prestige to promote their device for many years.\textsuperscript{141} In 1975, Volkoff and Oganesyan published a series of patients treated with distraction arthroplasty at the knee and elbow utilizing small transfixion wires attached to ring fixators. Their work went largely unnoticed in North America even though it was published in the American Journal of Bone and Joint Surgery.\textsuperscript{290}

Dr. David Fisher was exposed to Volkoff’s circular apparatus and designed a circular type fixator of his own. Instead of using thin tensioned wires as with the Russian device, he designed a fixator construct which allowed for significant pin separation, deviation of pins at various angles, and a semicircular configuration using larger Schanz half pins. He determined that fracture site stability could be increased using these circular configuration concepts.\textsuperscript{94,115}

As the traditional Soviet Ilizarov type devices were quite cumbersome and complex compared with the more straightforward AO and Hoffman type fixators, Kroner, in 1978, refined and modified the Russian devices by employing plastic components and transfixion pins in place of the thin wires used by the Ilizarov technique.\textsuperscript{1,115,140}

For many years, the Ilizarov method was restricted to the region of Kurgan in Siberia. In 1980, the technique was introduced in Western Europe thanks to the persistence of world famous Italian explorer, Carlo Mauri. Mauri traveled to Russia specifically for this technique, and was successfully treated for an infected pseudarthrosis of the tibia by Ilizarov. His fracture had occurred 10 years earlier in a mountain climbing accident. Through the friendship established by Mauri with Professor Ilizarov, the technique was introduced to Mauri’s initial treating surgeons, and subsequently, Ilizarov was invited to speak at the XXII Italian AO conference in Bellagio, Italy. This was the first clinical presentation that Ilizarov gave on his techniques outside of the “Iron Curtain.” Italian surgeons realized the significance of his methods and brought the techniques back to Italy under the guidance of Professor Roberto Cattaneotto and his associates, Villa, Catagni, and Tentori. They began the first western clinical trials with transosseous osteosynthesis utilizing Ilizarov’s fixator in Lecco, Italy, in 1981.\textsuperscript{1,140,141}

When the political climate in the Soviet Union changed under different leadership in the 1980s, the possibilities of the

\[\text{FIGURE 8-11 A, B: The original patent application for Bittner’s circular external fixator with the principle of tensioned thin fixation wires.}\]
Ilizarov method that had previously been unrecognised in the West became more apparent. These techniques were presented at various orthopedic meetings in Italy and other centers in Western Europe in the early 1980s. Victor H. Frankel (then president of the Hospital for Joint Diseases) saw the external device at a scientific exhibition while attending a meeting in Spain. He investigated further and eventually traveled to Kurgan to visit Ilizarov’s center along with Dr. Stuart Green MD in 1987. This began a progression of North American surgeons, notably Victor Frankel, James Aronson, Dror Paley, and Stewart Green, who were exposed to Ilizarov’s work. They recognized the potential of this methodology as applied to difficult contemporary orthopedic problems and all began clinical applications in the mid 1980s. In 1989, Stewart Green, who had significant expertise in treating nonunions and osteomyelitis with external fixation techniques, was entrusted by Ilizarov to translate his original basic science work into English. This was published in Clinical Orthopaedics and Related Research in 1989.

The North American experience was popularized by a small cadre of American surgeons in the late 1980s. In an effort to simplify and apply these techniques to traumatology, the tensioned ring concept was married to the unilateral fixator, and the hybrid external fixator was developed to address periarticular injuries with all the advantages of tensioned wires, while limiting the disadvantages of tethering large musculotendinous units with through-and-through transfixion wire constructs. (Fig. 8-13). However, this “advancement” had a relatively short life span because of inferior biomechanics.

A significant innovation in deformity correction and precise fracture reductions was developed by Charles Taylor and others to correct complex deformities through the use of simple ring constructs using half-pin fixation. These “hexapod” fixators have rings interconnected and manipulated by a system of adjustable struts, which allow for six-axis correction of bone fragments (Fig. 8-14). The development of this concept, as well as the ability to interface deformity correction with web-based software, has vastly simplified frame construction and is the basis for contemporary circular external fixation techniques in use at this time.

FRAME TYPES, BIOMECHANICS, AND COMPONENTS

External fixation systems in current clinical use can be categorized according to the type of bone anchorage utilized. This is accomplished by using either large threaded pins, which are screwed into the bone or by drilling small-diameter transfixion wires through the bone and then placing the wires under tension to maintain bone fragment position. The pins or wires are then connected to one another through the use of longitudinal bars or circular rings. Thus the distinction is made between monolateral external fixation (longitudinal connecting bars) and circular external fixation (wires and/or pins connecting to rings). Circular fixation may use either threaded pins or small tensioned wires to attach the bone to the frame. Monolateral fixation is accomplished using
various diameter threaded pins; however, these may occasion-
ally involve the use of centrally threaded through-and-through
transfixion pins.

Large Pin Fixation

Large pin fixator constructs are attached to the bone using vari-
ous sizes of terminally threaded pins. The half pins have a wide
range of diameter ranging from 2 to 6 mm with all intermedi-
ate sizes available. In addition, there are large-diameter pins
with threads in the midportion of the device (centrally threaded
pins), for use in transfixion-type constructs, that is, Hoffman-
Vidal configurations (Fig. 8-15A–E).

The basic indications for large pin external skeletal fixation
are numerous. The actual biomechanical function that a mono-
lateral frame will perform is dependent upon the placement of
the pins and orientation of the connecting bars applied. These
factors, as well the inherent skeletal pathology treated, com-
bine to impart a specific biomechanical function to the fixation
construct. The ability to neutralize deforming forces is the most
common mechanical principle exploited by external fixation.
This is especially true for acute fractures accompanied by severe
soft tissue damage. The use of monolateral fixation for the stabi-
zation of acute fractures deals with the soft tissue compromise
in the immediate posttrauma/postoperative period. Following
resolution of the soft tissue injury, secondary procedures such
as bone grafting or delayed internal fixation are performed.
The primary function of fixators used in this way is to provide

![Figure 8-13](image1.png)

**FIGURE 8-13** A: An early version of a hybrid external fixator which combines periarticular tensioned wires and diaphyseal half-pin con-
figurations. B: Clinical picture of the same hybrid frame on a patient
with a tibial plateau fracture.

![Figure 8-14](image2.png)

**FIGURE 8-14** Hexapod external fixator with multiple oblique con-
necting struts through which the limb segments can be manipulated
for simultaneous correction of multiple deformities.
FIGURE 8-15 A: Large centrally threaded Schanz pin placed as a distal femoral transfixion pin in a temporary knee-spanning external fixator as seen on radiographs. Clinical image of proximal transfixion pin and quadrilateral spanning frame with intercalary half pin mid tibia. B–E: Multiple pin types; (B) 5-mm self-tapping predrilled pins with a short thread length, (C) 5-mm self-tapping predrilled pin with long threads, (D) 6-mm hydroxyapatite self-drilling pin, note self-drilling tip, and (E) 6-mm self-tapping predrilled titanium pin. (continues)
relative stability to maintain temporary fracture reduction and length to avoid collapse of the fracture construct (Fig. 8-16). It should be noted, however, that this type of stabilization is reasonably "flexible." It is nearly impossible to achieve absolute rigidity to achieve primary bone healing utilizing monolateral external fixation.

Monolateral as well as circular frames can also be used to bring areas of metaphyseal or metadiaphyseal bone into close contact through the use of compression techniques. This may be useful in arthrodesis, osteotomy, or nonunion repair (Fig. 8-17). Similarly, distraction forces can also be applied across pin groups to effect deformity correction, intercalary bone transport, or limb lengthening.

**Components**

No matter what the biomechanical function of the frame type, the most important factor regarding the longevity and performance of the frame is the strength and competency of the pin–bone interface. Pin loosening with subsequent pin sepsis continues to be problematic. There are many biomechanical factors, which have been evaluated for the prevention of pin tract problems.

1. Pin geometry and thread design
2. Pin biomaterials and biocompatibility
3. Pin insertion techniques and pin–bone interface mechanics

**Pin Design**

It has been determined that both the screw thread design and the type of cutting head have a significant effect on the holding power of screws. Screw diameter is crucial in determining the stiffness of the frame, as well as determining the risk of stress fracture at the pin site entry portal. The bending stiffness of the screw increases as a function of the pin's radius raised to the fourth power \( S = r^4 \). Placing a screw hole greater than 20% or 30% of the bone's diameter will substantially increase the risk for pinhole fracture. It is important to match the pin diameter to the diameter of the bone being stabilized. In general, it is recommended to err on the side of using a smaller pin diameter.

Calculations have determined that in adult bone, a pin diameter of 6 mm is the maximum that can be used to achieve a stable implant without suffering the consequences of stress fracture through the pinhole itself. This risk will resolve in 6 to 8 weeks through bone remodeling once the pin has been removed. However, the pin site does remain a stress riser until full remodeling of the pin site can occur.

In addition to the variable diameter of the pin, the screw thread may also have differing pitch angle and pitch height. The screw design must make allowances for the quality and

---

** FIGURE 8-15 (continued) F–J: Multiple thread designs are used for specific purposes; (F) tapered pins facilitate subsequent pin removal, (G) self-drilling pins with drill-type pin tip, (H) pins with larger thread diameter suitable for cancellous bone insertion, (I) small pitch angle and narrow thread-diameter pins are applied in cortical bone, and (J) hydroxyapatite-coated pins improve the pin–bone interface by encouraging direct bone apposition and ingrowth.**

** FIGURE 8-16 Simple triangular ankle-“spanning” fixator across a distal tibial injury, with a transfexion pin through the calcaneal tuberosity and two midtibial half pins. This maintains the reduction but is not “rigid” and requires additional temporary splinting.**
location of the bone to which the screw is applied. Pins with a small pitch height and low pitch angle are usually applied in regions of dense cortical bone, such as femoral and tibial diaphysis (Fig. 8-15F–J).

As the pitch vertex angle increases and the curvature and the diameter of the thread increases, the area captured by each individual thread is broader and more likely to be applied in cancellous bone rather than hard cortical bone. Conical pins have been designed so that the threads taper and increase in diameter from the tip of the pin to the shaft. This allows the pins to increase their purchase theoretically by cutting a new larger path in the bone with each advance of the pin. This conical taper also produces a gradual increase in radial preload and thus the screw–bone contact is optimized (Fig. 8-15F–J). Micromotion typical of a straight cylindrical screw is avoided.  

**Pin Biomaterials and Biocompatibility**

Traditionally, external fixator pins have been composed of stainless steel offering substantial stiffness. Finite element analyses of the near pin–bone interface cortex revealed stress values which were significantly increased by the use of deep threads.