The Taylor spatial frame for correction of proximal tibial varus deformity

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Background
Genu varus deformity secondary to tibia vara is one of the common deformities of the knee joint, and correction by using the Taylor spatial frame (TSF) is an effective method of treatment.
Aim of the study
This study evaluated the clinical, functional, and radiological outcomes after using the TSF for the correction of proximal tibial varus deformity.
Patients and methods
This prospective study was done on 14 patients, with eight males and six females, attending Saudi German Hospital in Saudi Arabia between October 2011 and January 2014, and the mean age was 18 years (range, 12–28 years) at the time of surgery. Patients included in the study have nontraumatic genu varus deformity secondary to tibia vara without degenerative changes in the knee. Follow-up evaluation of the results after 1 year of surgery was done using SF-36 scores, the American Academy of Orthopedic Surgeons Lower Limb Module scores, and an objective grading system modified by Tucker and colleagues.
Results
Patients had a preoperative mechanical axis deviation of 42 mm (range, 25–62 mm) medial to the midline, which was improved postoperative to an average of 4 mm (range, 2–8 mm) medial to the midline. The correction of medial proximal tibial angle was accurate, and the medial proximal tibial angle was improved from preoperative of 65° (range, 45–74°) to postoperative 88° (range, 86–92°). The posterior proximal tibial angle was corrected from preoperative of 72° (range, 66–74°) to postoperative 82° (range, 79–84°). Preoperative limb-length inequality was corrected in all patients, and the average was 0.5 cm (0–2 cm). There were no significant differences between preoperative and postoperative range of movements of both ankle and knee joints. The average postoperative range of motion of the knee joint was 0–130° and for the ankle joint was a 0–40°. Pin-tract infection was found in 42% of patients and treated by frequent dressing and oral antibiotics, and no patients had deep infection. Frame loosening was found in one (7%) patient and was treated by addition of wires. Follow-up evaluation after 1 year postoperatively was done by using SF-36 Health Survey scores, and it was improved in all categories, and according to the American Academy of Orthopedic Surgeons Lower Limb Module Patient Health Outcome score, it was increased from 64 to 92. In addition, according to the objective grading system of Tucker and colleagues, excellent results were achieved in 12 (86%) patients and good result in two (14%) patients.
Conclusion
Correction of genu varus deformity secondary to tibia vara through using TSF by proximal tibial osteotomy is an effective method to correct the deformity and restoring knee stability with early weight-bearing and high satisfactory results.

Keywords:
Taylor spatial frame, tibia, varus deformity

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Introduction

Acute correction of deformity of the tibia often can be done with the use of internal fixation. This method has limitations, and the presence of infection with poor skin, multiplanar deformity, shortening, and lack of postoperative ability for correction shows the disadvantages of this method [1,2].

The problem of a limb deformity will alter the proper transmission of forces across adjacent joints. In the knee, even moderate malalignment facilitates the progression of osteoarthritis [3–5]. Koshino *et al.* [6] reported in their study that osteotomy of the tibia can correct malalignment and may lead to cartilage regeneration. In another study, achieving overcorrection with a high tibial osteotomy is very important for attaining long-term improvement in the treatment of unicompartmental arthrosis [2].

Although the closing wedge osteotomy can be used to correct malalignment, the technique has many complications. These include shortening results from removal of bone segments and the inability to adjust alignment without additional surgery. The procedure decreases tibial bone stock in the metaphysis, which can lead to ligament laxity [7–10]. More recently, the medial opening wedge osteotomy was another option to correct varus deformity and to avoid the complications associated with the closing wedge technique. This technique also requires acute correction and no ability to correct any residual deformity [11].

In the study of Robert *et al.* [12], optimal leg alignment is the main aim of tibial osteotomy. The Taylor spatial frame (TSF) and the Ilizarov external fixator methods enable gradual realignment of angulation and translation in the coronal, sagittal, and axial planes, therefore, the term six-axis correction.

The Ilizarov external fixator has several distinct advantages over other surgical techniques in the treatment of bone loss, nonunions, and deformities of the lower limb [13]. It uses hinges and translation mechanisms that are specifically selected for each clinical problem, and it requires sequential correction for multiaxial deformities. On the contrary, the use of hinges together with independent lengthening, translation, and rotation mechanisms sequentially or simultaneously is very time consuming [14].

Many authors reported also that the TSF is an alternative circular external fixator with rings, bolts, nuts, and attachments similar to those of the Illizarov but uses a hexapod-like arrangement of six telescopic struts and special universal joints for attaching the two rings together. It has been used commonly in children and young adults [15–17].

The study by Mohamed and Gamal [18] reported that correction of residual deformity is difficult through using the Illizarov system, as in order to correct residual translational and/or rotational deformities, it is necessary to make further adjustments after the oblique plane angular deformity has been corrected. This leads to an undesirable sequential correction of the deformity.

They emphasized also that the TSF uses the slow correction principles of the Ilizarov system but adds a six-axis deformity analysis incorporated within a computer program. In addition, the TSF provides a way for gradual correction of varus deformity with percutaneous osteotomy independent of magnitude, complexity, or location. Without the need for complex frame modifications, the TSF can be used to correct deformity in six-axis directions. The associated web-based software has simplified planning and performance of deformity correction for patients and physicians.

Taylor [19] considers also that the multiple angles and translations of a particular deformity can be managed simultaneously using the TSF, which relies on the use of a computer software.

The deformity parameters were entered into the TSF web-based software computer program and generated an adjustment schedule. The program requires input of deformity, frame, and mounting parameters, and a structure at risk, which determines the rate of correction [20]. Svetlana *et al.* [21] reported that the computer program has two models. The chronic mode requires in putting deformity parameters and rebuilding a frame before surgery. The total residual mode is a newer program, which allows application of the rings first followed by easy connection of struts and the use of the program following surgery.

Robert *et al.* [12] reported in their study that using TSF for correction of tibia vara is particularly useful when there is a history of infection, leg length discrepancy (LLD), and a poor soft tissue envelope. Many authors confirm also that the use of the TSF is associated with few complications and is very helpful in correction of complex tibial deformities in adults and children [22–24].

However, published studies on the TSF have included small numbers of patients and have combined various bones and etiologies. In addition, the methods of correcting deformity and alignment have been variable [17,25,26].

Patients and methods

This prospective study was done on 14 patients, with eight males and six females, attending Saudi German

Hospital in Saudi Arabia between October 2011 and January 2014, and the mean age was 18 years (range, 12–28 years) at the time of surgery. This study was approved by ethical committee of Department of Orthopaedic Surgery, Suez Canal University, Ismailia, Egypt. All patients signed an informative consent form. Patients included in the study have nontraumatic genu varus deformity secondary to tibia vara without degenerative changes in the knee. Patients included those of congenital, developmental, and neurologic etiologies. The criteria for deformity were malalignment greater than 10° in the coronal plane, with or without oblique plane, and rotational deformity. We excluded patients who underwent deformity correction with a different method than the TSF and posttraumatic deformity.

In the current study, the TSF (Smith and Nephew, Memphis, Tennessee) design with software computer analysis was used for correction of deformity of patients included in the study, and the indications for using the TSF were correction of genu varus deformity secondary to tibia vara by proximal tibial osteotomy with minimal skin incisions, and the treatment goal was correction of the mechanical axis deviation (MAD) to the neutral of 0 mm (center). Clinical preoperative evaluation, including history and physical examination, was done. Gait was observed according to Paley *et al.* [27], and measurements were calculated both clinically and radiologically.

According to Christopher [28], preoperative radiographic studies were done and consist of a standing full-length film of both lower extremities from the pelvis to the foot and anteroposterior (AP) and lateral views of the entire tibia. It is also important that the image captures a true AP view of the knee, and to accomplish this, the patient stands so that each patella is pointing straight anterior regardless of the position of the foot. In addition, the MAD and joint orientation angles, lateral distal femoral angle, medial proximal tibial angle (MPTA) correction, and posterior proximal tibial angle (PPTA) were measured.

Through a 1-cm incision, the tibial osteotomy was performed using a multiple drill-hole technique, and it was completed with an osteotome. The location of the osteotomy was at or near the apex of the deformity. Osteotomies were complete but left none displace. Fibula osteotomies were performed in all cases, and the location of the fibular osteotomy was the middle of the bone. The smallest ring that allows one to two fingerbreadths of circumferential clearance was used, and the distal ring was usually one size smaller than the proximal ring because of the cone shape of the leg. In obese patients, 2/3 of the ring was used proximally that opens posteriorly to allow greater range of knee flexion. TSFs were fixed to the bone with tensioned wires and hydroxyapatite-coated half-pins. The first wire placed proximally is an olive wire directed from lateral to medial above the osteotomy site and placed orthogonal to the bone and the olive seated on the near cortex of the tibia, which was confirmed by fluoroscopy. The proximal ring was held so the master tab is directed anterior and centered on the tibia and perpendicular to the sagittal plane of the tibia. The distal ring is generally fixed with half-pins to avoid transfixing the soft tissue compartments of the leg. All corrections were made gradually after 1 week. The total residual software program was used in all patients.

The ‘print-out schedule’ was followed carefully for turning and adjusting the controls on the struts and checked every visit for follow-up. This will result in full correction of the deformity when the struts have been restored to their neutral lengths. The patient is instructed to perform gradual adjustments of the six struts of the TSF once per day. At the end of the schedule, usually between 2 and 5 weeks, limb alignment was determined with physical examination and radiographs. Through radiograph, the leg lengths, MAD, and joint orientation angles were measured using the same methods used before surgery. The criteria used in the current study for frame removal were time of at least 2 months, ability to walk with assistance, and the presence of bridging callus on three of four cortices using the AP and lateral radiographs.

The mean time for the frame to be used dynamically was 20 days (range, 10–35 days) to turn struts on the TSF, and the rate of struts lengthening is 1 cm per day. In addition, the mean time for wearing the frame until removal was 3 months (range, 2–5 months).

Postoperative weight bearing and to stop using the crutches were allowed as tolerated. Most of the patients were walking without the need for two crutches at 5–7 weeks after surgery. Physiotherapy program for both the knee and ankle was encouraged three times per week. In addition, postoperative daily pin care and cleaning with hydrogen peroxide and then coverage of the pin sites with dry sterile gauze wrap were done and explained for the patient to do at home daily after discharge and to come for follow-up in the clinic every 1 week for the first month and then every 2 weeks. Radiographs were taken at appropriate intervals until alignment was corrected and the adjustments ended. Then the frame was removed according to the criteria described before.

For all patients, deformity parameters, including degree of varus, apex anterior and posterior deformity, and internal rotation deformity were recorded, and this illustrated the magnitude and nature of the preoperative deformity (Table 1). According to Paley [3], rotational deformity was measured clinically by observing gait, foot progression angle, and thigh-foot axis in the prone position. In addition, assessment of alignment of the proximal tibia was done through measuring MAD, MPTA, and PPTA preoperatively and postoperatively after 1 year to confirm improvements. The outcome of MAD was evaluated according to the preoperative treatment goal of neutral alignment. We recorded also time of wearing of the frame, knee, and ankle range of motion and complications.

Follow-up evaluation after 1 year was done by using SF-36 Health Survey scores. The SF-36 uses eight health scales to measure three aspects of health functional status, well-being, and 'overall evaluation of health.' The responses to the questions on each scale are summed to provide eight scores between 0 and 100 (physical function, role physical, bodily pain, general health, vitality, social functioning, role emotional, and mental health) [29]. Second evaluation system was the American Academy of Orthopedic Surgeons (AAOS) Lower Limb Module (LLM) Patient Health Outcome score [30]. Finally, an objective grading system was developed using a modification of that devised by Tucker *et al.* [31], which was used also for evaluation of the results. The results were rated as excellent if the target was completely achieved and if the following criteria were found: full knee extension, knee flexion greater than 125°, dorsal flexion of the ankle above neutral with plantar flexion of more than 30°, LLD of less than 1 cm, angulation of less than 5°, rotation of less than 15°, and no infection. If the target was achieved with one criterion missing, the result was rated as good. Incomplete achievement of the target with one criterion missing was rated as fair, and all others were rated as poor.

Statistical analysis

Analysis of data was performed by using statistical program of the social sciences (version 16; SPSS Inc., Chicago, Illinois, USA). For analysis and description of these data, mean and SD, and comparison of quantitative parameters before and after the surgical procedure, *t* test was used. A 95% confidence interval had been calculated, and a *P* value less than 0.05 had been considered significant.

Table 1 Preoperative deformity parameters corrected by Taylor spatial frame

Deformity	Degree
Varus	22 (11–45)
Apex anterior	14 (8–40)
Apex posterior	12 (4–16)
Internal rotation	18 (6–28)

Results

Patients with a varus deformity had a preoperative MAD of 42 mm (range, 25–62 mm), medial to the midline, which was improved to an average of 4 mm (range, 2–8 mm), medial to midline (Table 2). The correction of MPTA was accurate, and the MPTA was improved from preoperative of 65° (range, 45–74°) to postoperative 88° (range, 86–92°) (Table 3). The PPTA was corrected from preoperative of 72° (range, 66–74°) to postoperative 82° (range, 79–84°). Sagittal deformity (apex anterior and apex posterior) and axial plane deformity of internal rotation were corrected to a satisfactory degree in all patients. Finally, preoperative limb-length inequality was corrected in all patients, and the average was 0.5 cm (0–2 cm).

There were no significant differences between preoperative and postoperative range of movements of both ankle and knee joints. The average postoperative range of motion of the knee joint was 0–130° and for the ankle joint was a 0–40°.

Follow-up evaluation after 1 year postoperatively was done by using SF-36 Health Survey scores. The SF-36 uses eight health scales, and it was improved in all categories (Table 4). Another evaluation system, the AAOS LLM Patient Health Outcome score, was done after 1 year postoperatively, and it was increased from 64 to 92. In addition, an objective grading system according to Tucker *et al.* [31] was used for evaluation of the results, and excellent results were achieved in 12 (86%) patients and good results in two (14%) patients.

Table 2 Preoperative and postoperative correction of mechanical axis deviation

	Degree of MAD deformity
Preoperative MAD	42 (25–62)
Postoperative MAD	4 (2–8)

MAD, mechanical axis deviation.

Table 3 Preoperative and postoperative correction of medial proximal tibial angle

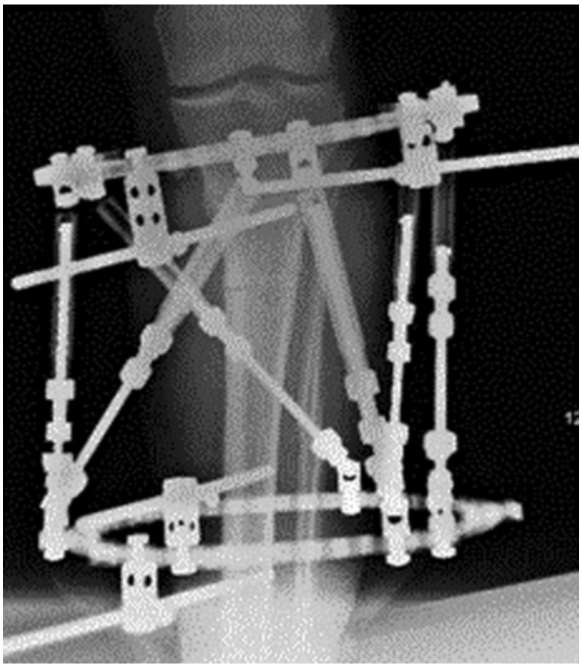
	Degree of MPTA deformity
Preoperative MPTA	65 (45–74)
Postoperative MPTA	88 (86–92)

MPTA less than 85=varus. MPTA, medial proximal tibial angle.

Table 4 SF-36 healthy survey scores measured preoperatively and 1 year postoperatively

	Preoperative	Postoperative
Physical functioning	38 (10–98)	90 (60–100)
Pain	52 (22–90)	92 (62–100)
Role physical	52 (42–94)	86 (70–100)
General health	80 (60–100)	94 (82–100)
Vitality	48 (32–90)	78 (66–100)
Social functioning	54 (40–100)	90 (82–100)
Role emotional	60 (44–88)	92 (82–100)
Mental health	54 (44–100)	88 (74–100)

Figure 1



Postoperative radiograph AP view after applying TSF for proximal tibial osteotomy. AP, anteroposterior; TSF, Taylor spatial frame.

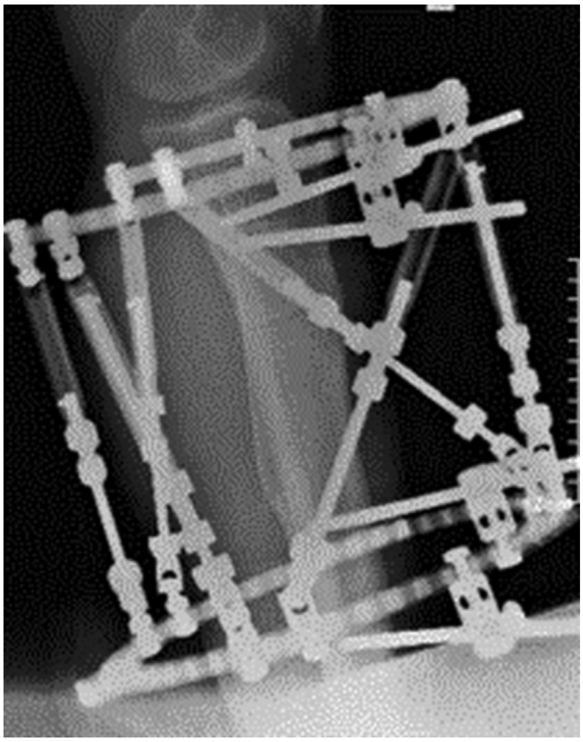
Pin-tract infection was found in 42% of patients and treated by frequent dressing and oral antibiotics and no patients had deep infection. Frame loosening was found in one (7%) patient and was treated by addition of wires.

Figures 1 and 2 show AP and lateral radiographs of the left leg of a 25-year-old male patient who had varus deformity, and proximal tibial osteotomy was done and fixed by TSF.

Figures 3 and 4 are of the same patient after removal of the TSF, with correction of deformity and good callus formation.

Figures 5 and 6 show AP and lateral radiographs of the right leg of an 18-year-old male patient, and proximal tibial osteotomy was done and fixed by TSF for gradual correction of the deformity.

Figure 2



Postoperative radiograph lateral view.

Figure 3

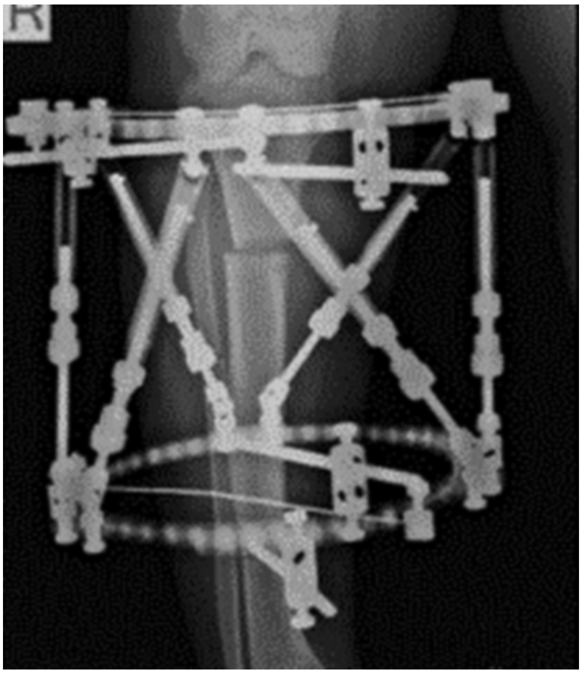
Follow-up radiograph AP view after TSF removal and good callus formation at osteotomy site. AP, anteroposterior; TSF, Taylor spatial frame.

Figures 7 and 8 are of the same patient after removal of the TSF with correction of deformity and good callus formation.

Figure 4

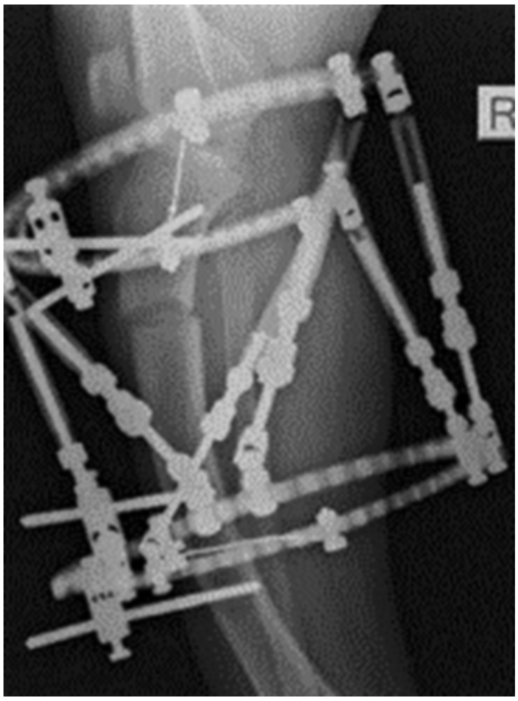
Follow-up radiograph lateral view.

Figure 5



Postoperative radiograph AP view with TSF applied for proximal tibial osteotomy. AP, anteroposterior; TSF, Taylor spatial frame.

Figure 6



Postoperative lateral view.

Figure 7

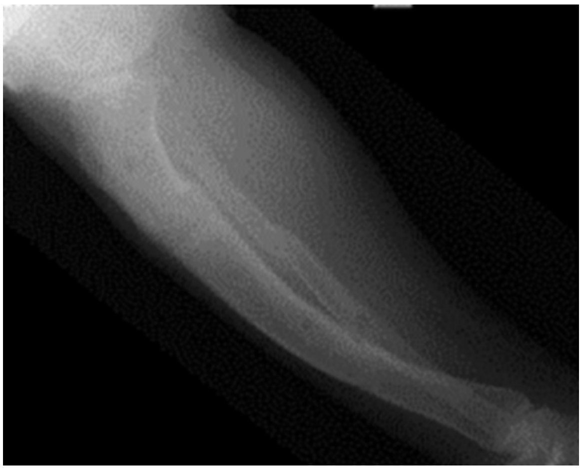
Follow-up radiograph AP view after TSF removal and good callus formation at osteotomy site. AP, anteroposterior; TSF, Taylor spatial frame.

Discussion

Many techniques were used for correction of varus deformity like hemiepiphysiodesis, proximal tibial osteotomy, elevation of the medial tibial plateau, and gradual correction with a uniplanar dynamic fixator [32,33]. Some authors confirmed that correction of tibial deformity by using the Ilizarov method without using the TSF also has been used with success [10,34,35].

The TSF is an evolution of the classic Ilizarov frame. It uses a computer program that helps to calculate a schedule for gradual strut and frame adjustment to correct multiple deformities at the same time around a virtual hinge. There are few

Figure 8



Follow-up radiograph lateral view.

reports in the literature regarding deformity correction using TSF [21].

Several authors reported complications with 'acute' corrective osteotomy in the management of tibia vara, such as residual deformity, peroneal nerve palsy, compartment syndrome, delayed union, limb-length inequality, and failure of fixation [32,36–38]. According to Feldman *et al.* [39], gradual deformity correction is a more accurate treatment method of tibia vara than acute correction.

In another series, Feldman *et al.* [40] were able to correct multiaxial deformities through using the TSF with relative ease, especially as they made use of a computer software program that made planning and correction of the deformity relatively straightforward. In addition, they recommended using the 'total residual program' that allows deformity correction without first making the rings parallel. They performed residual deformity correction in seven patients and achieved successful correction in all. There is also experience of other authors who have used computer-assisted, six-axes correction by a TSF [41,42].

Many authors reported that TSF technique is very useful and efficient in cases of compromised skin infection, shortening, and in the correction of multiplanar deformity [12,40].

Feldman *et al.* [17] presented the first report of using a TSF in the treatment of tibia vara with success in 13 patients who had adolescent tibia vara. On the basis of mechanical axis correction, these patients were corrected to within 3° of normal alignment. In another study of Mohamed and Gamal [18], they emphasized that the Ilizarov method using the TSF offers a wide approach to correct all aspects of a tibial deformity, and in their work, they reply many questions about the MAD correction, the correction of both the MPTA and lateral distal tibial angle (LDTA) at the proximal and distal tibia, and the correction of the tibial diaphyseal deformity.

In addition, similar outcomes were achieved in different studies of TSF technique, and many studies were done for evaluating TSF in the correction of tibia vara through proximal tibial osteotomy [12,20,22,23,25,26].

In the study of Robert *et al.* [12], they retrospectively reviewed 84 patients treated with percutaneous osteotomy of the proximal tibia and did gradual correction with the TSF. The minimum follow-up after frame removal was 10 months (average, 48 months; range, 10–98 months). The total time wearing the frame averaged 130 days. The MPTA was improved from 80 to 89° in patients with a varus deformity. There was associated LLD in some patients (1 cm average; range, 0–6.6 cm). The average final LLD was 0.3 cm (range, 0–5 cm). This explains the long distraction time and time wearing the frame for some patients. Patients who underwent deformity correction without lengthening typically wore the frame for 3 months.

In another study of Feldman *et al.* [40] examining MAD correction by gradual correction at a proximal osteotomy, the average MAD was 3.1 mm. They examined the accuracy of joint orientation angle in correction of varus deformity by measuring the MPTA and they reported correction to within 3° of normal in 94% of patients, and for frequency of correction of the PPTA, they reported correction within 5° of normal in 94% of the patients. For internal rotation deformity, all patients had accurate correction of rotation at follow-up. Finally, correction of preoperative limb-length inequality was achieved in all patients. Their results are comparable to the results of the study done by Robert *et al.* [12]. In addition, Svetlana *et al.* [21] reported that the average medial MAD was improved from 28 mm (range, 9–100 mm) to 4 mm medial (range, 0–9 mm). Simultaneous lengthening of 2.1 cm (range, 0.4–6 cm) was done in 33% of patients. Average time for wearing the frame was 131 days (range, 77–355 days).

In the study of Fragomen *et al.* [24], 94% of patients had LLD less than 15 mm and 5° angular deformities. In the study of Siapkara *et al.* [22], three patients had tibia vara that was corrected by proximal tibial osteotomy, and the outcome for coronal plane deformity and LLD was corrected to normal in all patients.

In the current study, patients had a preoperative MAD of 42 mm (range, 25–62 mm) medial to the midline, which was improved postoperatively to an average of 4 mm (range, 2–8 mm), medial to midline. The MPTA was improved from preoperative of 65° (range, 45–74°) to postoperative 88° (range, 86–92°) and the PPTA was corrected from preoperative of 72° (range, 66–74°) to postoperative 82° (range, 79–84°). Sagittal deformity (apex anterior and apex posterior) and axial plane deformity of internal rotation were corrected to a satisfactory degree in all patients. Finally, preoperative limb-length inequality was corrected in all patients, and the average was 0.5 cm (0–2 cm). Our results are comparable to the results of the studies done by others [12,21].Many evaluation systems were used, and in the study of Robert *et al.* [12], which examined SF-36 and LLM scores in correction of proximal tibial deformity by TSF, the authors reported outcomes of the SF-36 Health Survey scores, which improved postoperative in all categories, and LLM scores were also improved from preoperative 76 (range, 5–100) to postoperative 86 (range, 51–100). In the study of Svetlana *et al.* [21], SF-36 was improved in four categories, and AAOS LLM scores increased from 76 to 89.

In the series of Mohamed and Gamal [18], they used the TSF for correction of tibia vara in four patients, and according to the objective grading system that was devised by Tucker *et al.* [31], there were excellent results for all patients without major complication.

In the current study, follow-up evaluation after 1 year postoperative was done by using SF-36 Health Survey scores, and it was improved in all categories, and LLM Patient Health Outcome score was increased from 64 to 92. These results are comparable to the results of other studies [12,21]. In addition, according to the objective grading system of Tucker *et al.* [31], excellent results were achieved in 12 (86%) patients and good results in two (14%) patients.

The complications reported in the study of Robert *et al.* [12] showed that most of the patients had superficial pin infections, which successfully responded to oral antibiotics. There were no deep infections. Two (1.9%) patients developed cellulitis, which required a 10-day course of intravenous antibiotics. In addition, one (0.9%) patient had delayed union and lost some of the correction after frame removal, and two (1.9%) patients had peroneal nerve neurapraxia that improved by slowing the correction. These results were comparable to those experienced by others [15,37].

In the study of Mohamed and Gamal [18], the reported complications were pin-tract inflammation, which occurred in all patients, and 54% required antibiotic. Frame loosening was found in 13% of patients and was treated by debridement, addition, or replacement of wires. Fracture of the regenerated bone happened in 9% of patients owing to the early removal of the frame, and deep venous thrombosis was reported in 4% of patients. In addition, adjustment was required in 27% of patients to maintain stability and allow repeat corticotomy. In the study of Svetlana *et al.* [21], cellulitis was reported in 2.4% of patients and was successfully treated with intravenous antibiotics, and neuropraxia in 7% of patients, which was resolved after nerve release surgeries, and there were no nonunions.

In the current study, pin-tract infection was found in 42% of patients and treated by frequent dressing and oral antibiotics, and no patients had deep infection. Frame loosening was found in one (7%) patient and was treated by addition of wires. No deep vein thrombosis (DVT) or neurological injury was reported, and no patients had delayed union or nonunion.

We can conclude that one of the advantages, in addition to the aforementioned ones, is that using the TSF will allow all patients to follow their frame adjustment schedules easily. On the contrary, one of the disadvantages of using the TSF is the high cost of the TSF, which limits the frequency of its use. Finally, even with high cost of the TSF and the need for teaching the patient how to follow the frame during the follow-up, the excellent results and fewer complications are very encouraging for using the TSF for correction of genu varus deformity.

Conclusion

Correction of genu varus deformity secondary to tibia vara through using TSF by proximal tibial osteotomy is an effective method to correct the deformity and restoring knee stability with early weight-bearing and high satisfactory results. In addition, the TSF uses small incisions and minimal soft tissue stripping with minimal complications.

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Conflicts of interest

There are no conflicts of interest.

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