Foot Deformity Correction with Hexapod External Fixator, the Ortho-SUV Frame(TM)

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Title

Foot deformity correction with hexapod external fixator, the Ortho-SUV Frame

Authors

Munetomo Takata, MD, Postdoctoral Fellow[1]

Victor A Vilensky, MD, PhD[2]

Hiroyuki Tsuchiya, MD, PhD, Professor and Chairman[1]

Leonid N Solomin, MD, PhD, Professor[2]

Affiliation

[1] Department of Orthopaedic Surgery, Graduate School of Medical Science, Kanazawa University, 13-1 Takara-machi, Kanazawa, 920-8641, Japan

[2] Vreden Russian Research Institute of Traumatology and Orthopedics, 8 Baykova Str., St. Petersburg, 195427, Russia

Corresponding author

Leonid N Solomin: Vreden Russian Research Institute of Traumatology and Orthopedics, 8 Baykova Str., St. Petersburg, 195427, Russia.

Phones: +7(812)670-8743, 670-9596

Mobile: +7 904 519 39 89

E-mail: solomin.leonid@gmail.com

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Corresponding Author: Dr. Leonid Nikolaevich Solomin, Prof., MD, PhD

Corresponding Author's Institution: Vreden Russian Research Institute of Traumatology and Orthopedics

First Author: Munetomo Takata, MD

Order of Authors: Munetomo Takata, MD; Victor A Vilensky, MD, PhD; Hiroyuki Tsuchiya, MD, PhD, Professor and Chairman; Leonid Nikolaevich Solomin, Prof., MD, PhD

Abstract: External fixators enable distraction osteogenesis and gradual foot deformity corrections. Hexapod fixators have become more popular than the Ilizarov apparatus. The Ortho-SUV Frame (OSF), which is a hexapod that was developed in 2006, allows flexible joint attachment so that multiple assemblies are available. We assessed the reduction capability of several assemblies. An artificial bone model with a 270-mm-long longitudinal foot was used. A 130-mm tibial full ring was attached 60 mm proximal to the ankle joint. A 140-mm, 2/3-ring forefoot was attached perpendicular to the metatarsal bone axis. A 130-mm, 2/3-ring hindfoot was attached parallel to the tibial ring. A V-osteotomy, which was combined with 2 oblique osteotomies at the navicular-cuboid bone and the calcaneus, was performed. The middle part of the foot, including the talus, was connected to the tibial ring. Five types of forefoot applications and 4 types of hindfoot were assessed. The range of correction included flexion/extension in the sagittal plane, adduction/abduction in the horizontal plane, and pronation/supination in the coronal plane. Additionally, we reported short-term results in 9 clinical cases. Forefoot applications, in which the axis of the hexapod was parallel to the axis of the metatarsal bones, had good results with 52/76 (flexion/extension), 48/53 (adduction/abduction), and 43/51 (pronation/supination) degrees. Hindfoot applications, in which the hexapod encircled the ankle joint, had good results with 47/58, 20/35, and 28/31 degrees, respectively. Clinically, all deformities were corrected as planned. Multiple assemblies and wide ranges of corrections are available with OSF.

Introduction

Foot deformity corrections include acute corrections and gradual corrections with external fixators. In conventional acute corrections, extensive soft tissue releases, tendon transfers, resection osteotomies, and arthrodesis with screws or wires are used (1, 2, 3). Sometimes, these corrections may result in skin necrosis, lack of correction, and neurovascular complications, especially in the presence of multiplanar deformities or scar tissues due to histories of infection, burns, or multiple operations where the motion of nerves and blood vessels are potentially restricted (4, 5). The surgical goals are maximum correction with minimal bone resection and the establishment of a functional, pain-free, and plantigrade foot with good mobility (6).

The use of external fixation can avoid complications and is less invasive. It also enables distraction osteogenesis in contrast to simple shortening due to resection osteotomy for acute corrections. The Ilizarov apparatus has been widely used for foot deformity corrections, and many reports have described its advantages (4-9). However, hexapod frames, which have become popular recently, enable us to correct complicated deformities simultaneously, while the Ilizarov apparatus needs to be reassembled and adjusted for each deformity (4). Corrections with the Taylor Spatial Frame (TSF) (Smith and Nephew Inc., Memphis, TN), which is the most widely used hexapod, have been reported (10-12).

The Ortho-SUV Frame (OSF; Ortho-SUV Ltd., Vreden Russian Research Institute of Traumatology and Orthopedics, St. Petersburg, Russian Federation) was developed in 2006, and so far it has had success in long bone corrections and knee contractures (13-19). OSF, which is the same as the TSF, can be adjusted in all 6 spatial degrees of freedom by 6 struts (Figure 1A). On the strut, a mobile cylinder rotates in order to change the length, and it has a minimum length of 94 mm (Figure 1B). Joints can be attached to the many kinds of base apparatuses, including the Ilizarov, TSF, and other kinds of rings, and the attachable places and levels are not limited (Figure 1C). This flexibility is the biggest difference in the OSF compared to the TSF, and it allows for various kinds of assembly. After measuring all of the lengths of the struts and the distances between the adjacent joints and inputting the data into the computer software, multiplanar corrections are available with a user-friendly program with which mistakes rarely occur (Figure 2).

Applying the hexapod to the foot is difficult due to its L-shaped contour in the lateral view. The narrow space may result in a collision between the struts, frames, and skin, and, thus, consideration of these issues ahead of time is necessary in order to acquire a wide range of correction. In addition, the flexible joint attachment of the OSF allows for multiple applications, which are possibly confusing to select. The aim of this study was to assess the reduction capabilities of several configurations of the OSF. In addition, we assessed the short-term outcomes of 9 adult patients who were treated with OSF.

Materials and Methods

Artificial bone model and basic components

The ranges of correction vary according to the shape of the bone and the size and location of the rings. The basic composition in this study is described below.

Artificial bone models of the tibia, the fibula, and the whole foot were obtained from Pacific Research Laboratories, Inc. (Vashon, WA, USA). The length of the tibia was 38 cm, and the longitudinal length of the foot from the rear edge of the calcaneus to the toe point was 27 cm. The components of the Ilizarov apparatus were obtained from the experimental factory of Kurgan Research Ilizarov Center (Kurgan, Russia). They included several kinds of rings, threaded rods, female/male posts, hinges, plates, twisted plates, washers, 6-mm-diameter half-pins, half-pin fixators, 1.8-mm-diameter olive wires (wire with stopper), wire-fixation bolts, bolts, and nuts.

First, bones were assembled and fixed in a neutral position without plantar/dorsal flexion of the ankle joint. A 130-mm full ring was attached 60 mm proximal to the ankle joint with a wire that was inserted through the fibula and tibia, and two half-pins were inserted into the tibia. The talus was fixed with a wire (for forefoot correction) or a wire and a half-pin (for hindfoot correction) and then fixed to the tibial ring. A 140-mm 2/3 ring was attached to the forefoot with wires at the base of 1st metatarsal bone and the mid-diaphyseal of the 5th bone. The ring was perpendicular to the axis of the metatarsal bones. A 130-mm 2/3 ring was attached at the calcaneus, and it was parallel to the tibial ring. Two crossed olive wires and a half-pin that went through the longitudinal axis of the calcaneus were inserted. During the forefoot correction, a calcaneal ring was connected to the tibial ring so that the posterior composition was more stable (Figure 3).

Type of OSF assembly

The OSF has 6 joints. Three each are attached to the proximal and distal components. The proximal component is called the “base-,” and the distal one is called the “mobile-,” and opposite setting is possible. The struts contain the serial numbers from the first to the sixth (Figure 1). The anterior 2 struts were set as the first and the second in this assessment. The minimum length of the struts was 94 mm. We set 290 mm as the maximum in order to avoid the risk of bowing or instability, even though there is technically no limit.

The 3 factors that defined the configurations are considered below:

- The hexapod included the foot inside it or not.
- The axis of the hexapod was parallel to the tibia, forefoot, or hindfoot.
- The direction of the joint attachment (triangle formed with 3 proximal joints) faced anteriorly/posteriorly or superiorly/inferiorly.

With these factors, 5 forefoot and 4 hindfoot assemblies were considered (Figure 4 and 5).

In F1 and F2, a 100-mm full ring was attached to the anterior part of the tibial ring, and a U-shaped frame was attached to the forefoot ring in order to install the joints. In F3 and F4, a 140-mm full ring was attached distally to the forefoot ring in order to maintain enough distance between the base and the mobile components. In F4, a 130-mm half ring was attached to the plantar side and connected perpendicular to the tibial ring with rods. In F5, a 240-mm half ring was attached to the forefoot ring posteriorly around the calcaneus.

In H1, two 110-mm full rings were attached to the tibial and foot rings posteriorly in order to install the joints. In H3, a 150-mm half ring was attached to the foot ring, placed at the dorsal part for joint installation, and a 130-mm half ring was attached proximal to the tibial ring in order to maintain enough distance between the base and mobile components. In H4, a 240-mm 2/3 ring was attached perpendicular to the hindfoot ring posteriorly.

Additionally, we show the configuration of the combination type and whole-foot type, although assessments of these types were not performed in this report (Figure 6 and 7).

Range of correction

Two oblique osteotomies were performed at the level of the navicular-cuboid bone and the calcaneus, which formed a V-shape (6). The range of correction was measured with a goniometer by mobilizing the forefoot/hindfoot fragments from a neutral position and toward the 6 directions: flexion/extension in the sagittal plane, adduction/abduction in the horizontal plane, and pronation/supination in the coronal plane (Figure 8). For the flexion/extension and adduction/abduction, the movements were performed while keeping contact with 1 side, which was assumed for open-wedge osteotomies. The extent of simple lengthening of each assembly was also measured.

Patients and surgical technique

From September 2009 to April 2012, 12 foot deformities of 9 patients had been treated with OSF. Table 1 provides the details of the patients. Deformities were assessed according to the definitions previously noted (Figure 8). The mean age of the patients at the time of the operation was 40 (range, 21 to 63).

An osteotomy was performed with an osteotome or gigli saw. The correction was started between the second and fifth day after the surgery. The OSF was applied only during the correction. Except for this period, the Ilizarov component was used to connect it and to enable the patients to have easier physical exercise and to have more comfortable daily activities with smaller-sized frames.

This research was approved by the institutional review board of Vreden Russian Research Institute.

Results

Assessment of the range of correction with the artificial bone model

Table 2 shows the range of correction of each assembly.

Among the forefoot groups, F3 and F4 had good results with a wide range of correction for every deformity, each of which acquired a total range of over 80 degrees. In particular, F3 had the widest range (128 degrees) of flexion/extension correction. F1 and F5 had the widest range in flexion and pronation, respectively, although the others were not wide compared to F3 and F4. F2 had poor results except for adduction/abduction.

Among the hindfoot groups, H1 and H2 had good results with over 50 degrees of total range for every deformity. With H1, H2, and H3, the ranges of adduction/abduction were the same because the edge of the 2/3 ring contacted the bone at this range, and this limit was thought to be due to the basic configuration and not to the type of assembly. H3 and H4 had poor results for pronation/supination and adduction/abduction, respectively.

The mean length of the lengthening correction was 114 mm in the forefoot assemblies and 95 mm in the hindfoot.

The lengths of the struts were measured in all configurations. The results of F1 are shown in Table 3. The mean length at the neutral position was 159 mm. In the 5 directions of extension, adduction/abduction, and pronation/supination, one of the struts was the minimum length of 94 mm, which limited the range. In all 54 assemblies (except for the lengthening model), the maximum correction range depended on the following 3 factors: the collision between the struts, frame, and bone (25 assemblies), the strut length (23 assemblies), and the mechanical limit of the angle at the joint between the strut and the frame (6 assemblies) (Table 4). Among the forefoot group, the most numerous factors were the strut lengths (57%), and, among the hindfoot group, the most numerous factors were the collisions (67%).

Clinical results

Table 1 shows the clinical case results. The mean follow-up period was 18 months (range, 12–32). The mean correction period was 35 days (range, 7–58). The frames were removed an average of 152 days (range, 22–286) after the surgery. Intramedullary nailing was performed just after the correction in 1 case (patient 7), which resulted in a short period of external fixation.

All deformities were corrected as planned, and the plantigrade positions were acquired after correction (please see the example of patient 1 in Figure 9). According to Paley's evaluation of treatment, 8 patients had satisfactory results, with an improved gait and relieved pain, and 1 had unsatisfactory results (patient 3 hindfoot) (6).

One severe case of osteomyelitis occurred due to a collision between swelled skin and the edge of the calcaneal ring during the maturation period after the correction, and this required removal of the whole frame (patient 3). In addition, a reosteotomy was also necessary for an early consolidation (patient 8). Although there was 1 wire problem of breakage that required removal (patient 7), there was no pin-track infection that required removal or reinsertion.

Discussion

This is the first assessment of the correction capability of hexapods in foot deformities according to their assembly type. The ranges of the 6 directions and the lengthening were compared in 5 forefoot and 4 hindfoot configurations. Many had wide reduction abilities with various ranges. In practice, the feet sizes and the types/degrees of deformities differ in each patient, and, thus, infinite assemblies are possible with multiple sizes of rings, levels of applying, and numerous parts of the external fixator. A comparison between the assemblies with the classifications in this report will help in selecting frame configurations.

Although F1 and H1 have good correction capabilities, their disadvantages include their bulkiness because they do not contain the foot. In addition, a hemi-laterally assembled frame could result in slight bending of the frame, and the correction force may possibly not be distributed equally. F5 also has a possibility of bending because the posterior joint is apart from the forefoot ring. The heaviness of the additional components in F1, F2, H1, H3, and H4 required to install the joints or to maintain enough distance for movement of the struts is also a drawback. Thus, the recommended assemblies were F3 or F4 and H2. Among them, a combination of F4 and H2 was desirable, while the anterior struts could interfere in the combination of F3 and H2 (Figure 6). The ranges of the adduction/abduction in the hindfoot group were limited due to collisions between the skin and the edge of the ring because of the basic configuration. In order to overcome this difficulty, a primary calcaneal ring should be applied because of the deformity direction. Lengthening of 158 mm and 164 mm was better acquired in F1 and H1, respectively. However, in clinical cases, a long lengthening is usually not necessary, and about 30 mm is enough. All of the assemblies were thought to be able to lengthen the fragments. The ranges of correction were limited by 3 factors (Table 4). They could be excluded in clinical cases in which the deformity was in either direction, although 2 contrary directions were assessed in 1 basic configuration in this study. The ideal configuration that is suitable for each patient should be planned preoperatively.

With both the Ilizarov apparatus and the hexapod frame, one can acquire the desired correction gradually after the operation, and correction speed and direction are also adjustable depending on neurovascular or skin problems. Thus, it can be ensured that the patient is comfortable and satisfied with the foot position prior to accepting the final position (6, 11, 12). The hexapod can correct multiplanar deformities simultaneously. However, hinge adjustments and rotational corrections remain difficult with the Ilizarov apparatus. The foot deformities usually contain more complicated deformities than the long bones, and the hexapod frame works effectively. An accurate correction of a foot deformity using TSF is expected as the accuracy of the lower limbs had been reported (20, 21). Eight types of TSF configurations for feet are available (12, 22), and some of them have been used clinically and the good results are reported (10, 11).

In this report, the direct comparison of reduction capability between OSF and TSF was not performed because the condition, which is appropriate for both of them, with multiple configurations, could not be established. Other than that, OSF has some advantages: Difficulties with changing the struts are saved because the cylinder can be transported on the rod, without changing the whole strut length, to enable a wider range of lengthening or shortening (Figure 1B). OSF does not require an internet connection for programming, and, with the software, there are merits for the surgeon due to less parameter numbers to input, confirmation of the bone contours before and after corrections, marking the anatomical or mechanical axis on the bone contour, setting 2 points of so-called "structure at risk" in TSF, and fine adjusting the lengthening speed with a minimum of 0.25 mm per day. The direction of the X-ray is not strictly defined, and only 2 planes which are angulated over 60 degrees are necessary. The biggest advantage of the OSF is the flexible attachment of the joints to the any parts or levels, with multiple frames. Therefore, staged corrections are available with reassembling configurations for pes equinus following forefoot and hindfoot fixing after each correction. The disadvantage of OSF is the frame bulkiness due to its flexible joint installation with Z-shaped plates.

The external fixation periods were comparatively long in this clinical series because of patient distance and the additional treatments of limb lengthening adjacent to the foot. The correction period was related to the severity of each case. Several complications occurred, but they were typical of foot deformities with external fixators and were not peculiar to the OSF. This study was limited due to the small number of patients and the short follow-up period, so that the common problem of recurrence was not addressed.

Gradual correction with an external fixator is time consuming for the surgeon. The correction plan must be reviewed frequently and adjusted, if necessary. And foot deformities are difficult to assess objectively and accurately. The fixed plantar-flexed first ray can cause pronation at the forefoot and varus or supination at the flexible hindfoot during weight bearing (2). Furthermore, during correction, accurate assessments with X-ray or CT are difficult with the external fixator due to its messy components. Although the anatomical/mechanical axes of the long bones are usually used for correction (23) and there are several orientation angles of the foot (24), unquestionable axes of the talus, calcaneus, metatarsal bones, and other tarsal bones are hardly detected because they are not simple tubular bones. In the clinic, skeletal foot components are assessed with plain radiography, computed tomography, magnetic resonance imaging, or manual assessment with goniometers directly from its appearance (2, 4, 7, 11, 25). Six factors, including angular/translation deformities in 2 planes, rotation, and shortening (axial length), should be considered in 3-dimensional correction using hexapod correction. Future work will focus on 3-dimensional assessments of the foot deformity based on the clear orientation.

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Table 1. Foot deformity cases treated by Ortho-SUV Frame.

Patient	Sex/Age	Follow-up period (months)	Etiology	Type of deformity *	Assembly type	CP † (days)	EFP ‡ (days)	Complications
1 forefoot	F/21	32	Spina bifida	Flx, Add, Sup, Sht	C3 (F4)	25	286	no
hind foot	-	-	-	Ext, Add, Sup, Sht	C3 (H2)	20	286	no
2 forefoot	F/54	19	Developmental deformity due to osteomyelitis	Ext, Abd, Prn	C3 (F4)	46	181	no
hind foot	-	-	-	Ext, Add, Prn, Sht	C3 (H2)	46	181	no
3 forefoot	M/61	19	Unknown (deformity after several operations)	Flx, Abd, Prn, Sht	C3 (F4)	58	115	no
hind foot	-	-	-	Flx, Add, Prn, Sht	C3 (H2)	58	115	Osteomyelitis
4 whole foot	F/22	13	Malignant osteolysis	Ext, Abd, Prn, Sht	Whole foot	38	93	no
5 hind foot	F/28	14	Malunion, post traumatic neuropathy	Ext, Add, Sup, Sht	H2	26	176	no
6 forefoot	M/22	25	Post traumatic neuropathy	Flx	F4	20	149	no
7 whole foot	M/63	12	Dislocation fracture of ankle	Flx, Abd, Prn, Sht	Whole foot	16	22	Wire breakage
8 hind foot	M/43	14	Malunion	Flx, Add, Sht	H2	49	53	Early consolidation
9 whole foot	M/46	13	Pes equinus, knee ankylosis	Flx	Whole foot	7	165	no

* Flx, flexion; Ext, extension; Add, adduction; Abd abduction; Prn, pronation, Sup, supination; Sht, shortening
† CP, correction period
‡ EFP, external fixation period

Table 2. Range of correction according to the types of assembly.

Type	Flexion/Extension	Adduction/Abduction	Pronation/Supination	Lengthening
	(Total range of correction)			
F1	53/22 (75)	35/36 (71)	13/26 (39)	158
F2	4/9 (13)	51/29 (80)	13/13 (26)	78
F3	52/76 (128)	48/53 (101)	43/51 (94)	105
F4	45/55 (100)	56/48 (104)	33/49 (82)	142
F5	25/29 (54)	40/18 (58)	50/28 (78)	86
H1	28/31 (59)	20/35 (55)	47/20 (67)	164
H2	47/58 (105)	20/35 (55)	28/31 (59)	60
H3	31/28 (59)	20/35 (55)	21/16 (37)	62
H4	77/25 (102)	20/20 (40)	28/24 (52)	95
			(degrees)	(mm)

Table 3. Length of the struts at the each maximum correction in F1 assembly.

	Length of the struts (mm)					
	1	2	3	4	5	6
Neutral position	176	152	138	164	172	149
Flexion	280	275	162	186	198	163
Extension	**94**	104	122	144	173	122
Adduction	210	**94**	160	162	177	131
Abduction	**94**	179	123	159	175	146
Pronation	181	137	168	181	146	**94**
Supination	175	177	**94**	121	200	163
Lengthening	**290**	279	134	206	228	175

Table 4. Factors that limited the range of correction

Type	Collision of strut/frame/bone	Strut length	Joint angle
F1	1	5	0
F2	0	3	3
F3	1	4	1
F4	3	3	0
F5	4	2	0
H1	4	1	1
H2	3	3	0
H3	5	1	0
H4	4	1	1
Total	25	23	6 (assemblies)

Table titles and legends

Table1. Foot deformity cases treated by Ortho-SUV Frame.

(No legend)

Table 2. Range of correction according to the types of assembly.

Among the forefoot groups, F3 and F4 had good results with total range of over 80 degrees. Among the hindfoot groups, H1 and H2 had good results with over 50 degrees of total range for every deformity.

Table 3. Length of the struts at the each maximum correction in F1 assembly.

The mean length at the neutral position was 159 mm. In the 5 directions of extension, adduction/abduction, and pronation/supination, one of the struts was the minimum length of 94 mm, which limited the range.

Table 4. Factors that limited the range of correction

The maximum correction range depended on the 3 factors. Among the forefoot group, the most numerous factors were the strut lengths (57%), and, among the hindfoot group, the most numerous factors were the collisions (67%).

Figure titles and legends

Figure 1A-C. Structure of the Ortho-SUV Frame

Struts and joints are numbered counterclockwise from 1 to 6 in a view from above (**A**). The length of the strut is changed by rotating the cylinder (**B**). Each joint is attached to the ring with 2 kinds of connecting devices, which are short (**C above**) and z-shaped (**C below**).

Figure 2. The input screen of the Ortho-SUV Frame program.

The direction of the 6 struts and joints are traced on the imported anteroposterior and lateral X-ray images. After inputting the data, confirmation steps can be acquired.

Figure 3. The basic assembly for forefoot corrections.

The tibial ring was fixed 60 mm away from the ankle joint and connected to the calcaneal 2/3 ring. A wire was inserted into the talus, which is connected to the tibial ring by rods. The 2/3 ring was attached to the metatarsi. An osteotomy was performed at the navicular-cuboid bone.

Figure 4 Forefoot correction assembly.

F1: The hexapod does not include the foot. The axis is parallel to the tibia. The proximal-joints triangle faces posteriorly.

F2: The hexapod does not include the foot. The axis is parallel to the tibia. The proximal-joints triangle faces anteriorly.

F3: The hexapod includes the foot. The axis is parallel to the forefoot. The proximal-joints triangle faces superiorly.

F4: The hexapod includes the foot. The axis is parallel to the forefoot. The proximal-joints triangle faces inferiorly.

F5: The hexapod includes the foot. The axis is parallel to the tibia.

Figure 5. Hindfoot correction assembly.

H1: The hexapod does not include the foot. The axis is parallel to the tibia.

H2: The hexapod includes the foot. The axis is parallel to the tibia. The proximal-joints triangle faces anteriorly.

H3: The hexapod includes the foot. The axis is parallel to the tibia. The proximal-joints triangle faces posteriorly.

H4: The hexapod includes the foot. The axis is parallel to the hindfoot.

Figure 6. Combination of forefoot and hindfoot correction.

C1: F1 and H1 are attached.

C2: F3 and H1 are attached.

C3: F4 and H2 are attached.

Figure 7. Whole-foot correction.

A horseshoe-shaped ring is attached to the foot. The axis of the hexapod is parallel to the tibia. The deformity between the lower leg and the whole foot can be corrected.

Figure 8. Definition of the deformity direction.

A navicular-cuboid bone osteotomy was performed for a forefoot correction, and an oblique posterior calcaneal osteotomy was performed for a hindfoot correction. The directions of the deformities are defined as illustrated.

Figure 9.

A 20-year-old woman had a deformity due to spina bifida that recurred 3 years after the first surgery (patient 1). The type of deformity (**A-D**) and assembly type (**E**, **F**) are noted as in table 1. After the correction (**G**, **H**).

Figure

Click here to download Figure: Figure 1.ppt

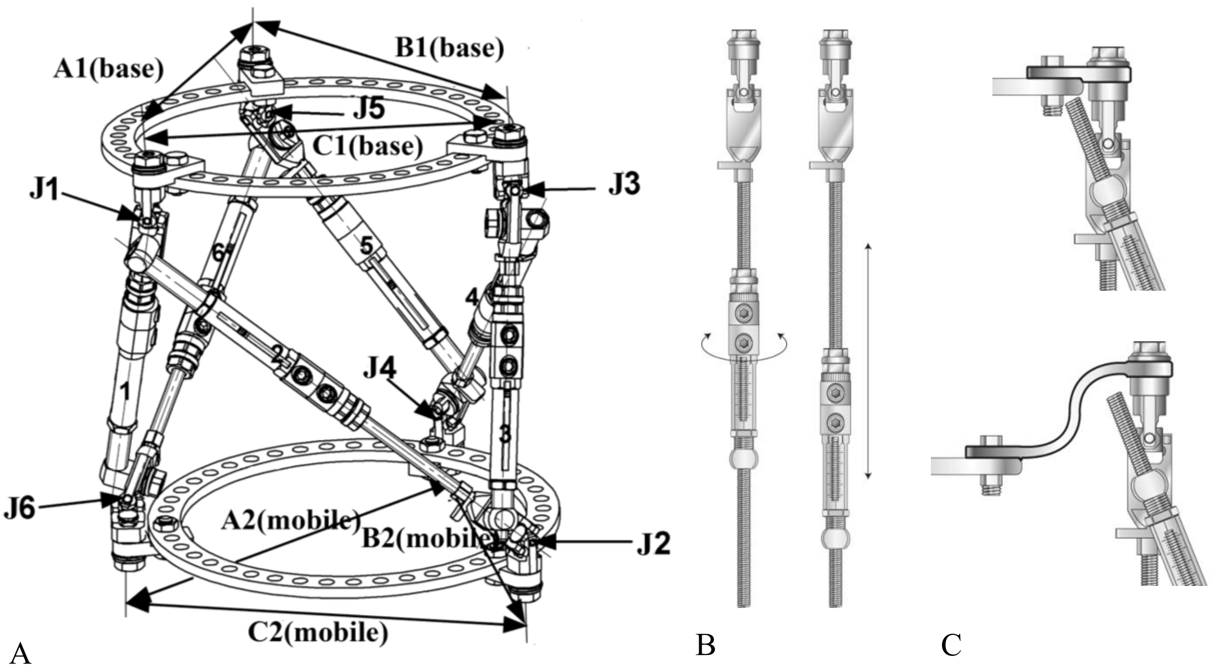

Figure 1A-C. Structure of the Ortho-SUV Frame.

Struts and joints are numbered counterclockwise from 1 to 6 in a view from above (**A**). The length of the strut is changed by rotating the cylinder (**B**). Each joint is attached to the ring with 2 kinds of connecting devices, which are short (**C above**) and z-shaped (**C below**).

Figure
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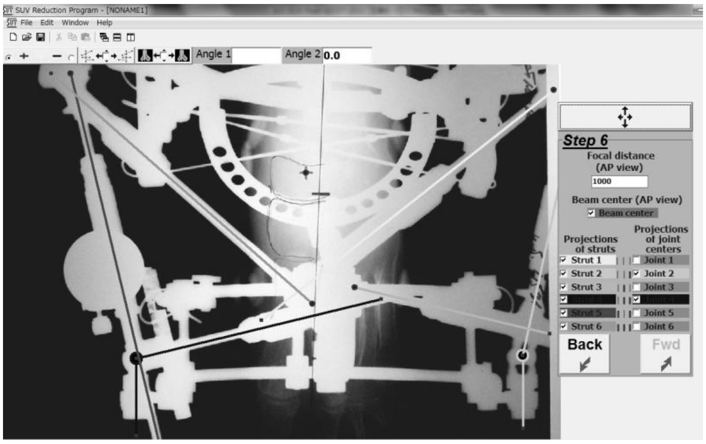

Figure 2. The input screen of the Ortho-SUV Frame program.
The direction of the 6 struts and joints are traced on the imported anteroposterior and lateral X-ray images. After inputting the data, confirmation steps can be acquired.

Figure

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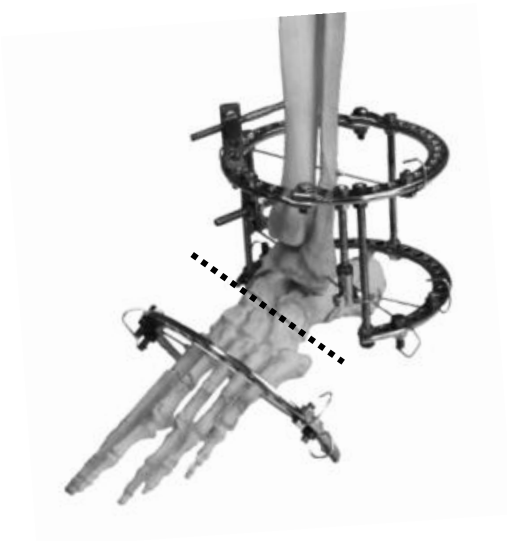

Figure 3. The basic assembly for forefoot corrections. The tibial ring was fixed 60 mm away from the ankle joint and connected to the calcaneal 2/3 ring. A wire was inserted into the talus, which is connected to the tibial ring by rods. The 2/3 ring was attached to the metatarsi. An osteotomy was performed at the navicular-cuboid bone.

Figure

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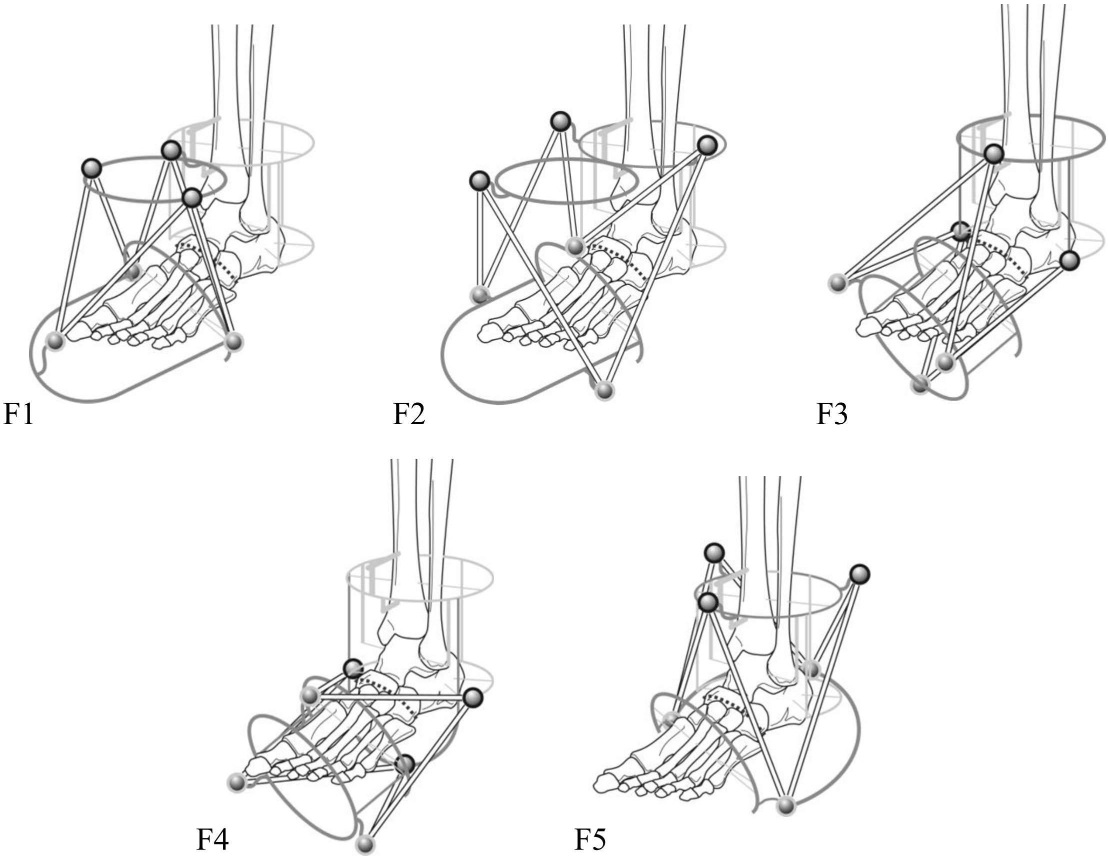

Figure 4 Forefoot correction assembly.

F1: The hexapod does not include the foot. The axis is parallel to the tibia. The proximal-joints triangle faces posteriorly.

F2: The hexapod does not include the foot. The axis is parallel to the tibia. The proximal-joints triangle faces anteriorly.

F3: The hexapod includes the foot. The axis is parallel to the forefoot. The proximal-joints triangle faces superiorly.

F4: The hexapod includes the foot. The axis is parallel to the forefoot. The proximal-joints triangle faces inferiorly.

F5: The hexapod includes the foot. The axis is parallel to the tibia.

Figure
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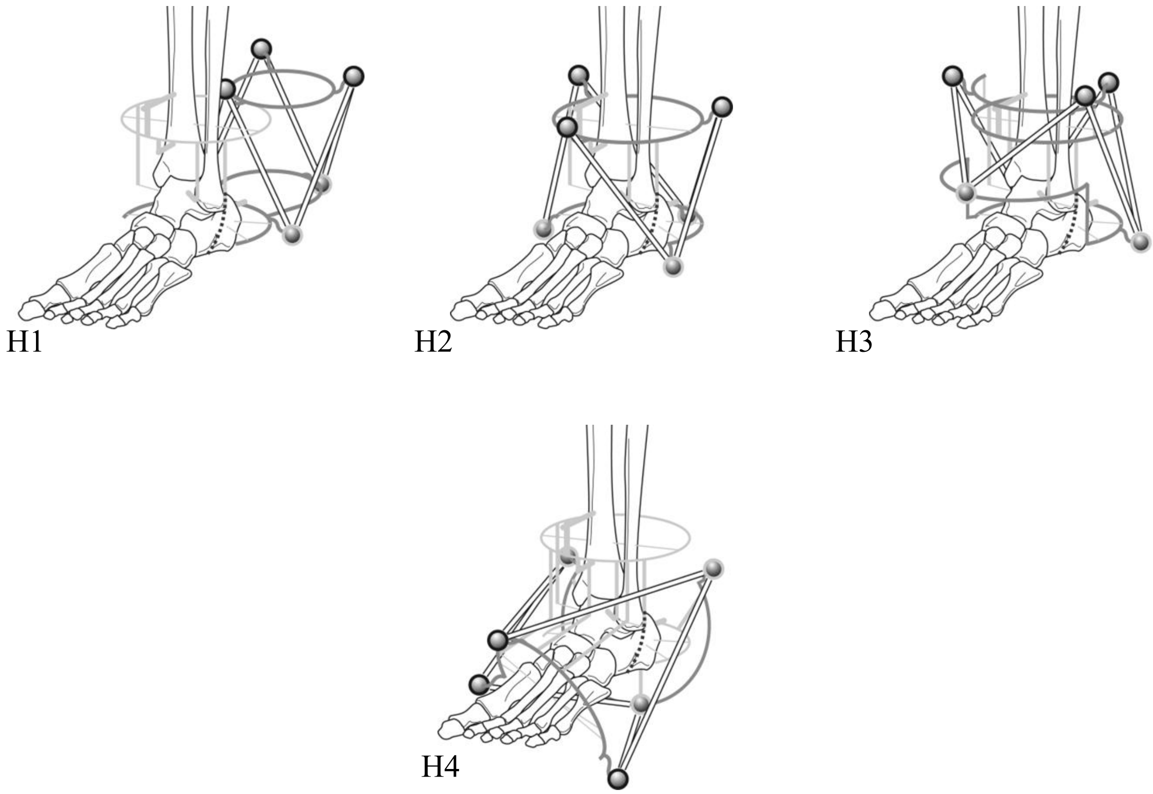

Figure 5. Hindfoot correction assembly.
H1: The hexapod does not include the foot. The axis is parallel to the tibia.
H2: The hexapod includes the foot. The axis is parallel to the tibia. The proximal-joints triangle faces anteriorly.
H3: The hexapod includes the foot. The axis is parallel to the tibia. The proximal-joints triangle faces posteriorly.
H4: The hexapod includes the foot. The axis is parallel to the hindfoot.

Figure
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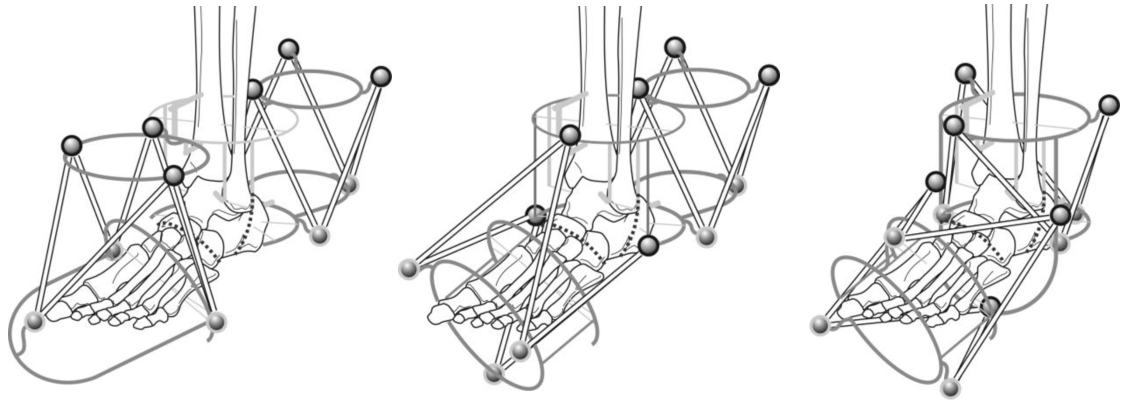

Figure 6. Combination of forefoot and hindfoot correction.
C1: F1 and H1 are attached.
C2: F3 and H1 are attached.
C3: F4 and H2 are attached.

Figure
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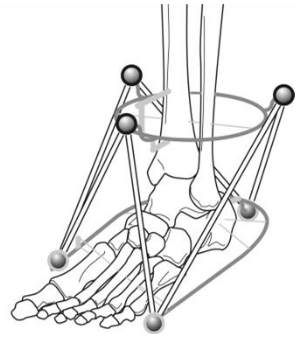

Figure 7. Whole-foot correction.
A horseshoe-shaped ring is attached to the foot. The axis of the hexapod is parallel to the tibia. The deformity between the lower leg and the whole foot can be corrected.

Figure

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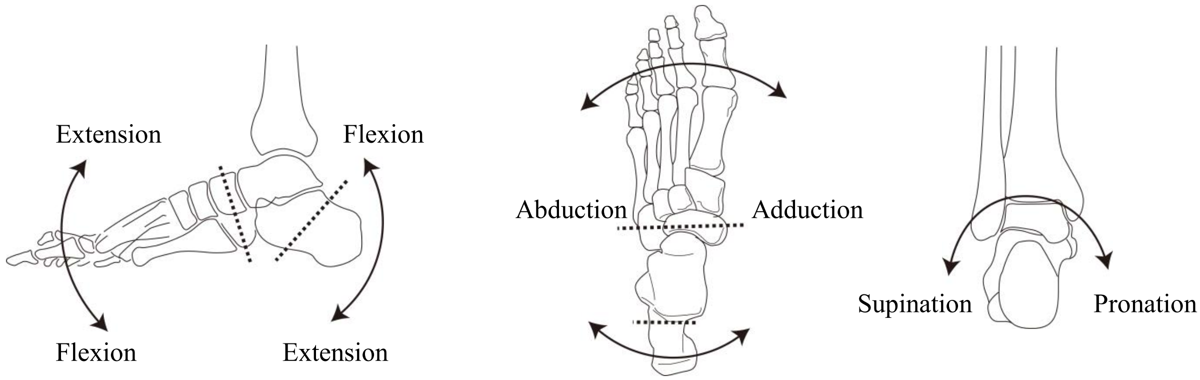

Figure 8. Definition of the deformity direction.
A navicular-cuboid bone osteotomy was performed for a forefoot correction, and an oblique posterior calcaneal osteotomy was performed for a hindfoot correction. The directions of the deformities are defined as illustrated.

Figure
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Figure 9.
A 20-year-old woman had a deformity due to spina bifida that recurred 3 years after the first surgery (patient 1). The type of deformity (**A-D**) and assembly type (**E**, **F**) are noted as in table 1. After the correction (**G**, **H**).