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An Overview of Ilizarov External Fixation

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Abstract

The modularity and ease of application of modern external fixation has expanded its potential use in the management of fractures and other musculoskeletal conditions. In fracture care, it can be used for provisional and definitive fixation. Short-term provisional applications include “damage control” and periarticular fracture fixation. Circular external fixation, including the Ilizarov method, is a complex and often long-term treatment used for various orthopedic conditions. Due to the complexity of the hardware, frequent postoperative complications, and the potential for significant radiographic changes between visits, it is important for the radiologist to have a basic understanding of ring fixators. This publication reviews indications for external fixation versus internal fixation and whether to use a circular or uniplanar construct if external fixation is elected. Indications for and characteristics of static circular frames, intercalary and non-intercalary transport frames, and deformity circular frames will also be discussed. While general similarities exist between frame types, each has unique components of which radiologist must be aware. An emphasis is placed on the important features and complications that arise during treatment.

Keywords: Ilizarov, External Fixation, Circular External Fixation, Uniplanar External Fixation.

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1. Introduction

The Ilizarov external fixation method is a versatile and effective technique for managing complex tibial plateau fractures, especially in cases where internal fixation might not be feasible due to severe soft tissue damage or infection risks. This method offers several advantages, including stability, the ability to make gradual corrections, and the promotion of early mobilization [1]. The Ilizarov method is one of current methods used in bone reconstruction that originated in middle of the past century and comprises several bone reconstruction techniques performed with a ring external fixator developed by Ilizarov (1921-1992) in 1951 in former Soviet Union. Bone repair and reconstruction with this method are realized by means of applying compression or distraction forces to bone fragments for bone consolidation, axial alignment or new bone formation through phenomenon of distraction osteogenesis induced by tension stress with the Ilizarov apparatus based on external supports and transosseously drilled wires that, driven with threaded units, can produce multi planar actions on bone fragments [2]. The Ilizarov method techniques became known to world orthopedic community and started to be used in several European countries in the 1980s. Since then, original method has used along with a number of its modifications and developments due to emergence of new fixation devices and techniques of their application. The geography of their application has expanded much while advancements in bone reconstruction that followed are of international significance and gave rise to a relatively new orthopedic subspecialty which has termed limb lengthening and reconstruction surgery (LLRS) [3].

2. Biomechanics

Mechanical properties of the Ilizarov device, particularly in comparisons with other external fixators have been an area of research interest. The stability provided by fixation devices is an important variable; instability can lead to ineffective bone regeneration, while an overly rigid fixation can lead to a delay of fracture consolidation. A limited degree of axial micro motion is important to promote osteogenesis and thus it is hypothesized that an optimal fixation device will provide stability while still permitting some axial micro motion [4]. The overall stiffness of the apparatus is high, which prevents displacement under high loads, thus allowing early ambulation and weight bearing in clinical situations. The apparatus stiffness is low at low loads which allows micro motion at the fracture site, that may be useful for the stimulation of fracture callus, whereas its stiffness increases at higher loads which protects the fracture gap tissue from strains exceeding the tolerance values for a successful repairing process. The biomechanics of Ilizarov’s apparatus depends on the apparatus-related factors (extrinsic stability) and intrinsic stability of treated segment [5].

3. Extrinsic Stability

1. Rigidity of the assembly: The material from which the half rings are made must be extremely solid to allow minimal bending when subjected to loading and wire tensioning. Steel (6 mm in thickness) is considered the best with respect to weight-rigidity-cost [6].
2. The diameter of the ring is inversely proportional to rigidity of frame. The effect of ring size on other stiffness parameters shows a similar trend, with an average of

20% decreases. It is recommended that a minimum distance of 2 cm between soft tissues and frame be maintained to be increased to 3 cm where significant swelling may occur and to allow for pin site care [7].

3. The number of rings is directly proportional to stability of the system. Therefore, it is better to construct frames that have two rings per segment. Number of connections b/w rings is directly proportional to frame stability [8].
4. Distance between the rings: The stability of the apparatus is inversely proportional to the distance between the rings. So, in a frame constructed for lengthening, where the osteotomy must be performed in metaphyseal region, as well as in periarticular fractures, it is advantageous to move intermediate rings closer together [3].
5. Connection of the apparatus to the bone: The diameter of the wire is directly proportional to the stability of the assembly. Wires of 1.5 and 1.8 are commonly used. Normally, in an adult, 1.8 mm diameter wires are used, while in a child or an adult forearm, a 1.5 mm wire is used. The reason the Ilizarov fixator uses 1.5 mm or 1.8 mm wires is to optimize this low stiffness property while maintaining sufficient strength to resist breakage or wire deformation (ductility). The number of wires is directly proportional to stability of the apparatus. The minimum number in a wire configuration is 2 wires per ring [8].
6. The type of wires: The use of counterposed olive wires led to significant increase in bending, torsion and axial stiffness making Illizarov apparatus very advantageous for deformity correction or deformity prevention [9].
7. Offset wires: Adding a wire (offset or drop wire) a short distance from the ring and fastened to the ring by two attached supports increases the stability as the wire in another level and can be introduced in a direction different from that of the main ring wires [10].
8. Diameter and crossing of half pins: The original Ilizarov apparatus (rings and wires) modified for femoral and humeral configuration. This was done with introduction of arches of smaller dimension fixed to bone with half pins 5 to 6 mm in diameter. This innovation described by Catagni-Cattaneo increased stability of the whole system with the pins crossing at 60-90 º (the delta pattern) [5].
9. Centralization of the bone axis with respect to the central axis of apparatus: The closer longitudinal axis of bone is to center of frame, more stable apparatus will be [11].
10. Tension of the wires is directly proportional to the stability. If properly tensioned, the thin wires develop stiffness almost equal to that of a thick pin. Correct wire tensioning ensures solidity and stability of fixation in the entire frame. The exact strength of tensioning depends on the wire diameter, local frame construct, weight of the patient and functional wire loading [12].

4. Intrinsic Stability

1. Area of contact between bone ends: The larger the surface area, the better the stability and therefore, the possibility of allowing weight bearing [4].
2. Modulus of elasticity of the tissues between bone ends: The loading bypass through the apparatus decreases as the interstitial tissue modulus of elasticity increases and as the area of contact of this tissue (e.g callus) increases.
3. Length of the gap between the bone ends: The shorter this gap is the greater the stability.
4. Mechanical configuration and interlock between the bone ends affects the internal stability.

5. Indications

Ilizarov circular external fixation indicated for complex tibial plateau fractures, particularly those classified as Schatzker types V &VI. These fractures often involve [13]:

1. High-energy trauma: Typically observed in younger patients, leading severe comminution and displacement.
2. Severe soft tissue injury: Including open fractures with substantial soft tissue damage.
3. Multiplanar instability: Cases where maintaining reduction with traditional methods is challenging.
4. Articular depression: Fractures with significant joint line depression requiring elevation and stabilization.
5. Comminution: Extensive fragmentation of the bone that precludes stable fixation with internal devices alone.
6. Osteoporotic bone: In elderly patients where bone quality might not support internal fixation.
7. Failed previous fixation: Cases where initial internal fixation failed, necessitating robust stabilization method.

6. Circular vs. uniplanar external fixation

External fixation is an orthopedic technique permitting the percutaneous treatment of fractures, deformities, and developmental/congenital conditions. In general, there are two broad types of external fixators: uniplanar and multi planar/circular. Uniplanar fixators allow half pins placed in the bone to be connected to external clamps and rods. A uniplanar construct is most used for acute, temporary stabilization of fractures in damage-control orthopedics and in highly unstable open and closed fractures to control limb length and alignment until definitive fixation can be achieved. Less commonly, uniplanar fixators may be used for definitive treatment [14]. Multi planar circular fixators, such as the Ilizarov fixator and Taylor Spatial Frame have improved biomechanical characteristics that allow for definitive management of complex extremity injuries. Common indications for circular external fixation include definitive treatment of acute per articular fractures, fractures involving bone loss that require specialized transport frames to gradually replace bone loss.

Reconstruction of nonunion, malunions, or complex deformity, and definitive treatment of fractures with open physes or correction of Blount’s disease in the pediatric population [15]. Less common indications include soft tissue management of joint contractures, protection of flaps or grafts, protection of ligament repairs, stature lengthening, or arthrodiastasis (joint distraction) for Perthes disease or ankle arthritis. There is markedly improved rigidity due to multiple points of fixation with both half pins and tensioned wires oriented in several planes, which creates an environment conducive to healing. Stability in long-term external fixation is further augmented using hydroxyapatite-coated half pins, creating a solid bone/pin interface, which decreases problems with loosening. The portion of construct proximal to fracture or deformity is termed proximal fixation block, and distal portion is termed distal fixation block [16].

7. Surgical Procedure

The surgical procedure for Ilizarov circular external fixation begins with the administration of spinal anesthesia, which is preferred for its effective pain control and favorable risk profile compared to general anesthesia. Reduction of fracture is typically achieved using indirect methods. Calcaneal traction is applied on a fracture table or a femoral distractor is used on a radiolucent table. Knee is positioned at the desired degree of flexion under continuous radiological control to ensure precise alignment. This method minimizes further soft tissue damage while achieving necessary reduction. In cases where indirect reduction does not suffice, open reduction is performed. This involves making small incisions to provide direct access to fracture site especially in cases with persistent condylar depression [17]. For fractures involving significant articular depression, the joint line is elevated through a metaphyseal window. This creates space to insert a cortico-cancellous bone graft, which is harvested from the ipsilateral iliac crest. The bone graft provides the additional structural support and facilitates healing by filling gaps and stabilizing the reduced fracture fragments. This step is crucial for the restoring normal anatomy of the tibial plateau and ensuring long-term joint function. In selected cases, the internal fixation is employed to further stabilize the fracture.

This involves the use of 7 mm cannulated cancellous screws (CCS) to secure the reduced fragments. These screws are carefully inserted to maintain the alignment and stability achieved during the reduction process, ensuring that the bone fragments remain in place as healing progresses [18]. The assembly of the Ilizarov fixator begins with the placement of first ring in juxta-particular region of tibia, close to fracture site but without compromising the joint. The second ring is positioned just below fracture to provide additional support, and third ring is placed in supramalleolar region to stabilize lower segment of the tibia. Tensioned olive wires used to hold fracture reduction securely. These wires provide necessary stability while allowing for micromovement, which promotes bone healing. Non-olive wires are used for remaining segments to maintain overall stability of the construct [2]. In some cases, 5 mm Schanz screws are applied to diaphyseal segments according to the surgeon's preference. These screws offer additional support to long bone segments and help maintain alignment during healing process [19]. For patients with severe articular comminution or ligamentous instability, an additional distal femoral ring is used to span knee. This construct is typically maintained for four to six weeks, providing necessary the stability during early phases of healing [20].

8. Postoperative Management

- Mobilization: Encourage knee mobilization as much as fixator permits. Patients with spanning external fixators can bear full weight with crutches immediately post-surgery. Those with non-spanning fixators should begin partial weight-bearing and progress as tolerated [21].
- Follow-up: Conduct weekly clinical follow-ups for pin tract infections and monthly radiological assessments for axial alignment and fracture healing.
- Fixator Removal: Decide to remove fixator based on evidence of bridging in two orthogonal views and satisfactory stress test results after removal of rods between first 2 rings [22]. Protect limb with a removable brace during weight-bearing for 3–5 weeks post-removal, allowing only partial weight-bearing during this period [23].

9. Advantages of Ilizarov External Fixation

1. Minimally Invasive Approach

- The Ilizarov method requires only small stab incisions, resulting in minimal soft tissue disruption and reduced blood loss compared to traditional open surgical methods. This leads to fewer complications such as infections & wound dehiscence [24-25].

2. Early Weight Bearing and Mobilization

- One of key benefits of the Ilizarov fixator is that it allows patients to begin weight-bearing and joint mobilization early in recovery process. This is crucial for maintaining joint function, reducing stiffness, accelerating rehabilitation [26].

3. Adjustable and Dynamic Fixation

- The Ilizarov apparatus provides excellent stability and allows for post-operative adjustments to correct alignment issues. This dynamic ability to adjust fixator can help in achieving precise anatomical alignment during the healing process.

4. Biological Favorability

- Technique promotes biological healing by maintaining micro-movements at the fracture site, which stimulates callus formation and bone healing. Preservation of periosteal blood supply is another significant advantage, as it enhances biological environment for bone repair.

5. Versatility

- The Ilizarov fixator can be used to treat a wide range of complex fractures, including those with severe comminution, nonunions, and cases with significant soft tissue injuries. Its modularity and adaptability make it suitable for various clinical scenarios.

6. Lower Risk of Infection

- Compared to internal fixation methods, risk of deep infection is lower with external fixation. The pins and wires are outside zone of injury, and their placement is less likely to compromise the local blood supply. Parameswaran et al [27] showed an incidence of 0% in deep infection in 59 patients with Schatzker V-VI, managed with Illizarov fixation.

7. Avoidance of Additional Soft Tissue Injury

- By avoiding extensive dissection and exposure of fracture site, Ilizarov method reduces risk of additional soft tissue injury, is especially important in fractures with compromised surrounding tissues. Debnath et al. [6], Gill and Raza [28], believe that Ilizarov technique is better for management of complex tibial plateau fractures, have extensive comminution with compromise of soft tissue and should be preferred over other methods.

10. Advantages with Minimal Internal Fixation

1. Enhanced Stability

- Combining Ilizarov external fixation with minimal internal fixation, such as cannulated screws or k-wires, can enhance the overall stability of the fracture construct. This combination can provide more rigid fixation, which is particularly beneficial in maintaining the reduction of complex fractures [19].

2. Improved Reduction

- Minimal internal fixation helps achieve and maintain precise fracture reduction, especially in cases with significant articular involvement. This can lead to better restoration of joint congruity and potentially improved functional outcomes [17].

3. Facilitation of Early Rehabilitation

- Added stability from internal fixation allows for more confident early mobilization and weight-bearing, which is crucial for joint health and overall patient recovery.

4. Less Soft Tissue Compromise

- By using minimal internal fixation, extensive dissection and periosteal stripping are avoided. This preserves the blood supply to the bone and surrounding tissues, promoting better healing and reducing the risk of complications such as delayed union or nonunion.

5. Reduced Need for Secondary Procedures

- The combination of Ilizarov external fixation with minimal internal fixation can reduce the need for secondary surgical procedures. The enhanced stability and precise reduction provided by internal fixation elements can lead to faster and more reliable healing.

6. Flexibility in Management

- The combined approach offers flexibility in managing various stages of fracture healing. Internal fixation can provide immediate support during the initial phase, while the Ilizarov fixator can be adjusted as needed throughout the healing process to address any changes or complications [15].

11. Complications

1. Muscle Contractures

- Muscle contractures are usually a result of tension generated on the muscle due to distraction. They tend to occur in the overpowering muscle groups. There may be a difference in the rate and maximum potential for histogenesis between muscle and bone [29].
- A contracture arises when muscle length becomes relatively short compared that of bone. Another etiologic consideration is transfixion of muscles or tendons by pins of apparatus. Transfixion of tendons and fascia may restrict joint motion more than transfixion of muscle.

2. Neurologic Injures

- Pin-related Nerve Injury: the patient awakens with severe pain localized to the area of the offending pin. Also, tapping on the pin with a metal object will elicit paraesthesias in the distribution of that nerve.
- Corticotomy-related Nerve Injury: This may be due to direct injury from the osteotome or more likely a stretch injury from the osteoclasis maneuver used to ensure that the osteotomy is complete. Compartment syndrome is another cause of nerve deficit.
- Distraction-related Nerve Injury: It is a much less common etiology as nerves and vessels can tolerate up to 2 mm of distraction a day in many locations around the body if identified early, the first signs are hyperesthesia and pain. This is followed by hypoesthesia, then by decreased muscle strength, and finally by paralysis.

3. Vascular Injuries

- Rarely occur due to the small diameter of the wires used. Direct vascular damage can also result from the osteotome while performing the humeral corticotomy. Displacement of these osteotomies may also be the cause of vascular damage.

4. Edema

- Edema is a common problem during lengthening. It takes several months after removal of the apparatus until the edema finally disappears. It is not known whether this edema occurs from hyper vascularity of the limb secondary to the distraction or due to increased stasis from lack of normal muscle contraction.

5. Axial Deviation

- This is due to the imbalance between the muscle forces on different sides of the bone. The other cause of axial deviation is instability. This may be caused by an inadequate construct, loss of tension in the wires, or loosening of the pins.

6. Premature Consolidation

- This problem is most diagnosed as a failure of the osteotomy to open after the initiation of distraction. In the majority of cases, the problem is an incomplete osteotomy rather than premature consolidation. Premature consolidation, when it does occur, is usually due to an excessive latency period, allowing significant callus healing to block the distraction of the osteotomy. The wires can be seen to bow, with their convex sides facing each other on opposite sides of the osteotomy.

7. Delayed Consolidation

- This may be caused by a variety of factors. The technical factors to consider are traumatic corticotomy, initial diastasis, instability, and too rapid distraction. The patient factors are infection, malnutrition, and metabolic e.g. hypophosphatemic rickets. Frame instability should be suspected if the trabeculae seem to wander across the distraction gap rather than being all parallel and longitudinally oriented.

8. Pain

- Pain is the most common complaint during limb lengthening. Surgical pain may be quite intense the first few days after surgery. Contraction of any muscle transfixed by pins is initially painful but resolves within a week or two. The amount of pain obviously increases with the number of osteotomies. During the distraction phase of lengthening a chronic dull aching pain is often experienced. This varies from patient to patient. It is more common with longer lengthening. The probable cause is most likely the stretching of muscles and nerves. The pain, while present at all times, is usually only noticed at night and during physiotherapy and walking.

9. Soft Tissue Dystrophy

- Soft tissue dystrophy and pain may be related to neurological injury. Also, increasing fixation instability further inhibits functional limb use, creating a cycle of discomfort and disuse that characterizes reflex sympathetic dystrophy: altered vascularity, edema, joint stiffness and osteoporosis.

10. Psychological Problems

- Depression and behavioral disturbances secondary to persistent pain, poor function & unsatisfactory cosmetic appearance can develop [29].

4. Outcomes

The biggest advantage of Ilizarov fixation is probably the ability to reduce and stabilize the fracture with minimum or no soft tissue dissection in an already compromised soft tissue environment. Ring construct with tensioned wires provide more mechanical stability and superior Meta diaphyseal purchase and support, compared to conventional external fixators. Tensioned wires provide good purchase in soft cancellous bone. They act as a scaffold in buttressing the subchondral bone preventing collapse, restore the intrinsic stability of the fracture site with a bridging device, and allow the patient to transfer his or her weight through this flexible scaffold to the distal diaphysis, bypassing the comminuted area and permitting early joint movement and weight bearing while maintaining reduction. Weight-bearing can be started earlier with Ilizarov fixation compared with internal fixation, as the tensioned wires act as a scaffolding to buttress the subchondral bone and allow load transfer across the plateau. With a circular construct, the load is distributed equally to both plateaus, and cantilever bending on the pins is minimized. This minimizes risk of both angular deformity and pin tract infection. Early weight-bearing stimulates fracture healing by axial micro motion without shear. Simultaneous distraction on both sides of the joint helps to achieve a ligamentous reduction. A mechanically stable ring and adjustable fixator can span across a fracture gap in cases with comminuted or minimal bone loss.

Compression can be directed across site of bone loss or fracture gap without additional bone grafting. Rotational & translational deformities can be corrected as consolidation progresses. Careful management of the soft tissue injury is vital, and use of the Ilizarov system facilitates this. Presence of fracture blisters or extensive subcutaneous hemorrhage and bruising does not hinder percutaneous placement of the wires which avoids additional devitalization of the bone, since the periosteal and endosteal blood supply are not further damaged. In cases with presence of meniscal or ligamentous injuries, we did not do primary repair as this required arthrotomy, which increased risk of soft tissue compromise and joint infection. Several published studies have shown decreased complications when treating bicondylar tibial plateau fractures with Ilizarov fixation. Various studies on small sample size reported that most Ilizarov fixation operations wasn't associated with wound dehiscence, deep infection, osteomyelitis, or septic arthritis. However, Pin tract infection is a potential problem despite the use of small wires. To avoid complication, Kataria et al. [30] recommend placing wires at least 15 mm away from the joint surface, monitoring status of pin sites (especially at juxta-articular locations), and removing any pin revealing features of infection [31].

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