Limb lengthening and deformity correction in children using hexapodal external fixation: Preliminary results for 36 cases


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KEYWORDS
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Summary Limb deformities in children can be corrected using different techniques, notably external fixation following the Ilizarov principles. However, correction can be difficult in cases of multiple deformities. In 1994, Charles Taylor developed a new computer-assisted hexapodal external fixator system to treat these pathologies, the Taylor Spatial Frame™. The objective of this study was to evaluate the results obtained with this technique in treating lower-limb deformities in children.

Thirty-six patients were included in this prospective study, with a mean age of 11.1 years. The etiologies were distributed into six groups: congenital pathologies in 17 cases, fractures in five cases, post-traumatic pathologies in two cases, post-infectious sequelae in three cases, achondroplasia in three cases, and other causes in the last six cases. A total of 67 deformities in the three spatial planes were found in the entire group of patients. The procedure consisted of lengthening, correcting the axis, or both simultaneously. All the patients were managed with the same protocol: placement of an external fixator, AP and lateral X-rays, and planning of the correction using dedicated software.

In this group of 36 patients, the fixator was worn for a mean 183 days; when lengthening was performed, a mean 4.3 cm was gained with a healing index of 38.2 days/cm. Of the 67 initial deformities, 91% were corrected. The most frequently encountered complications were a superficial infection in 22.2% of the cases; one deep infection was also noted as well as three bone regenerate fractures.

Use of this computer-assisted fixation system seems effective in treating complex deformities of the limbs in children, and allows treating several deformities simultaneously.

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Introduction

Developed and introduced in the 1950s by Ilizarov [1], the external fixator has made it possible to treat a variety of orthopaedic pathologies. It can be used in traumatology,
notably for complex fractures, correcting deformities, and limb lengthening. One of the limitations of external fixation, however, remains the difficulty of correcting complex deformities, particularly when they involve several spatial planes.

To remediate these technical shortcomings, in the 1990s, Taylor [2] developed an original system of external fixation that facilitates the comprehension and treatment of these bone deformities, the Taylor Spatial Frame™ (Smith and Nephew, Memphis, Tennessee, USA). This circular fixator, linked to computer planning software, allows for simultaneous correction of all the axis defects without having to modify the fixator during correction. The software can produce a correction program that is easy to understand for the patient and family, so that the fixator can be adjusted daily with no problems.

The fixator base construction consists of two rings interconnected by six telescopic struts, identified with colored bands numbered from 1 to 6, screwed to the ring at locations that are preestablished by the manufacturer (Fig. 1).

Like the Ilizarov fixator, each ring is attached to its bone segment by a system of transosseous pins and hydroxyapatite-coated pins. Once the system has been assembled, a ring can be repositioned in relation to another one by simply adjusting the length of the struts with an adjustment screw. Thus, shortening, angulation, rotation, and translation can be corrected simultaneously by modifying only the length of the strut.

In this prospective study, we present the results of our experience with the Taylor Spatial Frame™ used to treat 36 patients.

**Materials and methods**

Thirty-six patients were included in this prospective study conducted between September 2004 and March 2007 on 25 boys and 11 girls with a mean age of 11.1 years (range: 3—18 years). The inclusion criteria were patients treated in the department who required isolated limb lengthening 4 cm or greater, lengthening with axis correction, or axis correction only. One patient was excluded from the study because this case involved a tibial tumor with vascularized fibula reconstruction; in this case, the fixator was not intended for limb lengthening. The etiologies were divided into six groups:

- congenital pathologies for 17 patients (femoral and tibial hypoplasia, external fibular hemimelia, tibial agenesis, radial club-hand);
- fractures for five patients (three tibial and two femoral fractures);
- post-traumatic sequelae for two patients (genu valgum) (Fig. 2);
- postinfectious sequelae for three patients (epiphysiodesis secondary to osteomyelitis and purpura fulminans sequelae);
- achondroplasia in three cases;
- other pathologies in six cases (three cases of sacral agenesis, one of poliomyelitis sequelae, one tumor, and one case of spina bifida).

The bone segment involved was the tibia in 26 cases (72%), the femur in six cases (17%), and other segments in four cases (two cases of radial club-hand, one fixed flexion knee contracture, and one ankle tumor).

The procedure consisted in lengthening alone in 14 cases (38.9%), lengthening and axis correction in 13 cases (36.1%), and axis correction alone in nine cases (25%).

A total of 67 deformities were found in the 36 patients. Sixteen patients presented a single deformity (44.4%), 12 presented two deformities (33.3%), five had three deformities (13.9%), and three had four (8.3%). The deformities were divided into the three spatial planes with a mean 13.5° deformity in the AP plane (varus—valgus); 14.2° in the sagittal plane (flessum—recurvatum), and 21.7° in the horizontal plane (internal—external rotation).

In the patients needing limb lengthening, the lower-limb length disparity was a mean 5 cm (range: 1.5—11.2 cm).

For all the patients in the series, the surgery was performed following the same procedure. The external fixator was installed in the operating room under general anesthesia by the same surgeon, with the patient in the dorsal decubitus position. Fixation of each ring to its bone segment did not differ from the Ilizarov bone fixation technique. Each ring was fixed to the bone using a system of transfixating pins and hydroxyapatite-coated pins. The computer-assisted correction plan was also standardized in three steps using the Smith and Nephew® software.
The first phase consisted in defining the bone deformity based on straight AP and lateral postoperative X-rays (Fig. 3A) on which the entire fixator was visible. We first had to identify the reference ring on the software, which then allowed us to detail each deformity in terms of the corresponding bone segment deformity in relation to the reference bone segment. In this series, the reference ring was systematically taken on the proximal bone segment. Once this reference had been defined, bone angulation and translation in the AP and sagittal planes were defined, as were any potential rotation and length problems.

The second phase defined the fixator characteristics, i.e., the size of the rings as well as the length of each strut and the lengthening position for these rings. Study of the radiographs then provided the position of the reference ring in relation to the reference bone segment in the AP, sagittal, and horizontal planes on a vertical axis (the distance between the ring’s center and the osteotomy site). These measurements were facilitated by two small threaded stems that represented the anterior and lateral edges of the reference ring.

The last step defined the correction program. Using all the data collected, the software deduced the exact position of the second ring in relation to its bone segment and provided a daily program for modifying the length of the struts so as to correct all the bone deformities.

In case of programming error or persistent deformity at the end of the program, but before the appearance of true bone continuity, it was possible and simple to adjust the therapeutic program software with new follow-up X-rays and correct the residual defects without intervening on the fixator.

The results were assessed prospectively by a single investigator (BB), independent of the operator (FL). The deformities were analyzed based on the pre- and postoperative radiographs with orthogonal images. The deformities measured were then entered in the correction software, which provided a correction program specific to each patient. The clinical follow-up was based on a medical file that was standardized for these procedures and systematically applied to all patients treated for bone deformity. The data collected were the following: demographic data, etiology of the deformity, type of surgery (lengthening, axis correction, or both), number of deformities and their characteristics, type of osteotomy, intraoperative lengthening, date weightbearing was begun and the beginning of the lengthening procedure, length of hospital stay, duration of the lengthening procedure and fixator wear, residual deformities, and the complications encountered.

The external fixator was removed when bone reunion was visible on at least two cortices on the AP and lateral X-rays and was deemed sufficiently strong by the operator.

During the follow-up phase, all complications were noted, including superficial infections at the fixator pin contact areas. Only pain was evaluated separately because of its subjective aspect, often difficult to evaluate. All 36 patients were followed up with clinical and radiological evaluation for the duration of fixator wear and then in regular consultation at three months, six months, and one year after fixator removal.

Results

Of the 36 patients included in the study, none had been lost to follow-up at the last visit. The mean duration of follow-up after fixator removal was 21.3 months (range: 4.3–43 months).
During the intervention, at the beginning of our experience, intraoperative lengthening was performed and then was abandoned because the value of intraoperative lengthening did not seem clearly advantageous in practice. In this series, no secondary bone graft for nonunion was necessary.

For lower-limb pathologies, weightbearing was authorized theoretically the day after surgery, but varied depending on pain, and was actually started on average the fifth day after surgery (range: 2–45 days). For the 27 patients who had lower-limb lengthening, weightbearing was begun on average on the sixth postoperative day (range: 2–14 days), with a mean gain of 4.5 cm (range: 2.8–8.3 cm).

The date the lengthening was started varied according to several criteria: pain intensity, time until good-quality postoperative radiographs were obtained so that the correction program could be calculated, and the patient’s pathology.

The mean duration of fixator wear for the entire series was 183 days (55–365 days). The mean healing index score for the entire series was 38.2 days/cm (range: 24.2–63.9 days/cm).

Fourteen patients with a mean age of 10.5 years (range: 3–18 years) had an isolated lengthening procedure: femoral lengthening in two cases and tibial lengthening in 12 cases, with a mean lower-limb length disparity of 6.07 cm (range: 4–10.3 cm). In this group, weightbearing was possible on the fourth day (range: 2–8 days) and lengthening was begun on average on the sixth day (range: 4–14 days). The mean duration of fixator wear was 200 days (range: 109–271 days) with a healing index of 35.38 days/cm (range: 24.17–45.17 days/cm).

The 22 remaining patients underwent axis correction with or without simultaneous lengthening. The mean age in this group was 11.4 years (range: 4–18 years), and the bone involved was the femur in four cases, the tibia in 14 cases, or another bone in four cases. The mean length disparity was 2.35 cm (range: 0–9 cm), weightbearing was started on average on the sixth day (range: 2–45 days), with lengthening if necessary begun on the fifth day (range: 2–9 days). In these patients who required axis correction, the mean duration of fixator wear was 172 days (range: 55–365 days) with a mean healing index of 41.8 days/cm (range: 27.45–63.93 days/cm).

The results for the patients who underwent lengthening alone or axis correction with or without lengthening are shown in Table 1.

Analysis of the follow-up radiographs of the series demonstrated that there was no residual deformity in 30 of the patients (83.3%). Four presented residual unequal length in the lower limbs less than 2 cm and did not require additional treatment. A valgus deformity was also diagnosed on an external correction of longitudinal ectromelia by premature consolidation of the fibula in a patient who did not present for two intermediary follow-up consultations seen later with shortened lateral struts. This patient required surgical revision 24 months later, with a new Taylor Spatial Frame™ correction program, currently ongoing. In another patient, a 5° varus deformity secondary to a post-traumatic genu valgum correction was diagnosed. This residual deformity corresponds to an error in the correction software.

### Table 1: Mean clinical data according to the type of procedure with the Taylor Spatial Frame™

<table>
<thead>
<tr>
<th>Number of patients</th>
<th>Mean age (years)</th>
<th>Mean LLD (cm)</th>
<th>First weightbearing (days)</th>
<th>Beginning of lengthening procedure (days)</th>
<th>Duration of fixator wear (days)</th>
<th>Healing index (days/cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lengthening alone</td>
<td>14</td>
<td>10.5</td>
<td>6.07 (4–10.3)</td>
<td>6 (4–14)</td>
<td>200 (109–271)</td>
<td>35.38 (24.17–45.17)</td>
</tr>
<tr>
<td>Axis correction with or without lengthening</td>
<td>22</td>
<td>11.4</td>
<td>2.35 (0–9)</td>
<td>6 (2–45)</td>
<td>172 (55–365)</td>
<td>41.8 (27.45–63.93)</td>
</tr>
</tbody>
</table>
programming and required simple monitoring with later recuperation of the deformity through bone growth.

Of the 67 deformities identified preoperatively, six residual deformities were found for 91% of the correction objectives reached (Fig. 3B and C).

Of the 36 patients included, 19 (52.8%) presented no complications while wearing the fixator or after its removal. Three patients (8.3%) presented a fracture of the bone regenerate (two treated orthopaedically and one requiring plate osteosynthesis). A superficial skin infection in the fixator pin area was diagnosed in eight cases (22.2%) and treated medically; one case (2.8%) of deep infection required hospitalization for intravenous antibiotic treatment. Five patients (13.9%) presented diverse complications: one case of compartment syndrome, two cases of transitory ankle equinus, and two cases of delayed union.

During postoperative pain assessment, seven patients (19.5%) required prolonged antalgesics; the 29 others (80.5%) required antalgesics only in the immediate postoperative period. The hospital stay lasted a mean seven days (range: 4–17 days).

During the study’s follow-up period, no fixator modification under anesthesia was necessary. The only changes required involved changing struts, which was carried out during the consultation.

Discussion
External fixation has encountered considerable success in many orthopaedic fields with Ilizarov’s work [1] followed by the development of the Taylor Spatial Frame™ in the 1990s by Taylor [2]; however, there are few reports on this technique in the literature. The first cases were reported by Rozbruch et al. [3] on the treatment of two cases of malunion of the tibia. The correction possibilities offered by this procedure were evaluated on series with diverse etiologies. In traumatology, Al-Sayyad [4] reported very good results in the treatment of unstable tibial fractures in children, as did Feldman et al. [5,6] in the management of tibial malunion and tibia vara. Nho et al. [7] had good results using the Taylor Spatial Frame™ to treat septic malunions with temporary shortening to obtain a skin cover before correcting the residual deformity.

The results of hexapodal external fixator treatments are also positive in limb lengthening and axis correction. Sluga et al. [8] and Radler et al. [9] found good results in their series, with a healing index of 48.4 days/cm and 52.73 days/cm, respectively, slightly better than the scores in the series treated with the classical Ilizarov fixator (31.5 days/cm according to Aaron and Eilert [10]).

In our experience, we found a healing index of 38.2 days/cm over the entire series, 35.38 days/cm for cases in which lengthening greater than 4 cm was necessary and 41.8 days/cm for axis correction cases with lengthening, which comes close to the results obtained using the Ilizarov method [10].

Like any external fixation system, one of the most frequent complications encountered is superficial infection in the pin contact area. We identified such infection in 22.2% of the patients studied, all treated medically. These data are also confirmed by the series studied by Eidelman et al. [11], who found them in 45% of the cases.

In terms of deformity corrections, the results obtained using the hexapodal system are at least as good as the results found with classical Ilizarov assemblies in terms of lengthening, with the Taylor fixator providing better correction of rotation, translation, and residual deformity [12–13]. The hexapodal fixator does not prevent deformities during lengthening, but, based on successive follow-up X-rays, it is possible to reprogram the software to correct any residual defects or secondary deviations.

Progressive corrections also provide better results in treating complex lower-limb deformities compared to immediate correction [14–15]. The results of the present study show precise corrections that required no surgical revision to modify the fixator.

In terms of pain, it seems that this external fixation mode causes less pain and that patients have shorter hospital stays than those treated with other types of fixators. The scientific explanation is difficult to find because pain assessment is difficult and subjective. However, in our opinion, it would seem that the lower level of pain is related to the fixator’s shape. The fact that there were six struts positioned diagonally around the ring distributed the stresses more homogeneously around the periphery of the ring, contrary to a fixator with three or four threaded stems perpendicular to the ring and contrary to a unilateral fixator, thus explaining the low level of pain.

The postoperative period was marked by a certain number of known complications that have been described in the literature. However, in our series, no cases of nonunion were diagnosed, probably stemming from the fixator shape, as for pain. Connecting the two rings with six telescopic struts provides an assembly of the stable elastic type that may well promote bone healing.

In conclusion, computer-assisted hexapodal external fixation for treating complex deformities of the lower limbs in children seems to provide good results. The pediatric population tolerates this treatment method well, with little pain during fixator wear. However, like any external method, it exposes the patient to infectious complications that are most often superficial and require medical treatment. The possibility of simultaneous correction of several deformities and correction of residual deformities without having to modify the initial assembly seem particularly advantageous, making the Taylor Spatial Frame™ an important tool in the pediatric surgical armamentarium.

Conflicts of interest
None.

References


