0.05$) and were within 0 degrees to 4 degrees of normal in the various deformity groups. Average preoperative AOFAS score was 40 (range, 12 to 67) and average postoperative AOFAS score was 71 (range, 34 to 97; $p < 0.001$). Complications included two patients with nonunions at the osteotomy site that healed with further treatment. Three patients went on to have ankle fusion.** ***Conclusion:*** **We feel that supramalleolar osteotomy using circular external fixation with six-axis deformity correction was an effective method for correction of distal tibial deformities in the adult population, particularly for those patients with complex oblique-plane deformities, associated rotational deformity, a compromised soft tissue envelope, or a prior history of infection.**

Level of Evidence: IV, Retrospective Case Series

Key Words: Ilizarov; External Fixation; Ankle Arthritis; Tibia; Malunion

INTRODUCTION

Management of distal tibial and ankle joint deformities is a challenge. Most of these deformities arise from distal tibial malunions. If left uncorrected, deformity about the ankle joint may lead to worsening pain and progressive ankle arthrosis.[16,32,33] Correction of deformity at the ankle results in improved force transmission across the joint, better functional outcomes, and prevents the development of arthritis.[26] Conventional surgical techniques such as open osteotomy with internal fixation (opening or closing wedge) can be utilized. However, this requires an acute correction which may be ill-suited for large or complex angular or translational deformities.[20,30] Additionally, the ankle joint has a soft tissue envelope with minimal muscular (and therefore vascular) content, leading to vulnerability of the bone to delayed healing, tendinous and neurovascular injury, infection, and difficult wound healing both at the time of trauma and during subsequent surgical correction.[21,30] Acute correction with plates involves open surgery with soft tissue stripping which may compromise healing. The insertion of internal hardware may be risky under poor quality skin and contraindicated in the presence of infection.[20]

Supramalleolar osteotomy using circular external fixation with six-axis deformity correction is particularly well-suited to such complex deformities at the ankle. The technique builds upon the traditional Ilizarov method and the principle of distraction osteogenesis[12,13] by utilizing computer

[1]Clinical Fellow, Harvard Medical School; Resident-Physician, Internal Medicine, Brigham & Women's Hospital, Boston, MA.
[2]Assistant Attending, Department of Orthopaedic Surgery Hospital for Special Surgery, New York, NY.
[3]Chief, Limb Lengthening and Complex Reconstruction Service Hospital for Special Surgery, New York, NY.
[4]Funds were received in support of the research or clinical study presented in this article from Smith and Nephew.

Corresponding Author:
S. Robert Rozbruch, MD
Hospital for Special Surgery
Limb Lengthening and Complex Reconstruction Service
535 East 70th Street
New York, NY 10021
E-mail: RozbruchSR@hss.edu

software to allow for precise correction of angulation and translation in the coronal, sagittal, and axial planes (Figures 1 and 2).[20] The gradual correction of large, complex deformities prevents acute stretching of neurovascular structures or the creation of large opening-wedge gaps requiring bone grafting. The circular external fixator also allows for residual correction of any residual malalignment postoperatively, thereby allowing for a precise and accurate deformity correction. Additionally, the technique allows a percutaneous approach with minimal soft-tissue stripping and immediate postoperative weightbearing

Supramalleolar osteotomy has been frequently reported as a surgical option in the pediatric population.[3,5,6,25] However, in the adult population, supramalleolar osteotomy for distal tibial deformity utilizing six-axis deformity correction is relatively underreported.[9,15,17,24] This retrospective study examined the hypothesis that circular external fixation with six-axis deformity correction would lead to accurate correction of distal tibial deformity.

MATERIALS AND METHODS

Patient selection

This study presents a consecutive series of patients who underwent supramalleolar osteotomy with circular external fixation and six-axis deformity correction over an 8-year period (2000 to 2008). Exclusion criteria included age less than 18 years, nonunion as the etiology of the deformity, or patients who were less than 6 months after frame removal. After exclusions, 29 females and 23 males (total, $n = 52$) were included in the study (Table 1). Mean patient age was 44 (range, 18 to 74) years. All patients' medical records and preoperative and postoperative radiographs were reviewed. Radiographic data was available for all 52 patients. Institutional Review Board approval and informed consent was obtained for this retrospective analysis.

The primary etiology of ankle deformity included post-traumatic tibial malunion ($n = 38$), degenerative ankle arthrosis with deformity ($n = 9$), congenital disease ($n = 3$), and polio ($n = 2$) (Table 1). No bilateral procedures were performed. Thirty-three patients had arthritis at the ankle joint. The degree of severity of preoperative arthritis was not available for data collection. Sixteen patients were noted to have a compromised soft tissue envelope. Six patients had a preoperative history of infection at the ankle joint. Eighteen patients had a limb length discrepancy. Of these, 17 had limb lengthening performed in conjunction with deformity correction. All patients had preoperative pain at the ankle joint. Average duration of symptoms at the time of procedure was 7 (range, 0.25 to 28) years. Patients had an average of two (range, 0 to 9) previous surgical procedures at the ankle joint.

Patients had sagittal, coronal, and axial plane deformities. Oblique plane deformity was defined as simultaneous malalignment in both the sagittal and coronal planes. A total of 11 deformity groups were analyzed: valgus procurvatum ($n = 4$), valgus recurvatum ($n = 2$), varus procurvatum ($n = 8$), varus recurvatum ($n = 8$), recurvatum ($n = 3$), valgus ($n = 10$), varus ($n = 12$), and rotational ($n = 5$) (Table 2). Ten patients from within the various deformity groups had simultaneous correction of both an angular and rotational deformity. No patients in this series had only procurvatum deformity.

Forty-three patients underwent gradual correction. Six patients had acute correction, and three of these received additional gradual correction for residual deformity postoperatively. The ability to perform residual correction of even minor postoperative deformity was one of the advantages of the circular external fixator utilized in this study.

Clinical evaluation and radiographic assessment

Preoperative work-up included a complete history and physical, with careful attention paid to previous surgical procedures, infection, antibiotic use, perceived leg length discrepancy, pain levels, narcotic use, and the ability to ambulate without support. On examination, leg length discrepancy was evaluated by placing blocks under the short leg until the iliac crests were level. Range of motion of the ankle and subtalar joint were recorded. The soft tissue envelope was also carefully examined, with attention paid to the posterior tibial and dorsalis pedis pulses, sensation, and motor strength on dorsiflexion and plantarflexion. To assess rotational deformity, the thigh-foot axis was measured in the prone position.

Radiographic assessment included weightbearing 17-inch anteroposterior (AP) and lateral views of the ankle and 51-inch bipedal erect leg radiograph. The anterior distal tibial angle was measured on the lateral ankle film as a measure of sagittal plane deformity (hardcopy images were measured with a protractor; PACS (digital images) were measured with the angle measuring tool on the PACS system). A normal anterior distal tibial angle was considered to be 80 (range, 78 to 82) degrees.[19] A measurement greater than normal indicated procurvatum deformity while a measurement less than normal indicated recurvatum deformity. The lateral distal tibial angle was measured on the AP radiograph as an indicator of the degree of coronal plane deformity. A normal lateral distal tibial angle was considered to be 89 (range, 86 to 92) degrees.[19] A measurement greater than normal indicated varus deformity while a measurement less than normal indicated valgus deformity. The 51-inch bipedal erect radiograph was utilized to assess leg length discrepancy and to identify any additional deformity. Patients with substantial leg length discrepancy were considered for concomitant limb lengthening. Quantity and location of hardware was noted, and hardware removal was performed intraoperatively when necessary. The tibiotalar joint space was evaluated. All 33 patients in this series with symptomatic ankle arthritis underwent concomitant ankle distraction arthroplasty. CT scan was used as needed to evaluate periarticular geometry.

Fig. 1: Preoperative radiographs (A and B) and clinical photograph (C) showing post-traumatic recurvatum deformity and shortening in a 60-year-old man. Radiographs (D and E) following distraction showing the corrected deformity while in the circular external fixator. Followup radiographs (F and G) and clinical photograph (H) 6 months after removal of the fixator.

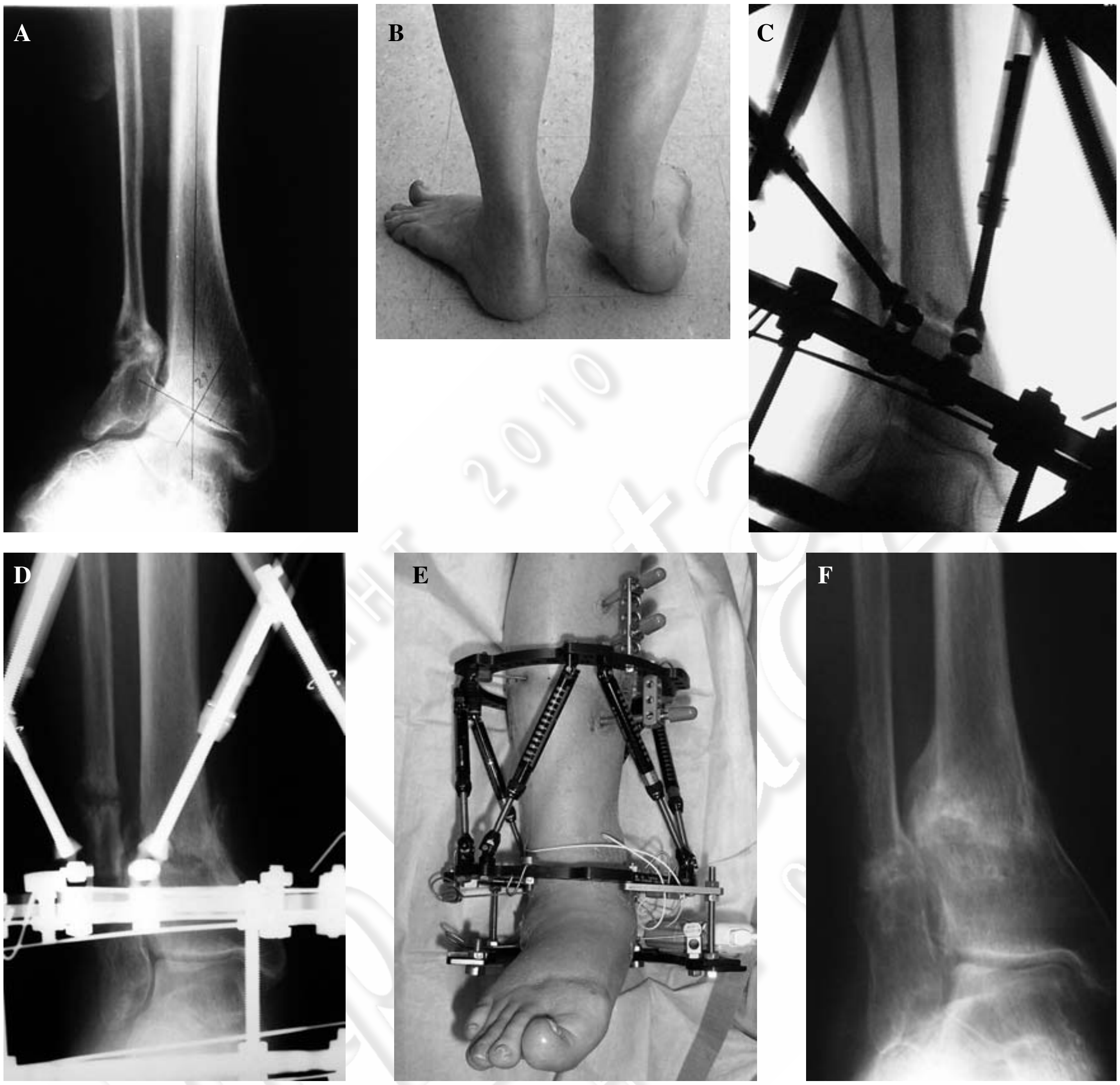

Fig. 2: Preoperative radiograph (A) and clinical photo (B) of a 76-year-old woman with rheumatoid arthritis showing a post-traumatic valgus deformity. Radiograph (C) at surgery showing the circular external fixator matching the valgus deformity. Radiograph (D) and clinical photo (E) showing the corrected deformity while in the circular external fixator. Followup radiograph (F) 6 months after frame removal.

Magnetic resonance imaging was used in selected patients to evaluate soft tissue structures, articular cartilage, and subchondral bone.

Surgical planning

The center of rotation and angulation (CORA) of the deformity was identified by locating the intersection of the proximal and distal tibial mechanical axes with the CORA considered to be the apex of the deformity.[19] An osteotomy site was selected, near or at the apex of deformity. If bone was sclerotic at the apex of deformity, then an osteotomy was performed nearby, and translation of the osteotomy site was planned in order to fully correct the deformity while maintaining the mechanical axis of the tibia.[19] All deformity parameters were measured and recorded. These numbers were then entered into a web-based computer program either for gradual deformity correction or to fine-tune acute corrections.

Technique

All procedures were performed by two surgeons (SRR and ATF) at one institution following a uniform technique. All patients had intravenous antibiotics 30 minutes prior to the procedure and then for 24 hours postoperatively. Spinal anesthesia was administered along with intravenous sedation. A tourniquet was used for the fibular osteotomy and in those cases where ankle joint arthrotomy was performed. Fibular osteotomy was performed near or at the level of the proposed

Table 1: Baseline Characteristics of Patients* ($n = 52$)

Characteristic	
Gender (#)	Female: 29 Male: 23
Age (yr)	44 ± 13 (range, 18 to 74)
Current smoker (#)	12
Duration of symptoms (yr)	7 ± 7 (range, 0.25 to 28)
Arthritis (#)	33
Limb length discrepancy (#)	18
Soft tissue compromise (#)	16
History of infection at ankle (#)	6
Previous surgical procedures (#)	2 ± 2 (range, 0 to 9)

*, Plus-minus values are mean ± SD

tibial osteotomy. The fibula was exposed through a standard lateral approach and the peroneal tendons were retracted posteriorly. An oblique osteotomy was performed with an oscillating saw to allow for fibular shortening in cases of varus and recurvatum corrections. In cases of mild fibular lengthening (valgus and procurvatum deformity), a transverse fibular osteotomy using a multiple drill hole osteotomy technique was used. The fibula was not stabilized with any internal fixation and the wound was closed in layers.

The tourniquet was deflated, and the external fixator was applied. A circular ring was applied orthogonal to the mid-distal tibia with two to three half pins and a tensioned wire. A second ring was applied to the most distal aspect of the tibia. This was also a closed circular ring and was applied orthogonal to the distal tibial axis. It was stabilized with one half pin and two to three tensioned wires depending on bone quality (Figures 1 and 2). Wires were tensioned to 130 kg. Half pins were 6.0-mm, tapered, and hydroxyapatite coated. They were pre-drilled with a 4.8-mm drill bit, placed by hand, and checked with fluoroscopy to ensure ideal depth of insertion.

Either the proximal or distal tibial ring was selected to be the reference ring for computer planning. The mounting parameters were then obtained for the reference ring and saved for later use with the computer program. Struts were attached between the two tibial rings, and these initial strut lengths were recorded. The struts were then removed for the tibial osteotomy.

The tibial osteotomy was performed using a percutaneous, multiple drill hole and osteotome technique. Fluoroscopy

Table 2: Preoperative Versus Postoperative Distal Tibial Angles for Each Deformity Group**

Group	*n*	Angle Measured	Preoperative Angle ± SD (Deviation from normal**)	Postoperative Angle ± SD (Deviation from normal***)	*p* Value
Aggregate Procurvatum	$n = 12$	ADTA	95 ± 12 (15)	80 ± 11 (0)	0.002*
Aggregate Recurvatum	$n = 13$	ADTA	62 ± 9 (−18)	79 ± 4 (−1)	0.002*
Aggregate Valgus	$n = 16$	LDTA	79 ± 7 (−10)	91 ± 5 (2)	<0.001*
Aggregate Varus	$n = 28$	LDTA	101 ± 6 (12)	90 ± 3 (1)	<0.001*
Valgus Only	$n = 10$	LDTA	80 ± 6 (−9)	93 ± 5 (4)	0.005*
Varus Only	$n = 12$	LDTA	100 ± 7 (11)	89 ± 3 (0)	0.002*
Recurvatum Only	$n = 3$	ADTA	60 ± 5 (−20)	80 ± 4 (0)	NS
Valgus Procurvatum	$n = 4$	LDTA	82 ± 5 (−7)	89 ± 3 (0)	NS
		ADTA	90 ± 4 (10)	80 ± 3 (0)	NS
Valgus Recurvatum	$n = 2$	LDTA	73 ± 12 (−16)	88 ± 1 (−1)	NS
		ADTA	62 ± 12 (−18)	77 ± 0 (−3)	NS
Varus Procurvatum	$n = 8$	LDTA	104 ± 6 (15)	91 ± 4 (2)	0.012*
		ADTA	97 ± 14 (17)	80 ± 14 (0)	0.012*
Varus Recurvatum	$n = 8$	LDTA	100 ± 5 (11)	90 ± 1 (1)	0.012*
		ADTA	64 ± 10 (−16)	78 ± 5 (−2)	0.017*
Rotational Only	$n = 5$	Clinically corrected	n/a	n/a	n/a

*, Significant at $\alpha = 0.05$, p values based on Wilcoxon signed ranks test. **, No patients had lone procurvatum deformity. ***, Normal ADTA, 80 (range, 78 to 82); Normal LDTA, 89 (range, 86 to 92), NS, not significant.

was used to identify the optimal location for the osteotomy. The osteotomy site was placed as distal as possible without jeopardizing the distal tibial fixation. A minimum of 1 cm of space was maintained between the most proximal half pin and the tibial osteotomy site. A 1-cm incision was made just medial to the anterior tibial tendon. A 4.8-mm drill bit was used to drill multiple drill holes in one plane transversely across the tibial metaphysis. This was done under fluoroscopy to improve safety. A 7-mm osteotome was used to perform the osteotomy, and a final mild rotational osteoclasis completed the osteotomy. For gradual correction the struts were replaced in the pre-osteotomy position, ensuring an anatomic reduction of the bone cut. For acute correction, the distal fragment was first translated appropriately using fluoroscopy and then angulated until the deformity appeared to be corrected. The surgeon held the reduction while assistants re-attached the struts at their new lengths. In most cases the deformity correction needed to be fine-tuned later in the office using the computer program.

Adjuvant procedures were performed where indicated. These procedures included ankle distraction arthroplasty (32), ankle arthrotomy with bone marrow aspirate injection (ten), ankle arthrotomy (seven), ankle arthroscopy (three), Achilles tendon lengthening (five), gastrocnemius release (four), posterior tibial nerve release (one), acute derotation osteotomy of femur (one), femoral osteoplasty with rail insertion (one), calcaneal osteotomy (one), fibular nonunion repair (two), and tarsal tunnel release (one). Three patients underwent double level tibial osteotomies with correction of deformity at both the proximal and distal tibial sites.

Outcome measures

The primary outcome was accuracy of correction of the distal tibial deformity. Radiographic measurements of preoperative and postoperative distal tibial joint orientation angles were performed on all 52 patients included in this study, and complete radiographic data is presented. In cases of oblique plane deformity, statistical analysis was performed on each deformity group (ie. varus procurvatum, varus recurvatum, valgus procurvatum, valgus recurvatum), and then each sagittal and coronal plane deformity from the oblique plane patients was also included in the aggregate varus, valgus, procurvatum, and recurvatum data (Table 2). The success of rotational deformity correction was assessed by physical examination.

Secondary outcome was measured as the change in preoperative to postoperative American Orthopaedic Foot & Ankle Society (AOFAS) score. All AOFAS scores were collected retrospectively based on chart review, telephone interviews, and clinic visits. The AOFAS score includes the clinician's assessment of a patient's pain severity, functional status, gait, range of motion, stability, and alignment. Good quality paired AOFAS scores were available for only 31 of 52 patients included in this study. While this manner of reporting AOFAS scores is not ideal and likely incorporates recall bias, we included this data as a secondary outcome to support the well-established notion that correction of deformity is directly associated with improved functional outcomes. Of note, AOFAS scores were available for at least 25% of patients within each deformity group. The valgus procurvatum group had the lowest percentage of paired scores (one out of four patients), while the rotational group had the highest number of available scores (five out of five patients).

Preoperative and postoperative radiographic angles and AOFAS scores were compared using Wilcoxon signed ranks test, with a p value of less than 0.05 considered significant. (Table 2)

RESULTS

The average time in frame was 4 (range, 3 to 11) months. Average followup time for radiographic analysis after external fixator removal was 14 (range, 6 to 80) months. Preoperative and postoperative distal tibial joint orientation angles changed significantly within each aggregate deformity group. Additionally, all postoperative distal tibial angles were within 0 degrees to 4 degrees of normal within each aggregate deformity group (Table 2).

All rotational deformities were sufficiently corrected based on documentation of the postoperative physical examination. In all cases, the frame was programmed to correct the rotational deformity and satisfactory deformity correction of rotational deformity was accomplished.

The average preoperative AOFAS score ($n = 31$) was 40 (range, 12 to 67; SD, 15.0) and average postoperative AOFAS score was 71 (range, 34 to 97; SD, 15.6). The mean change in preoperative to postoperative AOFAS scores was 31 points ($p < 0.001$).

Complications included 27 patients who experienced superficial pin site infections which were managed with local pin care and oral antibiotics. Four patients developed cellulitis requiring admission for intravenous antibiotics. One patient had wound breakdown and necrosis with concomitant osteomyelitis at the osteotomy site requiring surgical debridement. This patient subsequently developed a hypertrophic nonunion requiring reapplication of the circular external fixator. One patient developed septic arthritis at the ankle joint requiring arthrotomy with debridement and washout. Two other patients were found to have tibial nonunions. One nonunion was repaired via open repair with plating, bone grafting, and bone marrow aspirate injection, and the other via bone graft insertion while the original external fixator device was still in place. Three patients were admitted for narcotic dependence related to prescribed pain medications. One patient developed numerous pin site adhesions requiring release. Three patients underwent subsequent ankle arthrodesis due to recurrence of pain. All complications reported in this series are previously documented risks of gradual correction using the Ilizarov method.[20]

DISCUSSION

This retrospective analysis revealed significant improvement in alignment of the distal tibia after supramalleolar osteotomy using circular external fixation and six-axis deformity correction. The high rate of complex oblique-plane deformities, soft tissue compromise, previous surgical procedures, previous history of infection, and associated ankle arthrosis highlight particular advantages of this surgical technique. For many of these patients, arthrodesis or amputation would have been the only other surgical alternative. As a secondary outcome, the significant improvement in AOFAS scores should be encouraging to patients with severe distal tibial deformity and/or arthritis at the ankle joint who are seeking improved functional status.

To our knowledge, this is the first retrospective study looking specifically at accuracy of correction of multiplanar distal tibial deformity in adults via this surgical technique. Elomrani et al. published a retrospective analysis of 55 patients who underwent supramalleolar osteotomy using the traditional Ilizarov method. Their analysis revealed that 41 of 55 patients experienced a good to excellent result of the procedure.[4] However, studies which incorporate six-axis deformity correction with the aid of computer software have not exclusively examined supramalleolar osteotomy for distal tibial ankle deformity.[9,15,17,24]

Circular external fixation with six-axis deformity correction offers advantages over both the traditional Ilizarov method and internal fixation. The modular circular external fixator and computer software simplify the planning and execution of complex oblique-plane deformity correction. The surgeon is provided with precise deformity correction schedules based on a virtual hinge, and patient participation in the adjustment process is simplified by color-coded expandable struts and simple adjustment schedules. These deformity correction parameters are easily adjusted postoperatively, allowing for precise control over final joint alignment.[21] The gradual correction schedule that is frequently utilized minimizes the risk of neurovascular and soft-tissue compromise. Additionally, when patients have a poor soft-tissue envelope or a preoperative history of infection, percutaneous osteotomy and application of the circular external fixator avoids the necessity for large dissection and internal fixation. Finally, the technique is ideally suited for deformities in which there has been a loss of length in the affected limb in that simultaneous limb lengthening can be incorporated into the deformity correction schedule.[17]

Adjuvant joint preservation procedures can be performed along with six-axis deformity correction. The circular external fixator can be used in a modular fashion with the implementation of additional rings as necessary for the performance of multi-level correction, ankle distraction, or correction of contracture of the ankle. Other adjuvant procedures may include ankle arthrotomy, arthroscopy, proximal tibial osteotomy, tendo-achilles lengthening, tibial nerve release, iliac crest bone marrow aspiration and insertion at the ankle, and ankle joint distraction. Thus, a multi-faceted surgical approach can be easily tailored to each individual patient's needs without the necessity for multiple trips to the operating room.[21] The numerous adjuvant procedures performed in this study likely contributed to the notable improvement in our patients' AOFAS scores. There was no way to separate the confounding effects of these adjuvant procedures when calculating our outcomes. However, we prioritized the optimal care of our patients, and thus chose to perform the surgical interventions that would most likely afford our patients with an excellent outcome.

This study has several other limitations. Patients were reviewed retrospectively, and the majority of data points were obtained from the medical record. While most radiographic measurements were recorded in the patient chart, numerous instances arose in which angular measurements had to be performed retrospectively. Additionally, complete AOFAS scores were available for only 31 of 52 patients. Thus, not all deformity groups were equally represented within the AOFAS calculations and an element of recall bias may have confounded the scores. Lastly, adjuvant procedures were performed on the majority of patients, and the confounding impact of these procedures must be considered.

CONCLUSION

Our study demonstrated the utility of supramalleolar osteotomy using circular external fixation with six-axis deformity correction for management of distal tibial deformities. Distal tibial joint orientation angles were accurately corrected. In cases of severe deformity, soft tissue compromise, previous history of infection, limb length discrepancy, or in patients who may benefit from simultaneous adjuvant procedures utilizing the external fixator, this technique should be strongly considered as a safe and effective surgical technique.

REFERENCES

1. **Aqui, SZ; Thiryayi, W; Foster, A; et al.:** Correction of simple and complex pediatric deformities using the Taylor-Spatial Frame. J Pediatr Orthop. **28**:640–647, 2008.http://dx.doi.org/10.1097/BPO.0b013e3181831e99
2. **Benthien, R; Myerson, M:** Supramelleolar osteotomy for ankle deformity and arthritis. Foot Ankle Clin. **9(3)**:475–87, 2004. http://dx.doi.org/10.1016/j.fcl.2004.05.012
3. **Eidelman, M; Bialik, V; Katzman, A:** Correction of deformities in children using the Taylor spatial frame. J Pediatr Orthop B. **15**:387–395, 2006. http://dx.doi.org/10.1097/01.bpb.0000228380.27239.8a
4. **Elomrani, NF; Kasis, AG; Tis, JE; et al.:** Outcome after foot and ankle deformity correction using circular external fixation. Foot Ankle Int. **26**:1027–32, 2005.
5. **Feldman, DS; Madan, SS; Koval, KJ; et al.:** Correction of tibia vara with six-axis deformity analysis and the Taylor spatial frame. J Pediatr Orthop. **23**:387–391, 2003. http://dx.doi.org/10.1097/01241398-200305000-00022

6. **Feldman, DS; Madan, SS; Ruchelsman, DE; et al.:** Accuracy of correction of tibia vara: acute versus gradual correction. J Pediatr Orthop. **26**:794–798, 2006. http://dx.doi.org/10.1097/01.bpo.0000242375.64854.3d
7. **Feldman, DS; Shin, SS; Madan, S; et al.:** Correction of tibial malunion and nonunion with six-axis analysis deformity correction using the Taylor spatial frame. J Orthop Trauma. **17**:549–554, 2003. http://dx.doi.org/10.1097/00005131-200309000-00002
8. **Fragomen, AF; Rozbruch, SR:** Proximal Tibial Osteotomy for Medial Compartment osteoarthritis of the Knee Using the Taylor Spatial Frame. Techniques in Knee Surgery. **4(3)**:173–185, 2005. http://dx.doi.org/10.1097/01.btk.0000175882.99745.a3
9. **Ganger, R; Radler, C; Speigner, B:** Correction of post-traumatic lower limb deformities using the Taylor spatial frame. International Orthopaedics. **34**:723–730, 2010. http://dx.doi.org/10.1007/s00264-009-0839-5
10. **Graehl, PM; Hersh, MR; Heckman, JD:** Supramalleolar osteotomy for the treatment of symptomatic tibial malunion. J Orthop Trauma. **1**:281–292, 1987. http://dx.doi.org/10.1097/00005131-198701040-00003
11. **Harstall, R; Lehmann, O; Krause, F; et al.:** Supramalleolar lateral closing wedge osteotomy for the treatment of varus ankle arthrosis. Foot Ankle Int. **28(5)**:542–548, 2007. http://dx.doi.org/10.3113/FAI.2007.0542
12. **Ilizarov, GA:** The tension-stress effect on the genesis and growth of tissues. Part 1. The influence of stability of fixation and soft-tissue preservation. Clin Orthop Relat Res. **238**:249–281, 1989.
13. **Ilizarov. GA:** The tension-stress effect on the genesis and growth of tissues: Part II. The influence of the rate and frequency of distraction. Clin Orthop Relat Res. **239**:263–85, 1989.
14. **Lee, K; Cho, Y;** Oblique Supramalleolar Opening Wedge Osteotomy Without Fibular Osteotomy for Varus Deformity of the Ankle. Foot Ankle Int. **30(6)**:565–67, 2009. http://dx.doi.org/10.3113/FAI.2009.0565
15. **Matsubara, H; Tsuchiya, H; Takato, K; et al.:** Correction of ankle ankylosis with deformity using the Taylor spatial frame. Foot Ankle Int. **28(12)**:1290–93, 2007.
16. **McKinley, TO; Rudert, MJ; Koos, DC; et al.:** Pathomechanic determinants of posttraumatic arthritis. Clin Orthop Relat Res. **427**:S78–S88, 2004. http://dx.doi.org/10.1097/01.blo.0000143817.74887.55
17. **Nakase, T; Kitano, M; Kawai, H; et al.:** Distraction Osteogenesis for correction of three- dimensional deformities with shortening of lower limbs by Taylor Spatial Frame. Archives of Orthopaedic and Trauma Surgery. **129(9)**:1197–201, 2009. http://dx.doi.org/10.1007/s00402-008-0702-y
18. **Nho, SJ; Helfet, DL; Rozbruch, SR:** Temporary intentional leg shortening and deformation to facilitate wound closure using the Ilizarov/Taylor spatial frame. J Orthop Trauma. **20**:419–424, 2006. http://dx.doi.org/10.1097/00005131-200607000-00010
19. **Paley, D:** Principles of Deformity Correction, New York, Springer, 2002.
20. **Rozbruch, SR:** Percutaneous Supramalleolar osteotomy Using the Ilizarov/ Taylor spatial frame. In: Scuderi GR, Tria AJ: Minimally Invasive Surgery in Orthopaedics; Springer, New York 2010. http://dx.doi.org/10.1007/978-0-387-76608-9_55
21. **Rozbruch, SR:** Posttraumatic reconstruction of the ankle using the Ilizarov method. HSS J **1**:68–88, 2005. http://dx.doi.org/10.1007/s11420-005-0113-3
22. **Rozbruch, SR; Fragomen, AT; Ilizarov, S:** Correction of Tibial Deformity with Use of the Ilizarov Taylor spatial frame. Journal of Bone and Joint Surgery Am. **88(suppl 4)**:156–74, 2007. http://dx.doi.org/10.2106/JBJS.F.00745
23. **Rozbruch, SR; Helfet, DL; Blyakher, A:** Distraction of hypertrophic nonunion of tibia with deformity using Ilizarov/Taylor spatial frame: report of two cases. Arch Orthop Trauma Surg. **122**:295–29, 2002. http://dx.doi.org/10.1007/s00402-001-0370-7
24. **Rozbruch, SR; Segal, K; Ilizarov, S; et al.:** Does the Taylor spatial frame Accurately Correct Tibial Deformities?. Clin Orthop Relat Res. **468(5)**:1352–61, 2010. http://dx.doi.org/10.1007/s11999-009-1161-7
25. **Siapkara, A; Nordin, L; Hill, RA:** Spatial frame correction of anterior growth arrest of the proximal tibia: report of three cases. J Pediatr Orthop B. **17**:61–64, 2008. http://dx.doi.org/10.1097/BPB.0b013e3282f56dc1
26. **Stamatis, E; Cooper, P; Myerson, M:** Supramalleolar osteotomy for the treatment of distal tibial angular deformities and arthritis of the ankle joint. Foot Ankle Int. **24(10)**:754–764, 2003.
27. **Stamatis, E; Myerson, M:** Supramalleolar osteotomy: indications and technique. Foot Ankle Clin. **8(2)**:317–33, 2003. http://dx.doi.org/10.1016/S1083-7515(03)00018-4
28. **Takakaru, Y; Takaoka, T; Tanaka, Y:** Results of opening wedge osteotomy for the treatment of a post-traumatic varus deformity of the ankle. J. Bone Joint Surg. **80-A**:213–218, 1998.
29. **Takakaru, Y; Tanaka, Y: Kumai, T; et al.:** Low tibial osteotomy for osteoarthritis of the ankle: Results of a new operation in 18 patients. J. Bone Joint Surg. **77-B**:50–54, 1995.
30. **Teeny, SM; Wiss, DA:** Open reduction and internal fixation of tibial plafond fractures: Variables contributing to poor results and complications. Clin Orthop Relat Res. **292**:108–117, 1993.
31. **Tellisi, N; Fragomen, AT; Ilizarov, S; et al.:** Lengthening and reconstruction of congenital leg deficiencies for enhanced prosthetic wear. Clin Orthop Relat Res. **466**:495–499, 2008. http://dx.doi.org/10.1007/s11999-007-0041-2
32. **Thordarson, DB:** Complications after treatment of tibial pilon fractures: prevention and management strategies. J Am Acad Orthop Surg. **8**:253–265, 2000
33. **Thordarson, DB; Motamed, S; Hedman, T; et al.:** The effect of fibular malreduction on contact pressures in an ankle fracture malunion model. J Bone Joint Surg Am. **80**:1395–1396, 1998.