JPOSNA Journal of

Volume 5, Number 1, February 2023

Current Concept Review

A Review and Comparison of Hexapod External Fixators

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Received: December 5, 2022; Accepted: December 5, 2022; Published: February 1, 2023

DOI: 10.55275/JPOSNA-2023-627

Abstract

Hexapod external fixators, allowing for multiaxial deformity correction and fracture treatment, have been on the market for more than 25 years. The recent increase in the number of hexapod circular external fixators establishes the need for an easy-to-access overview of the different systems. An overview of the current options is provided, and a comparison is made of seven common hexapod circular external fixators. Highlights of each system's hardware, software, and educational opportunities are provided. The information collected from the manufacturers of each system was carefully and objectively edited to fit the structure of the review without including any additional subjective comments or recommendations. The authors believe that the development of multiple systems has had a positive effect on this technology. Only two clinical retrospective studies were found comparing the results of different systems, and there seems to be a clear opportunity for collaborative, multi-center comparative studies. The authors recommend choosing one hexapod system that feels comfortable and fits patient demands prior to pursuing mastering several systems.

Level of Evidence: Review; Level 4

Key Concepts

- Technical advances have driven the development of multiple high-quality hexapod external fixator systems.
- Surgeons should aim to master one system that fits their patient population before pursuing other systems.
- High-volume surgeons and clinics should invest in trials that directly compare different hexapod external fixators.

Introduction

Hexapod circular external fixators provide a powerful technique for correcting limb deformity and managing fractures. In its most basic form, a hexapod circular fixator consists of two rings connected by six obliquely oriented struts. This design allows the fixator to gradually correct multi-planar deformities sequentially or simultaneously. In addition, these fixators are paired with computer software that the surgeon can manipulate to control the desired correction speed and direction. As a result, in contrast to the previous generation of circular external fixators based on threaded rods, the surgeon can perform multi-planar corrections without having to make major adjustments to the fixator and without having to return to the operating room.

Recently, there has been a dramatic increase in the number of hexapod circular external fixators available on the market. While they all have similar software and hardware, specific nuances make each hexapod system unique. The sheer number of hexapod frame choices can be overwhelming and confusing for most surgeons, especially those who only apply a few external fixators a year. It is not practical to invest time and energy to attempt to master each and every system, nor is it necessary. Becoming comfortable with one or maybe two systems should be the goal and will provide the surgeon with the capability to handle virtually any patient's limb reconstruction needs.

This review aims to provide surgeons with an overview of the current options when choosing a hexapod circular external fixator. Furthermore, a comparison of the common hexapod circular external fixators currently available is provided. Highlights of each system's hardware, software, and educational opportunities are provided and can be used as a quick reference resource. With this information, the surgeon can determine which system has the optimal combination of variables that best fits their patient's needs. Due to multiple features such as fixation elements, frame material, and software possibilities within each frame system, a great variety exists when considering possibilities across all frame systems. Appendix 1 presents an overview of the current possibilities with hexapod circular external fixators available in the market.

Orthopedics Ortho SUV

Track Record: The system was initially released to the Russian market in 2008 and subsequently to the global market in 2013. The frame's minimized ("pediatric")

Figure 1. *Ortho SUV frame and minimized (pediatric) Ortho SUV frame.*

version was released in 2019. A PubMed search of the Ortho SUV external fixator identified five publications.

Educational opportunities: Basic, master's, and advanced courses are offered. (tstorthopedics.com)

Hardware: Carries 3 mm, 4 mm, 5 mm, and 6 mm Schanz pins. The struts can be used with rings of any geometry and any manufacturer. The rings can be placed with any inclination to the bone. Only three strut fixations are required for each of the rings, and the locations of strut fixation can be chosen freely (tabs are not required). It is possible to fix the struts not only to the base and mobile rings but also to stabilizing or dummy rings. Struts can be fixed to the holes of the rings directly or using straight or Z-plates that can be directed proximally or distally as required. The strut design is double telescopic and can be reversed. Due to the design, there is no need for strut changes from one size to another during the deformity correction period. It is possible to make a multi-level deformity correction using one set of struts (Spring Technique). A pediatric-sized frame is also available. Due to its smaller weight and size, it is ideal for pediatric deformity correction but can also be used in adult forearm and foot applications.

Software: Radiographs are uploaded to the software, and all the deformity correction planning can be made using the software tools. The software accepts radiographs uploaded in either jpeg, bmp, or dicom formats. Radiographs can be edited in the software (i.e., crop, rotate, flip). A unique instrument of the software is the so-called "Tree." It provides a convenient method for determining the axes of bone fragments. It allows the surgeon to determine 1/2, 1/3, or 1/5 of the joint line and to build the anatomic or mechanical axis with the requested angle (reference angle) to the joint. Deformity correction is simulated in the software by drawing the bone contour that shows the initial position of the mobile bone fragment and (calculated by the software) the expected final position. Two separate structures at risk points can be selected if necessary: one for the bone and one placed in the projection of a main nerve or vessel. The Multi-Total-Residual option is unique in that it allows multiple positions of the mobile fragment to be calculated. It is used when the deformity correction according to the integral trajectory has risks of bone fragments collision. For example, if there are overlapping bone segments, the software will calculate the steps of distraction, translation, and then compression using the mode multi-total-residual. The surgeon will be able to see this complex movement of the mobile fragment on the initial x-rays by the contours of the mobile fragment. This option can also be applied in patients with joint contractures when it is necessary to reproduce the complex curve of motion in the joint by multiple positions of the mobile fragment.

Highlights: This is not a "frame" but a unique universal software-based deformity correction unit. While all other hexapods are based on the Gough-Cappel-Stewart platform, which requires six points of strut fixation to the proximal ring and six points to the distal ring, this system is based on the SUV platform that is developed specifically for orthopaedic purposes. With Ortho-SUV, using prescribed strut fixation points (tabs) is not necessary. Instead, this platform fixed the struts by one end to the ring and the body of the adjacent strut. Consequently, this design requires only three points of fixation to each ring. This particular design creates hardware advantages such as free assembly, free choice of strut location, and the possibility to fix the struts to the base rings as well as to the stabilizing or dummy ring. The multi-total residual software mode is unique and sets this system apart from the competitors due to the possibility to move bone fragments according to the complex curve that is essential in cases of overlapping bone fragments or joint contractures.

Availability: This system is available in Europe, Asia, Africa, and South America. It is currently not available in North America or Australia.

Smith and Nephew Spatial Frame

Track Record: The SPATIAL FRAME™ was introduced in 1996 and remains one of the most widely used hexapod circular external fixators. Over 200

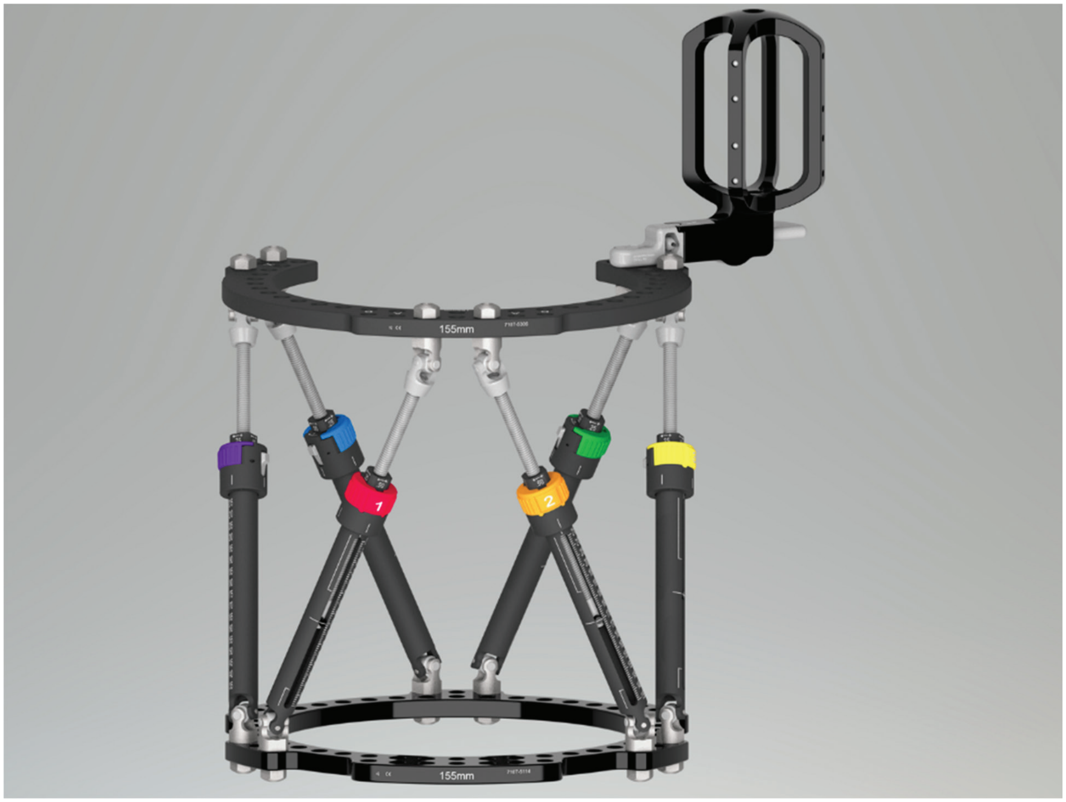

Figure 2. *Smith and Nephew spatial frame.*

peer-reviewed articles involving the Spatial Frame external fixator have been published.

Educational Opportunities: Basic training courses are conducted regionally and at orthopaedic conventions. Advanced training is possible via Visiting Surgeon Programs and/or the annual Limb Restoration Forum. In addition, educational content is located on the dedicated education and resources page of the SMART-TSF.com website.

Hardware: This system offers an extensive range of ring sizes (80 mm – 300 mm) and provides rings in full, 2/3, half, and foot (U) configurations. For the standard sizes, the rings are manufactured in multiple color choices (black, red, blue, green, gold, and purple). The struts have 0.25 mm adjustability and come in two styles: 1) standard struts with gradual adjustment optimized for correction around an osteotomy, and 2) FAST FX™ and SMART FX Struts that have both gradual and acute adjustment for fracture reduction. Step-off plates allow the strut to be mounted off of the ring. Dynamization is possible to enable controlled axial micromotion of the frame if desired.

Half pins are available with hydroxyapatite coating in 4.5 mm and 6.0 mm diameters. Titanium HexFix pins are available in 4 mm, 5 mm, and 6 mm diameters. Transfixion wires in both stainless steel and titanium are available in 1.2 mm, 1.5 mm, 1.8 mm, and 2.0 mm diameters. The wire tips have either bayonet or drill tip options and have smooth and olive types.

Software: Image upload is supported in the software. It is possible to perform an in-program digital analysis of the radiographic images. Detection of the ring-mounted beacon on the orthogonal radiographic images drives automated scaling, calibration, and calculation of the mounting parameters. The SuperDot and TraumaDots analysis methods can facilitate a digital cut of the radiographic images and visual correction to measure deformity parameters. The software still supports the traditional origin and corresponding point analysis method. Additional software features include: the direct scheduler (allows intentional bony deformity for soft tissue closure, followed by gradual correction, without the need for a full program); HIPAA and GDPR compliance; prescriptions can be scanned into a mobile app for patients; and the option of a "pediatric mode" novelty feature for children.

Highlights: This system has more than 25 years of clinically successful outcomes and 98 years of collective engineering expertise. There is flexibility of hardware placement to accommodate the patient’s anatomy. With the use of the beacon, there is automated calculation of the scaling, calibration, and mounting parameters. The software offers four options for deformity analysis. Digital measurement tools such as a ruler, Cobb angle, and joint line are available. The system uses cloud-based architecture for greater storage, processing efficiency, and security of the surgeon’s case information.

Availability: This system is available in North America, South America, Europe, Asia, Africa, and Australia.

Figure 3. *Orthofix TL Hex.*

Orthofix TL Hex

Track Record: This system was initially released for clinical use in 2012 and is featured in 29 peer-reviewed publications.

Educational Opportunities: The Orthofix learning curriculum consists of three levels of courses and provides the opportunity to develop tailored medical training in Foot & Ankle, Pediatrics, Limb Reconstruction, and Trauma. Fundamental courses provide an overview of the basic principles of bone fixation. Intermediate courses are focused on specific orthopaedic specialties: these classes are geared towards specialists early or intermediate in their careers who are interested in furthering their expertise and surgical skills. Master classes are dedicated to senior surgeons. These meetings provide the opportunity to debate and discuss current concepts, controversies, and approaches for the most complex orthopedic diseases and unique, challenging cases. Hospital-based observership programs are also available and are comprised of theatre case participation, wet and dry lab workshops, clinic visits, and lectures. In recognition of the high level of education provided through its courses, Orthofix Academy has been accredited by The Royal College of Surgeons of England.

Hardware: Both smooth bayonet wires and bayonet wires with stoppers are available in 1.5 mm and 1.8 mm diameters and in titanium or stainless-steel versions. Half pins also are produced in stainless steel or titanium with either 4 mm, 5 mm, or 6 mm diameters. The half pins have the option to be hydroxyapatite coated or uncoated as well as cylindrical or conical threads. Cylindrical pins are available in 3.5 mm, 4.5 mm, 5 mm, and 6 mm sizes, while the conical pins are available in 6.0-5.0 mm and 4.5-3.5 mm sizes. The half pins are also available in a self-drilling option.

TL-Hex offers pre-assembled and universal components that are easy to connect, align and operate. The TL-Hex provides exceptional frame stability due to its unique aluminum-stainless steel and patented metal-plastic interface. The system’s hardware allows extreme flexibility in the frame mounting configuration and has several potential advantages, including 1) a distinctive strut design that allows for independent and gradual adjustments, resulting in a greater overall adjustment range; 2) the outside of the ring strut mounting arrangement allows the surgeon to have all the holes of the rings free; 3) fewer strut exchanges necessary due to the telescopic design; and 4) an easy method to disconnect the struts from the frame when performing the intraoperative osteotomy. The struts have both a visual and an auditory click gradual strut adjustment. The 5/8 ring can be closed (or opened) by adding (or removing) a 3/8 ring connection piece. Pre-sterilized components are also available.

Software: The TL-Hex software allows the surgeon to pre-plan the frame and mounting parameters using digitally uploaded radiographs. There is a suggested bone length option to prevent bone segments from impinging. The surgeon can pre-plan the automatic strut configuration, and by using the “plan your frame option,” the struts are optimized according to where the rings are positioned. This feature helps to decrease the number of strut changes or adjustments needed. The prescription plan can also be optimized with the possibility to synchronize eventual strut change/adjustment on selected preferred days.

The myHEXplan™ mobile app is a free app that provides surgeons with a remote view of their patient’s post-operative treatment actions. The app also enables TL-Hex patients to 1) access their treatment(s) schedule on a smartphone, in addition to the paper one(s); 2) receive reminders for strut adjustments and pin-site care and mark these activities as complete; 3) access educational materials about treatment with the TL-HEX system; 4) receive motivational messages and access other useful features such as timelapse to visualize the frame changes over time.

Highlights: The hardware and software platforms are frequently updated with new components/solutions/tools. The TL-Hex is compatible with all Orthofix circular frame options and allows the surgeon to build a modular construct with a pin to bar solutions. The system offers a wide array of educational programs for both the surgeon and the patient. Patient support material is available. It has content designed for specific age ranges, including the unique mySuperheroAcademy™ edugame.

Availability: This system is available in North America, South America, Europe, Asia, Africa, and Australia.

Figure 4. *OrthoPediatrics Orthex.*

OrthoPediatrics Orthex

Track Record: This system was initially released for clinical use in 2016. Six peer-reviewed articles involving the Orthex external fixator have been published.

Educational Opportunities: OrthoPediatrics offers peer-to-peer surgeon training through the Visiting Surgeon Program and the Traveling Visiting Surgeon program. Frame specialists are available to travel for a surgeon’s first cases and review the surgeon’s preoperative planning. OrthoPediatrics also offers 1-2 day company-sponsored training seminars, primarily focused on frame mounting and the Orthex software features. In addition to these seminars, industry-sponsored training is available at the annual International Pediatric Orthopaedic Symposium (IPOS®) and CME workshops at the Baltimore Limb Deformity Course (Trauma, Foot and Ankle, Pediatrics).

Hardware: Stainless steel half pins are available with extended hydroxyapatite coating in two main families: 1) the large bone type which has a 6 mm shaft diameter and thread diameters of either 3.0 mm, 4.5 mm, or 6.0 mm; and 2) the small bone type which has a 5 mm shaft diameter and thread diameters of 3.0 mm, 4.0 mm, or 5.0 mm. The patented Orthex hydroxyapatite pin design features an extended HA coating, a tapered minor diameter providing greater compression, and a pitch differential between cancellous and cortical thread to promote radial compression. Orthex hydroxyapatite pins are compatible with the Orthex large bone and small bone ring systems, the OrthoPediatrics Monorail, and the OrthoPediatrics Drive Rail.

This system offers hydroxyapatite-coated smooth and olive wires. These wires are provided in 1.5 mm and 1.8 mm diameters. Smooth bayonet tip wires of 1.2 mm, 1.5 mm, and 1.8 mm and bayonet tipped olive wires of 1.5 mm and 1.8 mm are also available. Other tip styles for non-coated wires include drill tip and trocar tip wires.

The rings are constructed with two concentric rows of holes (slots). The outer row has slots connecting the six standard hexapod tabs to provide additional bending strength and options for hardware mounting. Holes are numbered with laser markings if a non-standard strut configuration is needed. Z-plates extend strut mounting above or below the rings to allow extreme deformity corrections that would cause "submarining" of struts or not be possible in other systems. Ring options include low-profile arches to enclose foot rings, full rings, partial rings, footplates, and half rings. Full and partial ring sizes are offered from 105 mm to 280 mm and small bone sizes from 75 mm to 130 mm. Double-column cubes are available, which diminish cantilever half-pin bending and can be secured to both rows of the ring to prevent rotation. The double-column half-pin cubes also improve drill guide accuracy and prevent half-pin deformation. The struts are telescopic with a patient-adjustable "A" portion that moves in one-fourth turn increments for each 0.25 mm correction. The telescoping "B" portion can be quickly positioned and then locked to maximize the amount of threaded "A" rod available for gradual correction. The telescoping struts decrease the number of required strut changes. The patient schedule can be separated to perform daily adjustments up to four times per day and schedules are able to be provided in millimeters or clicks.

Software: The Orthex system uses a point-and-click software interface and utilizes the center of rotation of angulation (CORA) method as its guiding principle. The CORA-centric deformity analysis and frame mounting are performed online (no mounting parameters) directly on digitally uploaded radiographs. The surgeon can set up four consecutive correction steps, separating parameters or deformity parameters to be corrected simultaneously or separately, each with its own correction rate (or days for correction). Simplified residual programming offers the surgeon insight into the completed correction without requiring new radiographs based on strut lengths. The software provides Integrated support of non-standard strut connections and Z-Plates. All of the software nomenclature follows standard orthopaedic terminology (i.e., the distal reference does not require a "reversal" of coordinate system or translation). The Orthex software offers joint-based planning lines (medial proximal tibial angle, lateral distal femoral angle, etc.) or mid-diaphyseal lines for long bones. In addition, there are multiple possible modes, including fracture mode, knee joint mode, foot and ankle modes for ankle and midfoot corrections of the foot, and upper extremity modes for humerus, forearm, and wrist.

In the Orthex system, the ring does not have to be mounted perpendicular to the bone, and the radiographs do not have to be perpendicular to the ring. The surgeon can custom select the axis of lengthening as well as the axis of rotation.

The surgeon can identify an independent (oblique) CORA between the AP and lateral radiographs. The midfoot planning offers an overview of the relevant impact of correction on Meary's angle, the metatarsal declination angle, the cavus angle, the calcaneal inclination angle, and the plantigrade angle based on the lateral radiograph. The surgeon can identify separate soft tissue and bony rate-determining points (RDPs). The software will calculate the correction rate at each RDP based on a chosen correction duration. Finally, the cross-sectional overlap at the osteotomy level is also calculated and displayed.

Highlights: In the Orthex system, all aspects of the deformity analysis are performed through simple pointing and clicking, localizing the frame to the bone, rather than the bone to a frame, through a user-friendly and graphically based interface. Deformity planning is performed online via the Orthex software without the need for mounting parameters. The software recognizes the relationships between the osteotomy, CORA, and the pivot point. The Orthex system provides its calculation, but all control is in the hand of the surgeon user to accept or modify these calculated parameters.

The Orthex hardware and software integrate using metal spheres temporarily attached to cardinal points on the outer edge of the preference ring before taking planning radiographs. The radiographs are digitally imported into the patient case, and the software calibrates the size of the ring and calculates its rotation, inclination, and location. Due to the distance between the radiographic spheres, the Orthex calibration is extremely accurate. Another powerful feature of the Orthex software is the ability to separate deformity correction into as many as four consecutive steps or perform all corrections simultaneously. From a hardware perspective, the Orthex system includes both large and small bone systems. The choice of system depends on the host bone size and body habitus. The small bone system can be particularly advantageous in the lower extremity and/or foot for very young pediatric patients and upper extremity indications. The components in the small bone system are approximately 40-60% lighter than comparable large

__Figure 5.__ Wishbone Smart Correction System.

bone system components. Both systems include a full complement of components (plates, hinges, posts, etc.) to perform Ilizarov-style corrections or construct a large or small bone hexapod fixator using struts. The Orthex hydroxyapatite implants are unique, with a wide variety of pin diameters and thread lengths, and thread diameters (see above). The Orthex system is the only system to offer HA-coated smooth and HA-coated olive wires. In addition to the technical characteristics of the hardware and software, the Orthex appearance is designed to be aesthetically pleasing to the surgeon and patient. Small bone rings are red and blue, and large bone rings are available in various colors for surgeons and patients to select colors, if desired, at no additional cost.

Availability: This system is available in North America, South America, Europe, Australia, and the Middle East.

Wishbone Medical's Smart Correction System

Track Record: The system was initially released in the United States in 2021 but was already available under WishBone's international subsidiary Response Ortho since 2009. Four peer-reviewed articles involving the Smart Correction external fixator have been published.

Educational Opportunities: WishBone Medical engages in hands-on cadaveric and didactic courses at industry, regional, and onsite events. In addition to hands-on courses, live and prerecorded peer-to-peer didactic courses are available via webinars and Wishbone's medical education hub.

Hardware: Half pins are offered in 4.5 mm, 5.0 mm, and 6.0 mm diameters, with self-drilling and blunt/self-tapping options available. Hydroxyapatite half pins are also provided, currently available in 6.0 mm diameter self-drilling/self-tapping configurations and are sterile packed. Wires with straight and olive configurations are offered in 1.8 mm and 2.0 mm diameters. All half pins and wires are stainless steel.

Freedom of strut placement with no discrete master tab allows the surgeon to mount struts wherever needed on a ring. This eliminates the need for a mounting parameter, master tab, or reference ring. The Smart Correction® assembly weighs 20% less than other comparably sized components (frames, wire clamps, and wires). The 6 mm ring thickness offers the lowest profile and allows for more fixation options within a defined ring span, allowing surgeons to address multiple issues in proximity. Smaller ring sizes (down to 70 mm) are available for small adults/pediatric patients. To help minimize children's anxieties and make the construct less intimidating, caregivers can purchase "Ring Bling" buttons to decorate the rings.

Software: The Click2Connect software offers a simplified four-stage format to generate the correction schedule and precise deformity correction in all geometric planes (axial, frontal, coronal, and translation).

Highlights: WishBone Medical's fixator has several unique features: 1) free strut placement enables maximum interoperative flexibility, 2) lightweight frame construction including 6 mm lower profile rings, and 3) "Ring Bling" accessories to help minimize children's anxiety. The Smart Correction® fixator demonstrates higher deformity correction accuracy than an Ilizarov external fixator, and alternative ring colors are available.

Availability: This system is available in North America, South America, Europe, Africa, and the Middle East.

A

Figure 6A. *Synthes Maxframe.*

B

Figure 6B. *Synthes Maxframe Autostrut.*

Synthes Maxframe and Autostrut

Track Record: The Maxframe system was released in 2017, and the Autostrut system was released in 2022. A PubMed search of the Maxframe and Autostrut system identified one publication.

Educational Opportunities: Learning journeys tailored to residents, fellows, and attending-level surgeons are offered. The blended learning journeys include national and regional in-person hands-on courses, on-demand digital education, peer-to-peer virtual coaching, virtual reality, and preceptorships.

Hardware: The wires (smooth and reduction) are available in 1.5 mm, 1.8 mm, and 2.0 mm diameters. The half pins (Schanz screws) are available in 4.0 mm, 5.0 mm, and 6.0 mm diameters with stainless steel, titanium, and hydroxyapatite-coated options. There are multiple wire and Schanz screw attachment options.

There are both quick adjust and standard struts for the hexapod configuration with 1 mm increments per adjustment click. Linear struts for a non-hexapod configuration (bone lengthening/transport) are also available for 0.25 mm increments per adjustment click. Full rings (from 90 mm to 270 mm diameter), 5/8 rings, and foot plates are offered. There is also a footplate support kit.

The Autostrut function offers fully automated strut adjustments up to 20 times per day.

Software: The software uses postoperative radiographs with the ENTIRE frame to generate the deformity and mounting parameters, although all the parameters can also be entered manually. It does not require radiographic scaling or adherence to the use of orthogonal x-rays. It also does not require strict orthogonal mounting of the reference ring. Up to five distinct treatment phases can be planned. The software provides a dynamic visualization of the treatment plan.

Autostrut: The hours that the autostruts are in operation can be selected.

Highlights: The extensive hardware offering enables versatility in ring fixation constructs. There are numerous variable thread length Schanz screw offerings to match patient anatomy. The first-of-its-kind automated hexapod ring fixation system offers fully automated strut adjustments. The automated struts are designed to improve the patient experience and clinical outcomes. The software utilizes perspective frame matching technology to improve accuracy and reduce complexity. There is no strict requirement for orthogonal radiographs or ring mounting. The software can calculate the deformity and mounting parameters. A dedicated limb deformity support team and educational resources are available to surgeons.

Availability: The Maxframe system is available in North America, Europe, Asia, Australia, and the Middle East. The Autostrut system is only available in the United States.

Figure 7. *Hoffmann LRF hexapod.*

Stryker Hoffmann LRF

Track Record: The Hoffmann LRF system was released in 2019. A PubMed search of the Hoffmann LRF system identified no publications.

Educational Opportunities: Stryker Trauma has a complete program of internal and external education for circular fixation. Internal training involves local and European activities, from virtual training, videos, tutorials, and hands-on workshops. This European circular fixation offer is completed with local and cross-country educational activities such as local cadaver labs, the TEACH educational truck, symposiums in the main congresses, and surgeon-to-surgeon visitations.

Hardware: The half pins in this system are available in diameters from 3-6 mm and have titanium, stainless steel, and hydroxyapatite-coated options. The wires are available in 1.5 mm, 1.8 mm, or 2 mm diameters with and without an olive.

This system offers radiolucent carbon-fiber rings that offer greater stiffness than aluminum rings. The system requires approximately 20% fewer components to do similar cases compared to competitive systems and has compatibility with all the Hoffmann lineup of products. Low-profile frame components are available.

In this system, it is possible to offset the strut attachment up to two holes from the nominal mounting sites for enhanced pin/wire placement freedom. This allows the surgeon to move struts to improve surgical site access and visibility. The struts have 0.25 mm adjustment granularity for precise variable rate of adjustment. The materials undergo high-performance machining, which produces precise tolerances to reduce frame "rattle" and minimize the shear forces at the healing site. The struts utilize click lock technology, providing a patient-friendly actuation and articulating adjustment feedback via pronounced visual, audible, and tactile adjustment confirmation. Multiple adjustment checkpoints verify the correction progress (barrel scale, click lock, driver counting wheel, individualized patient guide). The top actuated design is easy to access and manipulate during adjustments. Secondary strut locking features and driver actuation minimize the risk of inadvertent strut adjustment. Rocker shoes are available to attach to the rings for improved traction and ambulation.

Software: The software provides advanced case planning/management capabilities, including digital deformity measurement tools, 3D multi-planar visualization, correction simulation, accurate anatomic modeling, and an easy-to-use adjustment plan. There is a streamlined workflow with pre-op case planning and total residual navigation options. There is an option to consult your colleagues by sharing and transferring cases.

Highlights: This system offers unique radiolucent carbon fiber rings connected by struts that can actuate in 0.25 mm increments. The foot arches come fully assembled and have the option to use built-in hinged connection bolts that allow for angular adjustment of the arch for construct versatility. The wire fixation bolts feature a built-in grooved washer that grips the wire. Modular counter-torque tensioner noses eliminate the need for a separate counter-torque wrench to prevent the wire fixation bolt from rotating within the hole during tensioning and tightening. A built-in retention clip (on the short adaptor) allows for a provisional snap-fit connection to the ring without nuts and decreases the likelihood of dropped components.

Availability: The Hoffmann LRF system is only available in Europe.

Comparative Studies Between Different Hexapods

Despite the widespread use of hexapod external fixators and an increasing number of hexapods from different manufacturers, there are only a small number of studies comparing the different hexapod systems. Table 1 provides an overview of the six studies comparing different hexapods. In all studies, the Taylor Spatial Frame is one of the frames to be compared; the other frames included are TL-Hex and Orthex. Two of the six comparative studies are clinical studies, and the remaining four are experimental. The two clinical studies are both retrospective, with one study examining outcomes after pediatric tibial lengthening and deformity correction and one study examining outcomes after complex tibial fractures.

Discussion

Over the past 10 years, multiple new hexapod circular external fixation systems have become available to orthopaedic surgeons. Since most surgeons only utilize this technology occasionally in their practice, the decision regarding which system to use can be confusing, and using an unknown system for the first time can be intimidating. Consequently, this article aims to comprehensively compare the multiple hexapod external fixators currently available by coalescing pertinent information about each system into one easy-to-access resource.

While the authors are each experienced hexapod users, they have purposely tried to avoid any bias in the preparation of this document. The manufacturer has supplied the information provided about each system. Some of the content was carefully and objectively edited to fit the structure of the review, but it does not include any additional subjective comments or recommendations from the authors.

In the process of preparing this review, the authors did make several observations:

1) While the recent explosion of multiple different hexapod external fixators can create a confusing and crowded market to navigate, the development of multiple systems has had a positive effect on this technology. The competition between companies to create an attractive product has driven an impetus to improve hardware and software. We expect the economic pressure to succeed will continue to drive advances in the systems and help develop niche products as the industry searches for unique areas to capture business. This competition will potentially lead to better experiences and outcomes for our patients.

Table 1. Comparative Studies of Hexapod External Fixators

Authors	Year of publication	Hexapods compared	Comparison	Study design	Main finding
Basha et al.[1]	2022	TSF, TL-Hex, Orthex	Deformity correction	Biomechanical Sawbones models	TL-Hex software is better to estimate deformity than TSF or Orthex
					No difference in the accuracy of deformity correction
					No difference in frequency of strut change
Fenton et al.[2]	2021	TSF and TL-Hex	Stiffness characteristics	Axial and torsional load test in MTS machine	Higher toe-in laxity of TSF Cardan type struts than TL-Hex ball-in-socket struts
Messner et al.[3]	2021	TSF and Orthex	Clinical outcomes in pediatric tibial lengthening and deformity correction	Retrospective study of two cases series from different time intervals (TSF: 2014-2016 and Orthex: 2017-2019) at a single institution	Similar healing indices and limb deformity correction between TSF and Orthex
					Superior regenerate quality with Orthex
				The TSF rings were fixed to the tibia with smooth stainless-steel wires (1.8 mm) and partially hydroxyapatite (HA)-coated (thread only) half-pins The Orthex rings were fixed to the tibia with extended HA-coated (thread and shank) half-pins and fully HA-coated wires (1.8 mm)	Significant reduction in pin site infection rate with Orthex (18% in Orthex cohort versus 40% in TSF cohort)
Naude et al.[4]	2019	TSF and TL-Hex	Clinical outcomes of complex tibial fractures	Retrospective study of patients operated for complex tibial fractures with or without bone loss with a minimum follow-up of 12 months after treatment with a circular frame	Comparable clinical, functional, and radiographic outcomes for TSF and TL-Hex

Table 1. Continued

Authors	Year of publication	Hexapods compared	Comparison	Study design	Main finding
				The allocation of a TSF or TL-HEX was determined by implant availability and surgeon preference	
Iobst et al.[5]	2016	TSF and TL-Hex	Deformity correction	Experimental study	The Cardan-type universal joints (TSF) in smaller struts allow more translation and rotation, whereas the ball and socket joints (TL-Hex) allow more length
					For large rotational corrections and frames built with 90° of offset, the ball and socket joint design (TL-Hex) is better at avoiding soft tissue impingement
					The ball and socket joint design allows more correction with fewer strut changes for patients with severe deformities.
Ferreira and Birkholtz[6]	2015	TSF and TL-Hex	Radiographic analysis	Biomechanical study using a tibia fracture model	Differences in deformity and mounting parameters between TSF-software and TL-Hex software were observed when applying a ring oblique to the proximal segment
					The radiographic analysis for the TSF and TL-Hex are fundamentally different

2) The authors wanted to provide scientific data to help the reader choose the most appropriate hexapod system. In reviewing the literature, we found a decided dearth of clinical literature comparing the results of different systems. The six articles listed in Table 1 represent the current total number of articles found directly comparing hexapods; only two are clinical studies. There is a clear opportunity for collaborative, multi-center studies to investigate this topic.

3) Because there are so many different systems on the market, it is impossible or at least impractical to be proficient at all of them. While certain nuances are different between the systems, all of them are similar in their options and capabilities. Therefore, the authors feel that it is important for the surgeon to gain experience and skill with one system first. Choose the hexapod system that makes you feel the most comfortable and get good at it. Your patients will have better outcomes if you master one system. Avoid the tendency to switch from system to system, thinking that this will solve your issues with circular fixation. Once you have extensive experience with one system, you can add another system to your armamentarium if you think this will benefit your patients.

Conclusion

The development of multiple systems might have a positive effect on the advancement of external hexapod technology; however, comparative studies are needed to further investigate potential benefits and pitfalls of different systems with regard to specific patient populations. A possible strategy for surgeons undertaking these highly specialized treatments is to obtain clinical expertise in one external hexapod system prior to pursuing mastering several systems.

Disclaimer

C. Iobst: Consultant for Orthofix, Wishbone Medical, Inc., Smith and Nephew, and NuVasive; N. Ferreira: Consultant for Orthofix, Smith and Nephew, and Swemac; S. Kold: Consultant for Wishbone Medical, Inc.

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Appendix 1

Overview of Possibilities with Current Hexapod External Fixators

Countries with at least one hexapod system available:	
Albania / Argentina /Armenia/ Australia / Austria / Bahrain / Belgium / Brazil / Bulgaria / Canada / Canary Islands / Chile / China / Colombia / Costa Rica / Croatia / Cyprus / Czech Republic / Denmark / Egypt/ Estonia / Finland / France / Germany / Greece / Hong Kong / Hungary / India / Indonesia / Iraq/ Ireland / Israel / Italy / Japan / Jordan / Kuwait / Latvia / Lithuania / Libya / Luxembourg / Malaysia/ Malta / Mexico / Namibia / Netherlands / New Zealand / Norway / Oman / Philippines / Poland / Portugal / Puerto Rico / Qatar / Romania / Russia /Rwanda / Saudi Arabia / Singapore / South Africa / South Korea/ Slovakia / Slovenia / Spain / Swaziland / Sweden / Switzerland /Taiwan / Thailand / Turkey / United Arab Emirates / United Kingdom / United States	
Hexapod fixation (wires/half-pins)	
Fine wires:	Bayonet wires in titanium or stainless steel with and without olive: Ø 1.5 mm, 1.8 mm, 2.0 mm
	HA-coated bayonet wires without olive: Ø 1.2 mm, 1.5 mm, 1.8 mm
	HA-coated bayonet wires with olive: Ø 1.5 mm, 1.8 mm
	Trocar tip wires without HA coating
	Drill tip wires without HA coating
Half pins	HA-coated straight half pins: Ø 4.5 mm, 6.0 mm
	Titanium straight half pins: Ø 4.5 mm, 6.0 mm
	HA-coated or non-HA coated stainless steel or titanium conical pins: Ø: 3.5 mm, 4.5 mm, 5.0 mm, 6.0 mm
	HA-coated or non-HA coated stainless steel or titanium cylindrical pins: Ø: 3.0 mm, 3.5 mm, 4.0 mm, 4.5 mm, 5.0 mm, 6.0 mm
	Extended HA coated (beyond thread) stainless steel tapered pins - 5.0 mm shaft diameter with thread diameters: 3.0 mm, 4.0 mm, 5.0 mm - 6.0 mm shaft diameter with thread diameters: 3.0 mm, 4.5 mm, 6.0 mm
Hexapod rings	
Material	Aluminum-stainless steel
	Aluminum
	Radiolucent carbon-fiber
Shapes	Full ring, 2/3 ring, 5/8 ring, ½ ring, foot ring: U ring
Size range	70 mm – 300 mm
Colors	Different colors available
Strut assembly	
Strut mounting	Single row of holes on frame
	Double row of holes on frame

Appendix 1. Continued

	Partial double row of holes (tabs)
	Out of the ring strut mounting
	Step-off plates allow for strut mounting off the ring
	Z-plates extend strut mounting above or below the ring
Strut positioning	Strut attachment can vary from up to two holes from nominal mounting sites to no restrictions of strut positioning.
Strut function	
Strut adjustment	Single telescopic
	Double telescopic allows for a wider range of adjustments - Acute adjustment - Gradual adjustment Reversal of strut allowing for no need of strut change
Strut increments	Manual adjustment from 0.25 mm to 1 mm
	Automated adjustments up to 20 times per day
	Strut adjustments in millimeters (visual) or by clicks (sound, tactile)
Software	
Mathematical basement	Gough-Cappel-Stewart platform: 6 points of strut fixation to both the proximal and distal ring
	SUV platform: 3 points of strut fixation both to the proximal and distal ring
Corrections based on	CORA
	Origin and Corresponding Point
	SuperDot and TraumaDot
Planning	Preoperative planning tools, including joint orientation line-based planning
	Preoperative strut planning for reducing strut change or strut adjustments
Freedom of software	The ring does not need to be mounted perpendicular to the bone
	The X-rays do not have to be perpendicular to the ring
Mounting parameters	Manual typing
	Automated uploading from digital X-ray images Automated scaling and calibration
Deformity planning	Separate steps can be used and visualized on planning tool to ensure that bony impingement does not occur
	Structure at risk can be identified
Prescription plan	Possible to synchronize strut changes and strut adjustments on selected preferred days

Appendix 1. Continued

Mobile app solutions	Patients can access treatment schedule on a smartphone
	Reminders for strut adjustments
	Reminders for pin-site care
	Marking of completed activities
	Pediatric features for children, including educational games
	Available through App Store and Google Play Store
	Legal issues: HIPAA and GDPR compliant
Surgeon educational activities	
Online courses	Basic
Physical attending	Fundamental, intermediate, advanced courses and masterclasses
	Visiting surgeon programs
Release of hexapod system to the marked	
From 1996 to 2022	Changes have been made to the hexapod systems over time
Publications documenting clinical results	
Cases-series	Large variety of number of publications for specific hexapods
	Few comparative retrospective studies between different hexapods
	No prospective randomized controlled studies between different hexapods

HA: Hydroxyapatite, SUV: Solomin/Utekhin/Vilensky, HIPAA: Health Insurance Portability and Accountability Act, GDPR: General Data Protection Regulation.