Functional outcome of Taylor Spatial Frame for treatment of proximal tibial nonunion with medial compartment arthritis

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Received 29 March 2011
Accepted 5 April 2011

Egyptian Orthopedic Journal 2012, 47:380–385

Background
The management of proximal tibial nonunion has proven to be more difficult than that of diaphyseal tibial nonunion. The Taylor Spatial Frame (TSF) is an evolution of the original Ilizarov circular frame as it uses a virtual hinge and a computer program to simultaneously correct all aspects of deformities. The aim of this study was to assess the functional and radiographic outcome of the TSF with valgus overcorrection in patients with proximal tibial nonunion and medial compartment arthritis.

Materials and methods
Nine patients with proximal tibial atrophic nonunion were identified from our prospective functional TSF database. They included five men and four women with an average age of 64 years. The mean follow-up was 4 years. Patient charts were retrospectively reviewed for demographic data, mechanism of injury, comorbidities, surgical data, complications, and functional outcome. Radiographic films from studies which included radiographs for both lower limbs were reviewed for alignment and arthritic changes. Patients were treated using the TSF and by bone grafting with gradual valgus overcorrection.

Results
Bony union was the final result in all nine patients. Angular deformities included genu varum with an average angle of 25°, which was gradually corrected to genu valgus with an average angle of 6° in all patients. The SF-36 health status survey improved in all eight categories. Marked improvement was noted in two categories: physical function improved from a mean of 26.66 to 65 (t-value of 36.36, $P<0.001$) and general health status improved from a mean of 26.66 to 75 (t-value of 17.33, $P<0.001$) in the paired t-test.

Conclusion
Using the TSF to correct malalignment in both frontal and sagittal planes and overcorrecting it into a valgus position, in addition to offering compression at the grafted nonunion site, led to healing of the nonunion and significant improvement in the functional outcome in this group of patients, as demonstrated by the SF-36 health status survey and the excellent radiographic results.

Keywords:
nonunion, Taylor Spatial Frame, tibia

Egypt Orthop J 47:380–385

1110-1148

There have been numerous studies on the treatment of the diaphyseal tibial nonunion, but little has been documented on the proximal tibial nonunion. The management of the proximal tibial nonunion has proven to be more difficult than that of the diaphyseal tibial nonunion. In addition, the diaphyseal tibial nonunion may become complicated by stiffness of the knee joint, which will result in an increase in the forces across the nonunion site [1].

Traditionally, a tibial nonunion can be classified into hypertrophic and atrophic nonunions [2]. In hypertrophic nonunion, internal fixation and autografting usually results in bone union in most simple cases [3,4]. In atrophic nonunion, there is usually a gap between bone fragments, which could be treated with an external fixator using the principle of bone transportation [5,6].

The Taylor Spatial Frame (TSF) is an evolution of the original Ilizarov circular frame and uses the same concept of distraction osteogenesis as the classic frame. However, it uses a virtual hinge and a computer program to simultaneously correct all aspects of deformities including angulation, translation, and rotation [7–9].

Deformity overcorrection in patients with unicompartmental osteoarthritis using the TSF is well known among the deformity surgeons. Seah *et al.* [10] reported on 15 patients with unicompartmental arthritis or valgus deformity in whom they had performed intentional overcorrection and reported adequate correction and relief from symptoms in them.

The aim of this study was to assess the functional and radiographic outcome of the TSF with valgus

overcorrection in patients with proximal tibial nonunion and medial compartment arthritis. Nonetheless, our approach was applied to obtain union in an overcorrected valgus position in order to gain the positive effect of a high tibial osteotomy, equivalent to its effect on the arthritic medial compartment of the knee.

Materials and methods

After obtaining Institutional Review Board approval, all patients who were admitted or referred to our facility with post-traumatic neglected proximal tibial nonunion with deformity and who gave consent to external fixation treatment were included in the study, as this was the author's choice of treatment for such a condition.

From February 2002 to February 2008, nine patients with proximal tibial nonunion were identified from our prospective functional TSF database. A retrospective review of these nine patients was carried out. All patients were followed up until after the healing of the nonunion. In this study, all patients had an atrophic tibial nonunion that resulted from a neglected proximal tibial fracture and had a history of medial compartment osteoarthritis in the ipsilateral knee. No patients were lost to follow-up. Patient charts were retrospectively reviewed for demographic data, mechanism of injury, comorbidities, surgical data, complications, and functional outcome. Radiographic studies that included radiographs of all lower limbs and computed tomography scans of the affected limb in coronal, sagittal, axial, and three-dimensional reconstruction views were reviewed to assess the type of nonunion, location, deformities including angulations and shortening, and final postoperative alignment.

The study included five men and four women with an average age of 64 years (range, 61–69 years). The mean follow-up period was 4 years (range, 2–7 years). The cause of the primary injury was road traffic accident in six patients and injury after falling from a height in three patients. None of the patients underwent surgery immediately after the primary injury, and they were all treated primarily with closed reduction and above knee cast in other hospitals.

After obtaining a detailed history, only three of the patients had diabetes mellitus and were heavy smokers, four had osteoporosis, and all had medial compartment osteoarthritis of the knee, which was classified according to the Ahlbach arthritis classification [11]. On questioning, all of them had prefracture medial joint line pain, which affected the activities of daily living.

All nonunion cases were the result of closed fractures of the proximal tibia (metaphyseal) and were classified according to the Orthopedic Trauma Association classification. All were atrophic nonunions with no bone defect. Leg length discrepancy (LLD), varus deformity, and procurvatum were noted in all patients and none of them had infected nonunion.

Surgical technique

Prophylactic cephalosporin antibiotics were administered preoperatively to all patients. All the patients with nonunion were treated by application of the TSF (Smith and Nephew, Inc., Memphis, Tennessee, USA) using the ring first method, as described in detail by Binski and colleagues [12,13]. After frame application, the TSF struts were disconnected followed by the application of iliac crest bone grafts and 5 ml of demineralized bone matrix to expand graft volume after Fish scaling and adequate preparation of the nonunion site without an attempt at acute correction of the deformity. All patients underwent gradual deformity overcorrection into a valgus alignment of 6° using the extremity mechanical axis and long standing radiographs from the hip to the ankle in addition to full correction of the procurvatum, which was gradually preformed using the TSF web-based online program with the aim of obtaining a correction of 1°/day followed by compression at the nonunion site. If the desired realignment was not observed on the first postadjustment radiographs, fine tuning in the total residual mode was performed to obtain perfect alignment, according to the adjustment schedule, which was generated by the computer program.

Patient follow-up included weekly visits until the desired alignment was achieved, visits every 6 weeks until union was achieved, and yearly thereafter. During outpatient clinic visits, patient complaints were documented, physical examination for knee range of motion was conducted, and long radiographic films (standing anterior posterior view, hip to ankle), in addition to lateral radiographs, were reviewed to assess the mechanical axis of the affected tibia; after achieving the desired correction, we reviewed the anterior posterior and lateral tibial views for radiographic assessment of union. Wire and pin tract infection was classified according to the Dahl classification as follows: grade 1, inflamed – requiring daily pin care only; grade 2, serous discharge – requiring oral antibiotics; grade 3, purulent discharge – requiring oral antibiotics; grade 4, osteolysis – requiring pin removal; and grade 5, ring sequestrum – requiring debridement [14].

Outcome was further determined preoperatively at the final follow-up using the short form 36 (SF-36) health status survey, which is a generic measure of functional status and well-being [15]. The data (parameters of functional outcome) were collected before and after management. The data were presented as mean and SD. The mean difference between the means before and after management was also calculated. The paired *t*-test was applied to compare data before and after management. *P*-value less than 0.05 was considered significant (Fig. 1).

Results

All nine patients were classified according to the Orthopedic Trauma Association classification: five patients were classified as 41-A2.3 and the other four were classified as 41-A2.2. On radiographic examination, all

Figure 1

A 65-year-old man with neglected proximal tibia nonunion. Preoperative radiographs: (a1) anteroposterior and lateral radiographs at presentation with nonunion, shortening, and angulation, (a2) anteroposterior stress radiographs, (a3) standing long film of lower limbs showing nonunion and obvious deformity on the right side. Radiographs immediately after application of the Taylor Spatial Frame: (b) anteroposterior and lateral radiographs after frame application. Radiographs after deformity correction: (c) anteroposterior and lateral radiographs of the tibia after correction of deformity, (c) standing long film of lower limbs after overcorrection of deformity. Radiographs of the patient after union of the fracture site with and without the frame: (d1) anteroposterior and lateral radiographs with the frame showing healing of the nonunion, (d2) anteroposterior and lateral radiographs of the tibia after frame removal showing complete healing at the nonunion site. Radiographs at final follow-up of the patient: (e) standing long film of the lower extremities showing union of the nonunion site in the desired overcorrected valgus position.

patients had significant medial compartment osteoarthritis of the ipsilateral knee with significant knee pain before the fracture. According to the Ahlbach classification of arthritis [11], three patients were classified as grade 3 and six patients as grade 4 (Table 1).

The time in the frame averaged 190 days (range, 150–240 days), whereas the duration of distraction and/or compression averaged 29 days (range, 24–43 days). After the removal of the frame, all patients were followed up in the outpatient clinic for an average of 48 months (range, 24–84 months). Range of motion of both the knee and ankle joints was maintained without any loss as all patients were engaged in a physiotherapy program that stresses on muscle strengthening and range of motion of both the knee and ankle joints.

Bony union was the final result in all nine patients (100%). The average LLD was 15 mm (range, 8–33 mm) with the highest LLD of 33 mm observed in a patient

with a previously malunited ipsilateral tibial shaft fracture, which had healed with significant shortening. No attempt was made to lengthen the bone of the patient as she was diabetic and a heavy smoker and agreed to use a shoe raise. Angular deformities included genu varum with an average angle of 25° (range, 3–32°), which was gradually corrected to genu valgus in all patients with an average angle of 6° (range, 5–8°). The preoperative procurvatum angle (angulation apex anterior) averaged at 15° (range, 8–40°), which was gradually fully corrected in all patients.

With regard to the postoperative complications, three of nine patients (33.3%) developed grade 2 pin tract infection during clinical follow-up, which was treated successfully with oral antibiotics and daily pin care. No other postoperative complications were documented, such as neurovascular injury, refracture, ring sequestrum, and limitation of the range of motion of the knee and ankle.

The results of the SF-36 health status survey improved in all eight categories, including general health status, physical function, emotional well-being, pain status, and physical health role. Marked improvement was noted in two categories (Table 2): physical function improved from a mean of 26.66 to 65 (t-value 36.36, $P<0.001$) and general health status improved from a mean of 26.66 to 75 (t-value 17.33, $P<0.001$) in the paired t-test.

Discussion

Tibial nonunion is considered the most frequently observed post-traumatic long-bone nonunion in the body. Its importance lies in its vital role in gait and in the functioning of knee and ankle joints; it is also a main weight-bearing bone in the body [16]. Several factors have been presented as etiology of nonunion. Bong *et al.* [1] reported an easy-to-remember acronym for the etiologies of nonunion, which is MAGI: motion at the fracture site, avascularity of fracture fragments, gapping of the fracture site, and infection. All these factors should be taken into consideration before starting operative treatment of a nonunion.

There is a lot of controversy in the literature with regard to the management of tibial nonunion. Bone grafting or noninvasive stimulation [17,18] was used for selective patients. Other authors used plating methods [19–23] and intramedullary nailing [24–28], which were also selectively effective in acute correction but not applicable for tibial nonunion with large deformities, which needs gradual correction [29].

In contrast, on the basis of the principle of distraction osteogenesis [30,31], the TSF can gradually correct these large deformities and LLDs, and bone transport can also be considered in the treatment segmental defects [16,31–37].

In these proximal tibial nonunions, the deforming force of the patellar tendon and the quadriceps muscle resulted in significant deformity in the form of procarvatum, decrease in contact area, and motion at the fracture site. These forces need to be neutralized and the fracture needs to be reduced adequately to improve the contact area, which will eventually lead to healing. Arthritis *per se* does lead to an element of stiffness, which in turn makes

Table 1 Patient demographics

Cause of injury	Follow-up in years	Shortening (mm)	Procarvatum (deg.)	Varus (deg.)	Ahlbach arthritis classification	OTA classification	Comorbidities	Sex	Age (years)	Case number
RTA	4	11	12	19	4	41-A2.3	Diabetic/ smoker	Male	61	1
RTA	2	8	8	3	4	41-A2.2	Osteoporotic	Male	65	2
Falling from height	3	10	15	28	3	41-A2.3	Diabetic/ smoker	Male	62	3
RTA	7	33	40	27	4	41-A2.2	Diabetic/ smoker	Female	69	4
RTA	5	15	17	32	3	41-A2.3		Male	62	5
Falling from height	6	20	10	25	4	41-A2.2	Osteoporotic	Female	64	6
RTA	5	17	10	31	4	41-A2.3	Osteoporotic	Female	65	7
Falling from height	2	8	12	28	3	41-A2.3		Male	61	8
RTA	2	11	9	30	4	41-A2.2	Osteoporotic	Female	67	9

deg., degrees; OTA, Orthopedic Trauma Association; RTA, road traffic accident.

Table 2 SF-36 functional outcome health status survey results for the study cohort

Categories	Before (mean ± SD)	After (mean ± SD)	Mean difference	t-score	P-value
Physical functioning	26.66 ± 6.83	65 ± 4.47	38.3	36.36	$P>0.001$
Role limitation due to physical health	0 ± 0	41.66 ± 12.9	41.66	7.9	$P>0.001$
Role limitation due to emotional problem	11 ± 17.12	100 ± 0	88.88	12.64	$P>0.001$
Energy/fatigue	30 ± 7.74	76.66 ± 9.3	46.66	8.36	$P>0.001$
Emotional well-being	37.33 ± 7.44	85.33 ± 5.4	48	9.11	$P>0.001$
Social functioning	33.33 ± 12.9	88.33 ± 11.25	55	5.69	$P>0.002$
Pain	30 ± 11.16	82.5 ± 11.61	52.5	5.35	$P>0.003$
General health	26.66 ± 2.58	75 ± 4.47	48.33	17.33	$P>0.001$

fracture healing difficult as it increases the leaver arm and does not promote healing across the nonunion or fracture site [38].

Our aim was two-fold: improvement in terms of achieving union and realignment of the extremity into an unloaded valgus alignment to obtain a high tibial osteotomy alignment, hopefully delaying the future need for total knee replacement or avoiding it completely.

Viskontas and colleagues conducted a study showing the effectiveness of high tibial osteotomy using the TSF for medial compartment arthritis of the knee. Several advantages have been presented in this study including slow and gradual correction, which allows soft-tissue adaptation; ability for postoperative adjustments to achieve a desired mechanical alignment; no retention of hardware, which gives a better chance for bone healing; and the performance of osteotomy distal to the tibial tubercle, which allows for an intact patellofemoral mechanism [39]. In this study the nonunion site was distal to the tibial tubercle, and osteotomy could be used to correct the presented varus deformity.

All nine patients had atrophic nonunion, of whom eight had a proximal metaphyseal fracture and one a proximal metaphyseodiaphyseal segmental fracture, with no bone defect or infection in any of them. Three of the nine patients had diabetes mellitus and were heavy smokers, four of them had pre-existing osteoporosis, and all of them had medial compartment osteoarthritis of their knees with severe genu varum with an average angle of 25° (range, 3–32°), LLDs that averaged 15 mm (range, 8–33 mm), and procarvatum that averaged 15° (range, 8–40°). Varus and procurvatum deformities were fully corrected in all our patients.

Conclusion

Using TSF to correct malalignment in both frontal and sagittal planes and overcorrecting it into a valgus position, in addition to offering compression at the grafted nonunion site, led to healing of the nonunion and significant improvement in the functional outcome in this group of patients, as demonstrated by the SF-36 health status survey and the excellent radiographic results.

Acknowledgements

Conflicts of interest

There are no conflicts of interest.

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