

# Accuracy of the hexapod external fixator in treating tibial angular deformities with or without limb length discrepancy: a retrospective study

Murat Danışman<sup>a</sup>, Engin Türkay Yılmaz<sup>b</sup>, Erdi Özdemir<sup>c</sup>, Ozan Tuncay<sup>b</sup> and Güney Yılmaz<sup>b</sup>

**Objective** Hexapod external fixator systems allow simultaneous deformity correction in multiple planes as well as limb lengthening. The aim of this study is to evaluate the accuracy of a hexapod frame (smart correction frame) in different types of tibial deformities requiring correction with or without lengthening.

**Methods** A total of 54 tibial angular deformities and limb length discrepancies operated with a hexapod frame between January 2015 and January 2021 were classified into four groups: “Group A ( $n = 13$ ): only lengthening,” “Group B ( $n = 14$ ): lengthening and uniplanar correction,” “Group C ( $n = 16$ ): only uniplanar correction,” and “Group D ( $n = 11$ ): biplanar correction.” The accuracy of angular deformity correction/lengthening was calculated by dividing the actual correction/lengthening achieved after frame removal by the preoperative planned lengthening/correction.

**Results** The lengthening accuracy in Group A and Group B was  $96.3 \pm 7.1\%$  and  $95.7 \pm 5.9\%$ , respectively ( $P = 0.685$ ). The angular deformity correction accuracy was  $85.1 \pm 9.9\%$  for Group B,  $85.2 \pm 13.9\%$  for Group C, and  $80.2 \pm 18.4\%$  for Group D ( $P = 0.852$ ). A revision program

was performed in six cases (1 in Group B, 1 in Group C, and 4 in Group D) for full correction of the deformities.

**Conclusion** The accuracy of tibial lengthening is high with the hexapod frame and is minimally affected by simultaneous deformity correction; however, the accuracy of angular correction slightly reduces as the deformity becomes more complex. Surgeons should be aware that reprogramming may be required after complex deformity correction. *J Pediatr Orthop B* 32: 611–616 Copyright © 2023 The Author(s). Published by Wolters Kluwer Health, Inc.

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**Keywords:** deformity correction, hexapod external fixator, limb length discrepancy, limb lengthening, tibia deformity

<sup>a</sup>Department of Orthopaedics and Traumatology, Giresun University Faculty of Medicine, Giresun, <sup>b</sup>Department of Orthopaedics and Traumatology, Hacettepe University Faculty of Medicine, Ankara, Turkey and <sup>c</sup>Department of Orthopaedics & Rehabilitation, Penn State Health, Milton S. Hershey Medical Center, Hershey, Pennsylvania, USA

Correspondence to Erdi Özdemir, MD, Department of Orthopaedics & Rehabilitation, Penn State Health, Milton S. Hershey Medical Center, 500 University Dr, Hershey, Pennsylvania 17033, USA  
Tel: +1 717 343 0719; e-mail: eozdemir@pennstatehealth.psu.edu

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## Introduction

Lower limb deformity correction is a complex procedure in orthopedics practice. Treatment aims to restore anatomic alignment and prevent long-term complications of the deformity such as early osteoarthritis [1]. Several surgical procedures have been developed for the correction of lower limb deformities. Distraction osteogenesis with Ilizarov fixator is the former technique that permits gradual correction of multiplanar long bone deformities by the creation of a solid bone regenerate [2]. Despite many advantages of the Ilizarov fixator, correction of multiplanar deformities could be demanding. Hinges and translation devices may be necessary to correct complex deformities and even frame change may be required. These additional procedures

are time-consuming for surgeons and exhausting for patients [3–5].

External hexapod fixator systems have been introduced into the market for the treatment of complex deformities. In 1994, Taylor brothers developed the pioneer system, Taylor Spatial Frame (TSF) (Smith & Nephew, Memphis, Tennessee, USA) [6], that allows simultaneous six-axis and one-step correction of complex deformities. The working principle of TSF relies on an external fixator construct of two rings connected to each other with six telescopic struts and a computer software [7]. By adjusting only strut lengths, one ring can be repositioned relative to the other ring in all dimensions of space allowing correction of deformities in all three planes [8]. A web-based software is used to generate a schedule for daily strut adjustments. The surgeons must input the deformity data including deformity parameters, frame parameters, and mounting parameters into the software. The desired correction depends on the precise measurement of the input data [9]. Smart correction frame (SCF) (Response Ortho

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LLC, Edgewater, New Jersey, USA) is another type of external hexapod fixator system. The main differences of SCF from TSF are the radiographic analysis method and relatively easier assembly of the fixator [3].

Few studies examined the accuracy of the hexapod external fixators on deformity correction [7,10,11]. Little is known regarding the accuracy of hexapod external fixators on different types of deformities requiring correction in single or multiple planes, or simultaneous lengthening in addition to correction. The aim of the study is to determine how well the actual correction or lengthening matches the preoperatively planned measurements on SCF's web-based software in patients with tibial deformity and analyze the accuracy of SCF depending on the variety of the deformity.

## Materials and methods

We retrospectively reviewed the patients who underwent surgery with the SCF in our institution between January 2014 and January 2021. Patients with proximal 1/3 or mid-diaphyseal tibial deformity with or without length discrepancy due to tibial shortening, treated with a single tibial osteotomy, and had a follow-up of at least 1 year after frame removal were included in the study. Patients who had follow-up <1 year, underwent surgery due to segmental bone transport or bone tumors, underwent lengthening over nail or fixator-assisted nailing, and did not have appropriate radiographs were excluded. Patients only with proximal 1/3 or mid-diaphyseal tibial deformity were included to better homogenize the study population. A total of 54 tibial deformities of 46 patients with a mean age of 12.6 years (ranged 3.1–30.9) met the inclusion criteria and were included in the study. The mean follow-up after SCF removal was 27 months (range 12–53 months). The diagnoses of the patients are given in Table 1. The study protocol was approved by the local ethics committee. A written informed consent was obtained from each patient or parent for participation in the study.

Patients were classified into four groups based on the direction of tibial deformity correction. Group A ( $n = 13$ ) (only lengthening) consists of all cases with limb

lengthening procedure only, without any deformity correction. Group B ( $n = 14$ ) (lengthening and uniplanar correction) consists of all cases with limb lengthening procedure and additional deformity correction in only one plane. Group C ( $n = 16$ ) (only uniplanar correction) consists of all cases with deformity correction in one plane only, without any lengthening procedure. Group D ( $n = 11$ ) (biplanar correction) consists of all cases with deformity correction in two planes which can also be considered as a single oblique plane deformity.

For deformity analysis, standing full-length anteroposterior and lateral radiographs were obtained from all patients in preoperative evaluation. Besides, anteroposterior and lateral intraoperative radiographs of the affected segment after frame application were obtained and uploaded to the software. The deformity analysis was done using center of rotation of angulation method in hospitals picture archiving and communication system (PACS) system (Centricity PACS, GE Healthcare, Chicago, Illinois, USA) according to deformity principles by one independent observer who was not involved in the surgery [12,13].

All surgeries were performed by the same fellowship-trained orthopedic surgeon. One ring proximal and one ring distal to the apex of the deformity was placed. Each ring was applied perpendicular to sagittal and coronal planes of proximal and distal bone segments. To fix the rings to the bone, wires and half-pins were utilized (Fig. 1a). Multiple drill-hole osteotomy technique [14] was applied through a 1 cm incision and it was completed with an osteotome. The location of osteotomy was located at or near the apex of the deformity [15]. Fibular osteotomy was performed in all patients. Planning of angular correction was made on the web-based software by drawing anatomic axes of the tibia from the osteotomy level. Unlike other hexapod systems, the SCF can calculate the mounting parameters directly using information obtained from the intraoperative radiographs [16]. Pediatric small rings were used for younger children.

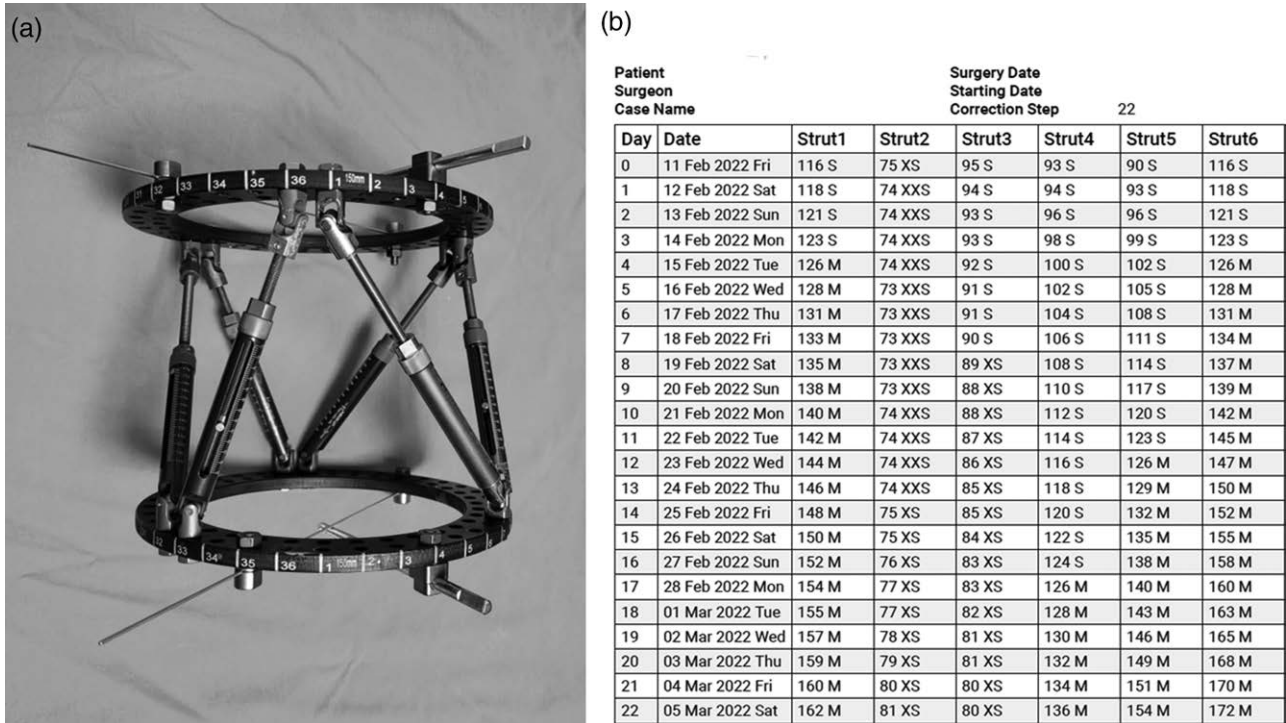
Postoperatively, patients were allowed to bear weight as tolerated. Active and passive range of motion exercises of the knee and ankle, and quadriceps strengthening exercises were started under the supervision of a physiotherapist immediately after surgery. After a latency phase of 5–7 days, the lengthening/correction program was started gradually in all patients at 1 mm with or without 1°/day. The patients were instructed to perform gradual adjustments of the six struts with the prescription prepared with the software (Fig. 1b). Radiographs were obtained weekly during the correction process and monthly during the consolidation process. The fixator was removed when at least three of four cortices showed sufficient bone formation on anterior-posterior and lateral radiographs.

The accuracy of SCF was calculated by a formula for lengthening (Fig. 2) and angular correction (Fig. 3)

**Table 1** Diagnosis of the patients

Diagnosis	Number (N)
Fibular hemimelia	15
Tibial hemimelia	3
Idiopathic	9
Blount's disease	5
Multiple epiphyseal dysplasia	4
Congenital pseudoarthrosis of tibia	2
Achondroplasia	2
Growth arrest	1
Hyperparathyroidism	1
Fanconi-Bickel syndrome	1
Hemihypertrophy	1
Malunion	1
Olier's disease	1

Fig. 1



(a) The appearance of the hexapod external fixator with two rings and six struts. (b) An example of the prescription prepared by the software.

procedures individually. For the lengthening procedures, the actual lengthening achieved after frame removal and the targeted lengthening preoperatively with the web-based software were measured in millimeters. For the angular deformity correction procedures, the actual deformity correction (ADC) achieved at the apex after frame removal and the preoperatively targeted deformity correction (TDC) at the apex of the deformity with the web-based software were measured in angles.

The accuracy of lengthening procedures:  $[1 - (|\text{targeted lengthening} - \text{actual lengthening}|) / \text{targeted lengthening}] \times 100$ .

The accuracy of deformity correction procedures:  $[1 - (|\text{TDC} - \text{ADC}|) / \text{TDC}] \times 100$ .

In biplanar deformities, the accuracy in both planes was averaged to give a single accuracy. The total external fixator time, reprogramming for residual deformity, and complications were recorded.

The normality analysis of the data was performed with Kolmogorov–Smirnov test. Continuous variables are presented as mean  $\pm$  SD, whereas categorical variables are given as frequencies. Continuous variables are compared with Mann–Whitney *U* test and Kruskal–Wallis test where appropriate. Confidence interval was accepted as 0.05. The data were made by SPSS v23 (IBM Corporation, Armonk, New York, USA).

## Results

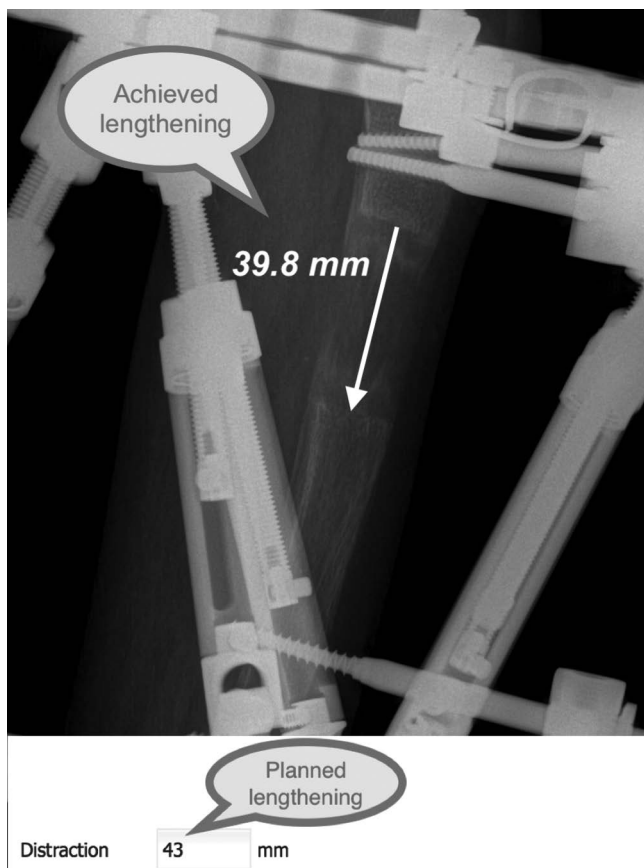
A total of 27 lengthening procedures and 52 angular deformity correction procedures were performed in the study population. Patient demographics according to the groups are presented in Table 2. The lengthening accuracy in Group A and B were  $96.3 \pm 7.1\%$  and  $95.7 \pm 5.9\%$ , respectively ( $P = 0.685$ ). The angular deformity correction accuracy was  $85.1 \pm 9.9\%$  for Group B,  $85.2 \pm 13.9\%$  for Group C, and  $80.2 \pm 18.4\%$  for Group D (Table 3) ( $P = 0.852$ ).

Complications included superficial pin tract infection in eight patients treated with antibiotics, two deep infections treated with debridement, two nonunion treated with bone grafting, two tibia fractures after frame removal in two patients treated with plate and screws, and one equinus deformity treated with vulpius Achilles tendon lengthening procedure. A total of six reprogramming procedures (one in Group B, one in Group C, and four in Group D) were performed during deformity correction.

## Discussion

The pioneer hexapod external fixator system, TSF, was developed by Charles and Harold Taylor in 1994, and gradually became one of the most useful implants in deformity correction [6]. TSF and SCF, relatively new hexapod fixators, use computer-based deformity planning and provide more versatile correction than the

Fig. 2

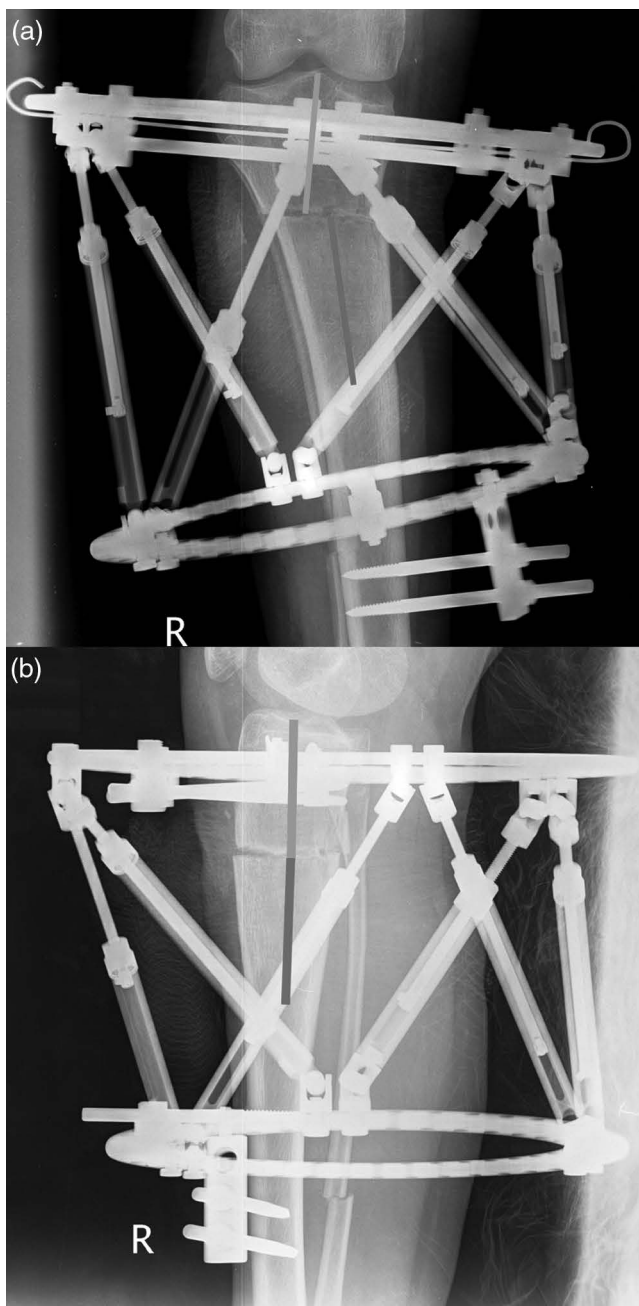


Measurement of the planned and actual achieved lengthening.

Iizarov system while allowing even a full weight-bearing mobilization. Because of their versatility, hexapod external fixator systems are increasingly being popular for the treatment of bone deformities, limb length discrepancies (LLD), and joint contractures [16–22]. However, the main clinical use of hexapod external fixators is still the simultaneous correction of multiplanar deformities. The accuracy of TSF in the treatment of different deformities has been studied [10,11] but the literature is scant for the accuracy of SCF. In the current study, we have investigated the accuracy of SCF in different types of tibial deformities and show that the accuracy of SCF is above 95% in lengthening procedures and above 80% in angular deformity corrections.

As being the pioneer hexapod external fixator system, TSF has been studied in varying studies [4,5,7,23–27]. Nevertheless, the SCF was introduced on the market in 2010, and came up with various unique features such as not being dependent of mounting parameters but only a few studies investigated this device [3,16,28]. The accuracy of TSF depends on mounting parameters which identify the exact location of the frame in relation to the deformity [29]. If there is an error in the mounting

Fig. 3



Intraoperative anteroposterior (a) and lateral (b) radiographs of a patient after application of the hexapod external fixator and tibial osteotomy. The angle between green line and red line represents the targeted angular deformity correction.

parameters, it results in residual translation-angulation deformity requiring subsequent correction [9,30]. To deal with this, various postoperative radiograph and intraoperative fluoroscopy techniques have been proposed [9,29,31–34]. However, SCF’s radiographic navigation system automatically reproduces the clinical scenario to a virtual scenario without using mounting parameters. The software does not need a reference ring

or specific radiographs for matching, and it accepts some degree of variation in radiographs. Also, the struts can be placed freely unlike TSE. Thus, time spend on the frame decreases and the probability of residual deformity can be reduced.

Due to the association of LLD with angular deformities in the tibia, we grouped patients to investigate the accuracy of the SCF in different clinical scenarios. The accuracy of lengthening was comparable in Group A (Lengthening only, 96.3%) and Group B (Lengthening and uniplanar correction, 95.7%), and both groups had successful accuracy in lengthening. Given this finding, we may argue that the angular deformity correction had no negative effect on the lengthening accuracy, and vice versa. Although hexagonal fixators have the six-axis deformity correction capability and are able to correct multiplanar deformities more accurately than the Ilizarov fixators [3,10,35,36], in the current study, although statistically insignificant, there was a slight reduction in the accuracy of Group D compared to other groups. Also reprogramming for residual deformity was higher in Group D. Considering the slightly reduced accuracy of SCF in complex deformities, surgeons should be aware that reprogramming may be required after complex deformity correction. The hexapod design often allows surgeons to carry out these secondary corrections either without a frame modification or with a strut adjustment or exchange that can be performed in the clinic, as opposed to an Ilizarov style fixator which could require a surgical procedure to modify the device if additional correction is needed.

**Table 3 The accuracy of the correction in the groups**

	Lengthening accuracy (%)	Angular correction accuracy (%)
Group A ( <i>n</i> = 13) (Lengthening only)	96.3 ± 7.1	–
Group B ( <i>n</i> = 14) (Lengthening and correction)	95.7 ± 5.9	85.1 ± 9.9
Group C ( <i>n</i> = 16) (Uniplanar correction)	–	85.2 ± 13.9
Group D ( <i>n</i> = 11) (Biplanar correction)	–	80.2 ± 18.4

**Table 2 The characteristics of the patients according to the groups**

	Mean age at surgery (years)	Gender (M/F)	Side (R/L)	Mean fixator time (days)
Group A ( <i>n</i> = 13) (Lengthening only)	9.2 ± 4.8	8/5	5/8	214.4 ± 52.8
Group B ( <i>n</i> = 14) (Lengthening and uniplanar correction)	10.8 ± 5.4	11/3	10/4	164.7 ± 52.2
Group C ( <i>n</i> = 16) (Uniplanar correction)	15.5 ± 7.5	9/7	7/9	122.1 ± 45.7
Group D ( <i>n</i> = 11) (Biplanar correction)	14.5 ± 8.2	8/3	5/6	117.6 ± 65.7

F, female; L, left; M, male; R, right.

SCF does not require mounting parameters to be input by the surgeon to the software due to its design [16]. The varying accuracy in different tibial deformities may be multifactorial. The difference between lengthening and correction accuracy of SCF can be explained by unrecognized angular deformities, software errors, or mechanical deficiencies in the frame. Also, positional errors in radiography cause more variation in angular deformities than in LLD. However, outcomes are comparable to those reported with the other hexapod external fixators [26,27,37–40].

This study has several limitations. First, this is a retrospective study and has small sample size. Second, there is no control group to compare the accuracy of correction, number of reprogramming, and total fixator times. Also, groups are heterogeneous due to different etiologies. The measurements were performed by a single observer.

### Conclusion

SCF is a safe and effective hexapod fixator for correcting tibial deformities and LLD with acceptable complication rates. The accuracy of lengthening procedures is minimally affected by simultaneous deformity correction; however, the accuracy of angular correction slightly reduces as the deformity becomes more complex. For successful outcome, human ‘treating doctor’ factor is still indispensable in planning and treating deformities whatever the recent advances of computed technology are used. Also, patients or families must be counseled for the possible need for frequent readjustment during the course of treatment as a response to any emerged inaccuracy especially in case of more complex deformities.

### Acknowledgements

This study was approved by the local ethics committee of Hacettepe University. Informed consent has been obtained from patients that grants permission for the publication of images as part of this work.

### Conflicts of interest

There are no conflicts of interest.

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