Doctoral Studies in Medicine
Charles University in Prague

Field: Experimental Surgery

Topic: Computer Assisted Deformity Correction using the Taylor Spatial Frame (TSF)

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The Summary of Dissertation was distributed on .................

The Defence of Distribution will be held on ................. at ................. in .................

The Dissertation is available at the Dean's Office of the First Faculty of Medicine of Charles University.
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1 Abstract

The management of multiapical and multidirectional deformities of the lower limb due to different aetiologies is still a challenging task for the orthopaedic surgeon. Internal fixation techniques for deformity correction are normally combined with open osteotomies and acute correction. For complex deformities these methods are restricted by several factors, particularly when additional leg length discrepancy has to be corrected.

In the last decades external fixators, especially the circular Ilizarov fixator, have become popular to correct complex deformities and perform bone lengthening. Despite several advantages, each Ilizarov frame is a special, custom-made construct for a given case. Treatment of multiaxial and especially rotational deformities may be difficult and time-consuming postoperatively due to frame adjustments.

The Taylor Spatial Frame was introduced in 1994 and became popular in the following years. It is a modular circular external fixation system using the same methods of frame attachment and the same gradual correction principles as the Ilizarov device.

It consists of two rings or 2/3 rings connected by six telescopic struts. In conjunction with an internet based software program a virtual hinge can be created to correct simple and most complex deformities with the same frame.

By adjusting only the strut length, calculated by the software, the TSF allows simultaneous six-axis correction without frame modification, even residual deformities may be restored with a second program without any reoperation. Different modes of the software program are available; the Total Residual Program is most helpful.

Despite using the same principles for callus distraction as the Ilizarov device, the computer-operated TSF allows a great number of advantages: The handling of the frame is less time consuming, no difficult changes of hinges are necessary. The duration of the correction time is predictable due to the prescription site, and what’s most important the results of treatment are more accurate than the Ilizarov device as shown in a study.

In 1999 at the Orthopaedic Hospital Vienna-Speising we started to change from the Ilizarov system to the Taylor Spatial Frame for treatment of complex deformities and leg lengthening.

From June 1999 to February 2009 we were able to perform correction of 501 segments with the TSF- system. The patients suffered from congenital and hereditary disorders (Congenital Femoral Deficiency, Fibular Hemimelia, Hypophosphataemia, Skeletal Dysplasia, Achondroplasia, Enchondromatosis, Osteochondromas), after infections and trauma with deformity and growth disturbance and from idiopathic disorders.

For treatment single and multilevel corrections were performed.

The results of follow-up studies have encouraged us to use this new external fixation system.

The Taylor Spatial Frame offers the experienced surgeon an accurate and reproducible correction technique with several advantages compared to previously used devices.
2 Hypothesis

The goal of the thesis was to report the results of leg length and deformity correction using the TSF for selected subgroups of patients. We hypothesized that the TSF allows full correction of multiplanar deformities and restoration of leg length with a minimum of complications. As a contribution of the outcome, the TSF can be recommended in different clinical settings in orthopaedic and traumatologic departments to improve the outcome of deformity correction.

3 Introduction

Modern techniques of callus distraction started with the work of Codivilla \(^9\) at the beginning of the 20\(^{th}\) century. Subsequently, different improvements were described in the following decades \(^59\) by various authors. Especially the introduction of the Ilizarov-Ringfixator by G.A. Ilizarov in the early 1950’s significantly influenced the further development \(^25-28\). The Taylor Spatial Frame, a circular hexapod system, was developed by J.C. and H.S. Taylor in 1994 \(^55\). The frame uses the same methods of frame attachment and the same principles of gradual correction as the Ilizarov device. Due to a software program a simultaneous six-axis correction is possible. Distraction osteogenesis is a method for regenerating new bone formation using gradual mechanical distraction after low-energy osteotomy. Ideal conditions are a stable fixation, an osteotomy in the metaphyseal area and a distraction rate of 1 mm / day. So the regenerate bone can successfully bridge the gap \(^2\).

When dealing with deformities, it is first important to understand the parameters of normal lower limb alignment. Two main aspects have to be taken into consideration: joint alignment and joint orientation \(^24,42,43,52\). Joint alignment refers to the colinearity of the hip, knee and ankle joint in normal limbs. Joint orientation refers to the orientation of each articular surface with respect to the axis of the individual limb segment (femur or tibia). For each long bone of the lower limb a mechanical and anatomic axis line can be defined in the frontal and sagittal plane.

A relationship of malalignment of the lower limbs and degenerative osteoarthritis is obvious, but the natural history of the process has not been adequately documented. Nevertheless, the reestablishing of joint alignment and joint orientation is an accepted goal of deformity correction \(^39\). The problem of altered joint loading through various combinations of frontal, sagittal and rotational deformities is often an indication for deformity correction. Patients also have to deal with esthetic problems, a limited range of joint motion and pathologic gait pattern. Leg length difference is not an uncommon additional deformity. Deformity corrections can be performed by different methods of fixation, internal and external procedures are available. The choice of hardware is dependent on various factors: age of the patient (open growth plate), level and number of osteotomies, type of osteotomy, acute or gradual correction, bone-, soft tissue- and joint factors \(^39\). In case of complex, mostly multiapical deformities the use of external fixators is often indicated \(^3,14,49,50,57\). With these devices an additional leg length difference can be corrected simultaneously. By the use of gradual correction also soft-tissue compromise may be present, residual deformities can be corrected simply by frame adjustments without reoperation.
Various diseases and syndromes may result in deformities of the lower extremities, each of them have their own properties, which have to be considered. Congenital deformities like Congenital Femoral Deficiency and Fibular Hemimelia, posttraumatic, postinfectious and hereditary deformities, and various idiopathic diseases.

4 Materials

Angular deviations of the femur or tibia induce angulation of the bone, but also of its axes. To identify the true source of the apex of the deformity, Paley and Tetsworth designed the so called Malalignment Test (MAT)\textsuperscript{42,43}. Normally the mechanical axis of the lower limb passes immediately medial to the center of the knee joint (4 – 14 mm medial)\textsuperscript{24,39}. The perpendicular distance from the mechanical axis line to the center of the knee is called Mechanical Axis Deviation (MAD). Abnormal MAD affects the knee, hip and ankle joint and leads to the loss of collinearity of these joints in the frontal plane.

When a bone is angulated, its mechanical and anatomical axes are also angulated and divided into a proximal and distal segment. The proximal and the distal line intersect in the so called Center of Rotation of Angulation (CORA) and form an angle, which characterizes the magnitude of the deformity. The CORA can appear at any level of the bone. Anatomical and mechanical planning methods are used to find the level of the CORA. These methods can be used both in the frontal and sagittal plane.

To correct an angular deformity, two basic osteotomy types can be defined: (1) angulation osteotomies and (2) angulation and translation osteotomies. The correction is performed around the Angulation Correction Axis (ACA). If the ACA is at the same level of the osteotomy, an open or closed wedge angulation will result at the level of the osteotomy. If the ACA is at a different level from the osteotomy line, an angulation and translation will occur at the osteotomy site\textsuperscript{39}.

Three osteotomy rules can be used:

Osteotomy rule 1 (according to Paley): When the osteotomy and the ACA pass through the CORA realignment occurs just with angulation without translation. An open or closed wedge osteotomy can result.

Osteotomy rule 2: When the ACA is through the CORA but the osteotomy is at a different level, the axis will realign by angulation and translation at the osteotomy site. Osteotomy rule 3: When the osteotomy and the ACA are at a level above or below the CORA, a translation deformity will result at the osteotomy site.

To measure frontal plane alignment, long standing radiographs of both lower extremities are preferred for the anterior-posterior view. The true AP view is obtained with the patella in a straight forward position. If there is a leg length difference, the discrepancy should be compensated with blocks to avoid mistakes due to compensatory mechanisms such as contralateral knee flexion\textsuperscript{39}.

The Taylor Spatial Frame (TSF)

In 1994 J.C. and H.S. Taylor introduced the Taylor Spatial Frame (TSF, Smith & Nephew, Memphis, TN, USA), a circular external hexapod fixation system, which allows correction of the simplest to the most complex skeletal deformities using the same frame. It consists of two full rings or two-third rings connected by six telescopic struts at special universal joints. By adjusting strut length only, one ring can be repositioned with respect to the other to correct all aspects of a six-axis deformity simultaneously. Strut length adjustments are calculated by an associated web-based software program and can easily be performed by the patient according to a provided
daily time schedule. Full and two-third rings are available in different sizes; the
telescopic struts are available in two different types and different lengths.
While each Ilizarov fixator is a custom made construction for a given deformity, the
handling of the frame can be more time consuming, difficult changes of hinges and
other devices may be necessary in complex deformity correction.
The TSF can correct simultaneously most complex multiplanar deformities with the
same frame construction and the support of a web-based internet program.
During surgery an orthogonal reference ring placement is strongly recommended,
both in the frontal and sagittal plane. Tensioned wires and half pins are used as a
hybrid method for the fixation of the rings at the bone, followed by a percutaneous
osteotomy.
Using the TSF, both the proximal and the distal fragment can act as the reference
fragment. The reference ring should be close to a joint line, which acts as a
landmark. After determination of the reference and the moving fragment, the Origin
and the Corresponding Point have to be defined. Origin and Corresponding Point
coincide after correction has finished. The Origin, which works as a virtual hinge, may
be chosen at any point along the reference fragment axis, as long as its
Corresponding Point can be identified at the axis of the moving fragment. The CORA
is a good choice for the Origin in many cases, especially in chronic deformities.
To correct a specific deformity with the TSF, several parameters have to be inserted
in the web-based software. The type and size of the rings and the type of the struts
have to be entered into the Frame Site. All deformity parameter measurements are
made relative to the reference fragment. An analysis of AP and lateral radiographs
and a clinical examination to determine malrotation are required.
A total of six deformity parameters are required to describe a single deformity: (1) AP
view angulation, varus or valgus; (2) lateral view angulation, procurvatum or
recurvatum; (3) axial view angulation, external or internal rotation; (4) AP view
translation, medial or lateral; (5) lateral view translation, anterior or posterior; (6) axial
view translation, short or long.
The mounting parameters characterize the position of the reference ring on the limb
with respect to the position of the origin. Four parameters have to be inserted: (1)
AP view frame offset, medial or lateral offset of the center of the reference ring to the
Origin; (2) lateral view frame offset, anterior or posterior offset; (3) axial frame offset,
proximal or distal offset of the reference ring; (4) rotary frame offset, the degree of
rotation between the master tab and the designated AP plane.
There are some more obligatory sites in the software program: The Report Site
provides a summary of all the input and output information, including a daily
prescription schedule for the patient.
Using the software, the Total Residual Deformity Method is mostly applied for
deformity correction. It can be described as the "crooked frame on crooked bone". The
software will calculate the final strut length to correct the deformity.

5 Patients and Method

We retrospectively analyzed our prospective database of patients being treated with
external fixation using the Taylor Spatial Frame which was started in June 1999.
We included all patients in whom correction and limb lengthening was performed with
the TSF. Between June 1999 and February 2009 a total of 320 patients were treated
with 501 Taylor Spatial Frames. Eleven cases with arthrodeses of the knee or ankle
joint were excluded. This left 309 patients with 490 cases for further analysis (distal femur 135 cases, proximal tibia 251 cases, distal tibia 14 cases, bi-level tibia 45 cases (90 frames).

There were 150 females and 160 males. The average age at operation was 17.52 years (2.86 to 72.35 years), the average duration of external fixation was 5.99 month (0.90 to 17.87 month).

Subgroups were defined, allowing analysis according to the different aetiologies. The diagnosis of Congenital Femoral Deficiency (CFD) was present in 38 patients, Fibular Hemimelia or Fibular Aplasia (FH/FA) in 44 patients, posttraumatic deformities (PT) in 63 patients, postinfectious deformities (PI) in 10 patients, hereditary deformities due to different syndromes (HER) in 112 patients, idiopathic deformities (IDIO) in 34 patients, and Congenital Pseudarthrosis of the Tibia (CPT) in 8 patients.

Patients with posttraumatic malalignment and shortening, and patients with congenital femoral deficiency were analyzed separately and more in detail. Additionally the external fixation index, the radiological and clinical outcome and complications of the procedure were described.

A study of posttraumatic patients was performed in 2005 including 22 patients with 25 corrections, operated between 2000 and 2004 with a minimum follow-up of 6 month. The deformities were classified into three groups according to the affected bone and the osteotomy level.

Another study was performed in 2008 reviewing 31 patients with 35 operative procedures between 1998 and 2007 suffering from Congenital Femoral Deficiency (CFD). The radiological and clinical outcome was assessed. Problems, obstacles and complications were described in detail; solutions were presented to avoid them.

6 Results

Results of the complete TSF-database:
From the 309 patients with 490 TSF-cases 7 subgroups were analyzed:

Group 1: Congenital Femoral Deficiency (CFD): Thirty-eight patients with 49 frames could be evaluated. Several patients had repeated surgeries because of recurrence of leg length difference or deformity during growth. The average age at operation was 10.83 years (3.45 to 41.03 years). The average duration of external fixation was 6.21 months (2.63 to 9.57 months).

Group 2: Fibular Hemimelia and Fibular Aplasia (FH/FA): Forty-four patients with 78 frames were found. In this group patients had single or bi-level osteotomies and bilateral or repeated surgeries. The average age at operation was 9.98 years (2.86 to 24.91 years); the average duration of external fixation was 5.63 months (1.63 to 10.57 months).

Group 3: Posttraumatic deformities (PT): Sixty-three patients with 85 frames could be analyzed. The average age at operation was 26.20 years (6.66 to 61.68 years); the average duration of external fixation was 6.81 months (0.90 to 14.73 months).

Group 4: Postinfectious deformities (PI): Ten patients with 19 frames could be evaluated. The average age at operation was 22.12 years (8.12 to 45.89 years); the average duration of external fixation was 7.73 months (4.20 to 9.70 months).

Group 5: Hereditary deformities (HER): Different syndromes and aetiologies were summarized in this group. One hundred-twelve patients with 198 frames could be evaluated. The average age at operation was 15.86 years (3.68 to 65.16 years). The average duration of external fixation was 5.83 months (2.20 to 17.87 months).
Group 6: Idiopathic deformities (IDIO): Thirty-four patients with 49 frames could be evaluated. The average age at operation was 24.24 years (7.50 to 72.35 years). The average duration of external fixation was 5.44 months (3.07 to 11.77 months).

Group 7: Congenital Pseudarthrosis of the Tibia (CPT): Eight patients with 12 frames could be evaluated. The average age at operation was 19.57 years (3.79 to 53.45 years); the average duration of external fixation was 7.32 months (3.03 to 9.83 months).

Accuracy of the TSF in comparison with the Ilizarov fixator (IRF)
In 2005 a study was performed at the Orthopaedic Hospital Vienna-Speising to compare the accuracy of deformity correction in the lower limb between the TSF and the Ilizarov ringfixator (IRF). The goal was to compare the final result after frame removal with the initial aim of deformity correction and lengthening.

Patients and methods: In a retrospective review, a total of 208 lower-limb deformity corrections in 155 patients operated either with the TSF or IRF between January 1985 and December 2004 were included in this study. The IRF was used in 79 cases; the TSF was used in 129 cases. The mean age at the time of operation was 13.2 years (range 2-49 years). Femoral corrections were performed in 58 cases; tibial corrections in 150 cases. For evaluation of the result, the final result was compared with the initial aim of deformity correction to assess the accuracy of both methods.

Specification of the type of deformity correction: Four types of deformity correction were specified:
- Type I: (one-dimensional deformity correction, 1D): all cases with leg lengthening only, without any axial correction.
- Type II: (two-dimensional deformity correction): all cases with leg lengthening and additional axial correction in one plane (frontal, sagittal, rotational).
- Type III: (three-dimensional deformity correction): all cases with leg lengthening and additional axial correction in two planes (frontal, sagittal, rotational).
- Type IV: (four-dimensional deformity correction): all cases with leg lengthening and additional axial correction in three planes (frontal, sagittal, rotational).

Results:
Dimensions of gradual deformity corrections:
Leg lengthening procedures (Type I) were performed in a significantly \((P < 0.05)\) higher percentage in the IRF-group (36.7%) than in the TSF-group (10.9%). The majority of cases consisted of Type II corrections with comparable percentages in both groups (IRF: 44.3%; TSF: 47.2%). In the group of Type III corrections, a significantly \((P < 0.05)\) higher percentage of cases was treated with the TSF (34.9%) than with the IRF (17.7%). In the group of Type IV corrections, again a significantly \((P < 0.05)\) higher percentage was treated with the TSF (7.0%) than with the IRF (1.3%).

Persistent axial deformity in the IRF and TSF group:
Of the 79 cases treated with the IRF, there was no residual deformity in 44 cases (55.7%). In the remaining 35 cases (44.3%) a persistent deformity was evident after frame removal. A minor deformity (<5°) was evident in 11 cases (13.9%), a moderate deformity (6-10°) was evident in 16 cases (20.3%), and a severe deformity (>10°) was present in 8 cases (10.1%).

Of the 129 cases treated with TSF, there was no residual deformity in 117 cases (90.7%). In the remaining 12 cases (9.3%) a persistent deformity could be measured after frame removal. A minor deformity was evident in 7 cases (5.4%), a moderate deformity in 1 case (0.8%), and a severe persisting deformity was present in 4 cases (3.1%).
Persistent axial deformity in connection with the dimensionality of the deformity correction:
In both groups, one essential finding was obvious. With rising dimensions of axial corrections, an increasing percentage of residual deformities could be seen.
The goal of treatment in Type I - corrections was achieved in 79.3% of the IRF-cases and in 100% of the TSF-cases ($P < 0.05$).
The goal of treatment in Type II - corrections was achieved in 48.6% of the IRF-cases and in 91.8% of the TSF-cases ($P < 0.05$).
The goal of treatment in Type III - corrections was achieved in 28.6% of the IRF-cases and in 91.1% of the TSF-cases ($P < 0.05$).
The goal of treatment in Type IV - corrections was not achieved in the single IRF-case, but it was achieved in 66.7% of the TSF-cases.
In conclusion the accuracy-study showed clear advantages of the TSF compared to the Ilizarov ringfixator. Especially in complex multiplanar deformities the TSF allowed much higher precision, whereas treatment with the Ilizarov fixator in multidimensional deformities more often resulted in residual malalignment.

Results of Posttraumatic Deformity Correction in the Lower Extremity using the TSF
A subgroup analysis reviewing posttraumatic patients was performed in 2005 as part of a student’s master thesis, the results were published in 2009.
The aim of the study was to evaluate the results of treatment in patients suffering from posttraumatic deformities at the lower extremities using the Taylor Spatial Frame (TSF).

Patients and methods: In the period from February 2000 to January 2004, 22 patients were included in this consecutive retrospective clinical and radiological study. 11 female and 11 male patients underwent deformity correction. The mean age of the patients at the occurrence of trauma was 14.3 years (2 to 46 years). The mean age at the time of correction was 22.7 years (12 to 48 years). The mean period between occurrence of trauma and deformity correction was 8.2 years (0.5 to 27 years). The mean duration of follow up was 21.1 months (12 to 43 months).
A total of 24 limb segments (9 femurs, 15 tibias) in 22 Patients were treated for lengthening, mostly with simultaneous gradual deformity correction because of their concomitant axial or rotational deformity.
The deformities were classified into three groups according to the affected bone and the osteotomy level. 9 deformities located in the femur formed group 1. Group 2 consisted of 9 proximal tibial deformities and group 3 consisted of 7 distal tibial deformities. A total of 25 lengthening and correction procedures were studied.

Results: Group 1 (distal femur): This group consisted of 9 cases, 6 valgus- and 3 varus deformities were treated, additionally one flexion- and one rotational deformity was corrected.
The mean mLDFA preoperatively was $84.4^\circ \pm 9.8^\circ$ ($64^\circ$ to $100^\circ$). The mean mLDFA postoperatively was $88.3^\circ \pm 1.5^\circ$ ($85^\circ$ to $90^\circ$). The mean difference between the pre- and postoperative mLDFA was $8.11^\circ \pm 7.0^\circ$ ($2^\circ$ to $26^\circ$).
The mean MAD preoperatively was $36.8 \text{ mm } \pm 18.3 \text{ mm}$ (10 to 80 mm). The mean MAD postoperatively was $7.1 \text{ mm } \pm 5.2 \text{ mm}$ (2 to 17 mm). The mean difference between the pre- and postoperative MAD was $31.7 \text{ mm } \pm 18.2 \text{ mm}$ (8 to 76 mm).
The mean amount of lengthening was $33.3 \text{ mm } \pm 15.6 \text{ mm}$ (15 to 62 mm).
The mean duration of external fixation was $5.8 \pm 1.3 \text{ months}$ (4 to 8.2 months). The mean external fixation index was $2.2 \pm 1.0 \text{ months per centimetre}$ (1.0 to 3.7 months per centimetre).
Group 2 (proximal tibia): This group consisted of 9 cases. Lengthening was performed in all of them. 5 valgus-, 1 rotational- and 3 recurvatum deformities were treated. The mean magnitude of preoperative leg length difference was 23.4 mm ± 13.3 mm (3 to 48 mm). Preoperatively the MPTA was outside normal range (85°-90°) in five cases. The mean value of these five cases was 92.4° ± 1.5° (91° to 95°). The mean MPTA postoperatively was 88.6° ± 1.7° (87° to 92°). The mean difference between the pre- and postoperative MPTA was 3.6° ± 1.0° (2° to 5°). The mean MAD preoperatively of all cases was 14.7 mm ± 13.3 mm (1 to 38 mm); it was outside normal range in 5 cases. The mean MAD postoperatively in all cases was 6.0 mm ± 4.4 mm (0 to 17 mm). The mean difference between the pre- and postoperative MAD was 10.7 mm ± 8.7 mm (1 to 35 mm). Preoperatively the PPTA was outside normal range (77°-84°) in 4 cases. The mean preoperative PPTA was 96.7° ± 5.3° (90° to 103°). Postoperatively the mean PPTA was 82° ± 0.8° (81° to 83°). The mean amount of lengthening was 24.0 mm ± 12.0 mm (7 to 52 mm). The mean duration of external fixation was 6.0 ± 2.2 months (2.1 to 10.6 months). The mean external fixation index was 3.0 ± 1.1 months per centimetre (1.4 to 4.7 months per centimetre).

Group 3 (distal tibia): This group consists of 7 cases; all of them were treated with lengthening and axial correction. 5 varus-, 1 valgus- 1 rotational- and 1 extension deformities were corrected. The mean magnitude of preoperative leg length difference was 25.8 mm ± 14.4 mm (8 to 49 mm). In 6 cases the LDTA was outside normal range (86°-92°). The mean preoperative value of these cases was 101° ± 13.1° (80° to 120°). The mean LDTA postoperatively was 90.3° ± 2.9° (84° to 93°). The mean difference between the pre- and postoperative LDTA was 14.3° ± 9.1° (5° to 28°).

The mean amount of lengthening was 22.3 mm ± 13.1 mm (3 to 44 mm). The mean duration of external fixation was 6.2 ± 1.4 months (4.8 to 9.3 months). The mean external fixation index was 4.8 ± 4.7 months per centimetre (1.2 to 16 months per centimetre).

Amount of lengthening and external fixation index in all cases: The overall mean preoperative leg length discrepancy was 27.6 mm ± 14.7 mm (3 mm to 61 mm). The mean amount of lengthening was 27.0 mm ± 14.8 mm (3 mm to 62 mm). The mean duration of external fixation was 6.0 ± 1.7 months (2.1 to 10.6 months). The mean external fixation index of all corrections was 3.2 ± 2.9 months per centimeter (1.0 to 16 months per centimeter). For lengthenings smaller than 30 mm the mean external fixation index was higher, and the variation of the index was larger than the index and the variation for lengthenings of 30 mm and more.

The mean external fixation index of femoral corrections was lower than the index of proximal tibial and distal tibial corrections. The index of proximal tibial correction was lower than the index of distal tibial corrections. In conclusion the outcome of this study encouraged us to continue the use of the Taylor Spatial Frame for correction of posttraumatic deformities. Complex multiplanar deformities could be treated simultaneously with minimal morbidity.

To avoid development or deterioration of osteoarthritis of the ankle joint due to a long period of immobilization in case of distal tibial malalignment and substantive shortening, we now today recommend the application of a tibial bi-level frame with proximal lengthening and just axial correction distally to minimize the time of immobilization of the ankle joint.
Complications after femoral lengthening in Congenital Femoral Deficiency (CFD) using the Ilizarov / Taylor Spatial Frame (TSF)

The aim of this study, performed in 2008, was to analyze the results and the complication rate of limb lengthening and deformity correction in CFD using external ring fixation. We hypothesized that new techniques and increasing experience are able to decrease the complication rate over the observed 10-year period.

Patients and methods: We retrospectively reviewed a consecutive series of 31 patients suffering from CFD between the age of 3.3 years and 17 years (mean 9.3 y) with 35 lengthening procedures. Additionally in 17 patients a fibular hemimelia or aplasia could be found.

Surgical treatment was performed between 1998 and 2007, either the Ilizarov fixator (10 cases) or the Taylor Spatial Frame (25 cases) was used. Rotational deformities were corrected with an additional proximal osteotomy (11 cases). In case of AP-instability the frame was extended over the knee (24 cases).

Results: After using our exclusion criteria, 31 patients with 35 lengthening procedures were analyzed. The mean preoperative shortening of the involved limb was 62.2 mm (32 to 125 mm). The mean shortening of the femur was 43.6 mm (14 to 107 mm); the mean tibial shortening was 11.8 mm (20 mm overlength to 48 mm short).

The mean MAD preoperatively was 18 mm lateral (42 mm medial to 70 mm lateral). The mean mLDFA preoperatively was 84° (78° to 110°). Three patients with a LDFA greater than 90 degrees had had previous operations elsewhere.

The mean MPTA preoperatively was 91° (80° to 110°).

The mean amount of lengthening at the femur was 44.3 mm (10 to 85 mm); nine patients had a simultaneous tibial lengthening of 24.2 mm (10 to 35 mm). The total amount was 50.5 mm (28 to 85 mm).

After frame removal a residual leg length difference of 11.7 mm (11 mm overlength to 60 mm shortening) could be evaluated. Postoperatively the mean MAD was 1.2 mm medial (20 mm medial to 38 mm lateral); the mean mLDFA was 89.3° (83° to 105°), the mean MPTA was 89.7° (82° to 102°).

The mean follow-up time was 35.8 months (6 to 9 months). At that time the mean MAD was 16.2 mm lateral (18 mm medial to 90 mm lateral); the mean mLDFA 87.3° (82° to 99°); the mean MPTA was 91.4° (85° to 113°). In patients with accessory fibular hemimelia a recurrence of valgus deformity could be seen frequently.

The mean duration of external fixation was 6.3 months (3.2 to 9.7 months). The mean external fixation index was 47.8 days/centimeter (21 to 127 days/centimeter).

Problems, obstacles and complications: Pin infections could be seen as a problem in nearly all patients, at least once, and were treated with oral antibiotics. Obstacless were evaluated in 12 cases. Three half-pins had to be removed due to infections. Nine fractures of the regenerate bone occurred after frame removal and required intramedullary rodding. Sixteen patients showed complications. As a major complication 4 patients developed a dislocation of the knee joint during lengthening in spite of spanning the frame over the joint. This resulted in decreased range of motion of the knee.

As a minor complication 4 patients showed a mLDFA outside normal range (93° to 99°). In 3 patients it was the result of fracture and insufficient reposition of the bone. In eight patients a reduced rate of knee flexion (less than 120°) could be evaluated. Six of them had a short follow-up time between 6 and 9 months, and continued physiotherapy.

In conclusion, despite several complications, ring fixators, especially the Taylor Spatial Frame, are an effective method to treat these rare and complex deformities.
The complication rate can be decreased with experience. The knowledge of possible complications can help to avoid them.

7 Discussion

The Taylor Spatial Frame can be used for correction of simple to the most complex multiplanar deformities using the same frame construction. A web based computer program calculates the daily strut length adjustments to perform the simultaneous six-axis correction. The TSF can be used in the majority of aetiologies and deformities; it can be used in different age groups, as shown in the review of our complete TSF-database.

We separately analyzed a subgroup of 31 CFD-patients with 35 procedures. Lengthening and deformity correction in CFD is frequently associated with a higher complication rate, as the adjacent joints and the soft tissue formation lead to problems. Grill and Dungl described 2 dislocations of the hip joint in case of previous existing dysplasia in a series of 37 CFD-patients. Suzuki found 5 dislocations in 12 lengthening procedures with a CE-angle less than 20°. No case of hip dislocation was found in our series. To improve the coverage of the femoral head, 3 operative procedures were prophylactically performed at the acetabulum before lengthening to prevent joint dislocation.

In the case of congenital aplasia of the cruciate ligaments, dislocation of the knee joint during lengthening may result. Paley recommended spanning the frame over the knee joint, using flexible hinges and physiotherapy. In our series we extended the frame over the knee in 27 of 35 cases. Despite that prophylactic procedure 4 of 35 knee joints dislocated during the lengthening period and required further surgical treatment. All of them showed a reduced range of motion at the time of follow-up.

In eight patients a reduced rate of knee flexion (less than 120°) was evaluated. Six of them had a short follow-up time between 6 and 9 months, and continued physiotherapy.

In CFD-patients, fractures of the regenerate bone after frame removal are a common complication described in the literature, resulting in loss of length and malalignment. Danzinger found a fracture rate after frame removal in 22% of posttraumatic cases, whereas the rate was 45% in patients with CFD. In our series, 9 of 35 cases (25.7%) fractured after removal of the frame. These patients were treated with rodding and casting. As prevention, we now perform prophylactic rodding after frame removal in all patients after antibiotic treatment during five days.

Axial malalignment after deformity correction may be a possible complication. In his heterogeneous group of 55 deformity patients Naqui described a rate of 12 patients (21.8%) with frontal deviation less than 5 degrees; 3 patients showed a deformity more than 5 degrees. In our group 4 patients (11.4%) showed a mLdFA outside normal range (93° to 99°). In 3 patients, it was the result of fracture and insufficient reposition of the bony ends.

Dahl and Brownlow described a lower frequency of complications with increasing experience. We analyzed our problems and complications in the first and the second five-year period. There was no difference assessing the superficial pin infections. Three of our four knee joint dislocations occurred in the first period, whereas just one could be found in the second period. After prophylactic rodding of the bone after frame removal, no more fractures were seen. With greater experience, however, we were able to reduce the complication rate of joint dislocation and fracture of the regenerate bone.
Manner\textsuperscript{32} described a higher accuracy of the Taylor Spatial Frame compared to the Ilizarov fixator, especially in four-dimensional deformity correction (3 planes and shortening). In CFD-patients mostly a two-dimensional deformity (valgus and shortening) can be estimated. Therefore, in our series no significant difference could be found between the TSF and the Ilizarov group in terms of deformity correction and joint dislocation.

In a second subgroup, 22 patients with 25 posttraumatic deformity corrections were analyzed in detail\textsuperscript{17,52}. The goal was to study the accuracy of the Taylor Spatial Frame, the clinical outcome, and the rate of complications. Tetsworth\textsuperscript{56} studied the accuracy of correction of complex deformities of the lower extremities with the Ilizarov fixator. In 8 of 14 cases (57%), the mLDFA was restored within 3 degrees of the normal value. In 17 of 22 cases (77%), the MPTA was restored within 3 degrees of the normal value. In 22 of 28 limbs (79%), the postoperative MAD was within normal range. Feldman\textsuperscript{14} reported excellent results in correction of tibia vara using the Taylor Spatial Frame. In 21 of 22 tibias (95.4%) he achieved a postoperative MPTA within 3 degrees of the normal range. The preoperative MAD was 53.9 mm medial in average, the postoperative MAD was smaller than 10 mm in all cases.

In our study, in the frontal plane, 19 of 25 joint orientation angles were outside normal range. Seventeen of these (89.4%) could be restored within 2 degrees of normal values. In the sagittal plane, 4 of 25 angles were outside normal range. All of them could be normalized within 2 degrees. MAD was restored in 15 of 18 cases (83.3%) within 7 mm of normal value.

Decreased range of motion during and after lengthening was reported by several authors. Herzenberg\textsuperscript{23} investigated the range of motion of the knee joint while lengthening with the Ilizarov fixator. After a mean lengthening of 6 centimeters, 2 of 25 patients (8%) had lost more than 15 percent of their preoperative flexion at their latest follow-up examination. The average follow-up flexion was 94 percent of the preoperative flexion. In our study, in 19 of 22 patients (86.3%) the range of motion of the knee and ankle joint could be normalized at the last follow-up examination. One of the 9 distal femur patients (11.1%) lost more than 15 percent of his preoperative flexion. Two of the 7 distal tibia patients (28.5%) showed reduced dorsiflexion of the ankle joint and radiological signs of osteoarthritis at the latest follow-up.

Different factors can influence the consolidation of the regenerate bone, and therefore the duration of treatment. Paley\textsuperscript{40} compared the results of lengthening with the Ilizarov device between 12 adult and 48 pediatric patients. Patients older than 20 years healed more slowly than younger. Fischgrund\textsuperscript{15} analyzed the variables in 114 patients with 140 limb lengthenings. Again, patients younger than 20 years healed faster than older ones. Metaphyseal lengthenings healed faster than diaphyseal procedures. Bi-level lengthening reduced the total external fixation time. Femoral lengthenings healed faster than in the tibia. Another important finding was that the external fixation index decreases with increasing the amount of lengthening.

In our study the femoral corrections had a lower external fixation index than in the tibia, the proximal tibia had a lower index than in the distal tibia. Patients younger than 20 years had a lower index than older ones. The external fixation index showed a huge variation in the group with mainly axial correction and short lengthening distance, whereas in lengthening procedures more than 30 mm it was similar to other reports.
In conclusion, the Taylor Spatial Frame offers several advantages compared to other lengthening devices. It allows simultaneous correction in any dimension, even in complex multiplanar deformities, following the same principles of osteogenesis than the Ilizarov fixator. A virtual hinge can be created at any position to perform the correction without difficult exchange of hinges. A web-based internet program helps to create the prescription schedule for strut adjustment, which can be handled very easily by the patients. Several studies have shown the high accuracy of the system. For those reasons, the TSF has achieved high acceptance for bone lengthening, deformity correction and fracture treatment, both in the group of surgeons and patients.

8 References


9 Publications

Publications in Extenso related to the present study:


Publications in Extenso not related to the present study:


IF = 0,573