A comparative study of the correction of femoral deformity between the Ilizarov apparatus and Ortho-SUV frame

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Abstract

Purposes This study compared the six-axis external fixator Ortho-SUV Frame (OSF) and the Ilizarov apparatus (IA) in femoral deformity correction. Our specific questions were: (1) which of the fixators (OSF or IA) provides shorter period of femoral deformity correction, and (2) which of the fixators (OSF or IA) provides better accuracy of correction.

Methods We retrospectively analysed 123 cases of femoral deformities (127 femora): 45 (47) treated with OSF (20 male and 27 female) and 78 (80) with IA (53 male and 27 female). The average age in the OSF group was 34.6 (range, 18–66) and in the IA group 35.8 (range, 18–76). All the deformities were categorized according to the number of planes and deformity components as simple, middle and complex deformities.

Results Elimination of simple deformities in the IA group took 58.3 ± 21.4 days, EFI 58.8 ± 39.8 days/cm, and lengthening was 4.6 ± 1.98 cm. Middle deformities were 71.3 ± 26.2 , 61.9 ± 30.3 and 4 ± 2 , respectively. In complex deformities we had 105.2 ± 21.8 , 79.3 ± 35.4 and 3.2 ± 1.45 , respectively. Normal alignment was achieved in 55.0 % of cases in IA. In 45.0 % of cases we had residual deformity. Elimination of simple deformations in the OSF group took 55.3 ± 12.8 days, EFI 47.5 ± 23 days/cm, and lengthening 4.5 ± 1.1 cm. Middle deformities were 43.6 ± 18.9 , 59 ± 14.6 and 3.6 ± 2 , respectively. In complex deformities we had 44.9 ± 11.5 , 57.5 ± 9.4 and 3.6 ± 1.7 , respectively. In the OSF group normal alignment was achieved in 85.1 %. In 14.9 % there was residual deformity.

Conclusion Using OSF simplifies deformity correction and reduces its period by 2.3 times in complex deformities and by 1.6 times in middle deformities. Accuracy of correction with OSF was significantly higher than correction with IA.

Keywords Femoral deformity · Deformity correction · Ilizarov · Ortho-SUV Frame · Hexapods

Introduction

Femoral deformities can be caused by a wide range of orthopaedic pathologies. They can be acquired as a result of trauma [6, 13] or diseases [12], and congenital [18]. Femoral deformities alter axial alignment and orientation of the joints of the lower limb that leads to overload on the joints and early onset of osteoarthritis [9, 16]. Also, femoral deformities are frequently combined with limb shortening. Gradual correction using external fixation is the optimal method to manage femoral deformities with limb length discrepancy (LLD). The Ilizarov apparatus (IA) is well known for its use in deformity correction of long bones [1, 8, 24]. IA can correct angulation, translation, rotation and length deformities in a step-by-step fashion. Angulation is corrected using hinges, translation correction using a translation mechanism, rotation correction using a rotation mechanism and lengthening using longitudinal threaded rods [8, 10, 24]. During deformity correction with IA, modification of the external fixator (change of the different corrections constructs) is required [8, 14]. This is time consuming and it is technically complicated to build these constructs even for experienced surgeons when there are multiple deformities to correct. An improper assembling of correction construct leads to secondary deformity. It will require additional changes (partial frame modifications) in the frame and can have negative influence on the accuracy of correction and can increase the external fixation time.

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Nevertheless, the modularity and accuracy of correction of IA remains the gold standard for comparison.

The process is simplified by using computer-dependant external fixators. These devices are software-based hexapod frames or six-axis correction devices. Angulation, rotation, translation and length can all be addressed at the same time or individually [4, 5, 17, 20, 25]. One of these devices is the Ortho-SUV Frame (OSF) (Ortho-SUV Ltd. and Vreden Russian Research Institute of Traumatology and Orthopedics, St. Petersburg, Russian Federation), which was developed in 2006 [22].

The OSF is a kinematically new device because in the basis of this frame lies a new parallel platform [14, 22, 23]. Modality of the nodes of this platform provides some great features of this frame, i.e. there is no necessity for orthogonal fixation of the rings, no strict locations for strut fixation (can be chosen optionally), the struts are fixed to each ring in only three places, external supports of any geometry can be used (rings, half-rings, 5/8 rings, triangles, polygonal), struts can be fixed to the basic rings as well as to the stabilizers, and there is no necessity to change the struts during deformity correction (Fig. 3a) [22, 23]. The software application for OSF has some peculiarities, for example, the X-rays are downloaded directly in the software, most of the measurements are made in the software, special tools of the software allow drawing the bone contours and axes of bone fragments, the software visualizes the prognosis of deformity correction and the user can manipulate with the tools of the software to reach the desired deformity correction result, and if the user had made a mistake while making measurements the software notices this mistake.

In the current literature there are few studies which approve the advantages of other computer-dependant devices in comparison with IA [3, 10]. However, there is still no study comparing OSF with IA.

We therefore asked: (1) which of the fixators (OSF or IA) provides shorter period of femur deformity correction, and (2) which of the fixators (OSF or IA) provides better accuracy of correction.

Patients and methods

We retrospectively reviewed 123 patients (127 femora) who underwent gradual deformity correction using either IA or OSF in our institute between April 2001 and May 2012. We treated 45 patients (47 femora) with OSF and 78 patients (80 femora) with IA. Of those 70 (89.7 %) and 40 (88.9 %) were available for follow-up at a minimum of 12 months. Both groups were comparable in age, gender and etiology (Table 1).

Indications for surgery were the same for both groups, that is, acquired or congenital deformations of femur altering normal alignment of limb and presence of LLD.

Table 1 Demographics

Variables	Ilizarov apparatus	Ortho-SUV frame	<i>p</i> value
Age (years)	35.8 (18–76)	34.6 (18–66)	<i>p</i> >0.05
Men	53 (66.25 %)	20 (42.6 %)	<i>p</i> <0.01
Women	27 (33.75 %)	27 (57.4 %)	<i>p</i> <0.01
Acquired deformities	65 (81.25 %)	35 (74.5 %)	<i>p</i> >0.05
Congenital deformities	15 (18.75 %)	12 (25.5 %)	<i>p</i> >0.05

Minimum follow-up was 12 months (mean, 32 months; range, 12–81 months) for the OSF group and 99 months (mean, 99 months; range, 45–152 months) for the IA group. Longer follow-up period in the IA group can be explained by the fact that most cases of IA application are dated from 2000 till 2006 before we started using OSF. No patients were recalled specifically for this study; all data were obtained from medical records and radiographs.

Data gathering included diagnosis, the magnitude of deformities, the time of correction, the time of consolidation and the bone healing index (BHI), the total time wearing the frame and the external fixation index (EFI), the complications and additional surgical interventions.

For X-ray examination we used antero-posterior (AP), long leg standing X-rays and lateral views of the femur. Pre-operatively we measured limb malalignment, magnitude of deformity and LLD. The final result of deformity correction and amount of lengthening were measured after removal of the frame. To quantify the accuracy of correction we measured the mechanical axis deviation (MAD), mechanical lateral distal femoral angle (mLDFA) and anatomical posterior distal femoral angle (aPDFA) according to Paley [16]. Deviation of these parameters from the physiological values was considered as deformity. The magnitude of deformity was determined by measuring the angle made by intersection of the proximal and distal mechanical axis of the femur. CT was used to measure torsion.

According to our deformity classification [22], we divided all our cases into simple (one-plane—one-component), medium (one-, two- and three-planes—two- and three-components) and complex (two- and three-planes—multicomponents).

All the operations in the IA group were performed by the senior author (LNS). The operations in the OSF group were performed by two authors (LNS, VAV). When assembling IA we placed the rings perpendicular to the anatomic or mechanical axis of a femur. Hardware and software of OSF make it possible to mount the rings at any angle to the bone. This simplified frame assembly decreased operating room time. Osteotomy was made through a 1–1.5-cm incision using a multiple drill-hole, osteotome technique. The location of the osteotomy was at or near the CORA. The reasons for out of CORA osteotomy were: presence of internal fixation (1), osteomyelitis (4), abnormal bone pathology at the CORA

(8), multiplanar CORA with frontal and sagittal plane CORA's at different levels (5), and location of CORA at the joint line (5). Performance of osteotomy away from CORA level led to additional translation [15]. In the presence of two CORA two osteotomies were done and two OSF were assembled (five cases).

Deformity correction began five to seven days after surgery. In all cases gradual correction with lengthening was carried out. When using IA the order of deformity correction was: angulation—lengthening—rotation—translation. Partial frame modifications to change the corrections constructs were done one time for simple deformities and up to five times for complex deformities (Figs. 1 and 2).

When using OSF deformity correction calculations were made with the help of OSF computer software. Twelve parameters measured from the frame and four parameters measured from the X-rays were input into the program. Deformity correction planning was performed using AP and lateral radiograph input. Program tools allowed calibration for magnification, bone contour marking and drawing of anatomical or mechanical axis on the bone fragments. After calculation the software showed the final position of mobile bone fragment in

two planes and generated an adjustment schedule. Correction rate was calculated by the software taking into account both structures at risk and lengthening required. Correction was carried out 0.25-mm four times per day. Changes were made in the software and it was not necessary to modify the external fixator as was required in IA (Figs. 3 and 4).

On the second postoperative day patients were allowed to partially weight bear using the crutches and start physical therapy to maintain knee range of motion. The frame was dynamized when X-ray signs of consolidation and full weight bearing were possible shortly after the frame removal.

We divided the results of correction into four groups according to persistent deformity after frame removal as it was reported previously by Manner et al. [10]. Cases without any persistent axial deformity were included in group I. Group II contained cases with minor persistent deformity $\leq 5^\circ$. Group III included cases with moderate persistent deformity of 6–10°. Group IV included cases with severe persistent deformity $>10^\circ$.

Statistical analysis was performed using the program STATISTICA for Windows (version 9.0). Quantitative variables are described by the mean and standard deviation (mean $\pm$ SD). The mean values of the subgroups were

Fig. 1 **a** The pre-operative front view of a 21-year-old woman with dyschondroplasia, short stature, genu varum and internal rotation deformities of both limbs before the surgery. **b–d** Stages of deformity correction of right femur using Ilizarov hinges and a custom-made frame system for each component of deformity. **e** A front view obtained three months after frame removal shows correction of the deformity and lengthening.

The total time of correction was 60 days, period of osteosynthesis was 187 days. **f–h** Stages of deformity correction of left femur. The total distraction-adjustment time was 62 days; the total external fixation time was 206 days. **i** A front view obtained six months after frame removal shows correction of the deformity and leg-length discrepancy (LLD). **j** Functional result of the treatment

Fig. 2 **a** The pre-operative bipedal 51-in. radiographs show MAD 53 mm, mLDFA 101° and 30° internal rotation for the left limb; MAD 21 mm, mLDFA 110° and 30° internal rotation for the right limb. **b** An AP radiograph of the right femur shows the frame on the femur during correction. **c** An AP radiograph of the left femur shows the frame configuration during correction in the same patient. **d** A bipodal 51-in.

radiograph was obtained one year after frame removal, and the LLD was corrected. For the left limb the mLDFA was 87° and the MAD was 3-mm medial to the midline. For the right limb the mLDFA was 85° and the MAD was 4 mm medial to the midline. *MAD* mechanical axis deviation, *mLDFA* mechanical lateral distal femur angle, *LLD* leg-length discrepancy

compared with the nonparametric Mann–Whitney test, Kruskal–Wallis, median test, and one-way analysis of variance (ANOVA). Preoperative percentages of the type of femoral

deformities (simple, medium, or complex) were compared between the two groups with chi-square test, and Fischer's exact test. Significance was set at the $P < 0.05$ level.

Fig. 3 **a** A model of Ortho-SUV Frame (OSF) illustrating some of its features. **b** The pre-operative front view of a 23-year-old woman with a complex congenital deformity of the left femur and the tibia. **c** Front view of the leg after surgery shows the Ortho-SUV applied to match the deformity. **d** A 2.5-cm lengthening and deformity correction were done. The time of deformity correction was 36 days. **e** Follow-up six months after frame removal. The total time wearing the frame was 139 days

Fig. 4 **a** The pre-operative bipedal 51-in. AP radiograph shows a valgus deformity with a MAD of 37 mm lateral to midline, mLDFA of 70°, and 2.5 cm LLD. **b, c** CT scans showing 24° of excessive external rotation of the left femur. **d** An AP radiograph of the left femur was obtained after surgery. **e** A lateral radiograph of the left femur was obtained after surgery. **f** A bipedal 51-in. AP radiograph shows correction of the deformity. **g** A

bipedal 51-in. AP radiograph was obtained five months after frame removal: the LLD was corrected, the mLDFA was 88°. The MAD was 29-mm medial to the midline because a varus deformity of proximal tibia existed. *MAD* mechanical axis deviation, *mLDFA* mechanical lateral distal femur angle, *LLD* leg-length discrepancy

Results

Pre-operative angulation in the frontal plane in the IA group was found in 40 cases, and the mean value was 18°. In the OSF group, in 42 cases, the mean value was 17.1°. Pre-operative angulation in the sagittal plane in IA group was found in 18 cases, and the mean value was 15.4°. In the OSF group, in 21 cases, the mean value was 18.8°.

Torsion in the IA group was found in 17 cases, and the mean value was 27.4°. In the OSF group, in 18 cases, the mean value was 23.7°. Shortening in the IA group was found in 76 cases, and the mean value was 4.8 cm. In OSF group, in 45 cases, the mean value was 4.7 cm.

The number of simple deformities was significantly higher ($p < 0.05$) in the IA group (22 cases) than in the OSF-group (5). The number of medium deformities in the IA group (40 cases) was not significantly different ($p > 0.05$) from the same in the OSF group (25 cases). The number of complex deformities was significantly ($p < 0.05$) higher in the OSF group (17 cases), than the IA group (18 cases).

Limb lengthening was carried out in all cases included in this study. The average amount of lengthening was similar between the IA group and the OSF group. Clinical results were collected (Table 2).

No differences were revealed in the IA and OSF groups in correction period of simple deformities ($p > 0.05$). OSF reduced the time of medium deformities correction by 1.8 times (43.6 %) ($p < 0.05$) and complex deformity correction by 2.2 times (53.6 %) ($p < 0.05$). The bone healing index (BHI) was not significantly different between both methods ($p > 0.05$). Decrease in time of deformity correction in the OSF group reduced the external fixation index (EFI) ($p < 0.05$).

Results of correction of axial deformities in frontal and sagittal planes were measured in both groups (Table 3).

In the OSF group MAD, mLDFA and aPDFA were restored to normal values more precisely ($p < 0.05$).

The accuracy of correction was examined for both groups after frame removal. In the IA group normal alignment was achieved in 45 (56.3 %) cases. In 36 (45.0 %) cases residual deformation was found, namely, 15 cases (18.75 %) with minor persistent deformity, 12 cases (15.0 %) with moderate persistent deformity and nine cases (11.25 %) with severe persistent deformity. In the OSF group normal alignment was achieved in 40 cases (85.1 %). There was residual deformation in the remaining seven cases, with minor persistent deformity in four cases (8.5 %), moderate persistent deformity in two cases (4.3 %) and severe persistent deformity in one case (2.1 %).

Table 2 Clinical results

Parameter	OSF	IA	p value
Time of deformity correction (days)	44.9±16.3 (13–76)	75.8±29.3 (22–152)	<i>p</i> <0.001
Simple	55.3±12.8 (39–70)	60.8±23.1 (22–117)	<i>p</i> >0.05
Middle	43.6±18.9 (13–76)	77.3±29.9 (32–146)	<i>p</i> <0.001
Complex	44.9±11.5 (27–60)	96.8±22.6 (68–152)	<i>p</i> <0.001
Time in frame (days)	210±72.8 (116–339)	237.1±72.9 (116–447)	<i>p</i> <0.05
Simple	217±86.5 (141–339)	223.4±69.3 (117–349)	<i>p</i> >0.05
Middle	187.8±63 (116–320)	241.2±78.4 (130–447)	<i>p</i> <0.05
Complex	202±60.8 (116–312)	248.1±66.2 (156–383)	<i>p</i> <0.05
Lengthening (cm)	3.7±1.8(1.5–8)	3.7±1.6(1.5–8)	<i>p</i> >0.05
Simple	4.5±1.1 (3–6)	4.6±1.98 (1.5–8)	<i>p</i> >0.05
Middle	3.6±2 (1–7.5)	4±2 (1–8)	<i>p</i> >0.05
Complex	3.6±1.7 (2–9)	3.2±1.5 (1–6)	<i>p</i> >0.05
BHI (days/cm)	50.1±22.2(13.5–153.5)	48.6±25.8 (13.5–153.5)	<i>p</i> >0.05
Simple	31.2±5.7 (26.7–39.5)	49.0±29.8 (19.7–153.5)	<i>p</i> >0.05
Middle	50.4±16.4 (15.7–70.5)	47.1±24.1 (13.5–151.2)	<i>p</i> >0.05
Complex	55.2±20.5 (28.3–111)	51.3±24.4 (22.7–103)	<i>p</i> >0.05
EFI (days/cm)	62±22.1 (29.3–74.5)	73.1±34.9 (30.1–174.8)	<i>p</i> <0.05
Simple	47.5±23 (42.6–56.5)	68.2±33.4 (30.7–168)	<i>p</i> <0.05
Middle	59±14.6 (29.3–74.5)	73.3±34.1 (30.2–174.8)	<i>p</i> <0.05
Complex	57.5±9.4 (38.7–71)	82.2±39.5 (37–172)	<i>p</i> <0.05

Mean value and standard deviation (SD) are shown, ranges shown in parentheses
OSF Ortho-SUV Frame, *IA* Ilizarov apparatus, *BHI* bone healing index, *EFI* external fixation index

Discussion

In literature it is reported that femoral deformities lead to early set and progress of osteoarthritis [9, 16]. Deformity correction and restoration of normal joint orientation allows preventing and slowing down progress of the osteoarthritis [7, 21]. Gradual correction using external fixation is the optimal method to manage complex femoral deformities,

especially those combined with shortening or LLD. IA has been widely used for deformity correction of long bones and has many advantages. Nevertheless this method has limitations. Different correction constructs of IA need to be adjusted for each deformity. These procedures are very time consuming. The computer dependant external fixators are aimed to simplify correction of multiple deformities. Comparative studies turned out to be an appropriate instrument to elaborate the

Table 3 Pre-operative versus postoperative measurements of radiographs in both groups

Measurement	Pre-operative mean (range)		<i>p</i> value	Postoperative mean (range)		<i>p</i> value
	OSF	IA		OSF	IA	
Frontal plane						
Varus						
mLDFA	94.9±3.97 (91–105)	95.3±4.57 (91–112)	<i>p</i> >0.05	88.3±1.32 (85–90)	90.3±5.5 (84–104)	<i>p</i> >0.05
MAD	34.5±23.46 (11–94)	37.3±14.2 (19–74)	<i>p</i> >0.05	8.3±8.2 (0–28)	11.1±11.7 (3–35)	<i>p</i> <0.05
Valgus						
mLDFA	80.7±3.3 (73–84)	79.9±2.95 (71–84)	<i>p</i> >0.05	87.8±2 (83–90)	87.6±2.6 (84–92)	<i>p</i> >0.05
MAD	15.5±11.72 (3–94)	18.15±16.01 (4–60)	<i>p</i> >0.05	0.1±17.5 (0–46)	4.6±12.4 (9–35)	<i>p</i> >0.05
Sagittal plane						
Procurvatum						
aPDFA	75.8±8.4 (61–83)	79.2±6.1 (68–83)	<i>p</i> >0.05	79.8±7.1 (69–88)	80.9±5 (70–89)	<i>p</i> >0.05
Recurvatum						
aPDFA	89.3±9 (79–114)	86.3±9 (82–110)	<i>p</i> >0.05	84.6±4.8 (75–93)	86.1±8 (74–90)	<i>p</i> >0.05

Mean value and SD are shown, ranges shown in parentheses

mLDFA mechanical lateral distal femoral angle, *aPDFA* anatomical posterior distal femoral angle

advantages and limitations of new devices [2, 3, 10]. We wanted to evaluate the advantages and limitations of the new software based external fixator OSF. Regarding this, we asked the following: (1) which of the fixators (OSF or IA) provides shorter period of femur deformity correction, and (2) which of the fixators (OSF or IA) provides better accuracy of correction.

Our study had several limitations. First, the patients were reviewed retrospectively and all data were retrieved from the charts. We needed to retrospectively measure radiographs, but these measurements were made by one author (PVS) using a uniform method. Second, our study was not randomized. However, we believe that selection bias was minimized in this study as most of our patients who underwent deformity correction since 2006 were treated using OSF except the cases that had chosen the protocol of treatment using IA. A total of 95.3 % of all the cases (93.6 in OSF and 96.3 in IA) were operated directly by one of the authors (LNS).

The most important result of our research is that the software-based Ortho-SUV Frame reduces the time of deformity correction compared to IA in correction of medium deformity by 1.6 times and complex deformity correction by 2.3 times. However, we didn't find significant differences in time of simple deformity correction. Simple deformities in most cases were presented by single shortening, in few cases there was single angulation and rotation. This corroborates other studies comparing other hexapods and traditional IA [3, 11]. Dammerer et al. compared results of deformity corrections performed with one of the most popular hexapods—the Taylor Spatial Frame (TSF)—versus traditional IA and the unilateral Orthofix fixator in a consecutive patient series with 135 bony deformity corrections [3]. The distraction time was lower for the TSF than the other two devices, and did not differ significantly between the three devices when corrected for the severity of deformity (minor lengthening). The distraction-consolidation time was also significantly lower for the TSF than the other two devices.

Some authors reported that the consolidation or healing index did not differ between the different devices [3, 19]. We also did not find significant differences in consolidation and healing index between IA and OSF.

A decrease in time of deformity correction reduces the EFI. Our study showed that a mean EFI for the OSF was 56.9 days/cm (range, 29.3–94 days/cm) and a mean EFI for the IA was 73.1 days/cm (range, 30.2–174.8 days/cm). Similar EFI in femoral deformity correction by TSF were reported by Marangoz et al. (2.2 months/cm) and by Ganger et al. (2.1 months/cm) [6, 11].

In our study in the IA group normal alignment was achieved in 45 (56.3 %) cases. In 36 (45.0 %) cases residual deformation was found, including 15 cases (18.75 %) with minor persistent deformity, 12 cases (15.0 %) with moderate persistent deformity and nine cases (11.25 %) with severe

persistent deformity. In the OSF group normal alignment was achieved in 40 cases (85.1 %). There was residual deformation in the remaining seven cases, including minor persistent deformity in four cases (8.5 %), moderate persistent deformity in two cases (4.3 %) and severe persistent deformity in one case (2.1 %). Thus, OSF provides better accuracy of correction than IA. The similar results were published by Manner who compared the final result of deformity correction by TSF versus IA after frame removal with the initial aim of deformity correction and lengthening [10]. A total of 278 cases (79 in the IA group and 129 in the TSF group) were analysed. In the IA group only 55.7 % of results were without residual deformity. In the TSF group 90.7 % of results were without residual deformity. In both groups, one finding was consistent, namely, there was a higher residual deformity rate with increasing number of axes of correction. They concluded that the hexapod showed an advantage in complex multiplanar deformities. Dammerer et al. reported a comparison of the TSF with the traditional IA and a unilateral Orthofix fixator [3]. Axis correction was performed in 81 cases, of which 60 were combined with lengthening. The mean values after deformity correction of all patients were within the normal values of a healthy population. However, the mean measures after correction did not differ significantly between the three devices, but the variance of the results was lower for TSF than for IA and Orthofix devices.

In conclusion, OSF reduces the time of deformity correction, and provides a greater accuracy of deformity correction than IA. The simplicity of use of the hardware and the friendly software facilitate and simplify the procedure of deformity correction by circular external fixation.

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Conflict of interest No competing interests declared.

Ethical review committee statement Each author certifies that his or her institution has approved or waived approval for the human protocol for this investigation and that all investigations were conducted in conformity with the ethical principles of research.

A statement about the location This study was made at the Vreden Russian Research Institute of Traumatology and Orthopedics, St. Petersburg, Russia.

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