Biomechanics of the Ilizarov Apparatus

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The Ilizarov apparatus, as an external fixator, distinquishes itself from other monoaxial fixators, because, before it is applied it has to be constructed by the surgeon for the type of treatment desired, considering not only the dimensions of the segment to be treated, but it also can account for numerous other variables.

Many surgeons consider the Ilizarov fixator to be the only elastic and dynamic fixator, but elasticity and dynamics are an intrinsic characteristic of all fixators which reflect the character of the connection between the bone and the fixator. For example, every fixator where the connection bone-apparatus lies in a straight line, like monoaxial fixators, allows for dynamic and elastic movement that, due to the configuration, reflects how the bone moves in compression but also in angulation.
This last movement, angulation, according to many studies, is defined as "parasitic" and therefore can negatively influence the bone healing.

The real advantage of the Ilizarov apparatus, as an external fixator, like all circular fixators, is that it uses transosseous wires which minimize "parasitic" movement (angulation and rotation) without eliminating the elasticity which appears favorable for bone healing from many biomechanical studies.

But elasticity does not mean weakness of the fixator, therefore, it must be constructed "monolithic" like Ilizarov said, and dynamic does not mean to have fewer connections between the bone and the apparatus. Ilizarov, in his work and lectures, always spoke of stability of the apparatus, intending to refer to the bone-fixator connection.

In evaluating the Ilizarov apparatus system, that is the stability of the fixator, connection and bone, one needs to take into consideration the following variables:

1) Rigidity of the assembly

2) Connection between the apparatus and the bone

3) Intrinsic stability (or internal) of the treated segment

We will look now, point for point, at the various elements that have to be considered when we set out to build our apparatus.

Rigidity of the assembly

The material, in the first place, from which the half rings are made, has to be extremely solid and allow for the least bending when subjected to the stress of loading and the tensioning of the wires.

The steel used currently, with a thickness of 6 mm, is considered the best by report by weight-rigidity-cost. The carbon fiber rings of the same diameter allow for adequate rigidity to loading, but have a tendency to twist if subjected to the stress of wire tensioning; however, with an augmented thickness to 7-8 mm, this problem disappears.

The diameter of the ring is inversely proportional to the rigidity of the construct. So the surgeon, who has a choice, should favor the smallest diameter. However, there is always a requirement of a minimum distance between the soft tissues and the frame of at least 2 cm, increasing to 3 cm where the formation of significant edema may occur.

The number of rings is directly proportional to the stability of the system. Therefore, if possible try to construct frames that have two rings per segment like, for example, 4 rings for a lengthening. (fig. 1A, b)

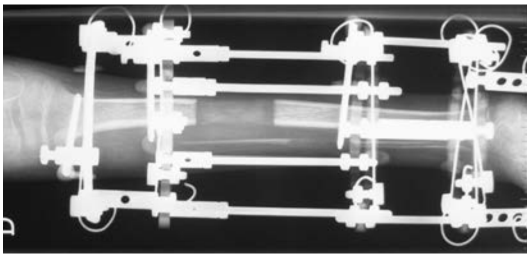
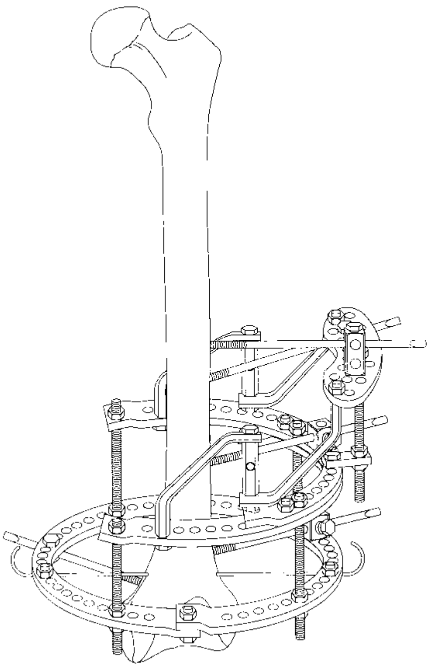


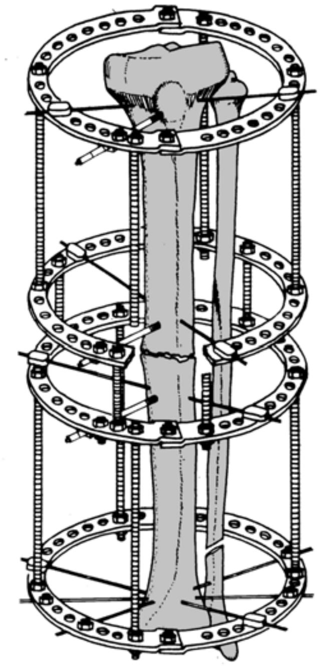
Fig. 1a

Fig. 1b

The number of connections between the various rings is directly proportional to the stability of the assembly. On the other hand, the more connections that are applied, the fewer holes that are available for the application of other parts. The correct number of connections for minimal stability is at least four. **(Fig. 2ab)**

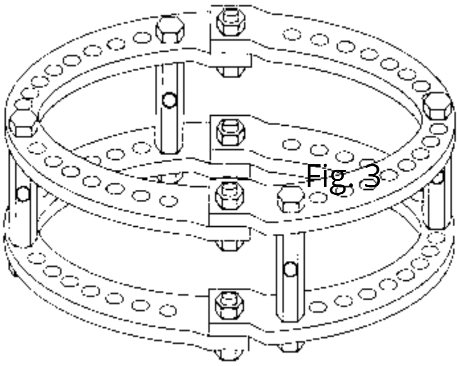


(Fig. 2a)

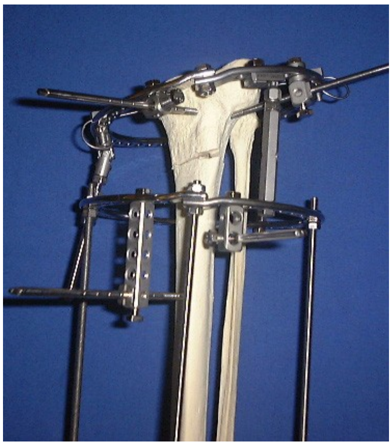


(Fig. 2b)

Another influence on the stability of the assembly depends on the type of connection between the various rings; for example, a block of two rings connected with a hexagonal socket is much more stable than a block that uses a threaded rod or a threaded rod with conical washers, which allows for “parasitic” angular or rotational motion between them. **(Fig. 3)**



The stability of the apparatus is inversely proportional to the length of the connection, so that, also in the frame for lengthening, where, by necessity the osteotomy has to be performed in the metaphyseal region, it is advantageous to move the intermediate rings closer together. **(Fig. 4)**

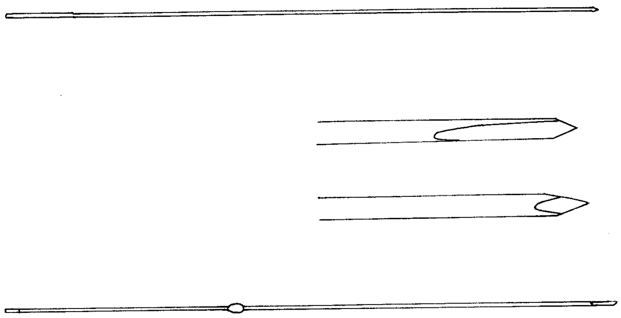


(Fig. 4)

Connection of the apparatus to the bone (original Ilizarov)

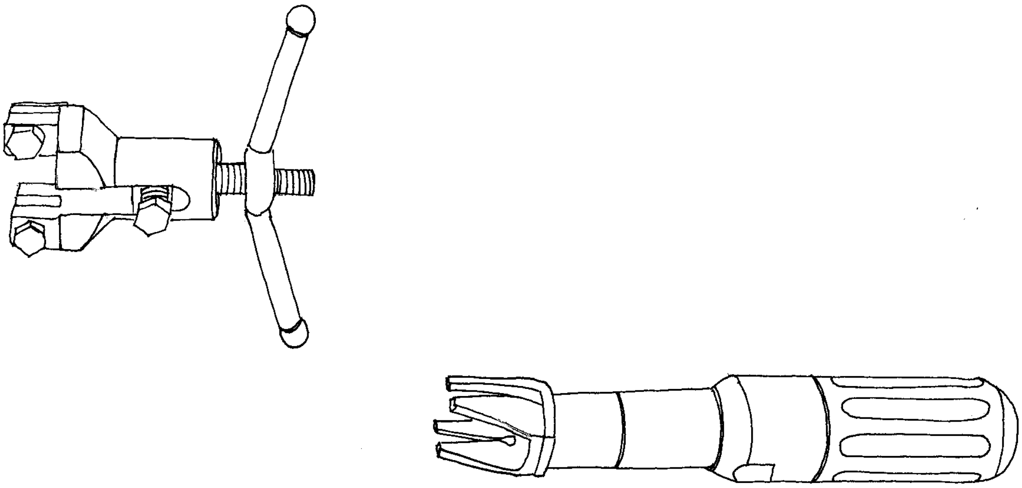
The diameter of the wire is directly proportional to the stability of the assembly, that is, a bigger diameter corresponds to more stability.

Normally, in an adult, the wire is 1.8 mm in diameter, while in a child or an adult forearm, the diameter is reduced to 1.5 mm. 8. **(Fig 5)**

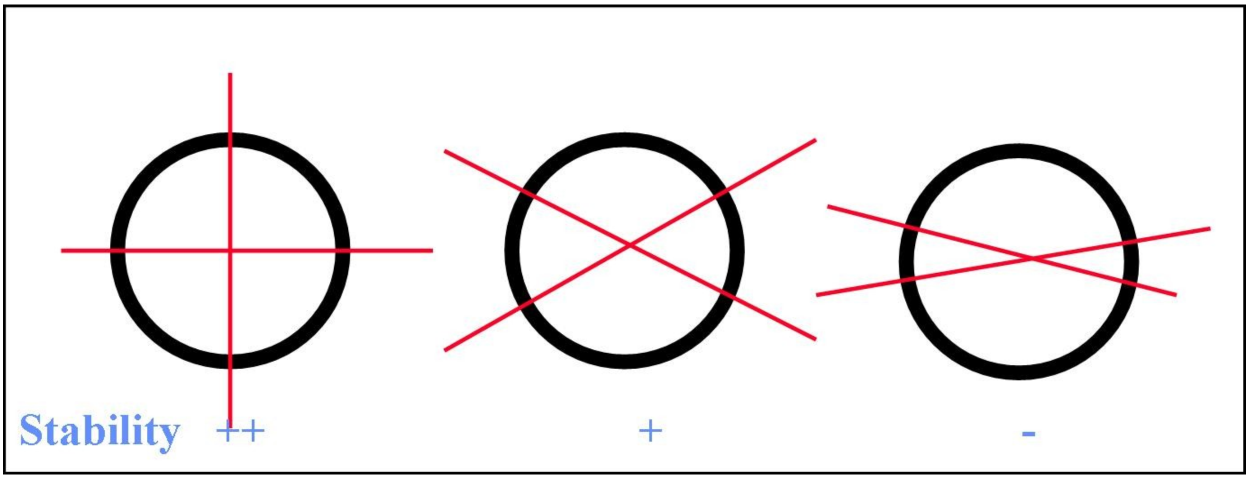


(Fig. 5)

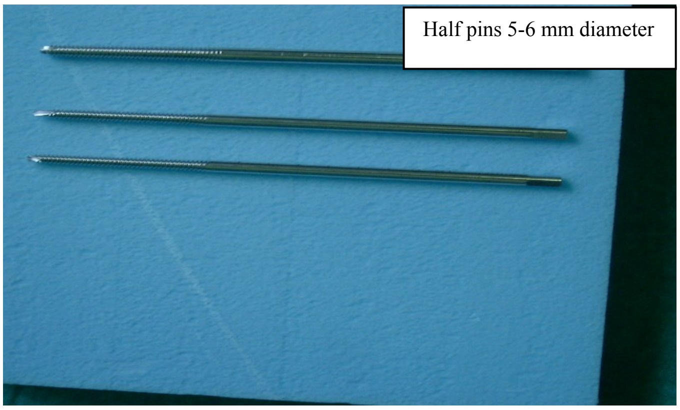
Also the number of wires, for each part, that is ring, is directly proportional to the stability of the apparatus. The least number, in a wire configuration, is two per ring. The tension of the wire is directly proportional to the stability and, normally, for a 1.8 mm diameter wire is around 110 kg, while in a 1.5 mm diameter wire it is 90 kg; less tension has to be applied to a half ring or a five-eighths ring (max 50 kg). **(Fig. 6)**



Regarding the crossing of the wires, the best configuration is 90° between one wire and the other. The larger the angle of intersection, the greater the stability of the basic part (ring and two wires). The stability decreases with a lesser angle, but is relatively sufficient if the final angle is 45°, below this angle the stability decreases rapidly in the plane of the obtuse angle of crossing, invariably motion occurs in the other plane. **(Fig. 7)**

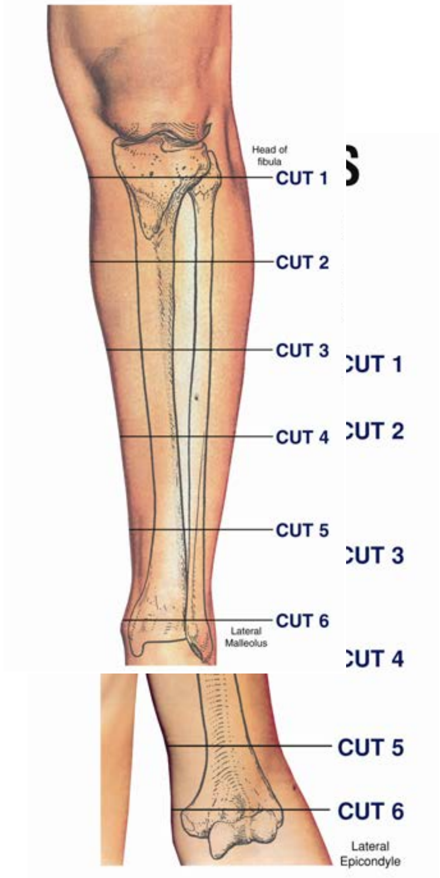


On 1986, the original Ilizarov apparatus (rings and wires) was modified for the femoral configuration, with the introduction of smaller dimension arches, fixed to the bone with half pins of 5 to 6 mm diameter. The same modification was applied in the humerus (1987) the tibia (1989), and forearm (1990)

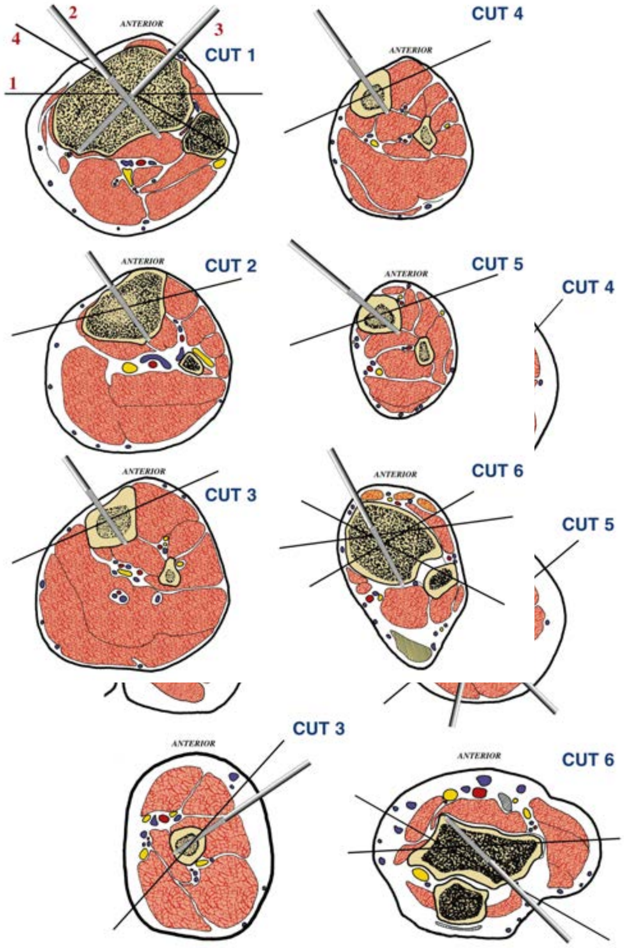


Obviously, as well, this innovation influences the stability of the whole system, that is, more rigid materials and greater diameter half pins increases the stability of the system. In the pin configuration, as described by Catagni-Cattaneo, there is better stability with pins crossing at 30-90°, the so called delta pattern. This configuration is the fruit of observation of another fixator (Hoffman-Vidal) and the clinical experience of the creator of the assembly.

TIBIA and FIBULA left



INSERTION WIRES AND HALF-PINS - LEFT



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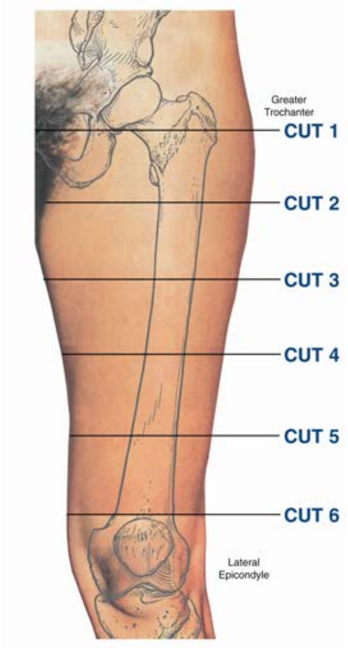
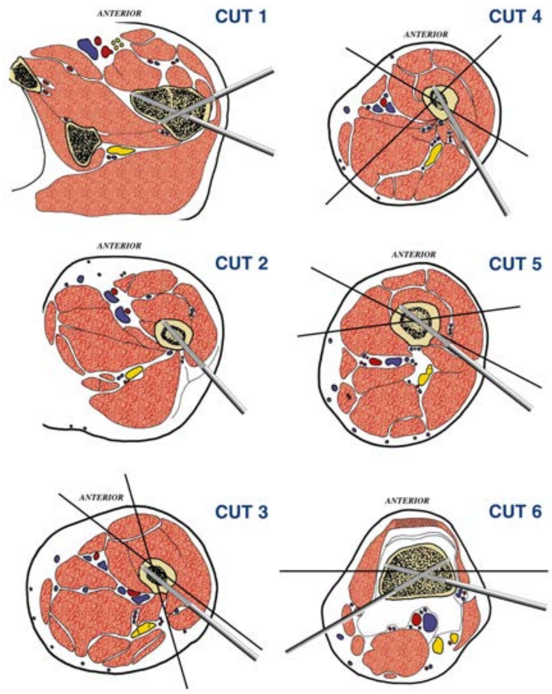
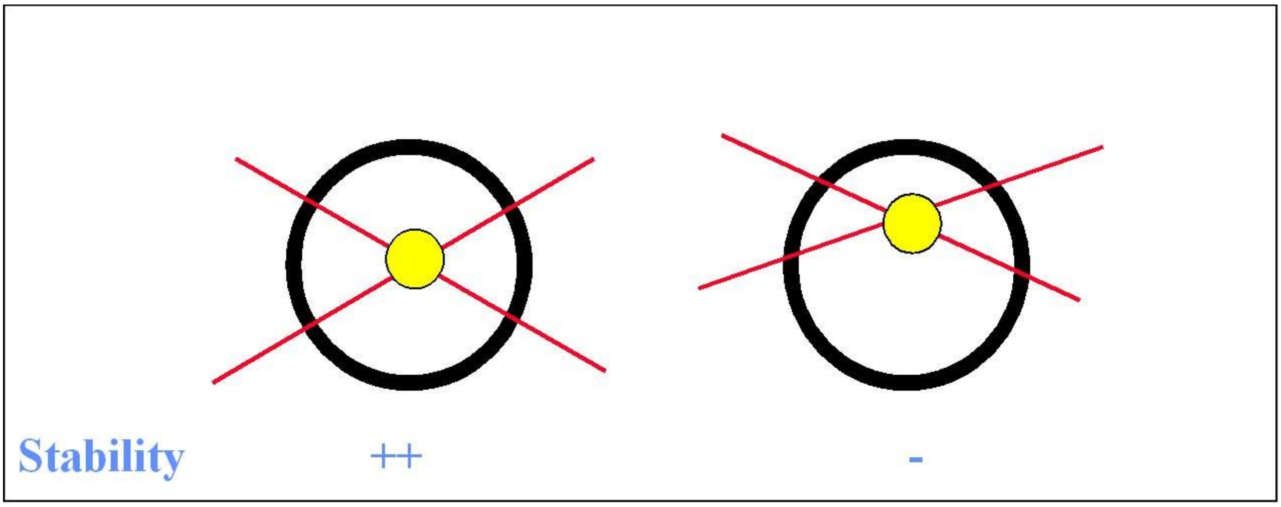


INSERTION WIRES AND HALF-PINS - LEFT



Finally, one needs to consider, with regard to the connection fixator-bone, the centralization of the bone axis with respect to the central axis of the apparatus. The closer the longitudinal axis of the bone is near to the central aspect of the frame, the more stable the apparatus will be; unfortunately for anatomic reasons (soft tissues) this ideal configuration is difficult to achieve in the tibia while it is more easily obtained in the femur, humerus, or forearm.



Intrinsic stability

Very important, to the stability of the system, is that which is more easily defined as internal stability.

Initially, in a fracture or pseudoarthrosis, one needs to evaluate the surface area of contact of the injured bone: the larger the surface area, the better the stability and therefore the possibility of granting weight bearing.

The lengthening of a bone, the quality of the regenerate, its diameter, and its maturation, interfere with the intrinsic stability. The better the maturation and the diameter, and the less the length of the same, the more the resulting system is stable. One needs to also remember the quality and the quantity of the soft tissues that surround the bone part in treatment.

And last don't forget, the length of the treated segment: in fact, more length interferes negatively with the stability of the whole system.

Summary:

Variables directly proportional to the stability of the system:

- Rigidity of the materials of the rings
- Number of rings
- Rigidity of the connection between the rings
- Number of connections between the rings
- Diameter of the wires
- Number of wires

-Tension of the wires
- Crossing angle of the wires
- Diameter and angle of crossing of the half pins
- Centralization of the apparatus
- Surface area of contact of bone ends
- Diameter of the regenerate and its maturation

Variables inversely proportional to the stability of the system:

- Length of the connection between the rings
- Length of the regenerate
- Length of the treated segment

Now we can look at what variables are under the control of the surgeon:

-Construction of a stable apparatus, with enough rings (at least two levels of fixation per each bone segment)

- Enough wires and half pins per each basic part (ring or arch) (two wires per ring or one wire and one half pin or one wire and two half pins)

- Considering the internal stability, it is necessary to have a good reduction of the fracture and adequate surface contact of the pseudoarthrosis, eventually with open surgery to reduce the fracture well or to remodel the bone ends in the nonunion.

- The diameter of the regenerate depends on the level of the osteotomy, it needs to be in the metaphyseal region where the bone has a wider surface area.

- Obviously, for a good regenerate, the osteotomy needs to be accurate without damaging the
the periosteum and without traumatizing the bone, avoiding the use of an oscillating saw or aggressive manipulation.

- The maturation of the regenerate can be guided by careful observation and applying a rhythm of elongation that respects the biology of the patient; eventually the surgeon can intervene with an Accordion maneuver or in extreme cases of atrophic regenerates, apply bone graft.

In conclusion, we review again the basics for stable construction of a circular frame:

- Select an appropriate diameter ring
- At least four connections between each two rings
- Minimum distance between the level of the rings and the point of bone instability
- Two levels of fixation for each injured bone segment
- Monitor frequently the stability of the parts of the fixator, eventually changing during treatment as indicated
- Osteotomy at low energy, subperiosteal, percutaneous in metaphyseal region
- Observe closely the regenerate bone with ultrasound and x-ray