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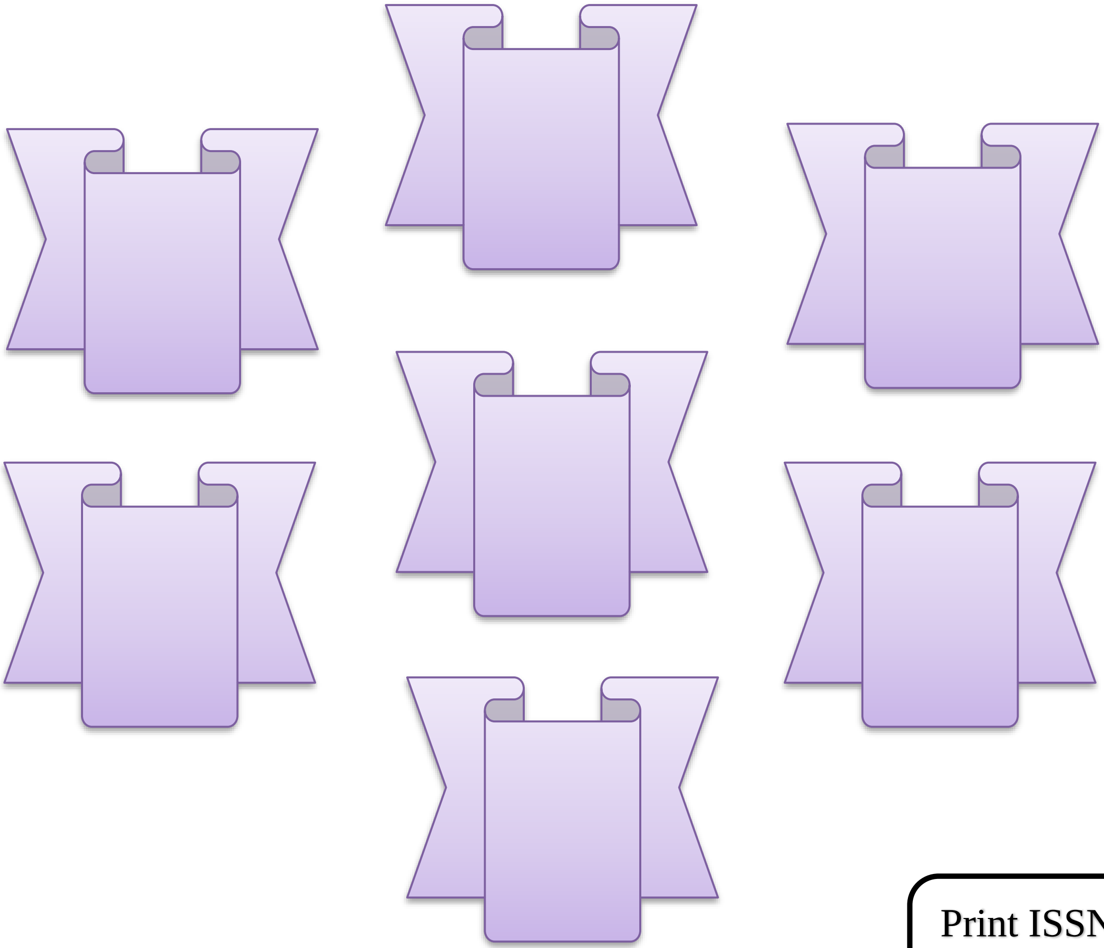

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Original Article

Correction of Proximal Tibial Deformities using Ilizarov-Taylor Spatial Frame

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ABSTRACT

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Background: The Taylor Spatial Frame [TSF] is a circular external fixation system that attaches through screws and uses the same principles of correction as the Ilizarov device.

Aim of the work: To assess the Ilizarov-Taylor Spatial Frame in the correction of the Proximal tibial Deformities.

Patients and Methods: The present study comprised a sample of 15 patients, with a total of 20 tibiae, who underwent surgical tibial osteotomy for the purpose of correcting proximal tibial deformities by using the TSF. According to the treatment goal, patients were grouped into: group 1; mechanical axis deviation [MAD] center within 5 mm medial or lateral, group 2; MAD overcorrection from 6 mm to 12 mm medial or lateral, and group 3; MAD improvement with femoral origin residual deformity.

Results: For patients with a goal of a MAD central [group 1], tibial origin varus deformity with preoperative average MAD of 48 mm medial to the midline, this improved to a range of 5 mm medial and 5 mm lateral to midline. For patient with tibial and femoral origins varus deformity and with preoperative MAD 104 mm medial to midline, this improved to 2 mm medial to midline. Statistical analysis for all proximal tibial angles and MAD showed significant improvement with P value < 0.05. The most common complication encountered was pin site infection. Six patients [30%] complained from superficial wire site infection that improved with wire removal in the outpatient clinic.

Conclusion: The TSF can be used to treat severe tibial abnormalities with minimal risk of complications.

Keywords: Tibia; Ilizarov Technique; External Fixators.

INTRODUCTION

The existence of proximal tibial deformities disrupts the effective transmission of forces within the knee joint. According to reports, even a moderate malalignment of 5° is said to initiate or facilitate the progression of osteoarthritis [1].

Knee realignment osteotomy may be advised for individuals who exhibit deformity, reduced activity levels, gait disturbances, pain, or a combination of these symptoms. The orthopedic surgeon continues to face significant challenges in managing lower limb deformities with multiple apical and multidirectional signs resulting from various causes. The typical approach for correcting deformities through internal fixation involves the combination of open osteotomies and acute correction. The efficacy of these methods is limited in cases of intricate deformities, mainly when there is a need to address coexisting leg length discrepancy [2].

External fixators, particularly the circular Ilizarov fixator, have gained significant popularity in the field of orthopedics for the purpose of addressing intricate deformities and facilitating bone lengthening procedures. Although the Ilizarov frame offers numerous benefits, it is important to note that each frame is specifically designed and tailored to suit individual cases [2, 3].

It is not possible to execute a one-step repair for complex abnormalities that involve translational, rotational, and angular deformities. Correction is achieved through the utilization of different components, such as hinges and translation devices that are connected to rods. Furthermore, it may be imperative to postpone the mandated elongation process as a result of deformity correction. The execution of these procedures typically necessitates the alteration of various components, a process that can induce discomfort in the patient and result in fatigue for both the patient and surgeon [2].

Spatial fixators are used in the treatment of deformities as a unified vector, with correction being executed based on this vector through the utilization of a virtual hinge. The implementation of this single corrective measure has the potential to ultimately result in a significantly reduced duration of correction, thereby potentially decreasing the overall period of external fixator usage. It is feasible to achieve greater precision in the correction of deformities [3, 4].

The Taylor Spatial Frame [TSF; Smith and Nephew] first appeared on the market in 1994 and has since gained widespread acceptance. Similar to the Ilizarov device, this circular external fixation system uses frame attachment and gradual corrective techniques [5, 6]. It's built from a pair of rings joined together by six telescoping supports. Using an online software application and a 3D model, a virtual hinge may be designed to fix even the most severe abnormalities. The TSF enables simultaneous six-axis correction without frame alteration, and residual abnormalities may be recovered with a second program without any reoperation by simply altering the strut length, as computed by the software [7].

The program can be run in either the chronic or the more advantageous total residual mode. While the computer-controlled TSF and the Ilizarov device both distract calluses, the former has many more benefits. It takes less time to move the frame, no complicated adjustments to the hinges are required, and the duration of the adjustments may be estimated [8, 9].

The efficacy of the spatial frame resides in its meticulous management of the ultimate limb length and alignment, as well as its capacity to rectify any remaining deformities. According to Paley's findings, it was observed that the Taylor spatial frame exhibits increased rigidity across all axes. The multiplanar circular fixator exhibits a high degree of stability, enabling the patient to bear weight at an early stage of recovery. Additionally, this fixator creates an optimal setting for the regeneration of new bone and the healing of soft tissues. Additionally, the computer software facilitates the streamlining of preoperative planning and the rectification of deformities that may arise after application [10].

So, the aim of this study is to assess the Ilizarov-Taylor Spatial Frame in the correction of the Proximal tibial Deformities.

PATIENTS AND METHODS

The present experimental study comprised a sample of 15 patients, corresponding to a total of 20 tibiae, who underwent tibial osteotomy surgery.

Prior to the surgical procedure, informed consent was obtained from the participants for the purpose of correcting proximal tibial deformities using the Taylor Spatial Frame [TSF] manufactured by Smith and Nephew, located in Memphis, Tennessee, USA. The surgeries were performed between the months of June 2019 and April 2023, under the supervision of the lower limb deformity unit at Al-Azhar Damietta Orthopedic Hospital.

Ethical approval was obtained from the committee of Al-Azhar university.

According to the treatment goal, patients were grouped into: group 1; MAD center within 5 mm medial or lateral, group 2; MAD overcorrection from 6 mm to 12 mm medial or lateral depending on the presenting problem in the patients who had unicompartmental arthritis, and group 3; MAD improvement with femoral origin residual deformity.

The inclusion criteria were: 1] The presence of a uniplanar coronal plane deformity exceeding 10°. 2] Sagittal plane deformity. 3] The existence of rotational deformity is observed**.**

The Exclusion criteria were: 1] Individuals diagnosed with non-unions. 2] individuals who underwent tibial lengthening as the primary procedure. 3] Individuals who underwent deformity correction using a method other than the Taylor Spatial Frame [TSF].

Data collection

A comprehensive preoperative assessment encompassing both a thorough patient history and a comprehensive physical examination.

A measurement was taken of the frontal plane deformity observed on a long lower limb standing radiograph. The radiograph was utilized to measure limb length discrepancy [LLD], as well as the lengths of the femur and tibia. The methods described by Paley were employed to measure mechanical axis deviation [MAD] and joint orientation angles, namely the lateral distal femoral angle [LDFA], medial proximal tibial angle [MPTA], lateral distal tibial angle [LDTA], posterior distal femoral angle [PDFA], posterior proximal tibial angle [PPTA], and anterior distal tibial angle [ADTA].

The clinical assessment of rotation involved the examination of the thigh-foot axis in the prone position and the measurement of the angle between the patella's upward axis and the heel bisector axis in the supine position. In two cases, radiological evidence in the form of CTRP was utilized due to the presence of isolated rotational deformity.

The proximal piece was used as a standard for measuring the degree of deformation. Six different axes were used to assess the severity of each proximal tibial deformity: the coronal plane [varus, valgus] and translation [medial, lateral], the sagittal plane [procurvatum, recurvatum] and translation [anterior, posterior], and the axial plane [internal, external, short, long].

The patients underwent surgery after anesthetist acceptance. The patients were administered prophylactic antibiotics with anesthesia induction. Tourniquet was not used during the procedure. Common peroneal nerve release was done in 13 cases for rotational deformities more than 15° and/or valgus deformity more than 10° [Figure 1].

Fibular osteotomy was performed in all cases. The location of the fibular osteotomy was the middle of the fibula. TSF frame had been attached to the bone using one tensioned wire as a reference wire for proximal ring and three perpendicular hydroxyapatite [HA] coated half pins. For distal ring, three HA coated half pins in different planes were used for fixation. A 2/3 ring was used proximally to accommodate posterior leg swelling and allow knee flexion. The osteotomy for the tibia was performed with multiple drill holes and an osteotome. Osteotomy was complete but left non-displaced.

Final mounting parameters were calculated after placement of the TSF. After surgery, patients were allowed to use crutches during mobilization with partial weight bearing as tolerated and range of motion exercises of the knee and ankle were encouraged. A daily shower, including washing the pin sites with antibacterial soap [Chlorhexidine Gluconate 4%], was encouraged one week postoperatively. This was followed by pin care with Chlorhexidine 0.5% in water then wrapped with sterile gauze had wetted with Chlorhexidine 0.5% in water.

The TSF web-based software tool was used to input the deformity parameters and produce an adjustment schedule with total residual operating mode.

Deformity, frame, and mounting parameters, as well as a structure at risk, are input into the computer to establish the correction rate.

Five to seven days following surgery, deformity correction began. Patients were released from the hospital with instructions to walk with crutches and perform partial weight bearing as tolerated. Patients were directed to gradually adjust the TSF's six struts three times daily, two at a time, for four to six weeks after the end of the adjustment program. At 2 weeks, radiographs were performed to check on the progress of the osteotomy.

During the clinic visits, patients were given weekly diversion assignments. Once the alignment was fixed, they returned once a month until the frames were removed. Physical examination and radiographs were used to determine limb alignment at the end of the 2–10-week regimens.

Using the same techniques as before surgery, we measured MAD, MPTA, PPTA, and LLD on a standing radiograph of the patient's long lower leg. The patella up test and the TFA were used to analyze the rotation. When there was still some distortion, we devised a new rectification plan and put it into effect.

Using anteroposterior, internal oblique, external oblique, and lateral radiographs, we determined that the patient met the criteria for frame removal when they were able to walk with minimum assistance, experienced no discomfort at the osteotomy site, and a bridging callus had formed on three of four cortices.

Schedules, adjusting weeks, total frame wearing time, problems, knee and ankle range of motion, and months of follow up after frame removal were all recorded for each patient. It was noted the extent to which deformities such varus, valgus, pro-curvatum, recurvatum, and internal and exterior rotation deformities were present [table 1].

Scoring system: Due to the similarity between the TSF and the Ilizarov procedure in terms of callus distraction, the ASAMI [Association for the Study and Application of the Methods of Ilizarov] grading system was used to assess the bony and functional outcomes of the study [table 2].

Table 1: The magnitude and nature of the preoperative deformity

Tibial deformity	No. of the cases	Degree's limit	Cases' range
Varus	16	MPTA < 85°	52° - 82°
Valgus	2	MPTA > 90°	96° - 97°
Procurvatum	8	PPTA < 77°	67° - 75°
Recurvatum	2	PPTA > 84°	91° - 104°
Internal rotation	15	TFA ≤ 0°	-28° - 0°
External rotation	4	TFA > 10°	+24° - +45°

Table [2]: ASAMI score descriptions for bony result and functional result

Bony results	Description
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 + any 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	**Description**
Excellent	Active, no limp, minimum stiffness [loss of <15° knee extension and/or dorsiflexion of the ankle <15°], 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

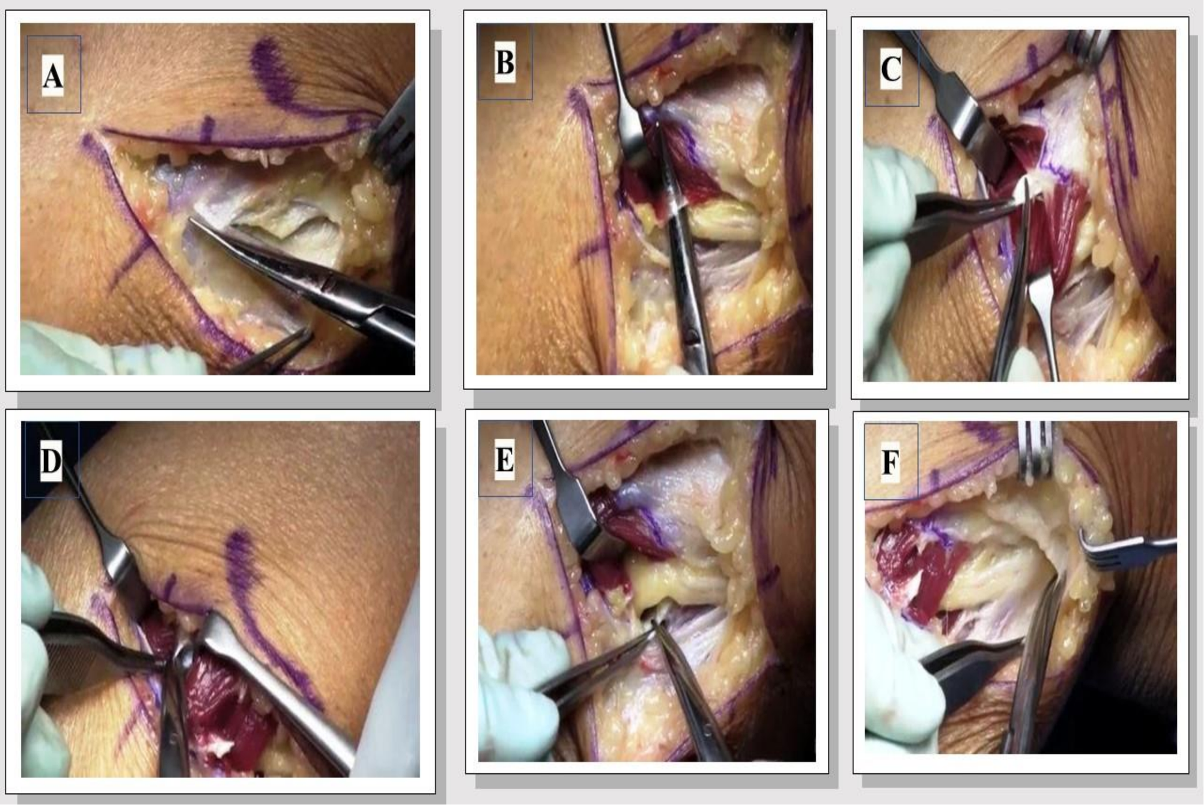

Figure [1]: Common peroneal nerve dissection. A: Release fascia superficial to the CPN. B: Release Peroneal muscles arcade. C: Release intermuscular septum between lateral and anterior compartment. D: Release intermuscular septum between EDL and TA. E: Release intermuscular septum between Peroneal muscle and Soleus muscle. F: Release proximally for fascial covering

Statistical analysis

The software SPSS for Windows Release 10 [SPSS Inc, Chicago, Illinois, USA] was used for all statistical calculations. Each variable was tested for its normal value using the Kolmogorov–Smirnov test and exact P values were calculated. Significance was set at the P value less than 0.05

RESULTS

There were 6 females and 9 males with an average age of 21.5 [range, 10–33 years]. Five [2 females and 3 males] of the fifteen patients had bilateral corrections.

MAD-aimed groups reported separately lateral or medial to the midline, pre and post-surgical correction. All medial and lateral MAD data points were averaged and the ranges were recorded. Other goals of our study were to examine the accuracy of joint orientation angle; MPTA, PPTA and rotational correction, so that, all orientation angles were recorded before and after using the TSF. For all patients we recorded the number of schedules needed, adjusting weeks, total wearing period of the frame, complications, knee and ankle range of motions and follow up in months post frame removal.

For patients with a goal of a MAD central [group 1], tibial origin varus deformity with preoperative average MAD of 48 mm medial to the midline, this improved to a range of 5 mm medial and 5 mm lateral to midline. For patient with tibial and femoral origins varus deformity and with preoperative MAD 104 mm medial to midline, this improved to 2 mm medial to midline [table 3].

Patients In whom the goal was MAD overcorrection [group 2], tibial and femoral origins varus deformity with preoperative average MAD of 102.5 medial to the midline, this improved to a range of 6 mm and 11 mm lateral to the midline [table 3].

For patients with a goal of a MAD improvement [group 3], tibial and femoral origins varus deformity with preoperative average MAD of 61 mm medial to the midline, this improved to a range of 17 mm and 58 mm medial to the midline. Patient with tibial origin valgus deformity and had a preoperative MAD of 28 mm lateral to the midline, this improved to 0 mm to midline [table 3].

Patient with tibial and femoral origins valgus deformity and had a preoperative MAD of 60 mm lateral to the midline, this improved to 5 mm medial to midline [table 3].

The corrections of MPTA were accurate. The MPTA improved from 73° to 89.5° in patients with a varus deformity, and from 96.5° to 89.5° in patients with a valgus deformity [table 4].

Sagittal deformities [procurvatum and recurvatum] [table 5] and axial planes deformities [internal and external rotation] [table 6] were corrected to a satisfactory degree in all cases.

There were no statistical significance differences between preoperative and postoperative ankle and knee range of motion [table 7].

All the complications occurred with using TSF during this study were recorded [table 8]. The most common complication encountered was pin site infection. Six patients [30%] complained from superficial wire site infection that improved with wire removal in the outpatient clinic.

All cases [100%] developed pin site reaction during the adjusting or consolidation period for one or more of the half pins and resolved with daily dressing. One case [5%] had developed pin site colonization and erythema that required a 10-days course of intravenous antibiotics.

One case [5%] had developed pin site infection that not respond to daily dressing and intravenous antibiotic, so required operative intervention in the form of half pin removal with no consequence complication. No cases of osteomyelitis were reported in this study.

All the patients had performed a physiotherapy program from the first day post operatively until the end of adjusting period then continue daily training exercise for the knee and ankle joints during consolidation period until frame removal. So, in this study no joint stiffness recorded for the knee and ankle joints.

Prophylactic fasciotomy was done for all cases through fibular osteotomy incision and no compartment syndrome complication was recorded in the study.

Two cases reported significant osteotomy site pain in early post-operative days even with good pain control medication and had improved with early compression software program.

All the patients had received antithrombotic medication and followed physical measure of prophylaxis in the form of intermittent pneumatic compression device and early mobilization. No deep vein thrombosis complication was recorded in the study.

For valgus deformity more than 10° and rotational deformity cases more than 15°, a prophylactic Common peroneal nerve release was done and no nerve palsy complication was recorded. No cases were recorded with the complication of RSD.

All the cases healed within the expected time of healing, range from 12 to 18 weeks with no reported cases of non-union. With complete osteotomy technique and reasonable latency period no premature consolidation was reported.

Depending on multi and perpendicular planes of the fixing wire and half pins no hardware failure complication was reported.

In central and overcorrection groups of the patients, the aim was achieved and complete deformity correction was occurred and no residual deformity accepted, so that any residual deformity had been corrected with new software correcting program. While in the third group of improvement, it was expected to found residual deformity with femoral origin.

ASAMI scoring systems for bony results and functional result of the study were highly satisfied [Table 9].

Bony results were excellent in 65% [*n* = 13], good in 35% [*n* = 7], no fair or poor results were seen in the study. Functional results were excellent in 100% [n = 20]. Good, fair, poor and failure results not recorded for any patient of the study.

Table 3: Preoperative versus postoperative MAD [mm]

Preoperative deformity	MAD Aimed group	Preoperative MAD		Postoperative goal			
				Central		Over.	Improv.
				M	L	L	L
MAD medial [Varus]	**Central**	Tibial origin	48 [24-95]	0.8 [0-5]	3.8 [3-5]		
		P Value		**0.001**	**0.01**		
		Tibial & Femoral origins	104	2			
	Over.	Tibial & Femoral origins	102.5 [100-105]			8.5 [6-11]	
		P Value				**0.03**	
	Improv.	Tibial & Femoral origins	61 [78-44]				37.5 [17-58]
		P Value					**0.002**
MAD lateral [Valgus]	**Central**	Tibial origin	28	0			
		P Value		**0.001**			
		Tibial & Femoral origins	60	5			
		P Value		**0.02**			

MAD: Mechanical axis deviation

Table 4: Preoperative versus postoperative MPTA [degrees]

Preoperative deformity	Preoperative MPTA	Postoperative MPTA	P Value
Preoperative MPTA < 85° [varus]	73 [52-82]	89.5 [87-92]	**0.002**
Preoperative MPTA > 90° [valgus]	96.5 [96-97]	89.5 [89-90]	**0.001**

MPTA: Medial proximal tibial angle

Table 5: Preoperative versus postoperative PPTA [degrees]

Preoperative deformity	Preoperative PPTA	Postoperative PPTA	P Value
Preoperative PPTA < 77° [Procurvatum]	70.7 [67-75]	81.6 [80-83]	**0.001**
Preoperative PPTA > 84° [Recurvatum]	97.5 [91-104]	83	**0.002**

PPTA: Posterior proximal tibial angle

Table 6: Preoperative versus postoperative TFA [degrees]

Preoperative deformity	Preoperative TFA	Postoperative TFA	P Value
Preoperative TFA < 5° [internal rotation]	-12.6 [-28-0]	10	**0.004**
Preoperative TFA > 15° [external rotation]	+33 [+24-+45]	10	**0.002**

TFA: Thigh foot axis.

Table 7: Preoperative versus postoperative knee and ankle ROM [degrees]

Period/P Value	Knee ROM		Ankle ROM	
	Extension	Flexion	Dorsiflexion	Plantar flexion
Preoperative	[10h-15]	[125-140]	[0-10]	[40-45]
Postoperative	[10h-0]	[130-140]	[5-10]	[40-45]
P Value	0.35	1.00	0.60	0.10

ROM: Range of motion; h: Hyperextension

Table [8]: The cases with TSF complication

Complication		Case No.	Total	Percentage %
Wire infection		3b/4b/5/6/8/13c	6	30
Pin site	Reaction	1a-20	20	100
	Colonization	11	1	5
	Infection	5	1	5
Joint stiffness		-	-	-
Osteotomy site pain		2a/17e	2	10
Others*		-	-	-

*: include compartment syndrome, deep vein thrombosis, nerves palsy, reflex sympathetic dystrophy, delayed union and non-union, premature consolidation, hardware failure, residual deformity.

Table [9]: ASAMI score for bony results and functional results

Variables	No. of the cases	Percentage %
Bony results		
Excellent	13	65
Good	7	35
Fair	Nil	0
Poor	Nil	0
Functional results		
Excellent	20	100
Good	Nil	0
Fair	Nil	0
Poor	Nil	0
Failure	Nil	0

DISCUSSION

The study's overarching objective was to look into how well the TSF can repair proximal tibial deformity. Acute correction and internal fixation are effective methods for correcting tibial deformity, but they are not without their drawbacks. The lack of postoperative adjustability, poor skin quality, multiplanar deformity, infection history, limb length discrepancy, and the presence of poor skin quality all demonstrate the limits of this approach [11-14].

One of the most significant developments in deformity treatment during the past century is the Ilizarov technique for limb lengthening [13]. This method remains the basis for deformity correction using internal and external fixation. Monolateral or circular fixators can be used to correct abnormalities. Monolateral fixators are less cumbersome and more convenient than bilateral ones, however they often cannot provide the desired stable correction. The Ilizarov frame has a number of drawbacks, including a steep learning curve, frequent frame changes, and the requirement for new hinges for repairing multiplanar abnormalities. In addition, even for the most skilled surgeons, correcting rotational abnormalities using the Ilizarov frame remains a challenge [15].

The rapid acquisition of hexapod mastery stands in stark contrast to the time-consuming nature of other skill development processes. This notable disparity may serve as a plausible explanation for the global surge in popularity observed in the field of TSF and other hexapod systems [14].

The biggest benefit of the TSF and comparable hexapod systems is that even the most severe malformations can be corrected using the same apparatus. Although spatial fixators may have superior mechanical properties and user friendliness, they are based on the same biological properties and host response as conventional Ilizarov fixators. Using a strut geometry based on hexagons, we may precisely move the proximal and distal pieces in relation to one another. However, the higher price tag associated with this enhancement is not without reason. The price of spatial fixators is anywhere from six to ten times that of more conventional external fixators like the Ilizarov circular variety. Because of this, it is crucial to determine which patients might benefit most from using spatial fixators [12].

One of the primary benefits of spatial fixators is their ability to correct both eyes at once. Due to the device's lack of movement, traditional Ilizarov-type external fixators need correcting the deformity component by component. Regardless of the mounting specifications, Smart Correction software is designed to fix all deformations in a single operation [16, 17].

The only information the program needs is the degree of the initial deformity, the location of the bone and any critical structures [such as the common peroneal nerve] in relation to the fixator, and the desired outcome. The software then determines a schedule for spinning the struts to achieve the necessary adjustment. Unlike with an Ilizarov fixator, where multiplanar repairs must be staged, this combination of fixator and software permits simultaneous angular and translational adjustments [3].

Since each turn of the Taylor Spatial Frame's struts results in the same amount of motion, this method may also be more precise. The frame parameters entered into the program are also relative to the position of the bone, so if the preoperative position does not exactly match that of the post-application position, the software can be adjusted accordingly. Input fresh values and have the software construct a new turning schedule to make residual corrections if the initial correction was insufficient. The turning schedules are color-coded to the struts, and the turning directions are clearly designated, making the process easier for the patients [9].

TSF offers a versatile approach to correct all aspects of proximal tibial deformities, so the study concept asked: [1] How accurate is the MAD correction? [2] How accurate is the MPTA corrections? [3] How accurate is the PPTA corrections? [4] How accurate is the rotational corrections?

The study's patients were very satisfied with the functional outcome as indicated by ASAMI score. All of the patients indicated that they would undergo the same procedure. The overall clinical results suggest that patient satisfaction was high with this procedure as long as there were no major complications.

External fixation always carries the risk of pin loosening and infection. Since multiple articles have examined HA-coated and uncoated pins in humans and found that HA-coated pins improved fixation, these pins were employed in the investigation [18].

Previous studies have shown that TSF is an effective surgical tool for correcting any kind of deformity with computer accuracy, and a survey of the literature from the past 15 years indicated that the majority of articles detailed deformity corrections employing TSF around the tibia [1, 17]. The corrections and bone healing in each case were successful. The complications mirrored those described in this analysis.

Long standing radiographs of the lower limb confirmed the correction of the mechanical axis and joint line due to the progressive nature of the treatment. There was no need for the patient to undergo another surgery for residual correction, reducing both their risk of complications and the surgeon's workload.

Although nursing-home employees can be successfully trained to do frame adjustments and pin care, these treatments are not optimal for elderly patients who have no support network and no ability to care for themselves. External fixation has traditionally been unsuitable for patients with severe or uncontrolled psychiatric disorder.

Conclusion

The Taylor Spatial Frame allows gradual correction with safe, simple, accurate procedure and in well tolerated manner. This is particularly useful when there are multiapical and multidirectional deformities or extensive limb length discrepancy.

Conflict of Interest and Financial Disclosure: None.

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