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ORIGINAL STUDY

Three-dimensional correction of complex leg deformities using a software assisted external fixator

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The Taylor Spatial Frame is a computer assisted hexapod system allowing simultaneous correction of every component of complex limb deformities (leg length discrepancy, angulation, translation and rotation).

We report our experience with this system in six patients. The planned correction was achieved in all cases. Minor complications occured in all but one patient without consequences ; there were four major complications : non union, callus fracture, plantar aponeurosis retraction and reflex sympathetic dystrophy in one case each. These complications were not in relation with the type of fixator used.

In patients requiring correction of complex deformities, the Taylor Spatial Frame is a useful device that simplifies the planning procedure and allows simultaneous correction of any deformity in every plane. Another major advantage is the possibility to correct any residual deformity at the end of the planned procedure.

Keywords : limb deformity correction ; hexapod system ; external fixator.

INTRODUCTION

The Taylor Spatial Frame® (TSF, Smith and Nephew, Memphis, Tennessee, USA) is a circular external fixator made up of two rings fixed to the skeleton with wires and half pins (fig 1). Six telescopic struts connect the rings, creating an hexapod system. Modifications in the struts length allow changes in the orientation of one ring, leading to simultaneous correction of every deformity (leg length discrepancy, angulation, translation and rotation). A TSF web-based software (free access on the web) simplifies the planning of the deformity correction. After introduction of all the deformity parameters in the software, a correction protocol is proposed and can be printed. Patients are instructed to lengthen or shorten the struts according to this protocol. The advantage of the TSF is its accuracy in final limb length and alignment and its ability to correct any residual deformity. Early weight-bearing is possible thanks to the excellent stability of this multiplanar circular fixator (fig 2).

We report our early experience with this new system.

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Fig. 1. — The Taylor Spatial Frame Hexapod system. This circular external fixator is made up of two rings fixed to the skeleton with wires and half pins. Six telescopic struts attach both rings to each other creating an hexapod system which allows movement of one ring relative to the other.

Fig. 2. — Patient with lengthening procedure of the right tibia. Walking was allowed during distraction and maturation time.

PATIENTS AND METHODS

Patients series

From July 2006 to April 2008, eight patients were operated on with use of the TSF external fixator. Only six patients who completed the correction program (after fixator removal) are included in this report (table I). Their mean age at surgery was 19.3 years (range, 12.7 to 30.9 years). The aetiology of the limb deformity was different in each case (infectious epiphyseodesis, Ollier's disease, idiopathic, vitamin D-resistant hypophosphataemic rickets, sequel of clubfoot and severe burn) (table I). The correction was at the tibia in 4 cases, the femur in one case and the foot in two cases. One patient had simultaneous correction of the femur and tibia. The planned correction was achieved in all six cases.

Preoperative planning

Patients were evaluated by physical examination. According to Paley's methodology (8), an AP full-length bipedal standing radiograph was taken to assess the leg length discrepancy and the deformity in the frontal plane. A lateral radiograph was performed with the knee in full extension to assess the sagittal deformity. On the frontal view (fig 3, table II), the lateral proximal femoral angle (LPFA), the mechanical and anatomical lateral distal femoral angle (m/a LDFA), the medial proximal tibial angle (MPTA) and lateral distal tibial angle (LDTA) were measured. On the lateral view, the posterior distal femoral angle (PDFA), the posterior proximal tibial angle (PPTA) and the anterior distal tibial angle (ADTA) were measured (8). The center of rotation of the angulation (CORA) was identified at the intersection of the proximal and distal mechanical axes, usually at the apex of the deformity (8). The osteotomy was performed as close as possible to the CORA.

Surgery

Rings were fixed to the bones with olive-wires and hydroxyapatite coated half pins. The wires were, inas-

Table I. — Clinical data of the 6 patients

Case	Age (years)	Origin of deformity	Bones to correct	Correction obtained	Complications	Treatment
1	17.5	infectious epiphysiodesis of proximal medial tibia	Right tibia	- correction 11° varus - correction 20° external rotation - lengthening 32 mm	- pin tract infection - equinus	- oral antibiotherapy - physiotherapy (total recovery)
2	16.4	Ollier's disease	Left femur	- correction 38° varus - correction 45° external rotation - lengthening 60 mm	- pin tract infection - knee flexum	- oral antibiotherapy - physiotherapy (total recovery)
			Left tibia	- correction 30° valgus - correction 40° internal rotation - lengthening 60 mm	- regenerate fracture of tibia - equinus	- orthopaedic treatment - physiotherapy (total recovery)
3	23.9	vitamin D-resistant hypophosphatemic rickets	Left tibia	- correction 15° varus (frontal view) - correction 19° anterior angulation (lateral view) - correction 20° internal rotation	- osteotomy nonunion	- autograft + plating
4	30.9	sequel of clubfoot	Left calcaneus	- lengthening 22 mm	- cavus deformity - algoneuro-dystrophia	- plantar aponeurosis lenghtening at the time of fixator removal - oral diphosphonate
5	16.7	idiopathic	Left tibia	- correction 11° valgus - lengthening 40 mm	- pin tract infection - botryomycoma on pin tract	- oral antibiotherapy - surgical resection
6	16.9	severe burn in childhood (7 years of age), scar retraction and severe foot equinovarus	Right foot	- correction of 85° of calcaneopedal block medial rotation - correction of 70° equinus		

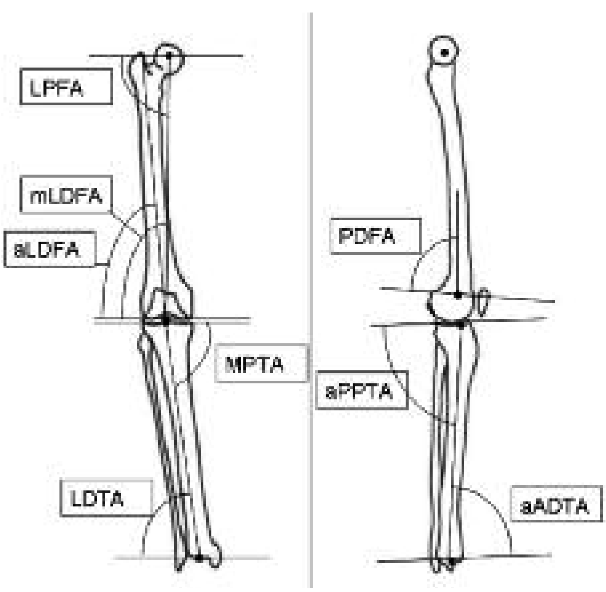

Fig. 3. — Preoperative planning (8) (Table II)

much as possible, placed at a right angle (or with an angle > 60°) to each other to increase the stability of the frame. The osteotomy was performed after the frame was fixed to the bone and was performed by predrilling the bone with a thin drill along the osteotomy plane and completing the osteotomy with a narrow osteotome. If a tibial lengthening was planned, fibular osteotomy and screw fixation of the ankle syndesmosis were performed. The fibular osteotomy was usually located at a level different from the tibial osteotomy in order to respect the local blood supply and encourage bone healing. No acute correction was attempted. Every correction was gradually applied.

Correction

The correction procedure started on the 7th day after surgery. The printed correction protocol was given to the patients. This protocol gave the daily length to be

Table II. — Lengthening (cm), distraction index (DI), maturation index (MI) and external fixation index (EFI) for the 6 cases

Case	Length gained (cm)	Distraction/ correction duration (days)	Maturation duration (from distraction end to fixator removal) (days)	Total duration of external fixation (days)	Distraction index (DI) (days/cm)	Maturation index (MI) (days/cm)	External fixation index (EFI) (days/cm)	Follow-up (months)
1	3.2	48	92	140	15	28.8	43.8	22
2 (femur)	6	110	55	165	18.3	9.2	27.5	19.7
2 (tibia)	6	110	153	263	18.3	25.5	43.8	19.7
3	0	55	48	103	NA	NA	NA	14.3
4	2.2	37	29	66	16.8	13.2	30	6.7
5	4.2	52	116	168	12.4	27.6	40	10.3
6	0	40	13	53	NA	NA	NA	4.7

achieved for each of the six struts. The patients were asked to reach each strut length at the end of the day. They were allowed to lengthen or shorten each strut as often as they wanted until they reached the planned length. During the correction period, radiographs were performed once every two to three weeks to check the progression of the correction. The patients were allowed to walk with two crutches, with full weight-bearing except for the two patients with foot deformity correction.

For all patients, the following data were registered (table I) : lengthening (cm), amount of deformity correction (degree), distraction index (DI), maturation index (MI), external fixation index (EFI) and complications *(6,11)*. DI was obtained by dividing the total duration of distraction by the obtained lengthening in centimeters. MI was obtained by dividing the total duration of maturation by the obtained lengthening. The maturation was the time from the end of distraction to fixator removal. EFI was the total duration of external fixation divided by the lengthening.

RESULTS

The six patients who completed their correction were analyzed. Two cases are illustrated in figures 4 and 5. The corrections obtained are summarized in table I. The expected corrections were achieved in all cases. The mean DI was 16.2 ± 2.5 days/cm. The mean MI was 20.9 ± 9 days/cm. The mean EFI was 37 ± 7.8 days/cm.

Classical minor complications occurred in all but one patient. Pin tract infection occurred in 3 cases and required oral antibiotherapy with oxacilline for 10 days. No pin or wire change or removal was needed. Transient equinus deformity occurred in two tibial lengthening procedures with complete recovery with physiotherapy. Hamstrings retraction occurred in one femur lengthening procedure with a knee flexum deformity which recovered with physiotherapy. One patient developed a botryomycoma that needed surgical excision.

Four major complications occurred in three patients. One patient sustained callus fracture (after external fixator removal) which healed with conservative treatment. Non-union occurred in the patient with rickets ; it healed after autografting and plate stabilisation. The calcaneus lengthening led to a cavus deformity which needed correction by release of the plantar aponeurosis at the time of fixator removal. This patient also developed reflex sympathetic dystrophy and was treated with oral diphosphonates.

DISCUSSION

The Ilizarov external fixator allows correction of various skeletal deformities. The main disadvantages of the Ilizarov technique are the difficulty in correcting multiplanar and complex deformities,

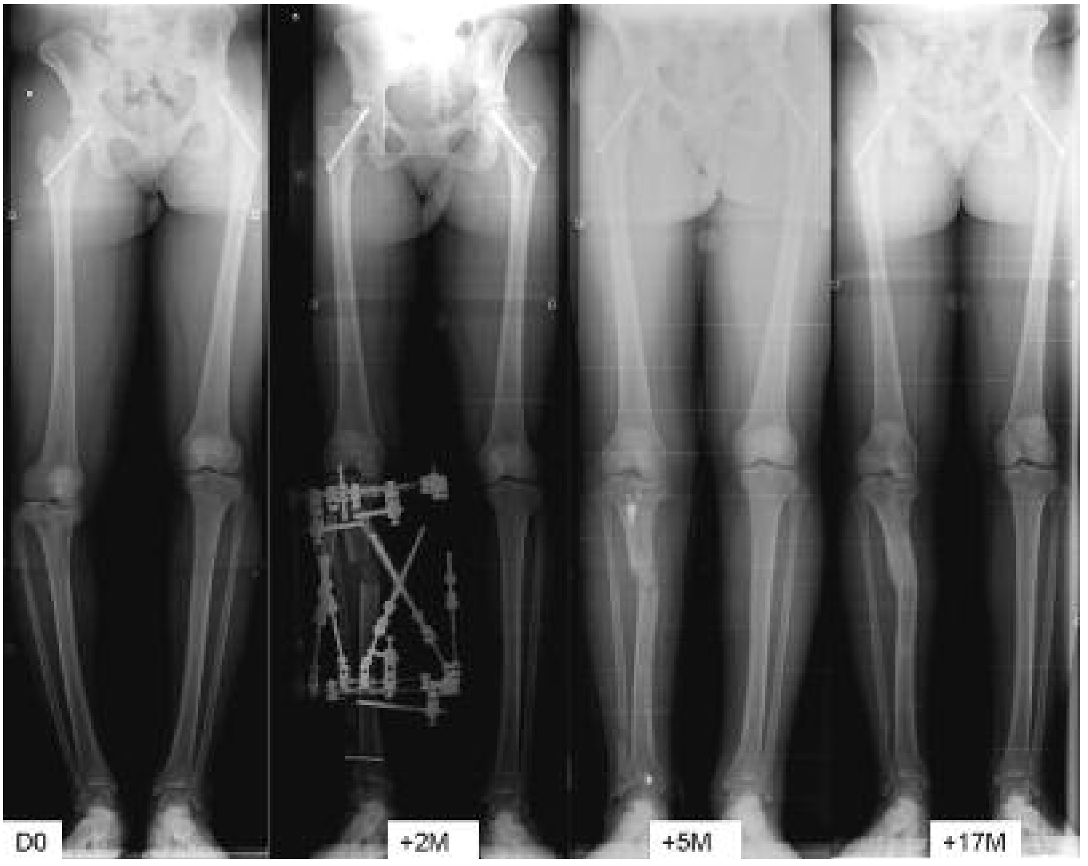

Fig. 4. — A 17-year-old girl with epiphyseodesis of the medial proximal tibia secondary to local bone infection. There is obvious depression of the medial tibial plateau and hypertrophy of the medial femoral condyle. The initial deformity was evaluated as 32 mm-shortening, 20°external tibial torsion and 11°genu varum. Correction was obtained in 47 days. The fixator was removed after 4.7 months and a protective Sarmiento brace was worn for 3 months. The correction obtained was clinically satisfactory and the patient reported relief from her knee pain. In this case the CORA was in the proximal tibial epiphysis on the frontal plane, and a more distal osteotomy site was chosen.

Table III. — Angles measured on plain radiographs for osteotomy planification

Angle	Frontal view	Mean value	Extremes
- lateral proximal femoral angle	LPFA	90°	85- 95°
- mechanical lateral distal femoral angle	mLDFA	88°	85- 90°
- anatomical lateral distal femoral angle	aLDFA	81°	79- 83°
- medial proximal tibial angle	MPTA	87°	85- 90°
- lateral distal tibial angle	LDTA	89°	86- 92°
	Lateral view		
- posterior distal femoral angle	PDFA	83°	79- 87°
- posterior proximal tibial angle	PPTA	81°	77- 84°
- anterior distal tibial angle	ADTA	80°	78- 82°

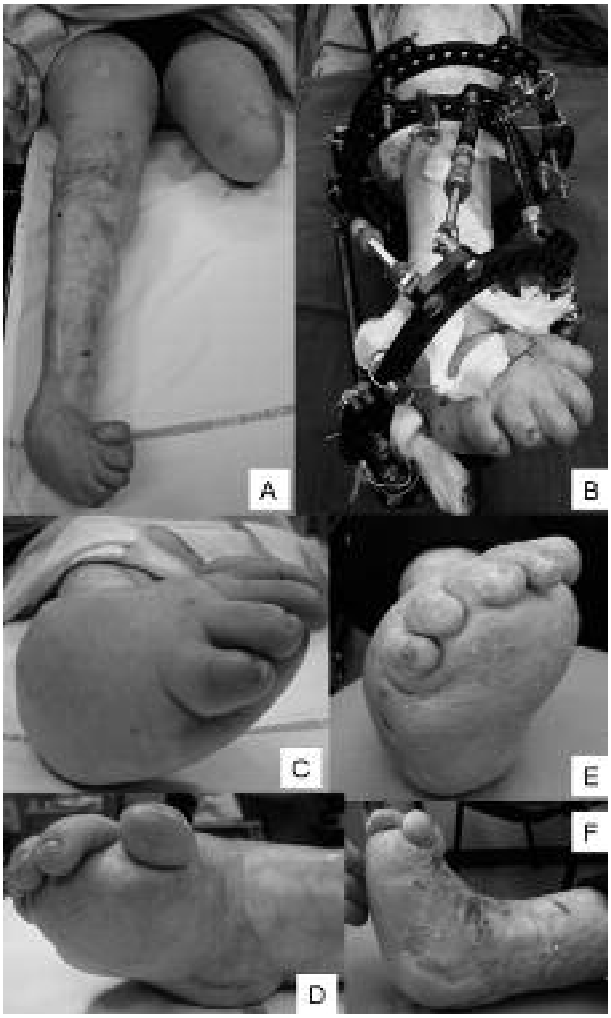

Fig. 5. — This 17- year-old girl was severely burned at the age of 7. Sixty-six percent of her whole body surface was burned. She had a left high-femur amputation (fig 5A) and was walking with an above-knee prosthesis. Her right foot had a severe equinovarus deformity and scars were present all around her foot. A severe retracted fibrous scar was present on the medial side of her foot. She had pain on walking despite using an orthopaedic shoe. An V-shaped osteotomy (2) and a progressive correction with a TSF (fig 5B) were performed.
– 5C and 5D : preoperative pictures.
– 5E and 5F : final result.

and a long learning curve. When rotation and translation have to be corrected, re-placement of hinges and frame adjustment need to be performed in most of the cases. TSF simplifies these problems and allows simultaneous correction of any deformity in every plane (leg length discrepancy, angulation, translation and rotation) without any frame modification other than strut length adjustments. When a strut becomes too short or too long, it must be changed but this is easy and can be performed without anaesthesia at the outpatient clinic.

A recent paper by Rozbruch *et al* gives useful information concerning preoperative planning and operative technique (*10*). We followed these instructions.

Numerous papers have reported results of deformity corrections using TSF. Eidelman *et al* reported a series of 31 children and adolescents (*1*) in which TSF was used to correct various deformities. They obtained anatomical correction in all but one patient and concluded that TSF gave accurate correction of complex deformities. In our series we obtained the expected correction in all cases. At the end of the program, all residual deformities visible on the radiograph were corrected by a final correction program to achieve the planned correction.

Feldman *et al* used TSF for correction of infantile and adolescent tibia vara in 19 patients (*3*). These authors showed that gradual correction with TSF was more accurate than acute correction (*4*). In our series, we never attempted to obtain acute correction. All corrections were obtained gradually. Rogers *et al* described a technique of acute intraoperative correction of complex multiplanar deformities of the distal femur with the TSF prior to definitive internal fixation with a percutaneous locking plate (*9*).

Other authors used the TSF for other indications. TSF was used for arthrodiastasis in patients with severe ankle arthrosis (*12*) and also for temporary shortening of the leg to facilitate wound closure in case of open tibial fracture with severe bone and soft-tissue loss (*7*).

Our mean external fixator index (EFI) was similar to those reported in literature, which range from 30 to 60 days/cm (*11*). Variables affecting time to bone healing in limb lengthening are the type of disorder, the length of the distraction gap, the age of the patient (children heal faster than adults), location of the osteotomy (metaphyses heal faster than diaphyses), previous surgery, and the use of dynamisation (*5,11*).

TSF is a useful device which has numerous advantages over traditional external fixators. In case of difficult deformity correction, TSF simplifies the planning and the correction procedures. Any mistake in the correction program or any residual deformity can be easily corrected by entering the residual deformity in the software and generating a new correction protocol. Its accuracy and the possibility of easy adjustments during the deformity correction, reduce the need for radiographic checks and their frequency. The minor complications we encountered are frequent with any type of external fixator ; they had no consequences on the final result. The major complications described are also frequently encountered in case of limb lengthening, whatever the type of external fixator used. The non union was probably related to the underlying hypophosphataemic rickets which compromised bone healing.

CONCLUSION

We have reported our early experience with the TSF technique in a small series of six patients. This method has several advantages. The computer software allows accurate deformity analysis and elaboration of a precise correction protocol. The correction is gradual and is accurate. A single frame is able to correct simultaneously and gradually any combination of leg length discrepancy, angulation, rotation and translation ; adjustments can be made during the correction procedure. The only disadvantage of this technique is the cost of the external fixator. Because of this financial consideration, TSF should be reserved to complex deformities requiring correction in more than one plane and/or associated leg lengthening.

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