5. **ILIZAROV RING FIXATOR**

5.1. **Components**

Osteosynthesis with Ilizarov apparatus is achieved by securing the bone fragments to the external fixator with wires. The apparatus is rigid yet versatile. A surgeon can assemble the individual components into any configuration needed to deal with a specific problem in orthopedics or traumatology.

The clinical indications for the Ilizarov ring fixator apparatus have expanded, leading to new and effective ways of treating diseases and disorders of the locomotor system. With an understanding of the mechanical principles of application, the versatility of the apparatus and the minimal nature of the surgical intervention create the optimal biologic and mechanical environment for rapid bone consolidation and early functional rehabilitation.
Figure 5.1 - A complete set of the apparatus.

The main support components are half rings (1), arches, (2), and long connecting plates (3). The auxiliary support components include shorter straight connecting plates (11), curved plates (12), twisted plates (13), and posts with either a threaded end or a threaded hole (14-17).

Wires (4) come with or without beads. Wire fixator’s are either clamps, with a solid frame (5) or an open frame (6), or bolts (7). The threaded rods come in solid (8, 9) and telescopic (10) models. Additional connecting elements include bushings (18),
threaded sockets (19), serrated washers (20), circular and semicircular plain washers (21), lock washers (22), bolts (23), and nuts (24).

5.1.1. WIRES

![Diagram of wires with points and stoppers]

Figure 5.2 - Wires: Points and stoppers

Wires are important components in the structure of the ring. Hence their properties are highlighted. Wires serve to connect bones or bone fragments to the support elements of the frame. They differ in diameter, length, shape of the point, and nature of the bead.

The bone density determines the choice of the wire, the fixation rigidity required, the size of the limb, and the goal of the treatment. In long bone osteosynthesis, wires of 1.5, 1.8, or 2.0 mm in diameter and up to 430 mm in length are used.

The wires are round in cross section. One end is flattened to allow fixation to drill, while the other features a point with a varying number of edges. Wires are referred to as one edged, bayonet, or trochar accordingly. The first two types are used for dense diaphyseal bone, while trochar point is inserted into a cancellous bone. For
all wires, the width of the point does not exceed the diameter of the wire, as any gap between bone and wire adversely affects the rigidity of fixation.

Wires with olives are used in cases where much force—up to 180 – 200 k pond is applied to the bone. Bent wires are used when less loading up to 50- 60 k pond is required. In osteoporotic bone, it is desirable to use wires with flat surfaced cones or wires with a corkscrew bend.

Tension of the wires also affects stiffness (particularly axial), maximum limits are 900 N for 1.5mm wire and 1300 N for 1.8mm wires because of yield strength of the stainless steel and slippage at the wire holders. For intact frames, doubling the wire tension from 600 to 1200 N produces a 10% increase in stiffness. It is interesting to note that the increase in stiffness is non-linear as the stiffness increase is not proportional to an increase in wire tension. (Rate of increase decreases with increasing tension) [79].
5.2. Construction

Figure 5.3 - ideal construct 4 rings connected to each other and wires crossing at 90° and transfixed to the tubular cortical bone.

Figure 5.4 - 5/8 ring used to have access to raw area. To use 5/8 ring in this configuration a high degree of frame stability must be assured by attaching to the proximal and distal full rings at a minimum of three connection sites.
Figure 5.5 - Ring Construct on a model for Distraction Osteogenesis.

Figure 5.6 - Measurement of ring size. - Preoperative. A. Measurer at the widest part and add 6 cm, B. Proper ring size, C. Templates.
Figure 5.7 - On table ring adjustment. A two fingers breath space between skin and ring.
Figure 5.8 - Russian ‘manual technique’ of wire tensioning. A, firm wire tensioning is achieved by simultaneously turning a wire fixation bolt and nut with two wrenches approximately one-half turn. B, turning of the wire fixation bolt tightens the wire by bending it off the 90-degree axis with the ring shown schematically above. This varies with the density of bone.
Nemkov, Karivashkian and Liberman [29] analyzed several external fixators both from a mechanical viewpoint and from the prospective of strength of materials. They recognized that a bone fragment supported in an external fixator could be viewed as a rigid beam whose sideways deflection was resisted by one or more resilient elements. The amount of displacement of a bone fragment under the influence of a loading force directly depends upon the fragments stability, which is determined by the stiffness of the wires and their placement with respect to the fragment and frame. In clinical practice, wire angles ranging from 60° to 120° offer satisfactory bone fixator stiffness. When anatomic constraints require angle crossings of less than 60° it is best to use olive wires for fixation, with the olives positioned to resist the likely direction of a deflecting load. It has been shown that an olive on a wire offers 100 times more resistance to fragment displacement against the olive than the same wire provides against fragment displacement perpendicular to the wire’s axis. Wire stiffness is directly dependant upon wire tension, a quantity determined by the initial wire tension and the additional tension created loading the fragment.

Another factor important to fixator rigidity is the frame design. Closed ring systems are of greater strength than open frames; an arch is less rigid than a ring of the same size. The strength and rigidity of the frame influences the amount of wire tensioning possible.

Threaded rods usually connect the supporting rings of tensioned wire external fixators. The strength of the configuration is dependant upon the bending strength of the rods and the stiffness of the rod ring junctions.

Wire tension depends on two factors: the initial wire tension created at the time of apparatus application and the secondary tension that develop during compression or distraction or limb loading.
The following requirements should be fulfilled by external fixator-

- The configuration should have a closed type and use a smallest ring.
- The materials used should have a high modulus of elasticity.
- Each bone fragment should be able to be secured with fixation points on both ends.
- The fixation should be independent of the direction of the wires.
- Minimize the unsupported length between the rings.
- Use more or large ring connectors or an intermediate ring.
- Use olive wires for control of bone segments or free ends, particularly in compression.
- Use large wires or a greater number per ring with maximum tension to control stiffness.
- Reuse of wire holding bolts is not recommended because of possible failure of these components caused by yielding during tightening.
- Attempt to provide wire crossing angles of at least 60°, where this is not possible add an offset wire (or another ring with wires at least 4 cm away).

Advantages over Internal Fixation devices:

- Compression can be maintained during the entire treatment period.
- Fixation can be obtained without inserting hardware at the site of pathology. This is especially valuable feature in infected pseudarthrosis.
- Less traumatic.
- Can be removed without an additional operation.

Ilizarov method exploits the plasticity of musculoskeletal structures that becomes manifest under appropriate conditions. With Ilizarov apparatus one can restore anatomic alignment of the locomotor system, control rehabilitation, and influence the shape forming processes of limb tissues. These techniques shorten treatment time and improve the management and outcome of many orthopedic disorders. One can cure injuries, diseases and deformities previously considered incurable. This method reduces the trauma or surgical exposure as well as the number of operations. Many of the procedures can be done percutaneously.
With this fixator- Ilizarov has been able to define for the first time, the optimum biologic and mechanical conditions for regeneration, remodeling and rehabilitation in the treatment of fractures and orthopedic diseases.

1963 Ilizarov discovered that bone forms during gradual distraction in any direction, overturning the commonly held notion that distraction inhibits osteogenesis.
5.3. Biomechanics of Ilizarov Ring fixator

The German Surgeon Martin Kirschner [21] for skeletal traction originally introduced the smooth nonthreaded wire. Ilizarov fixator that has been adapted for fracture fixation is characterized by the use of thin tensioned wires placed transversely through the fracture components instead of pins. They were mounted to full rings, which are then cross-coupled, creating the frame structure.

The mechanical characteristics of external fixators may influence the biologic environment at the fracture site and ultimately decide the outcome of a surgical procedure. Although an “ideal” biomechanics guideline for healing a particular problem has not been established. Too rigid a system can produce non-union, delayed healing, or disuse osteoporosis by stress shielding. A system that is too flexible can produce malunion, non-union, and device-bone interface problems.

The Ilizarov external fixator exhibits more isotropic mechanical properties in bending, non-linear axial stiffness than do unilateral and bilateral external fixators. Each frame element, wire size, tension, and orientation, as well as the ring type contributes to overall frame rigidity and stability. For any fixator system, there are two fundamental interrelated considerations: stability and rigidity. Stability is the ability of the fixator to maintain the necessary mechanical configuration during treatment: rigidity is a measure of the mechanical response of the fixator, which has importance in the healing response. The non linear behavior of the Ilizarov frame is attributable to increasing wire tension under loading. The Ilizarov frame is less stiff in bending, particularly in the lateral-medial direction, but its values for lateral-medial and antero-posterior bending are similar: bending stiffness increases with increasing axial loading. In torsion, the Ilizarov frames are somewhat less stiff [30].

The unique wire-ring combinations in the Ilizarov apparatus produces a much lower axial stiffness and axial loading force, which distributes load to all parts of the frame, than do the uniplanar fixators that use much heavier pins. At the same time it shows higher axial stiffness against loading from bending forces [21]. Fig 5.9.
The most important factor governing rigidity of this frame is bone contact. The most flexible system (two 1.8 diameter smooth wires in each fracture component loaded to 110 kg in tension without bone contact) is only 6.1% as stiff in axial loading as the intact tibia without bone contact [31]. Cortical contact and compression- 1.8 mm wire with 110 kg tension, stiffness increases to 94.4% of intact. With eight wires and no bone contact, axial stiffness increases to 53.7% of intact. While bone contact is the most important factor in gaining the axial stiffness, the number of wires governs the torsional stiffness of the frame [31].

The circular external fixator with wires supported at each end exhibits a self-stiffening effect such that wire stiffness increases with wire deflection. Mechanical slippage between the wire and fixation bolt is the primary reason for loss
of wire tension. Slippage can be avoided by adequate torque on the fixation nut (20 Nm) [32].

Nemkov, Karivashkian and Liberman [29] analyzed several external fixators both from a mechanical viewpoint and from the prospective of strength of materials. They recognized that a bone fragment supported in an external fixator could be viewed as a rigid beam whose sideways deflection was resisted by one or more resilient elements. The amount of displacement of a bone fragment under the influence of a loading force directly depends upon the fragments stability, which is determined by the stiffness of the wires and their placement with respect to the fragment and frame.

In Kristiansen et al [33] comparative study, AO external fixators with unilateral and stacked bars have an axial stiffness from 22.7% to 46.5%.

It is clear from studying mechanics that a fragment fixed at both ends on an apparatus is far stronger than a fragment fixed at one end. The rigidity of a beam fixed at both ends is 16 times higher than that of an identical beam fixed, cantilever fashion, at only one end [29].

Podlsky [34] found higher axial and torsional stiffness when the bones are eccentrically positioned.

Biomechanically better stability is achieved by: (1) use the smallest rings possible, allowing for soft tissue swelling. (2) Minimize the unsupported length between rings; use more or larger ring connectors or an intermediate free ring. (3) Use olive wires for control of bone segments or free ends, particularly in compression. (4) Use larger wires or a greater number per ring with maximum tension to control stiffness. Reuse of wire holding bolts is not recommended because of possible failure of these components caused by yielding during tightening. (5) Attempt to provide wire-crossing angles of at least 60°, where this is not possible, add an offset wire or another ring with wires, at least 4 cm away.

Fleming et al, analyzed biomechanical performance of the Ilizarov circular fixator, compared it with that of other conventional external fixators, and found that
the Ilizarov fixator allowed more axial motion at the fracture site: however, the overall stiffness and rigidity of the Ilizarov fixator were similar to those of the one-half pin fixators in bending and torsion [35].

The increase of overall stiffness of the Ilizarov fixator demonstrated by the axial preload torsional stiffness prevents further displacement under higher loads, thus allowing early ambulation and weight bearing in clinical situations [36].