Journal of Clinical and Investigative Surgery

https://doi.org/10.25083/2559-5555
https://proscholar.org/jcis/
ISSN: 2559-5555

Correction of all deformities in a single planned session with the application of a spider frame fixator

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ABSTRACT

Objectives. This study aimed to demonstrate the simultaneous correction of all deformities with the Spider Frame computer-assisted external fixation system, to determine the characteristics of the application technique, and to evaluate its effectiveness, complications and results. *Materials and Methods*. The evaluation was performed on 22 patients treated with a spider frame between 2012 and 2014. The lengthening amount, union status and bone angles were evaluated radiologically on the pre and postoperative orthoroentgenograms. In the preoperative evaluation, the Paley difficulty scale was used; the postoperative bone and functional results were evaluated according to the Paley criteria. The external fixator index and distraction index were evaluated. *Results*. The mean score of the Paley difficulty scale applied preoperatively, was 4.5 (range, 1-10). The mean duration of the fixator was 199 days (range, 104-300 days). The mean external fixator index was 105.3 day/cm (range, 38-300 day/cm). The mean distraction index was 11.4 day/cm (range, 7-22 day/cm). According to the Paley criteria, excellent and good results were obtained in 75% and moderate results in 25% of cases involving the femur. In the tibia cases, excellent and good functional results were obtained in 83.3% and excellent and good bone results in 91.6% patients. *Conclusion*. In cases of deformity, acute fracture and non-union, the computer-assisted external fixator system (spider frame®) without any modification provides single-stage correction by allowing postoperative intervention to the deformity. It is a new generation external fixator system which has shown successful functional results, and can therefore be considered for use.

Category: Original Research Paper

Received: July 3, 2022
Accepted: September 14, 2022
Published: November 20, 2022

Keywords:

deformity correction, external fixator, hexapod, spider frame

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Introduction

External fixators are rigid fixation devices that cause less damage to the bone periosteal circulation and soft tissues compared to intramedullary nail and screw plate fixations. Therefore, the use of an external fixator is a treatment of choice for fracture patients with poor skin structure (peripheral vascular disease, diabetes mellitus, Charcot disease, etc.) [1]. For the success of the external fixator, the biomechanics of the system are as important as the application technique. The system should always be stable and able to provide rigidity when needed. Stabilization is the maintenance of the mechanical configuration of the system, while rigidity is the mechanical response to the forces applied to the system. Although stabilization is essential for fixation, rigidity can negatively affect fracture healing. Dynamization can be applied to the system to prevent this negative effect [2,3]. With the hinge system used in classical Ilizarov methods, only angular deformities can be corrected, but rotational or translational deformities cannot be restored. This requires fixator system modification in complex limb deformities. Spatial fixators work in the same way as the principles described by Ilizarov but with different techniques. In this system, multi-orientation 2D imaging of the deformity is analyzed with computer software, and simultaneous corrections of all plane deformities are planned according to the prescription of the software. In accordance with the prescription, the length of the rods on the frame is changed daily by the doctor or the patient, and correction is achieved within the appropriate time (Figures 1-4) [4].

To cite this article: Saygılı MS, Tekin AÇ, Adaş M, Ayaz MB, Ergün T, Kalkar İ, Esenyel CZ, Gürbüz H. Correction of all deformities in a single planned session with the application of a spider frame fixator. *J Clin Investig Surg*. 2022;7(2):117-123. doi: 10.25083/2559.5555/7.2.1

The aim of this study was to show the successful and controlled treatment of complex deformities with a spider frame without the need for secondary surgery.

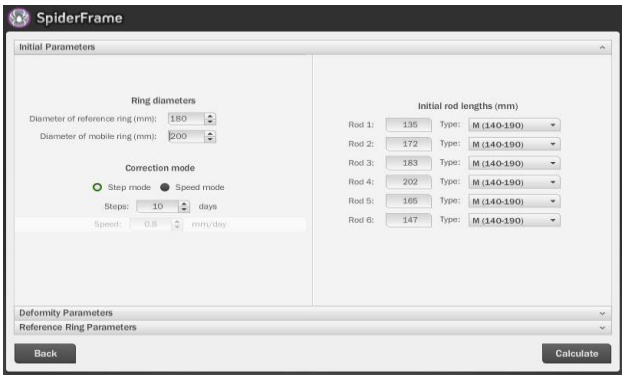

Figure 1. Entering the frame parameters into the system

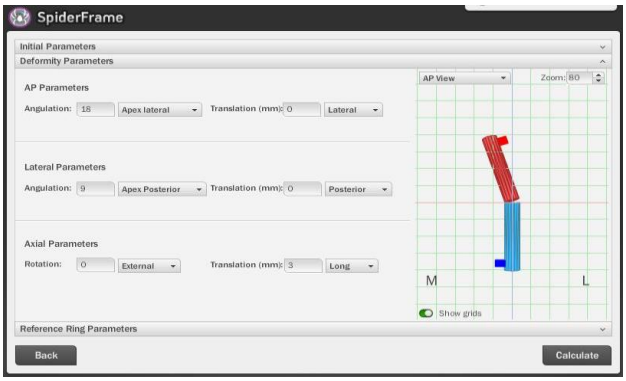

Figure 2. Deformity parameters calculated by the program after drawings

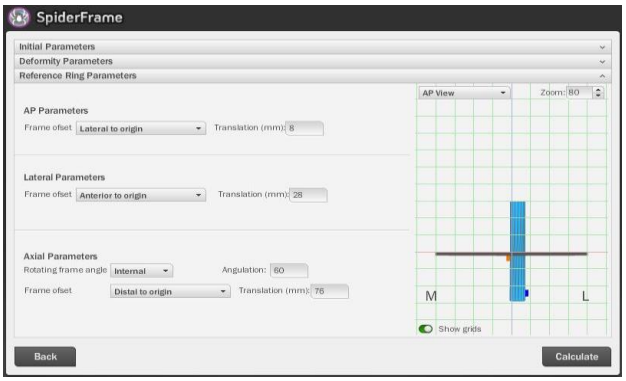

Figure 3. Assembly parameters calculated by the program after drawings

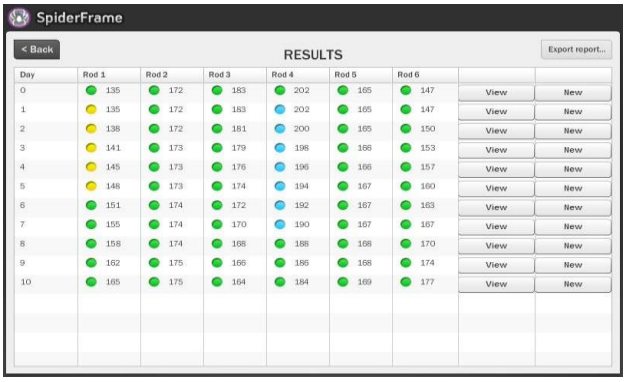

Figure 4. Correction prescription given by the program at the end of the calculations

Materials and Methods

Approval for the study was granted by the Clinical Ethics Committee of Okmeydani Training and Research Hospital, Istanbul (decision no 225, dated 09.09.2014).

The study included 22 patients who were treated with surgery and the application of a spider frame spatial fixator for deformity, fracture or non-union between 2012-2014 in Okmeydani Training and Research Hospital.

The 22 patients comprised 9 (40.9%) females and 13 (59.1%) males with a mean age of 34.81 years (range, 5-84 years). Late admitted tibia fracture was determined in 4 patients, non-union in 3, and deformity in 15 patients. Non-union was determined in the femur in 1 patient and in the tibia in 2 patients. The deformity cases comprised 6 tibia, 7 femur, 1 metatarsal and 1 radius.

The etiologies of the deformity cases were 4 malunion, 1 perthes sequelae, 1 osteogenesis imperfecta, 2 firearms injuries, 1 multiple enchondromatosis, and 6 were congenital deformities.

Of the total 22 patients, 9 deformities were in the oblique plane, 6 in the coronal plane, 1 in the sagittal plane, 2 were isolated rotational deformity, and 4 patients had isolated shortness.

In the radiological examination, orthoroentgenography, direct radiographs and in cases thought to have rotational deformity, computed tomography (CT) were used. By drawing the mechanical axis on the orthoroentgenographs, it was examined whether or not the mechanical axis passed through the center of the knee joint. Deformity analysis was made on the orthoroentgenographs.

When evaluating the patients and results, the Paley Difficulty Scale was used preoperatively. Cases were classified on this scale as mild (0-6 points), moderate (7-11 points) and difficult (>12 points) [5]. The presence of residual deformity was examined by repeating the deformity analysis on the orthoroentgenograph after removal of the postoperative external fixator. In the follow-up after removal of the fixator, the functional and bone results of the tibial lengthening were evaluated with the Paley criteria modified by Asami [6]. When evaluating the femoral lengthening results, the scoring system described by Paley formed from the clinical and radiological parameters, was used. According to this scoring system, scores are evaluated as excellent (95-100), good (75-94), moderate (40-74) or poor (<40). For all patients, the distraction index and the external fixator index values were calculated. These are obtained by dividing the duration of distraction by the total gained length and the duration of external fixator application divided by the total gained length.

Statistical Analysis

SPSS for Windows version 15.0 software (SPSS Inc., Chicago, IL, USA) was used for statistical analysis.

Descriptive statistics of the data were stated as mean ± standard deviation, median minimum and maximum values, frequency (n) and percentage (%).

Surgical technique

The patients were placed on the operating table in the supine position. At 1 hour before surgery, 1 g of the first-generation cephalosporin was administered as prophylaxis. A support was placed below the hip to position the patella in the midline. Preoperatively, bone images were taken with fluoroscopy to determine the appropriate locations of the device, and plasters were placed on the floor as markers. This enables less fluoroscopy to be used during surgery with less radiation exposure for the patient and the surgical team. After skin preparation, sterile supports were placed under the knee and the ankle and it was verified that the extremity was parallel to the ground. The fluoroscopy was positioned on the opposite side of the surgeon.

The size of the spider frame ring to be used is determined before surgery. It must be ensured that the rings are at least 2 cm away from the skin. A partial ring can be used instead of the full ring, especially in areas where the ring may restrict joint movement, such as around the knee. If osteotomy is to be performed, the location of the rings is determined under fluoroscopy before the osteotomy. Schanz screws were advanced to the fragments proximal and distal to the osteotomy line, perpendicular to the bone.

The rings were mounted on 1 Schanz screw advanced to the bone. That the ring axis was perpendicular to the anatomic axis of the bone fragment was confirmed with fluoroscopy, then the other Schanz screws were advanced to the bone fragments with the aid of a Schanz holder and fixation of the rings to the bone was achieved.

The rings were then mounted over each other with the aid of motor telescopic units of suitable dimensions. The length of each of the motor telescopic units was recorded and then they were removed. A percutaneous osteotomy was performed using a Gigli saw on the tibia and the multiple drilling method on the femur. In cases with tibial deformity, fibula osteotomy was performed with the multiple drilling method. After fluoroscopy confirmation that the osteotomy was complete, the motor telescopic units were mounted again in order. The numbers on the telescopic rods were recorded, then the wound sites were closed in appropriate order, and correction of the deformity was started after 5-7 days.

Results

The mean follow-up time of the patients was 16.77 months (range, 6-30 months). The mean duration of the fixator was 199 days (range, 104-302 days); this was determined as 197 days (range, 104-266 days) in femur cases, and 210.41 days (range, 114-302 days) in tibia cases. The mean bone lengthening was determined to be 3.3cm (range, 1-6cm). The bone lengthening was ≤3cm in 8 patients and >3cm in 7 patients (Table 1).

Table 1. The mean duration of external fixator according to the bones.

Bone	Mean duration of external fixator
• Femur	• 197 days
• Tibia	• 210.41 days
• Radius	• 124 days
• Metatarsal	• 152 days

To eliminate angular deformity and shortness, the mean correction time applied gradually was 37.62 days (range, 10-60 days). This period was mean 36.56 days in femur cases, mean 29.52 days in tibia cases, 40 days in the case applied with 1st metatarsal lengthening, and 20 days in the case with radius deformity (Table 2, Figure 5).

Table 2. The mean distraction index values and mean external fixator index values according to the bones.

Bone	Mean Distraction Index	Mean External Fixator Index
Femur (<3 cm lengthening)	• 10	• 112
Femur (≥3 cm lengthening)	• 9.6	• 45.8
Tibia (<3 cm lengthening)	• 11	• 191.6
Tibia (≥3 cm lengthening)	• 12.8	• 55
Radius	• 10	• 62
1st Metatarsal	• 20	• 76

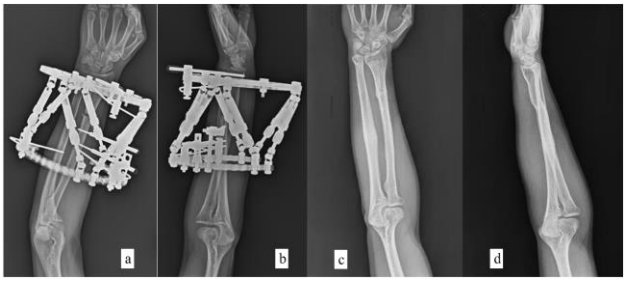

Figure 5. A-P and lateral radiographs of the results after spatial frame application (a,b) and frame removal 20 days later (c,d) for the correction of radius deformity.

The deformities were observed to be 9 in the oblique plane, 6 in the coronal plane, and 1 in the sagittal plane. In 4 cases there was isolated shortness, and isolated rotation deformity was present in 2 cases. The mean angular deformity was 22° (range, 12-30°). All the deformities in 22 bone segments were corrected in an ideal manner.

The mean score in the Paley Difficulty Scale applied preoperatively was 4.5 (range, 1-10). According to this scale, 18 cases were evaluated as mild difficulty, and 4 as moderate difficulty. There were no cases with a score of ≥12, which is evaluated as difficult on the Paley Difficulty Scale.

At the end of the follow-up period, the Paley scoring system was used in patients applied with femoral

lengthening. The mean score was 84.3 (range, 65-95). According to the scoring system, the result obtained was excellent in 3 patients, good in 3 patients, and moderate in 2 patients.

In the evaluation after the tibial corrections, the Paley criteria modified by ASAMI were used. Functional and bone results were obtained according to these criteria. The bone results were evaluated as excellent in 8 patients, good in 2, and poor in 2 . The functional results were evaluated as excellent in 5 patients, good in 6, and moderate in 1.

The pin was removed from 1 patient because of pin tract infection. Pin tract infection was observed in all the patients and was treated with oral antibiotherapy. There was no requirement for intravenous antibiotherapy in any patient.

In 2 of the cases with non-union, success was achieved by obtaining union tissue. Union was not observed in the third non-union case. This patient was first operated on in 2008 because of a tibia shaft fracture sustained in a traffic accident. Before the operation in 2013, the patient had been operated on 6 times with the application of external fixator, intramedullary nailing, curettage, and grafting in separate operations. In the last operation, the atrophic fracture line was osteotomised and removed, then autograft was applied. An osteotomy wass performed for lengthening of the tibia from the proximal. In this patient applied with bifocal osteotomies, union was not observed in either of the two osteotomy regions.

A supramalleolar osteotomy was performed on a patient with malrotation (14° in the coronal plane) in the left ankle joint because of malunion. Union was not observed during the follow up, so the external fixator was removed and grafting and a distal tibia plate were applied. In the follow up of 2 patients applied with distal femur osteotomy, a loss of >20° flexion was observed. This loss of flexion was resolved with physical therapy and full range of movement was obtained.

After the removal of the external fixator in a patient applied with isolated lengthening of 5cm in the tibia, the patient fell during the follow-up period and angulation was observed in the newly formed callus tissue. No additional intervention was made as analysis showed the deformity to be within physiological limits.

In another patient, at 7 months postoperatively after 6 cm femur lengthening, the patient fell while running for exercise and a fissure was determined in the distraction base. Conservative follow up was applied and no new deformity developed.

Discussion

External fixators are one of the oldest devices used in orthopaedic surgery, going back as far as the time of Hippocrates [7]. After the discovery of distraction osteogenesis and introduction of the principles of the external fixator to the western world in Italy by G.A. Ilizarov, it became widely used in the west. In cases where great difficulty is experienced in treatment such as non-union, deformity, and osteomyelitis, it has become the first option. It is also used as the first option in open fractures where there is an increased risk of infection. With the ongoing evolution of external fixators according to requirements, K-wires started to be used instead of Schanz screws in areas where required for the protection of anatomic structures at risk. To protect joint movements, partial rings started to be used instead of full rings around the joint [2-4].

With the creation of modifications, the concept of hybrid external fixators emerged. The hexapod external fixator system was introduced in 1994, which provided free movement in 6 axes by re-arranging the mechanical configuration of the frame according to the Charles principles without changing the biological factors of the Ilizarov external factor. This system, in which computer-assisted gradual correction calculations are made, provides the surgeon with a significant advantage compared to classic systems in the correction of deformities. Although it is more preferred in deformity correction surgery, hexapod systems can be used in all cases where an external fixator is indicated [8].

One of the greatest problems in deformity correction made with an Ilizarov circular external fixator is the emergence of residual deformity at the end of treatment. These deformities may not be able to be easily corrected and may require special operating conditions. This engendered the need to make modifications to the system to prevent it. To keep the number of modifications to a minimum possible, the order of deformity correction is first angulation, then shortness, rotation, and finally translation [9].

If hexapod systems are correctly assembled, residual deformities can be corrected only by changing the struts when necessary without the need for any other modification. As strut changes can be made in polyclinic conditions, the burden on both patient and physician is at the lowest level. As correction can be made at the same time to multi-directional deformities, the duration of use of the external fixator by the patient is shortened [10,11]. In the current study, strut change was required in 19 of the 22 patients applied with the spider frame, and these changes were made in the polyclinic. There was no requirement for additional surgery in any patient.

Residual deformities may remain after correction with hexapod systems. Although residual deformity is not expected theoretically, the most important reason for the occurrence of these residual deformities in practice is the miscalculation of the assembly, deformity, and frame parameters that are entered into the computer. These calculations are made postoperatively on direct

radiographs. If the magnification ratio of the radiograph is not taken into acount, or if the radiograph has not been taken correctly, incorrect results are obtained and residual deformities emerge [12,13]. To minimise the error rate and prevent residual deformity, it must be ensured that the reference ring is mounted perpendicular to the reference bone segment and that the reference ring is parallel to the floor when taking the radiograph. To achieve these conditions, Anastasios D. Kanellopoulos et al. [14] designed a radiolucent platform that would fix the reference ring completely perpendicular to the floor, and all the radiographs were taken using this platform. In this way, the number of radiographs taken to be able to obtain the correct image was successfully kept to a minimum. In the current study, the postoperative radiographs of the 22 patients applied with spider frame were taken by experienced personnel or under the supervision of a doctor, and successful results were obtained as the spider frame web-based application enabled this to be performed easily on the computer.

The mean external fixator index value of the cases in the current study was 105.3 days/cm. This rate in literature shows variation because of the range of cases. In a 2008 study, Salıh Marangoz et al. [15] reported that in cases of femoral deformities corrected with a Taylor spatial frame, the mean external fixator index was 2.2 months/cm. Eidelman et al. [16] found this value to be 0.9 months/cm in cases with correction made together with shortening. Lengthening of <3cm has also been reported to lengthen the external fixator index in a study by Sakurakichi K. et al. [17]. In another study in literature by Hidenori Matsubara et al. [18], the distraction index and external fixator index values were determined to be lower in cases applied with gradual correction compared to cases that underwent acute correction. In the current study, the mean external fixator index and distraction index values obtained with the use of the spider frame were consistent with the literature.

In addition to deformity cases, hexapod systems are also used in acute fractures. Mohammed J. Al-Sayyad [19] reported a case series of paediatric and adolescent tibia shaft fractures treated with the Taylor spatial frame. Blondel B. et al. [20] applied a hexapod system to 11 acute tibia fractures, and Seide et al. [21] reported that gradual fracture reduction decreased soft tissue damage. In the current study, the spider frame was not used in acute fractures but this type of external fixator was thought to be useful in deformity surgery.

The use of the classic Ilızarov method in the correction of complex deformities requires the surgeon to have a certain amount of experience [22]. This procedure in computer-assisted hexapod systems takes a shorter time than the classic Ilızarov method [23]. When prescribing further correction according to the follow-up radiographs in the current study, a further 4 corrections per patient were prescribed in the first 5 patients, whereas a mean 2 further prescriptions per patient were required for the last 5 patients with the hexapod system. This showed that the easy learning curve together with knowing how the system works without requiring surgical experience reduced the number of prescriptions.

The functional and bone results of tibia lengthening reported in literature are generally successful. Bone results at rates of 90-95% and functional results of 93-97% have been reported as excellent and good in literature [24,25]. In a series of femoral lengthening, Paley reported an excellent result of 94% according to his own criteria [26]. In the current study, the mean femoral lengthening score of 83% was lower than rates in literature and the tibial lengthening scores were also found to be lower than those in literature.

Although hexapod external fixators have some advantages compared to classic circular external fixators, the disadvantage of high cost has been stated in the literature [27]. The spider frame used in this study is the lowest cost computer-assisted fixator.

Limitations of this study can be said to be the absence of a control group, the relatively low number of patients, the limited homogeneity of the patients, and that there were no long-term follow-up results.

Conclusions

In cases of deformity, acute fracture and non-union, the computer-assisted external fixator system (spider frame®) without any modification provides single-stage correction by allowing postoperative intervention to the deformity. This new-generation external fixator system can be considered a suitable treatment option due to the successful functional results.

Conflict of interest disclosure

There are no known conflicts of interest in the publication of this article. The manuscript was read and approved by all authors.

Compliance with ethical standards

Any aspect of the work covered in this manuscript has been conducted with the ethical approval of all relevant bodies and that such approvals are acknowledged within the manuscript.

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