Taylor spatial frame in severe foot deformities using double osteotomy: technical approach and primary results

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Abstract

Purpose The treatment of severe foot deformities in children or adolescents is complex and demanding to the surgeon. This paper describes the technical strategy of using a Taylor spatial frame and reports on the functional outcome.

Methods The Taylor spatial frame was used by a single surgeon in patients with severe foot deformities. Seven patients with eight severe deformities were treated. Mean patient age at surgery was 15.1 (9–29) years. A double Taylor spatial frame reconstruction was mounted to the limb. All patients had a midtarsal osteotomy and an additional inverse dome-shaped calcaneus osteotomy. Assessed measures were pre- and postoperative deformity and associated complications and clinical results according to Ferreira et al.

Results Mean follow-up was 576.5 (359–987) days. The final functional outcome according to Ferreira was good in seven cases, fair in none, and poor in one. Early complications included pin-tract infection, temporary hypoesthesia, and temporary shortening of the tendon of the M. flexor digitorum. At follow-up there was no deformity recurrence.

Conclusion In children or adolescents, the innovative treatment using the Taylor spatial frame and a double osteotomy allows joint-preserving correction of severe foot deformities. However, the complication rate is relatively high due to the severely deformed feet. Furthermore, the Taylor spatial frame is expensive. Thus, this treatment is only recommended for severe foot deformities and should be handled by experienced orthopedic surgeons.

Introduction

Although the conservative treatment of clubfoot deformities has improved, there are still complex deformities due to overtreated, undertreated, or mistreated feet. In cases of recurrent or residual clubfoot, treatment in juvenile or young adult patients remains a challenge for the orthopaedic surgeon. Also, the limited soft tissue is often compromised by scar tissue, making walking difficult. The neglected clubfoot is relatively common in developing countries [3, 8, 13]. Conservative therapy using orthopaedic shoes, inlays or orthoses is a lifetime therapy, which is not convenient in daily life and therefore not well tolerated by young patients with a severe foot deformity. Also, the deformity is not corrected, and early arthritis is frequent. The common operative procedures include soft tissue operations, osteotomies, bone-wedge resections, arthrodesis or even talectomy [1, 2, 9]. As a result of the stiff soft tissues and prolonged joint deformity, the complication rate of operative therapy is high. Skin necrosis, secondary infections, paraesthesia and ischaemia are common. Furthermore, the functional outcome of complex bone corrections with arthrodesis or resection is poor [9, 16].

A joint-preserving technique for treating severe foot deformities is the Ilizarov technique. This method was first described by Ilizarov in the 1960s in the Soviet Union and brought to Western countries in the 1980s. It is based on the principles of distraction osteogenesis. A gentle, gradual correction of severe foot deformities is possible. Previously published studies demonstrated good results in children because they have a greater healing capacity than adults. It is a valuable tool for correcting multiplanar deformities [1, 2, 9, 10, 16].

The Taylor spatial frame (TSF) was developed by Charles Taylor and is also based upon the principles of distraction

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osteogenesis. The hexapod principle of the TSF allows the adjustment in all six spatial degrees of freedom by means of six linear adjusting elements. Therefore, deformities from simple to complex multiplanar deformities can be corrected with computer accuracy using a virtual hinge. Until now, the TSF has been widely used for displaced long-bone fractures [20]. Due to the variation of ring configurations, the TSF can be applied for treating severe foot deformities.

The aim of this study was to describe the surgical technique for correcting severe pes equinovarus, excavatus et adductus using the TSF with a double osteotomy, including an inverted dome-shaped calcaneus osteotomy. In addition, functional outcome and complications of this treatment are presented.

Methods

Eight feet, each with a severe deformity (Table 1), in seven patients (five girls, two boys) were treated using the TSF from November 2005 to December 2008. One patient required bilateral treatment due to severe deformities in both feet.

Indication

Indication for treatment using the TSF included:

- severe, multiplanar foot deformity;
- anatomical characteristics considered to be a high risk for the neurovascular bundle and skin necrosis without gradual correction;

- failure of conservative treatment or missed chances of successful conservative treatment;
- no primary or secondary osteoarthritis;
- residual range of motion;
- patient compliance.

Preoperative planning

Preoperative conventional X-rays of the deformity were used to determine the extent of bony deformity and joint congruence. In addition, preoperative manual assessment helped define the extent and type of deformity and evaluate the remaining range of motion and possible neurological deficits.

Operative technique

The surgical procedure was conducted in the supine position, with the affected limb prepared and draped freely. A tourniquet was applied at the thigh. The proximal semicircular ring was mounted perpendicular to the tibia within the middle third using one Schanz screw (Fig. 1a). A second ring was mounted in line with the hindfoot deformity. Both rings were connected by struts (Fig. 1b). Perpendicular to the second ring, a U ring was connected surrounding the calcaneus distally. This ring was fixed with Kirschner (K) wires or a Schanz screw to the calcaneus and distal to the planned osteotomy (Fig. 1c). The fourth ring was mounted perpendicular to the forefoot axis using 2-mm K wires. This ring was connected to the U ring via six struts (Fig. 1d). After mounting the TSF, the location of the planned osteotomy was located using fluoroscopy, followed

Table 1 Age, gender, age at surgery, diagnosis, previous treatment, wound-healing disorder, infection, nerve lesions, revision operations

Foot no.	Side	Age at surgery (years)	Previous treatment	Additional surgery	Wound healing Disorder/ Infection	Revision or further operations
1	Left	17	Conservative treatment	Additional lengthening of Achilles tendon	Pin-track infection → conservative treatment	Removal of plantar osteophyte
2	Right	20	Lengthening of Achilles tendon and medial release (1999)	-	Superinfection → secondary wound healing	No
3	Left	9	Surgical intervention at the age of 1 and 4 years	-	No	No
4	Right	13	Two attempts at lengthening the Achilles tendon and bony correction (Afghanistan)	-	Compression ulcer → secondary wound healing	No
5	Left	13	Attempts at lengthening the Achilles tendon and bony correction (Afghanistan)	-	Deep infection (2 months after TSF removal)	Soft tissue revision
6	Right	9	Tenotomy of Achilles tendon and dorsal capsulotomy	Additional lengthening of Achilles tendon	Infection of postoperative haematoma above the Achilles tendon	Reconstruction of a soft tissue defect (infected haematoma) by a flap
7	Left	11	Conservative treatment	-	No	No
8	Right	29	Conservative treatment	-	No	Hindfoot arthrodesis

TSF Taylor spatial frame

Fig. 1 **a** The proximal semicircular ring is mounted perpendicular to the tibia. The ring is fixed by a Schanz screw (5 mm). **b** The second ring is mounted in line with the hind-foot deformity. Both rings are connected by struts. **c** The U ring is mounted perpendicular to the second ring. It surrounds the calcaneus distally and is fixed with Kirschner (K) wires (or Schanz screw) distal to the planned osteotomy. **d** The fourth ring is mounted in line with the midfoot and forefoot deformity. The ring is connected to the U ring by struts. **e** The rings are fixed by K wire to the calcaneus and metatarsal bones. The first osteotomy is an inverted dome shape of the calcaneus. The midtarsal osteotomy is performed extraarticularly

by skin incision. Next, osteotomy of the midfoot was performed, beginning in the cuboid and continuing to the medial cuneiform whilst protecting the surrounding soft tissue. The osteotomy was distracted using chisels, showing complete sectioning. The second osteotomy was performed in an inverted dome shape in the calcaneus (Fig. 1e). The tourniquet was released, and after haemostasis, the wound was washed and closed in layers and the TSF was fixed in the final position. In the final step, the connecting struts of both TSFs were labelled, according to manufacturer's instructions, and the distance of each strut was recorded. Full weightbearing was allowed with the TSF.

The preoperative deformity in one patient is shown in Fig. 2a. Figure 2b shows the postoperative result of the right foot and the TSF mounted on the left foot.

Postoperative correction by distraction osteogenesis

Web-based planning of the correction was done on the Taylor spatial frame Web site (www.spatialframe.com). For

each patient, a separate file was established. The primary deformity was defined and the size of frames and struts, position of the initial frames to the foot, and length of the struts were entered. A limitation to the maximum daily distraction distance was defined by the surgeon. The programme then illustrated the final position of the foot and frames. At this point, the surgeon could correct the parameters, and it was possible to redefine the deformity by setting it during distraction. Finally, the description of the distraction plan was presented for each strut. In the special case of a combination of two TSFs, a distraction plan for both frames was created. The time for TSF removal was determined by bone healing shown on conventional X-rays. After TSF removal, the foot was placed in a below-knee plaster for four weeks.

Patient evaluation

To evaluate the correction of severe foot deformity using a TSF, the following parameters and data were assessed:

Fig. 2 Patient with severe multiplanar foot deformity affecting both sides. **a** Posterior view preoperatively. **b** The right foot is already corrected by a Taylor spatial frame (TSF). A TSF is now mounted on the left foot

surgical procedure, age at surgery, previous surgical or conservative treatment, preoperative symptoms, preoperative deformity and affected side, complications (wound-healing disorder, infection, nerve lesion, prolonged consolidation, or pseudarthrosis), duration of correction by changing TSF strut length, duration of mounted TSF, duration of hospital stay, pre- and postoperative footwear, secondary osteoarthritis, deformity recurrence, postoperative alignment and surgical revisions. Criteria for the final outcome included:

- lack of pain;
- capability to walk on plantigrade foot;
- absence of recurrence of deformity;
- individual satisfaction regarding the final outcome.

According to Ferreira et al. [9], the outcome was judged as good when all of the above criteria were accomplished. In case of three fulfilled criteria, the outcome was judged fair. If only two or less criteria were accomplished after one year, the outcome was designated poor.

Results

From November 2005 to December 2008, eight severe foot deformities (seven patients: five female and two male) were treated using the TSF. One patient from an Arabian country was lost to follow-up because he came to our hospital only for deformity correction. Therefore, his follow-up was only 359 days. The mean age at the time of surgical correction using the TSF was 15.1 (9–29) years. Three of the eight feet were skeletally mature (patients ≥ 14 years). Five deformities had had at least one surgical intervention before (Table 1). The other patients had had at least one conservative treatment before. Mean duration of the mounted TSF was 59.5 (33–89) days, whereas the mean interval of correction by changing the length of the TSF struts was 28.1 (10–49) days. The period for correction depended on the extent of deformity and the quality of soft tissue. Mean hospital stay for TSF mounting and the beginning of the correction was 17.4 (9–26) days. Mean follow-up was 576.5 (359–987) days. Table 2 gives an overview of individual data. All patients had severe pes equinovarus, excavatus et adductus. The exact preoperative deformity of each patient is illustrated in Table 3. Postoperative foot alignment at the latest follow-up is described in Table 4. No foot was corrected to full physiological position. Pathological preoperative supination of the forefoot was not fully corrected in five feet. In relation to the preoperative deformity, hindfoot correction was good in these patients, even though physiological valgus position was not achieved. Preoperative equinus deformity was also corrected, although in two patients, the results showed mild overcorrection.

This observational, retrospective study reveals good results in seven feet, fair results in no feet and poor results in one foot [9]. Five patients are able to walk in ordinary shoes.

Table 2 Time of follow-up and duration of correction, mounted Taylor spatial frame (TSF) and hospital stay

Patient	Follow-up (days)	Duration of correction (days)	Duration of mounted TSF (days)	Duration of hospital stay (days)
1	401	22	89	26
2	498	31	66	12
3	359	10	46	19
4	597	49	76	20
5	412	31	63	9
6	504	31	48	16
7	987	25	33	19
8	854	26	55	18
Mean	576.5	28.13	59.5	17.38

Table 3 Preoperative deformities

Foot no.	Adduction	Supination	Excavatus	Plantar flexion (ankle)	Varus (hindfoot)
1	20°	10°	15°	30°	40°
2	20°	5°	10°	10°	20°
3	20°	10°	10°	20°	25°
4	20°	80°	20°	0°	50°
5	10°	40°	10°	20°	30°
6	20°	0°	20°	30°	20°
7	25°	15°	10°	10°	15°
8	20°	20°	15°	15°	20°

Complications

Treatment of severe foot deformities is associated with several complications (Table 1). Early complications were limited, and a surgical intervention was not necessary. They included pin-track infection, swelling, lymphoedema, relative shortening of the tendon of flexor digitorum, with consequent elevation of the toes and temporary paraesthesia of the toes. Additional pain medication was given and, in cases with pin infection, antibiotics were added. Lymph drainage and physiotherapy were initiated in all patients. Due to existing scars following a previous Achilles tenotomy and skin necrosis above the Achilles tendon in one patient, reconstruction using a flap was necessary. In another patient, one strut compressed the skin and soft tissue on the lateral part of the foot. Despite protection, an ulcer occurred making wound management necessary to induce secondary wound healing. This lasted about five weeks until complete healing. In this patient, about three months after TSF removal, a subcutaneous infection necessitated surgical revision. Debridement with insertion of antibiotics chains resulted in complete wound healing. In one patient, a hindfoot arthrodesis was done for secondary symptomatic hindfoot osteoarthritis. A reason for the TSF

failure was that at the time of operation, this patient was already 29 years old. In no case did a prolonged consolidation or pseudarthrosis occur.

Discussion

This study describes the operative treatment of severe, multiplanar foot deformities using a TSF reconstruction and a double osteotomy. Essential steps of the surgical technique are illustrated. In addition, a follow-up of eight feet (seven patients) is presented. The use of conventional correcting methods (e.g. osteotomies or arthrodesis) is inappropriate because single surgical procedures are associated with a high risk of complications [9, 11]. Furthermore, in children or adolescents, an arthrodesis should be avoided. Treatment using the Ilizarov technique has the ability to gradually correct severe multiplanar foot deformities. TSF allows even greater ability to plan the final alignment, supported by a computer programme, and to re-evaluate the deformity during therapy to adjust the plan if necessary. Correction speed and direction is also adjustable, depending on neurovascular or skin problems. Thus, the final alignment is not the result of a one-step surgical procedure. However, the disadvantages of this method are the long duration of treatment and the need for expensive tools.

After achieving the final position, the TSF remains on the limb for approximately four weeks depending on the radiological appearance. When removing the TSF, the forces applied by muscles may lead to a slight recurrence of the correction. In our study, mild supination deformity recurred in four of eight feet. Therefore, we recommend a certain amount of overcorrection of forefoot supination/pronation. Due to distraction osteogenesis, foot shortening can be avoided, in contrast to conventional surgical treatments. Furthermore, a bone graft is not necessary and full weight bearing is possible during TSF therapy. However, this study also reveals complications associated with this

Table 4 Alignment of feet at latest follow-up

Foot no.	Adduction	Pronation	Supination	Excavatus	Plantar flexion (ankle)	Dorsal extension (ankle)	Varus (hindfoot)	Valgus (hindfoot)
1	0	0	0	5	0	5	5	0
2	0	5	0	0	0	0	0	5
3	5	0	0	0	5	0	0	5
4	10	0	15	10	0	10	10	0
5	0	0	10	5	0	0	5	0
6	5	5	0	0	0	5	5	0
7	10	0	5	0	10	0	5	0
8	5	0	5	10	0	5	5	0

treatment. The incidence of complication cannot be ignored. It is similar to the incidence of complications mentioned in earlier literature analysing TSF treatment or Ilizarov fixator [5, 8, 11]. The average duration of the mounted TSF was approximately 59 days in this study. This is important information, which patients need to know before treatment. Furthermore, patients must be informed that during correction with the TSF, regular clinical and radiological follow-up appointments are necessary and that this treatment takes at least three months until rehabilitation into activities of daily life. TSF therapy is also time consuming for the surgeon. The correction plan must be reviewed frequently and adjusted, if necessary – especially in the case of a combination of two TSF frames. Also, the struts must be frequently changed during therapy. All this, in contrast to conventional operation, makes TSF a time-demanding procedure. Additionally, the use of the TSF depends on Internet access and is also expensive. This limits the use of the TSF.

The TSF was primarily used to treat a wide variety of limb pathologies, including complex fractures, deformity correction and limb lengthening [4, 6, 12, 14, 15, 17, 21]. TSF can also be used to treat malunion or nonunion [7] as well as fractures [18]. However, these studies concluded that the combination of a stable external fixation device and the accuracy of the computer-based technology make the treatment suitable for precise correction of skeletal deformities [4, 19]. Ferreira et al. [8, 9] reported on the Ilizarov external fixator for multiplanar foot deformities. Good results were seen in approximately 80%, fair results in 8–15% and poor results in 9–13% after a mean follow-up of four years. With the availability of various ring configurations, new struts and a new foot programme, indications for treatment with TSF could be extended to severe foot deformities [5, 20]. Eidelman et al. [5] reported on 13 patients with various foot deformities. In 11, this treatment achieved good results, whereas mild residual deformities persisted in two patients. They concluded that treatment using TSF is a powerful and accurate surgical modality for both limb and foot deformities. Seybold et al. [20] also used the TSF to correct post-traumatic limb and foot deformities, concluding that the application of the TSF is simple and patients need a shorter stationary period.

The incidence of complications in our study is similar to that in reported studies. Eidelman et al. [5] report on joint subluxations, such as in the metatarsophalangeal or talar joint, during correction of foot deformities. We saw no talar luxations. Metatarsophalangeal subluxation is due to the relative shortening of tendons of the extensors of the lesser toes. To avoid luxation or subluxation, we recommend temporary transfixation of the metatarsophalangeal joints during TSF therapy and intensive physiotherapy after removing the TSF. In one patient, a hindfoot arthrodesis

was necessary for secondary osteoarthritis. This patient was already 29 years old at the time of TSF mounting. The advanced age and longer-standing deformity of this patient compared with the other patients may be the reason for the development of osteoarthritis.

This paper illustrates an innovative surgical technique for correcting severe foot deformities, including deformities in the hind foot, without the need for joint fusion. In addition it presents a short-term outcome of patients treated by this technique. Due to the low incidence of the condition and limitations we have outlined of using TSF, the number of cases is low.

Conclusion

Treatment with the TSF can correct severe foot deformities, as demonstrated in this study. The plan and surgical treatment are structured with precise end points. It is a dynamic therapy with an adjustable correction to treat individual deformities and conditions of patients' feet.

Conflict of interest The authors declare that they have no conflict of interest.

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