The Versatility of Taylor Spatial Frame in Treating Complex Posttraumatic Deformities of The Lower Extremity

Rami Khalifa, MD; Amr Abdelgawad, MD; Ahmed M. Thabet, MD, PhD

Department of Orthopaedic Surgery & Rehabilitation, Texas Tech University Health Sciences Center, El Paso, Texas

Corresponding Author Ahmed M. Hagag-Thabet, MD, PhD. Department of Orthopaedic Surgery & Rehabilitation, 4801 Alberta Ave. El Paso, Texas 79905 (email: ahmed-thabet.hagag@ttuhsc.edu).

Conflict of Interest The authors report no conflicts of interest.

Funding The authors received no financial support for the research, authorship, or publication of this article.

ABSTRACT

Background: The Taylor Spatial Frame (TSF) is a multi-planar external fixator with a computerized web-based program to provide accurate fractures reduction and deformity correction. This study aimed to evaluate our results after the treatment of complex lower extremity injuries with the external fixators including TSF.

Methods: This retrospective case series included eight patients with complex lower extremity injuries treated with TSF. The medical records and radiographs were reviewed. The ASAMI score was used as an outcome measure. Statistical analysis used Microsoft Excel descriptive statistics. No inferential statistical tests were done owing to the small sample size.

Results: The mean age was 37.5 years (range, 18-70 years). The study included a total of eight patients: seven men and one woman. The anatomic locations were six tibias and two femora. The mean external fixator time (EFT) was 5.2 months (range, 3-6 months). The mean follow-up time was 33.5 months (range, 24-48 months). One patient developed refracture due to premature frame removal (12.5%). Autogenous bone grafting was performed for three patients (37.5%) and was the most common secondary procedure after the index operation. Knee stiffness occurred in two patients (25%). Restoration of limb alignment occurred in all patients. All patients achieved bone union except one who developed nonunion. The ASAMI bony and functional outcome scores were excellent and good in seven (87.5%) and one (12.5%) patient, respectively.

Conclusions: TSF can be successfully used to treat various complex fractures, posttraumatic limb deformities, and bone nonunion with high minor complications major rate, intermediate major and 87.5% excellent outcome rate in this series.

Keywords: External Fixation Frames, Fracture Malunion, Complex Fractures Nonunion

INTRODUCTION

The use of circular external fixators have been used effectively in complex lower extremity fractures and posttraumatic deformities. External fixators are successful used for treating acute fractures and late reconstruction after trauma, including bone deformity, nonunion, and segmental bone defects. Furthermore, circular external fixators can be used effectively for high-energy comminuted fractures, fractures with soft tissue envelope, juxta-articular fractures, and fractures with bone loss.[1]

The Taylor Spatial Frame (TSF, Smith and Nephew, Memphis, USA) combines multi-planar fixation, ease of application and computerized accuracy in the reduction of fractures and deformities correction. Furthermore, TSF offers several advantages including reliability, versatility, and accuracy to simultaneously correct deformities in all planes including rotation, angulation, and translation deformities with adjusting only the strut lengths utilizing the virtual hinge concept.

The use of TSF is limited by the cost and other complications, as joints' stiffness and pin site infections. Several studies have demonstrated that the Ilizarov method may be used in conjunction with other treatment modalities to augment healing and corrective techniques.[2-5]

The current study discusses the different ways to use TSF for management of complex lower extremity injuries. The study presents a case series demonstrating the versatility of the TSF as a sole treatment or as an augmentation to other techniques for complex lower extremities injuries.

METHODS

This retrospective study included eight patients with lower extremity injuries treated with TSF between March 2007 and February 2011. The study was approved by the scientific committee of the Orthopaedic Department, Benha University, Egypt. The medical records and radiographs were reviewed. The ASAMI

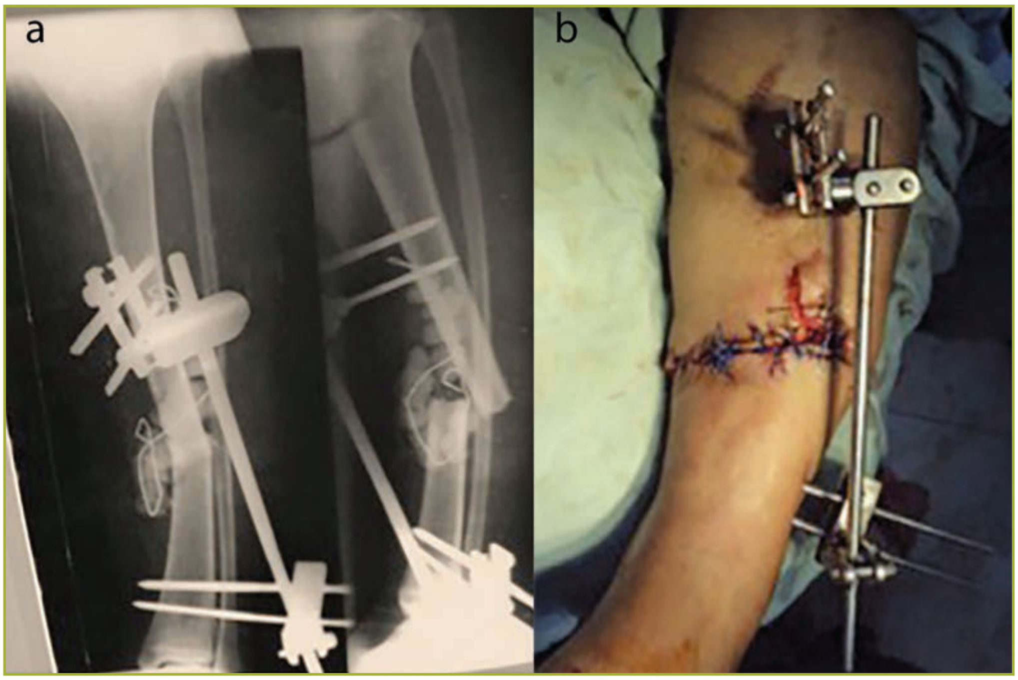

Figure 1. *Case 2 images. A) The fracture position in the uniplanar fixator. B) Primary closure of the wound in the intentional deformity.*

Table 1. Association for the Study and Application of Methods of Ilizarov (ASAMI) outcome scores

Bony results	
Excellent	Union, no infection, deformity < 7°, limb length discrepancy <2.5 cm
Good	Union + any two of the following: no infection, deformity < 7°,limb length discrepancy < 2.5 cm
Fair	Union +only one of the following: no infection, deformity < 7°,limb length discrepancy < 2.5 cm
Poor	Nonunion / refracture / union + infection + deformity > 7° + limb length Discrepancy > 2.5 cm
Functional results	
Excellent	Active, no limp, minimum stiffness(loss of < 15° knee extension < 15° dorsiflexion of the ankle), no Reflex Sympathetic Dystrophy(RSD), insignificant pain
Good	Active with one or two of the following: Limp, stiffness, RSD, significant pain.
Fair	Active with three or all of the following: Limp, stiffness, RSD, significant pain
Poor	Inactive (unemployment or inability to return to daily activities because of injury)
Failure	amputation

bony and functional scores were used to assess the outcomes, described in detail in Table 1. The treating surgeon used different surgical strategies to address the complexities of the cases. In three patients, TSF struts were used in combination with Ilizarov rings. A uniplanar fixator was used initially followed by application of combined TSF and ilizarov external fixators. The deformity correction was achieved using TSF followed by internal fixation and bone grafting were performed to address the non-union. TSF was used as initial treatment in case 1, definitive treatment in case 2, deformity correction in cases 3 through 5, additional support in case 6, and infection management in cases 7 and 8.

Case 1: TSF Used as Initial Treatment

An 18-year-old man sustained a transverse femur fracture shaft. The patient presented 6 weeks after the injury in a mal-reduced position. Combined TSF and Ilizarov construct were used as definitive fixation to gradually to restore the fracture alignment and to achieve bone healing. The fracture went on to healing with normal limb alignment at the final follow-up visit. The ASAMI scores were excellent as follows: active, no limp, full knee and ankle range of motion at final follow up, no reflex sympathetic dystrophy, and insignificant pain reported.

Case 2: TSF Used as Definitive Treatment

A 20-year-old woman presented with an open tibial shaft fracture (grade IIIB according to the Gustilo-Anderson classification). Varus, shortening, and internal rotation deformities were intentionally created to assist in wound closure. A uniplanar Hoffman frame (Stryker) was used to hold the fracture, and wound closure was achieved without any plastic surgical intervention (Figures 1A and 1B). After complete wound healing, TSF was applied as the definitive treatment to achieve deformity correction and bone healing (Figures 2A and 2B). The patient developed refracture due to premature frame removal. The refracture was treated with frame reapplication and autogenous bone grafting (ABG),

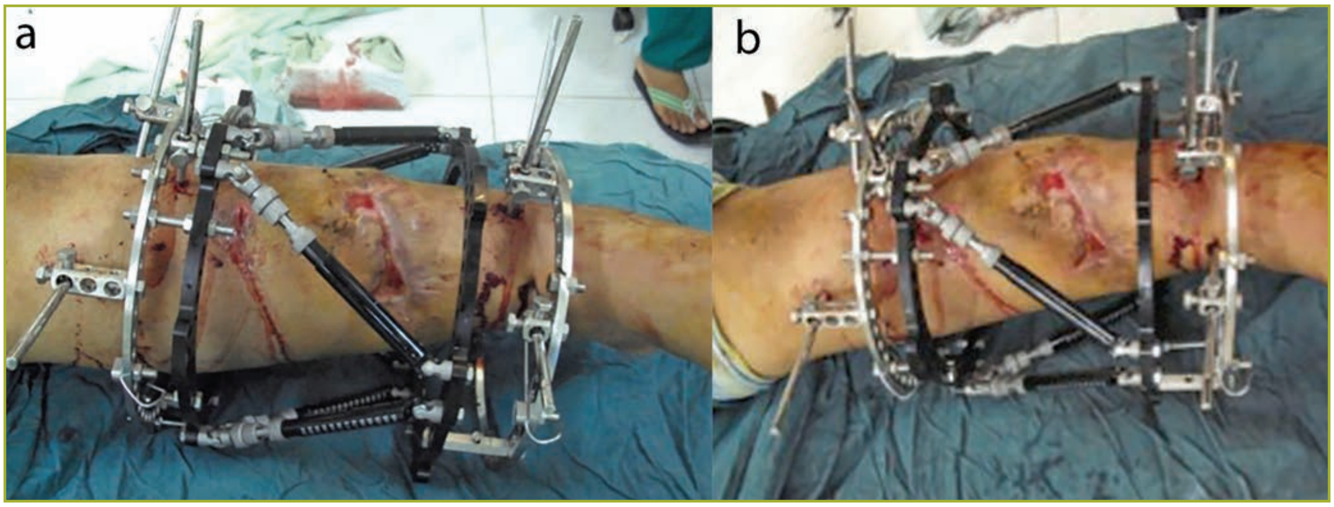

Figure 2. *Case 2 images. A, B) Clinical image of the Taylor Spatial Frame combined with the Ilizaov technique after wound healing and correction of the deformity.*

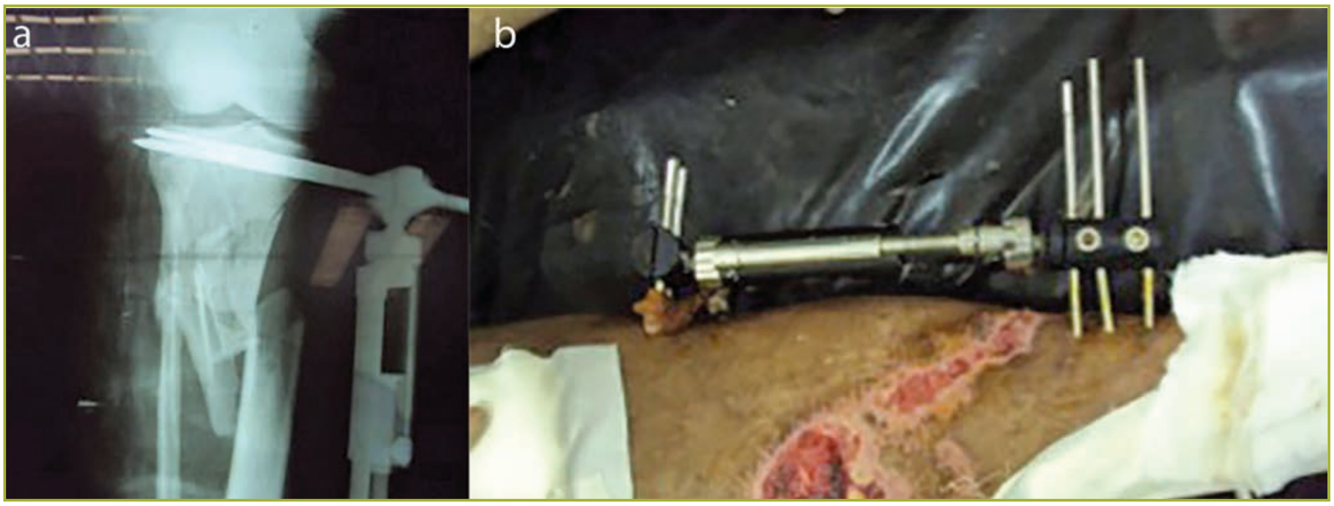

Figure 3. *Case 4 images. A) Radiographic image of the malreduced fracture fixed with the uniplanar fixator. B) Clinical image of the malreduced fracture fixed with the uniplanar fixator.*

followed by dynamization of the frame. Bone healing was achieved. The ASAMI bony and functional scores were excellent at the final follow up. .

Cases 3, 4, and 5: TSF Used in Correcting Deformity

In case 3, a 38-year-old man sustained a medial plateau fracture extended to the proximal tibia, which was treated with screws. The patient developed malunion. The patient presented with varus collapse with knee flexion contracture and medial joint line knee pain. TSF was used to correct varus deformity with lateralization of the mechanical axis to the lateral compartment to achieve pain relief as well as correct the knee flexion contracture by decreasing the knee slope. Knee arthroscopy was performed at the same time to check the internal knee structures and medial knee compartment. The knee ligaments and menisci were intact. At the last follow-up, the patient had complete bony union, deformity correction, full range of motion, and complete pain relief. The ASAMI functional and bony outcome scores were excellent.

Case 4 involved a 32-year-old man who sustained a high-energy fracture of the proximal tibia. Although the patient was treated with a uniplanar frame initially, the fracture was fixed in a mal-reduced position (Figures 3A and 3B). The patient underwent revision fixation with combined TSF and Ilizarov (Figures 4A and 4B). Deformity correction was achieved gradually using the TSF. The patient developed complications of ankle equinus contracture and delayed union. These complications were treated with ABG as a secondary procedure and Strayer gastrocnemius muscle recession to achieve bone union, respectively. Bone healing and restoration of normal limb alignment were satisfactory at the final follow-up.

Case 5 involved a 70-year-old man who presented with proximal tibia fracture nonunion and implant failure. Subsequently, all the hardware was removed and a TSF was applied to achieve deformity correction and bone union. At the final follow-up, normal alignment was restored with good bone healing. The ASAMI functional and bony out scores were excellent.

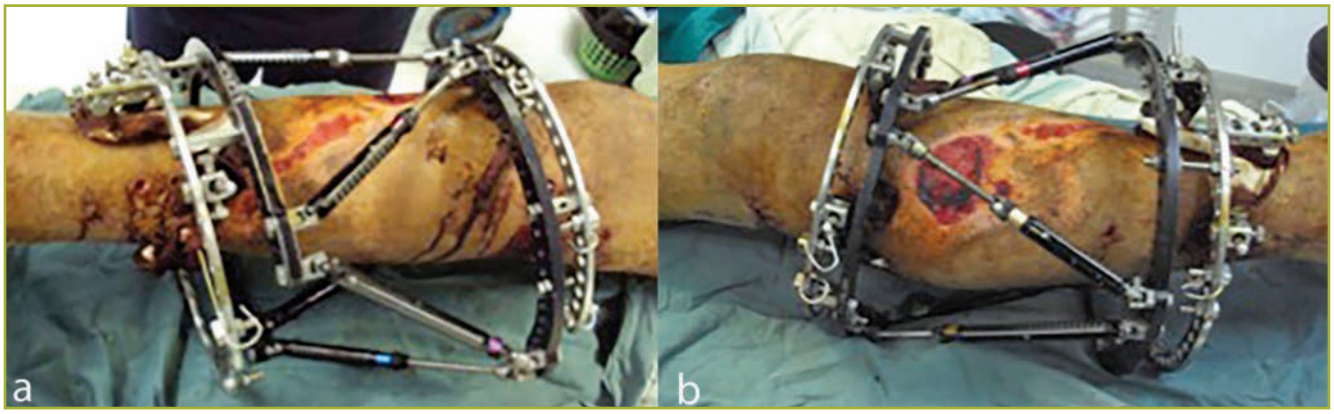

Figure 4. Case 4 images. A, B) Clinical image of the Taylor Spatial Frame combined with the Ilizarov technique after correction of the deformity.

Case 6: TSF Used as Additional Support in Managing Fragile Bone

A 62-year-old man presented 6 months after injury with nonunion and deformity of the distal femur (Figures 5A and 5B). The operative plan was to correct deformity using TSF followed by conversion to internal fixation and ABG to achieve healing. The change in the treatment course was enacted to treat the anticipated complication of nonunion, as well as several other reasons: 1) the patient lived in a remote part of the country and could not attend regular follow-up visits during TSF treatment, 2) the patient was not fully compliant with pin care protocol, and 3) the bone quality was poor due to old age. The patient stayed locally during the deformity correction program followed by conversion to plate fixation and ABG. The TSF was held in place for 6 weeks after plate application to increase the stability owing to poor bone quality (Figures 6A and 6B). The author paid attention to the pin sites during the combined period of internal and external fixation. Pins with any suspicious signs of infection were removed immediately to avoid deep infection of the plate. Deformity correction and bone healing were achieved (Figures 7A and 7B).

Cases 7 and 8: TSF Used in Managing Infection

In case 7, the patient was a 42-year-old man with a malunited tibial plateau fracture and an infected draining fasciotomy wound. The patient presented with severe varus and internal rotation deformity with a chronic draining wound secondary to fasciotomy. The application of the TSF promoted bone healing while correcting the varus deformity. This patient healed well with acceptable alignment at the final follow-up. The ASAMI functional and bony scores were excellent.

For case 8, an 18-year-old man sustained an ipsilateral transverse femur shaft fracture and open comminuted proximal tibia fracture. The patient presented late with an infected wound of the proximal tibia fracture and non-reduced transverse femur shaft fracture. The mal-reduced femur shaft fracture was treated with a combined TSF and Ilizarov construct. The infected proximal tibia fracture was then treated with bone transport after resection of the necrotic bone. A TSF was utilized for fracture reduction. Bone healing and restoration of normal limb alignment were satisfactory at the final follow-up. The ASAMI functional and bony scores were excellent.

Figure 5. Case 6 images. A) Anteroposterior and B) lateral radiographic views showing the distal femur fracture nonunion and deformity.

SURGICAL TECHNIQUE

Preoperative Planning

Full-length weight bearing lower extremity images as described by Paley and Maar were obtained.[6]

Operative Technique

The surgical technique comprised femoral and tibial applications of TSF external fixation with the patient positioned supine. Ring-first technique for TSF application was used in all cases. Intentional bony deformity was created in open fractures to help wound closure followed by gradual deformity correction after wound healing. Extensive soft tissues and bony debridement with or without application of antibiotics beads were done in cases with infection. Femoral arches

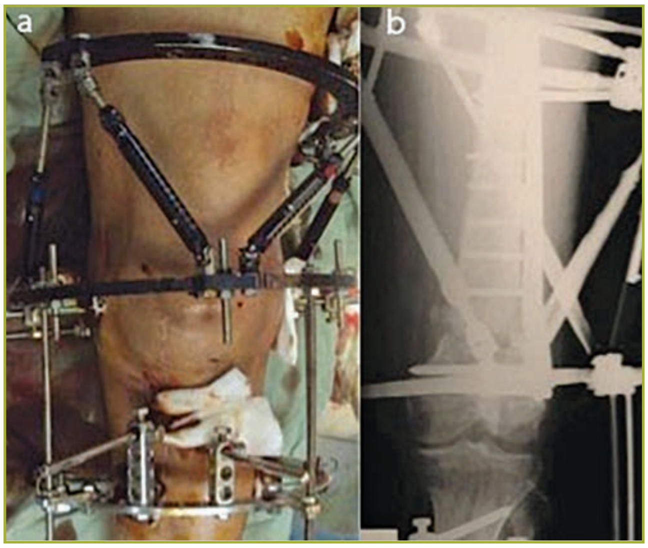

Figure 6. Case 6 images. A) Clinical image showing Taylor Spatial Frame combined with the Ilizarov after correction of the deformity. B) Radiographic image showing internal fixation with plate and screws combined with external fixation.

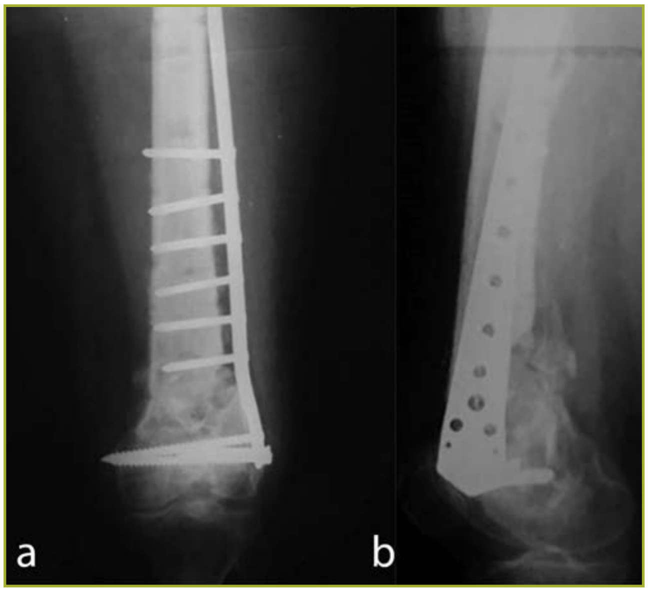

Figure 7. Case 6 images. A) Anteroposterior and B) lateral radiographic views showing the distal femur fracture healed in the corrected position.

were used in femur frames. The hybrid advanced frame mounting according to Paley et al was used in all cases.[7] The mounting parameters were collected at the end of the surgical procedure.

Postoperative Protocol

Deformity, frame, and mounting parameters were input into web-based software. A total residual program was used in all cases. Proximal reference was used in four patients and distal reference was used in the other four. Pin site care was done using a daily warm shower. Antibiotics were given to prepare for potential severe pin site infection. Pin removal or irrigation and debridement were done in case of osteomyelitis at the pin sites. Frames were removed after complete fracture healing as documented by follow-up images. Frame dynamization was done before frame removal. The frame removal was performed in the office, although four patients could not tolerate the pain during removal. The patients were instructed to restrict weight bearing after frame removal to avoid refracture.

RESULTS

The mean age was 37.5 years (range, 18-70 years). The study included a total of eight patients: seven men and one woman. The anatomic locations were 6 tibias and 2 femora. The mean external fixator time (EFT) was 5.2 months (range, 3-6 months). ABG was performed for three patients (37.5%) and was the most common secondary procedure after the index operation. Four patients were treated with only TSF rings and struts and the other four with combined TSF rings and struts attached to Ilizarov rings as the dead frame. Deformity correction and bone healing were achieved in all patients. Seven patients (87.5%) had excellent functional outcomes according to the ASAMI outcome scores. One patient (12.5%) had a good outcome.

Complications

Pin site infection was encountered in three patients. Pin site infection was grade III and controlled with daily pin care and oral antibiotics. One patient (12.5%) had refracture due to premature frame removal, which was treated with frame reapplication, ABG, and fibular shortening to enhance bone healing. Healing was achieved eventually. Knee stiffness occurred in two patients (25%) and was treated with an intensive physical therapy program after frame removal. One patient (12.5%) in case 4 developed delayed union and ankle contracture, which was successfully treated operatively.

DISCUSSION

TSF has demonstrated its efficacy in treating lower limb deformity.[8,9] The current study results support its efficacy in treating posttraumatic complications. The complexity of these injuries was related to late fracture presentation, bad soft tissue coverage, and initial treatment that complicated with posttraumatic deformities with and without nonunion.

The TSF is a versatile device.[10] In the current study, treatment was customized according to the patient's injury pattern, and TSF was used to achieve reduction followed by conversion to plate fixation and bone grafting. The TSF was left in place around the plate to maximize the stability until complete fracture healing. Complications included grade III pin site infection in three patients (37.5%), refracture due to premature frame removal in one patient (12.5%), knee stiffness in two patients (25%), and delayed union and ankle contracture in one patient (12.5%).

The risk of deep infection when combining both internal and external fixation is serious and well described. Kim et al reported the rate of deep infection in 63 patients with 118 limb segments.[11] Thirteen of the limb segments (11%) developed a superficial infection. The deep infection occurred in six limb segments (5%). The authors confirmed that deep infection of combining internal and external fixation is uncommon but a serious complication.

Wound closure in cases with open fracture can be achieved by the creation of deformity. Sharma and Nuun reported two cases with grade IIIB tibia open fracture.[4] The authors intentionally created bony deformities to help in wound closure. After wound closure, TSF was used to correct the deformity. The authors believed that two factors were important in this technique including soft tissue and bony factors. The soft tissue factors include wounds on the medial side to avoid the stretch of a neurovascular bundle. The unstable fractures with fibula are easier to deform and help in wound closure. Both patients did not need any plastic intervention for wound closure. Other authors have echoed the same results.[12,13]

Correcting deformity, lateralizing the mechanical axis to the lateral compartment, and correcting fixed knee flexion contractures can be done with TSF. The efficacy of TSF in managing posttraumatic deformities is well reported.[14-17] Ganger et al reported 22 patients with posttraumatic deformities treated with TSF.[18] The mean age at time of surgical procedure was 22.7 years (range, 12-48 years) and the mean follow-up was 21.1 months (range, 12-43 months). Deformity correction was achieved in all patients. The authors reported a total of 44 problems, 7 obstacles, and 10 complications during the study period.

Marangoz et al reported 22 femoral deformities in 20 patients treated with TSF.[19] The mean age at the index procedure was 13.9 years (range, 5.9-24.6 years). Deformity and limb length discrepancy correction were achieved in all patients. Infected nonunion is not uncommon after critical bone defects. Circular ring fixators and distraction osteogenesis are useful in this setting for equalizing limb lengths, healing the soft tissues, and eradicating infection.[8,15,20-21] Robinson et al reported the use of TSF for correcting varus deformity and medial compartment osteoarthritis (MCOA) of the knee in nine patients.[9] The mean age at operative procedure was 49 years (range, 37-59 years). Median follow-up was 19 months (range, 15-35 months). The mean Oxford knee score improved from 28.7 preoperatively to 35.4 postoperatively. The survival rate using total knee replacement (TKR) as the endpoint was 88.9%. Alterations in limb length can have significant effects on the patient. After TKR, outcomes of patients having greater than 15 mm of postoperative limb length discrepancy were seen to be lower than those having less than 15 mm of discrepancy.[22] The authors recommended using TSF for correcting varus deformity and MCOA.

Containment of healthcare costs is an important issue especially in institutions with limited resources. Combined TSF and Ilizarov were used to combat the cost of TSF. The costs of TSF rings and struts are expensive. The current study used the combined TSF and Ilizarov in four patients to reduce the TSF costs. The TSF rings were mounted to Ilizarov rings. The Ilizarov rings were attached to the bone with wires and half pins. The TSF program was used to achieve reduction. When reduction was achieved, the TSF rings and struts were removed. Ilizarov was kept in place until fracture healing, allowing recycling and using the TSF in a large number of patients. This protocol greatly helped reduce TSF costs and allowed its use in a large number of patients. This technique has been described in a previous report.[23] The author's institution allowed the recycling of TSF parts. Recycling of external fixators is a controversial topic.[24] Each institution has its policy on reprocessing external fixators. Horwitz et al reported the cost reduction for reusable parts of external fixators at 32% and total saving at 27% for the total external fixator charges.[24] The authors reported no failure of recertified parts during the clinical course of the study. Sung et al conducted a randomized clinical trial of new versus refurbished with consented patients, and the authors reported no statistical differences in the incidence of pin tract infections (46% vs 52%, $P = 0.32$), loss of fixation (4% vs 4%, $P = 0.70$), or loosening of the components (1% vs 1%, $P = 1.0$). The authors found a cost reduction of 25% for all new frames.[25]

The limitations of the current study are the retrospective nature, small sample size, and lack of comparison between TSF and other methods. Despite these limitations, deformity correction and bone healing were achieved in all patients with low complication rates. Further prospective studies with a larger sample size may be needed to show the benefits of TSF over alternative methods. In conclusion, TSF can be effective, accurate, and safe in the correction of posttraumatic deformities.

REFERENCES

1. Sala F, Thabet AM, Castelli F, et al. Bone transport for postinfectious segmental tibial bone defects with a combined ilizarov/taylor spatial frame technique. J Orthop Trauma. 2011;25(3):162-168. doi: 10.1097/BOT.0b013e3181e5e160.
2. Al-Sayyad MJ. Taylor spatial frame in the treatment of neglected fractures. J Child Orthop. 2011;5(2):135-141. doi: 10.1007/s11832-011-0332-8.
3. Sala F, Elbatrawy Y, Thabet AM, et al. Taylor spatial frame fixation in patients with multiple traumatic injuries: study of 57 long-bone fractures. J Orthop Trauma. 2013;27(8):442-450. doi:10.1097/BOT.0b013e31827cda11.

4. Sharma H, Nunn T. Conversion of open tibial IIIb to IIIa fractures using intentional temporary deformation and the Taylor Spatial Frame. Strategies Trauma Limb Reconstr. 2013;8(2):133-140. doi: 10.1007/s11751-013-0160-0.
5. Fadel M, Hosny G. The Taylor Spatial Frame for deformity correction in the lower limbs. Int Orthop. 2005;29(2):125-129. doi: 10.1007/s00264-004-0611-9.
6. Paley D, Maar DC. Ilizarov bone transport treatment for tibial defects. J Orthop Trauma. 2000;14(2):76-85. doi: 10.1097/00005131-200002000-00002.
7. Paley D, Catagni MA, Argnani F, et al. Ilizarov treatment of tibial nonunions with bone loss. Clin Orthop Relat Res. 1989;(241):146-165.
8. Semaya Ael-S, Badawy E, Hasan M, et al. Management of post-traumatic bone defects of the tibia using vascularised fibular graft combined with Ilizarov external fixator. Injury. 2016;47(4):969-975. doi: 10.1016/j.injury.2016.01.033.
9. Robinson PM, Papanna MC, Somanchi BV, et al. High tibial osteotomy in medial compartment osteoarthritis and varus deformity using the Taylor Spatial Frame: early results. Strategies Trauma Limb Reconstr. 2011;6(3):137-145. doi: 10.1007/s11751-011-0123-2.
10. Sala F, Albisetti W, Capitani D. Versatility of Taylor Spatial Frame in Gustilo Anderson iii c femoral fractures: report of three cases. Musculoskelet Surg. 2010;94(2):103-108. doi: 10.1007/s12306-010-0073-8.
11. Kim SJ, Cielo Balce G, Huh YJ, et al. Deep intramedullary infection in tibial lengthening over an intramedullary nail. Acta Orthop Belg. 2011;77(4):506-515.
12. Lahoti O, Findlay I, Shetty S, et al. Intentional deformation and closure of soft tissue defect in open tibial fractures with a Taylor Spatial Frame--a simple technique. J Orthop Trauma. 2013;27(8):451-456. doi: 10.1097/BOT.0b013e318284727a.
13. 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. 2006;20(6):419-424. doi: 10.1097/00005131-200607000-00010.
14. Glatt V, Bartnikowski N, Quirk N, et al. Reverse dynamization: influence of fixator stiffness on the mode and efficiency of large-bone-defect healing at different doses of rhBMP-2. J Bone Joint Surg Am. 2016;98(8):677-687. doi: 10.2106/JBJS.15.01027.
15. Rohilla R, Siwach K, Devgan A, et al. Outcome of distraction osteogenesis by ring fixator in infected, large bone defects of tibia. J Clin Orthop Trauma. 2016;7(suppl 2):201-209. doi: 10.1016/j.jcot.2016.02.016.
16. Rozbruch SR, Segal K, Ilizarov S, et al. Does the Taylor Spatial Frame accurately correct tibial deformities? Clin Orthop Relat Res. 2010;468(5):1352-1361. doi: 10.1007/s11999-009-1161-7.
17. Dabash S, Prabhakar G, Potter E, et al. Management of growth arrest: current practice and future directions. J Clin Orthop Trauma. 2018;9(suppl 1):S58-S66. doi: 10.1016/j.jcot.2018.01.001.
18. Ganger R, Radler C, Speigner B, et al. Correction of post-traumatic lower limb deformities using the Taylor Spatial Frame. Int Orthop. 2010;34(5):723-730. doi: 10.1007/s00264-009-0839-5.
19. Marangoz S, Feldman DS, Sala DA, et al. Femoral deformity correction in children and young adults using Taylor Spatial Frame. Clin Orthop Relat Res. 2008;466(12):3018-3024. doi: 10.1007/s11999-008-0490-2.
20. Rohilla R, Wadhwani J, Devgan A, et al. Prospective randomized comparison of ring versus rail fixator in infected gap nonunion of tibia treated with distraction osteogenesis. Bone Joint J. 2016;98-B(10):1399-1405. doi: 10.1302/0301-620X.98B10.37946.
21. Sadek AF, Laklok MA, Fouly EH, et al. Two stage reconstruction versus bone transport in management of resistant infected tibial diaphyseal nonunion with a gap. Arch Orthop Trauma Surg. 2016;136(9):1233-1241. doi: 10.1007/s00402-016-2523-8.
22. Kim SH, Rhee SM, Lim JW, et al. The effect of leg length discrepancy on clinical outcome after TKA and identification of possible risk factors. Knee Surg Sports Traumatol Arthrosc. 2016;24(8):2678-2685. doi: 10.1007/s00167-015-3866-3.
23. Thabet AM, Zahed MS. Use of combined Taylor Spatial Frame (TSF) and Ilizarov for delayed treatment of femoral shaft fracture presented 6 weeks after injury—a case report. Injury Extra. 2011;42-7:71-74.
24. Horwitz DS, Schabel KL, Higgins TF. The economic impact of reprocessing external fixation components. J Bone Joint Surg Am. 2007;89(10):2132-2136. doi: 10.2106/JBJS.F.01409.
25. Sung JK, Levin R, Siegel J, et al. Reuse of external fixation components: a randomized trial. J Orthop Trauma. 2008;22(2):126-130; discussion 130-1. doi: 10.1097/BOT.0b013e318162e55c.