High tibial osteotomy with use of the Taylor Spatial Frame external fixator for osteoarthritis of the knee

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Background: High tibial osteotomy (HTO) is used to treat medial compartment osteoarthritis of the knee in active patients with varus alignment. In this study we review the clinical and radiographic outcomes associated with the Taylor Spatial Frame (Smith & Nephew), and its use in HTOs, and we include an illustrative case report. **Methods:** In 7 patients with medial compartment osteoarthritis of the knee and varus alignment, the Taylor Spatial Frame was applied to the tibia in the operating room and a proximal tibial osteotomy was performed. Patients followed a computer-generated turning schedule until the desired correction was achieved. The frame was removed when the osteotomy site had healed. The lower extremity measure (LEM) was used to assess physical function. Clinical outcome measures relating to the Taylor Spatial Frame included latency, time to correction, time in the frame, number of residual corrections and complications. Radiographic outcomes included preoperative Resnick grades of osteoarthritis, pre- and post-correction limb alignment and tibial slope measurements. **Results:** Average (and standard deviation) LEM grade at a mean 41 (14) months follow-up after correction was 94% (5%). Average latency was 8 days, time to correction was 15 days, time in the frame was 23 weeks and number of residual corrections was 1.3. Complications were similar to those for external fixators. Radiographic correction goals were met in all patients. **Conclusion:** The Taylor Spatial Frame is a valuable asset when using HTO to treat medial compartment osteoarthritis of the knee.

Contexte : On utilise l'ostéotomie tibiale haute (OTH) pour traiter une arthrose de la loge interne du genou chez les patients actifs qui ont un alignement en varus. Au cours de cette étude, nous analysons les résultats cliniques et radiographiques associés au cadre spatial de Taylor (Smith et Nephew) et l'utilisation qu'on en fait dans l'OTH, et nous incluons un rapport de cas comme exemple. **Méthodes :** Chez sept patients atteints d'arthrose de la loge interne du genou et qui avaient un alignement en varus, on a mis en place le cadre spatial de Taylor sur le tibia à la salle d'opération et pratiqué une ostéotomie tibiale proximale. Les patients ont suivi un horaire de torsion produit par ordinateur jusqu'à ce que la correction souhaitée soit établie. On a enlevé le cadre une fois le site de l'ostéotomie guéri. On a utilisé la mesure du membre inférieur (MMI) pour évaluer la fonction physique. Les mesures des résultats cliniques reliés au cadre spatial de Taylor comprennent la latence, le temps nécessaire pour réaliser la correction, la durée d'application du cadre, le nombre de corrections résiduelles et les complications. Les résultats radiographiques comprennent les grades préopératoires de Resnick de l'arthrose, l'alignement du membre avant et après la correction et les mesures de la pente tibiale. **Résultats :** La MMI moyenne (et l'écart type) à un suivi moyen de 41 (14) mois après la correction s'est établie à 94 % (5 %). La durée moyenne de la latence s'est établie à huit jours, le temps nécessaire pour réaliser la correction, à 15 jours, la durée de l'application du cadre, à 23 semaines, et le nombre de corrections résiduelles, à 1,3. Les complications étaient semblables à celles que causent les appareils de fixation externe. Les objectifs radiographiques de la correction ont été atteints chez tous les patients. **Conclusion :** Le cadre spatial de Taylor se révèle avantageux lorsqu'on utilise l'OTH pour traiter une arthrose de la loge interne du genou.

Ring external fixators can be used to treat degenerative arthritis of the knee. If the changes are isolated to the medial compartment, high tibial osteotomy (HTO) can provide symptom relief, mechanical realignment and is associated with a survivorship of approximately 80% at 5 years and 60% at 10 years.[1–10] Dynamic external fixators are also used to perform HTOs and success in terms of function and survivorship are similar to open reduction and internal fixation.[11–18]

The Taylor Spatial Frame (Fig. 1)

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(Smith & Nephew) is a new, dynamic ring external fixator. Its hexapod design enables simultaneous angular and translational correction of proximal tibial varus deformities. This is an advantage over the use of traditional Ilizarov fixators (Smith & Nephew) that often require staged correction. Also, the computer software simplifies preoperative planning and correction of post-application deformity. Recently, it has been shown to be effective in treating post-traumatic malunion and nonunion of the tibia[19] and developmental tibial vara in children.[20]

The purpose of our study was to review clinically and radiographically HTOs performed for medial compartment osteoarthritis of the knee using the Taylor Spatial Frame.

Methods

Inclusion criteria for use of the Taylor Spatial Frame in performing an HTO in this study were patients with isolated, symptomatic, medial compartment osteoarthritis of the knee with varus alignment. The patients were all active, did not wish to have an arthroplasty, had good range of motion of the knee and were ligamentously stable. Exclusion criteria included the following: lateral compartment osteoarthritis, symptomatic patellofemoral compartment osteoarthritis, neutral or valgus knee alignment, femoral deformities and inability of the patient to manage an external fixator. Seven patients at a tertiary care centre met these criteria over a 2-year period. They were reviewed clinically and radiographically. The Resnick and Niwayama grading of osteoarthritis[21] was used to assess radiographic degenerative change (Table 1). There were 4 men and 3 women. The average age was 51 years (range 36–72 yr). The primary diagnosis was medial compartment degenerative osteoarthritis of the knee in all patients. All HTOs required angular as well as translational correction to shift the weight-bearing line into the lateral compartment of the knee.

Preoperative planning was done on all patients. Long-leg standing anteroposterior radiographs were obtained, and the mechanical axis of the lower limb was drawn on the radiograph. Then, the corrected mechanical axis was drawn, and the correction required was quantified. The site of the osteotomy was chosen, and the tibia was then divided into proximal and distal segments relative to that site. The software requires that 2 points be chosen, one on the proximal segment of the tibia ("point of origin") and one on the distal segment ("corresponding point"). These 2 points meet once the correction is complete. The positions of these 2 points relative to the reference ring, the deformity parameters on the anteroposterior and lateral radiographs, the ring sizes and frame height were input into the software. The "chronic deformity" mode was used, and the software defined the strut settings that allow the frame to conform to the shape of the deformity. The fixator was then ready for application.

The fixator was applied in the operating room with the patients under general anesthesia. Supplemental rings were added proximal and distal to the Taylor Spatial Frame to increase its stability. The fixator was applied using wires and half pins under fluoroscopic guidance. An osteotomy was performed just distal to the tibial tubercle. The frame position relative to the tibia was confirmed clinically and radiographically in the operating room. The patient was discharged home the same day or the first postoperative day and returned to clinic the following week.

At the first clinic appointment radiography was repeated to ensure the frame's position had not changed. Gradual correction of the deformity through opening and lateral translation of the osteotomy by 10 mm began 7–10 days after frame application to allow bone healing to begin. The patients were given a strut turning

FIG. 1. The Taylor Spatial Frame applied to the left tibia after a high tibial osteotomy. A distal reinforcement ring has been added to the construct for enhanced stability.

Table 1

Clinical and radiographic results for patients who underwent high tibial osteotomies with use of the Taylor Spatial Frame

Patient no.	Resnick score	Preoperative mechanical axis, ° varus	Postoperative mechanical axis, ° valgus	Correction angle, °	LEM score, %
1	1	2	2	4	99
2	1	4	2	6	96
3	2	5	2	7	—
4	2	9	3	12	88
5	2	12	3	15	—
6	3	13	6	19	98
7	3	13	6	19	88

LEM = lower extremity measure.

schedule that was generated by the computer software. The schedule was colour-coded to the frame struts so that the patients could easily turn them the indicated amount on a daily basis. Once the turning schedule was complete, the correction was assessed. If further correction was required, the software could be used to produce another turning schedule for residual correction. This was done until an adequate result was achieved. The frame was then locked in position and was worn by the patient until the osteotomy healed.

The outcome measures involved a score of physical function, clinical parameters specific to the Taylor Spatial Frame and a radiographic analysis. The lower extremity measure (LEM)[22] was used as a clinical outcome measure of physical function. After the frame had been removed, patients were contacted by telephone to complete the LEM questionnaire. The following parameters regarding the external fixator were assessed: latency (time from frame application to start of correction), time to correction, time in the frame, number of residual corrections, and complications. The radiographic assessment of the proximal tibial varus correction consisted of measuring the weight-bearing line through the knee[23] preoperatively and after the correction. The weight-bearing line was measured by drawing a line from the centre of the femoral head to the centre of the ankle and measuring where it intersected the tibial plateau. The tibial plateau was divided into percentages where 0% was the medial edge and 100% was the lateral edge. The goal of the correction was to place the weight-bearing line at 62.5% (±12.5%) of the width of the tibial plateau. The mechanical axis of the knee was also measured before and after correction by drawing a line from the centre of the femoral head to the centre of the knee and another line from the centre of the knee to the centre of the ankle. A correction was considered successful if the final hip–knee–ankle angle was 4° (±2°) valgus. As well, the tibial slope was measured before and after correction with the goal of leaving the slope unchanged.

Results

Five out of 7 patients completed the LEM questionnaire. Two were lost to follow-up. The average (and standard deviation) follow-up was 41 (14) months from the time the frame was removed. The average LEM score was 94% (5%) (Table 1). Only 1 patient indicated that she would not have the procedure repeated.

The average latency was 8 (range 5–13) days, time to correction was 15 (range 7–25) days, time in the frame was 23 (range 16–36) weeks and number of residual corrections was 1.3 (range 0–2).

Several complications were encountered. There was infection at the pin site in 5 patients, and all were treated successfully with no long-term sequelae evident at final follow-up (average 41 [14 mo]). One patient required an irrigation and débridement of the site, and the others were treated with antibiotics orally. Two patients had pin breaks; 1 required hardware revision. One patient who required 36 weeks in the frame was considered to have delayed union. When that patient is removed from the group, the average length of time in the frame was 21 (range 16–25) weeks. There were no cases of nonunion and no fractures through the osteotomy site.

In evaluating the proximal deformities, the average weight-bearing line through the knee before correction was at 14% (range 5%–38%) and post-correction was at 60% (range 50%–78%). The change in correcting the weight-bearing line varied from 21% to 82%. Six out of the 7 patients met the preoperative goal of the weight-bearing line passing through 62.5% (±12.5%) of the tibial plateau. The 1 patient with a weight-bearing line at 78% had very significant medial degenerative changes with a preoperative correction target weight-bearing line at 75%. The average pre-corrected mechanical axis was 8° (range 2°–13°) varus whereas the average post-correction axis measured 3° (range 2°–6°) valgus. The number of degrees of deformity correction ranged from 4° to 19°. All 7 patients were corrected to 4° (±2°) valgus (Table 1). The average tibial slope was 7° (range 2°–11°) before correction and 7° (range 2°–12°) after correction. There was no significant change (paired t test, $p = 0.8$) in slope from the pre-correction to the post-correction measurement.

Illustrative case report

A 60-year-old active man presented with ongoing medial-sided right knee pain despite appropriate non-operative management. He complained of a limp, swelling, decreased walking tolerance and inability to perform recreational activities. There were no mechanical symptoms or rest pain. He had a remote history of a proximal tibial fracture that left him with varus alignment. His medical history was unremarkable.

On physical examination there was varus alignment of the right knee, a mild effusion and localized medial joint-line tenderness. Range of motion was from 0° to 125° flexion. Ligaments appeared normal. Neurovascular, hip and ankle examinations all gave normal findings. The preoperative radiograph is presented in Figure 2.

The patient had osteoarthritis of his right knee isolated to the medial compartment secondary to a healed angulated fracture of his proximal tibia. One option was to correct the angulation through the previous fracture site. However, this would not necessarily have relieved his medial symptoms. An HTO was a better option as it would allow his weight-bearing line to be brought over to the lateral compartment. Also, he was relatively young and very active and was not a good candidate for knee arthroplasty.

The mechanical axis was measured on full-length standing views of his lower extremities and found to be 12° of varus angulation with the weight-bearing line at 0%. Because of the magnitude of this deformity (12° deformity plus 4° overcorrection into valgus), a gradual correction with the Taylor Spatial Frame was undertaken.

The patient was taken to the operating room where the Taylor Spatial Frame was applied and an HTO was performed through an anteromedial approach just distal to the tibial tubercle, with a proximal fibular osteotomy. The patient was discharged home on the first postoperative day. He was given a computer-generated turning schedule which he began on the eighth postoperative day for 7 days. On the fifteenth postoperative day he was seen in the clinic, and the residual deformity was measured at 8° varus. Two further sets of corrections, each occurring over 7 days, were used to reach the post-correction alignment goal. As well as the angular correction, his distal tibial segment was translated laterally 9 mm. His final corrected alignment (Fig. 3) was measured at 3° mechanical valgus and the new weight-bearing line was at 62%. The total correction time was 21 days with a total time in the frame of 20 weeks. Two pin-tract infections were treated with antibiotics taken orally, and he required 4 wire removals in total throughout the course. At follow-up (13 mo postoperatively), his osteotomy was very well consolidated (Fig. 4). He had no pain or swelling and a range of motion of 0°–145° of flexion.

FIG. 2. Full-length standing bilateral lower extremity radiograph illustrating the right tibial deformity and malalignment with osteoarthritis of the medial compartment of the knee.

FIG. 3. The post-deformity correction with the Taylor Spatial Frame applied to the tibia.

FIG. 4. At 13-month follow-up there is consolidation of the osteotomy and correction of the tibial deformity.

Discussion

Two techniques are available to correct tibial deformities: open reduction and internal fixation (ORIF) or gradual correction by corticotomy and use of an external fixator. Although ORIF is usually better tolerated by patients and requires less frequent follow-up and radiographic evaluation, the deformity correction cannot be changed postoperatively. In contrast, external fixators allow dynamic postoperative corrections. These are useful because slow corrections allow soft tissues to adapt, angular and translational corrections are possible, and adjustments can be made to achieve a more mechanically favourable alignment postoperatively. In a randomized trial of HTOs comparing gradual correction with external fixation and lateral closing wedge osteotomy, there were no significant clinical differences between the 2 groups. However, the external fixation group had more accurate corrections and a decreased rate of correction loss during the first postoperative year.[17] The external fixator used in that study was a unilateral fixator. There are no randomized trials evaluating the accuracy of ringed external fixators versus ORIF for deformity correction. However, a ringed fixator should theoretically be more accurate owing to its adjustability. As well, with external fixation the corrections are soft-tissue sparing and do not retain hardware, leaving a better niche for bone healing. Another advantage of using an external fixator for HTOs is that the distal tibial segment can be translated in a lateral direction. This helps to bring the mechanical axis in better alignment and decreases the amount of angulation required to achieve the correction, thereby decreasing the amount of tibial–talar valgus. This is not possible with an open reduction and internal fixation. One final potential advantage of using an external fixator is that since the osteotomy is made distal to the tibial tubercle the patellofemoral mechanics remain unaltered.

The tibial slope has been shown to decrease[16] when an HTO is done with open reduction and internal fixation. We found that the tibial slope did not change significantly using the Taylor Spatial Frame. This is an advantage as it simplifies future knee arthroplasty if needed.

In our study of a new dynamic ringed external fixator that is software driven, the only parameters required by the software are the original deformity, the position of the bone and structures at risk (e.g., common peroneal nerve) with respect to the fixator and the final goal that is to be achieved. The program then calculates a strut-turning schedule to obtain the correction. This fixator and software allow for simultaneous angular and translational corrections whereas with an Ilizarov fixator multiplanar corrections are staged. The Taylor Spatial Frame may also be a more accurate technique because the struts are calibrated so that every turn provides an equal amount of movement whereas the Ilizarov strut adjustment requires some subjective interpretation. Another advantage is that the frame parameters input into the software are relative to the position of the bone, so these can be changed if the preoperative position does not exactly meet that of the post-application position. If the original correction is not adequate, residual corrections can easily be made by inputting new numbers and having the software calculate a new turning schedule. Finally, the turning schedules are colour coded to the struts with the turning directions marked, simplifying the task for patients.

The patients in our study were very satisfied with the clinical outcome as indicated by the high LEM scores. All of the patients indicated that they would undergo the same procedure except one who had a delayed union and required a prolonged course of frame use. The overall clinical results suggest that patient satisfaction is high with this procedure as long as there are no major complications.

The latency period (the time from frame application to the start of correction) on average was 8 days. This is similar to the findings in other studies that describe osseous correction techniques using an external fixator.[12,14–17,24–26] The time to correction ranged from 7 to 25 days. The amount of deformity did not always correlate with the time to correction. The time in the frame ranged from 16 to 36 weeks (average 23 wk). Again, there was no specific correlation between the size of the deformity and the total time in the frame. However, the patient who required 36 weeks in the frame had a 19° correction, which may have influenced the length of time to union.

Complications included those that are common to any external fixation device. Pin-tract infections were seen in 5 of the 7 patients. This rate is comparable to those in other studies using Ilizarov fixators.[25–28] One patient required an irrigation and débridement in the operating room whereas the others were all treated with antibiotics orally. There were no deep-space infections, and all infections resolved with no long-term sequelae. There were 2 pin breakages; 1 required a hardware revision and the other broke when the osteotomy site had healed. There was one delayed union, which may have been due to the large correction required, and no nonunions.

Several studies have reviewed the results of the Taylor Spatial Frame used to correct developmental and post-traumatic tibial deformities.[19,20,29] All showed satisfactory results in terms of correction and bony healing. Complications were similar to the ones seen in our review. Another study of a computer software-driven hexapod fixator that is similar to the Taylor Spatial Frame for treatment of fractures, pseudarthroses and tibial malunion reported successful correction of deformities.[30]

Strengths of this study are the description of a new external fixator with a software-driven correction schedule and its ability to perform HTOs. As well, clinical and radiographic outcome measures have shown that this is a successful technique. Limitations were the small sample of patients, early use of the frame during the technical surgical learning curve predisposing to the correction of smaller deformities and the lack of prospective data. Currently at our centre, the Taylor Spatial Frame is used to correct alignment in varus knees with isolated medial compartment osteoarthritis requiring large corrections (> 15°) or in patients with soft-tissue compromise in which open procedures are contraindicated.

To our knowledge there are no published data on the use of the Taylor Spatial Frame in HTOs for osteoarthritis of the knee. Our results suggest that this frame is a good adjunct to the Ilizarov method of correction of proximal tibial varus deformities causing symptomatic medial compartment degenerative osteoarthritis. The computer software simplifies the correction for both the surgeon and the patient, the frame is more rigid than the Ilizarov fixator and the complication rate is similar.

Conclusion

The Taylor Spatial Frame is a valuable asset in performing HTOs for isolated medial compartment osteoarthritis of the knee in active patients requiring large corrections.

Competing interests: None declared.

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