International Journal of Multiphysics
Volume 18, No. 3, 2024
ISSN: 1750-9548

An Overview on Ilizarov External Fixation

Ahmed Abdelaziz Abdelaziz Darwish, Alaa Ahmed Mostafa Ibraheem, Ahmed Mohamed Abdelwahab and Ahmed Salah Ghorab

Orthopedic surgery Department, Faculty of Medicine, Zagazig University, Egypt

***Corresponding author:** Ahmed Abdelaziz Abdelaziz Darwish

Abstract:

Background: Ilizarov external fixation is a well-established technique in orthopedic surgery for the management of complex fractures and limb reconstruction. It is particularly valuable in high-energy tibial plateau fractures associated with severe comminution and compromised soft tissue conditions, where internal fixation may not be feasible. The method is based on the principles of distraction osteogenesis and ligamentotaxis, allowing for stable fixation, gradual deformity correction, and preservation of the biological environment for bone healing. Its biomechanical properties provide a balance between stability and controlled micromotion, which enhances callus formation and fracture consolidation. Over the years, the Ilizarov technique has evolved into a versatile tool used not only for fracture management but also for deformity correction, nonunion treatment, and limb lengthening.

Keywords: Ilizarov external fixation; tibial plateau fractures; circular fixator; distraction osteogenesis; ligamentotaxis; fracture management; orthopedic reconstruction

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)**.

History:

The Ilizarov method is one of the current methods used in bone reconstruction that originated in the 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 the 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 the 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 multiplanar actions on bone fragments **(2)**.

The Ilizarov method techniques became known to the world orthopedic community and started to be used in several European countries in the 1980s. Since then, the original method has been 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 the advancements in bone reconstruction that followed are of international significance and gave rise to a relatively new orthopedic subspecialty which has been termed limb lengthening and reconstruction surgery (LLRS) **(3)**. Bicondylar tibial plateau fractures usually are caused by high-energy trauma that results in severe bony and soft-tissue injuries. External fixation using the principle of ligamentotaxis is believed to give a satisfactory outcome as a definitive treatment of severely comminuted tibial plateau fractures. It is believed that once treatment complications are avoided, a better outcome is achieved in this type of injury. In this study they assessed the outcomes of treatment of bicondylar tibial plateau fractures with severe intraarticular comminution by ligamentotaxis and fixation with spanning external fixators **(4).**

External fixation in treatment of high-energy tibial plateau fractures could be either non spanning, which means that the fixator does not cross the joint with possible range of joint motion, or spanning, which means the fixator crosses the joint for reduction of fractures with severe articular comminution, depending on ligamentotaxis. The significance of ligamentotaxis is that traction is balanced by countertraction provided by soft-tissue and ligaments that align the fracture fragments while restoring the length and its maintenance by the external fixators.

The advantages of early knee motion include reduction of knee stiffness and improvement of cartilage healing. However, these benefits should be carefully balanced by risks, including loss of reduction or fixation failure. Although early range of motion has proved beneficial after treatment ofarticular fractures, several studies propose that the knee should be kept immobilized for weeks without causing long-term problems **(5).**

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 micromotion is important to promote osteogenesis and thus it is hypothesized that an optimal fixation device will provide stability while still permitting some axial micromotion **(5)**.

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 micromotion 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 the Ilizarov's apparatus depends on the apparatus-related factors (extrinsic stability) and intrinsic stability of the treated segment **(6)**.

- **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 **(7)**.

2. The diameter of the ring is inversely proportional to the rigidity of the 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 the soft tissues and the frame be maintained to be increased to 3 cm where significant swelling may occur and to allow for pin site care **(8)**.

3. The number of rings is directly proportional to the stability of the system. Therefore, it is better to construct frames that have two rings per segment. The number of connections between the rings is directly proportional to frame stability **(9)**.

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 the metaphyseal region, as well as in periarticular fractures, it is advantageous to move the intermediate rings closer together **(5)**.

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 the stability of the apparatus. The minimum number in a wire configuration is 2 wires per ring **(9)**.

6. The type of wires: The use of counterposed olive wires led to significant increase in the bending, torsion and axial stiffness making the Illizarov apparatus very advantageous for deformity correction or deformity prevention **(10)**.

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 **(11)**.

8. Diameter and crossing of the half pins: The original Ilizarov apparatus (rings and wires) was modified for the femoral and humeral configuration. This was done with the introduction of arches of smaller dimension fixed to the bone with half pins 5 to 6 mm in diameter. This innovation described by Catagni-Cattaneo increased the stability of the whole system with the pins crossing at 60-90 º (the delta pattern) **(6)**.

9. Centralization of the bone axis with respect to the central axis of the apparatus: The closer the longitudinal axis of the bone is to the center of the frame, the more stable the apparatus will be **(12)**.

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 **(13)**.

- **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 **(5)**.

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.

Indications

Ilizarov circular external fixation is indicated for complex tibial plateau fractures, particularly those classified as Schatzker types V and VI. These fractures often involve **(14)**:

1. **High-energy trauma**: Typically observed in younger patients, leading to 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 has failed, necessitating a more robust stabilization method.

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

multiplanar/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)**.

Multiplanar 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 periarticular fractures, fractures involving bone loss that require specialized transport frames to gradually replace the 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 the construct proximal to the fracture or deformity is termed the proximal fixation

block, and the distal portion is termed the distal fixation block **(16)**.

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 the fracture is typically achieved using indirect methods. Calcaneal traction is applied on a fracture table and ligamentotaxis is applied on a radiolucent table. The 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 the necessary reduction. In cases where indirect reduction does not sufficent, open reduction is performed. This involves making small incisions to provide direct access to the 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 corticocancellous bone graft, which is harvested from the ipsilateral iliac crest. The bone graft provides additional structural support and facilitates healing by filling gaps and stabilizing the reduced fracture fragments. This step is crucial for restoring the normal anatomy of the tibial plateau and ensuring long-term joint function. In selected cases, 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 the first ring in the juxta-articular region of the tibia, close to the fracture site but without compromising the joint. The second ring is positioned just below the fracture to provide additional support, and the third ring is placed in the supramalleolar region to stabilize the lower segment of the tibia. Tensioned olive wires are used to hold the fracture reduction securely. These wires provide the necessary stability while allowing for micromovement, which promotes bone healing. Non-olive wires are used for the remaining segments to maintain overall stability of the construct **(19)**.

In some cases, 5 mm Schanz screws are applied to the diaphyseal segments according to the surgeon's preference. These screws offer additional support to the long bone segments and help maintain alignment during the healing process **(20)**. For patients with severe articular comminution or ligamentous instability, the additional distal femoral ring used for ligametotaxis is maintained for 4 to 6 weeks, providing the necessary stability during the early phases of healing (Fig 1, 2).

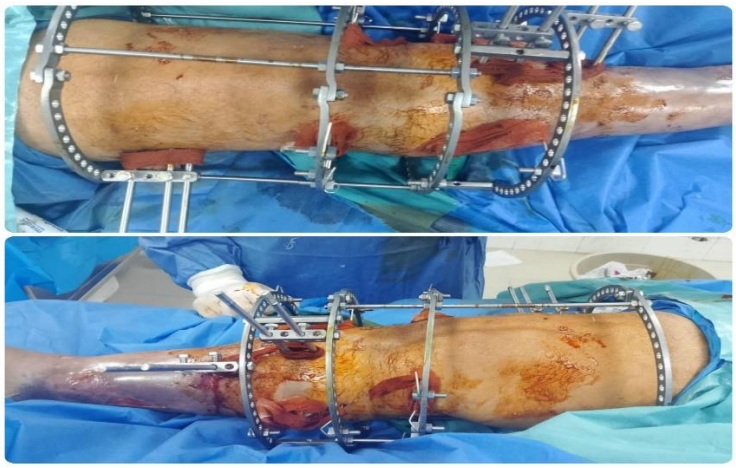

Figure (1): Ilizarov frame.

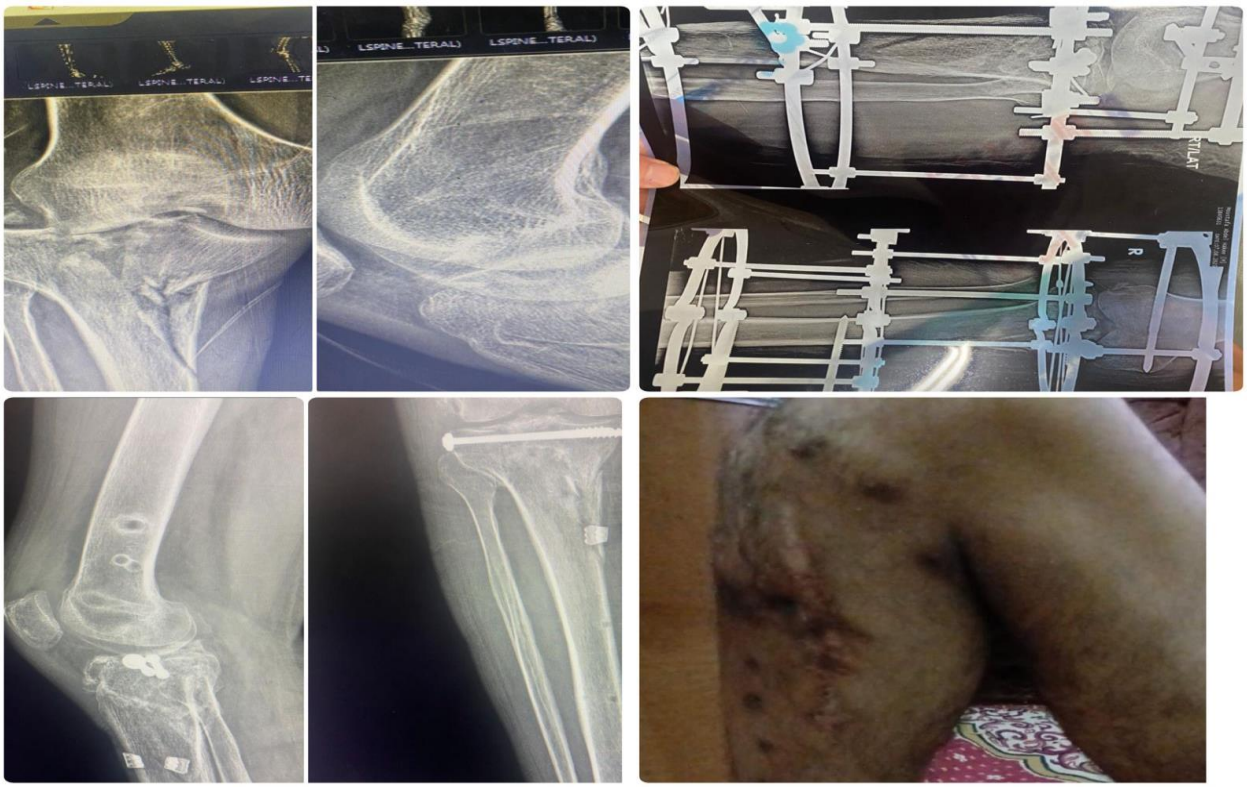

Figure (2): A 53-year-old male patient with rt tibial plateau fracture. showing Preoperative anteroposterior and lateral radiographs; Immediate postoperative anteroposterior and lateral radiographs; Anteroposterior and lateral radiographs at external fixator removaland Final follow-up showing ROM.

Postoperative Management:

- **Mobilization**: Encourage knee mobilization as much as the 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 (Fig. 3-5).

• **Fixator Removal**: Decide to remove distal femur ring of ligametotaxis after 4-6 weeks and to removr the fixator based on evidence of bridging in two orthogonal views and satisfactory stress test results after removal of rods between the first two rings **(22)**. Protect the limb with a removable brace during weight-bearing for 3–5 weeks post-removal, allowing only partial weight-bearing during this period **(23)**.

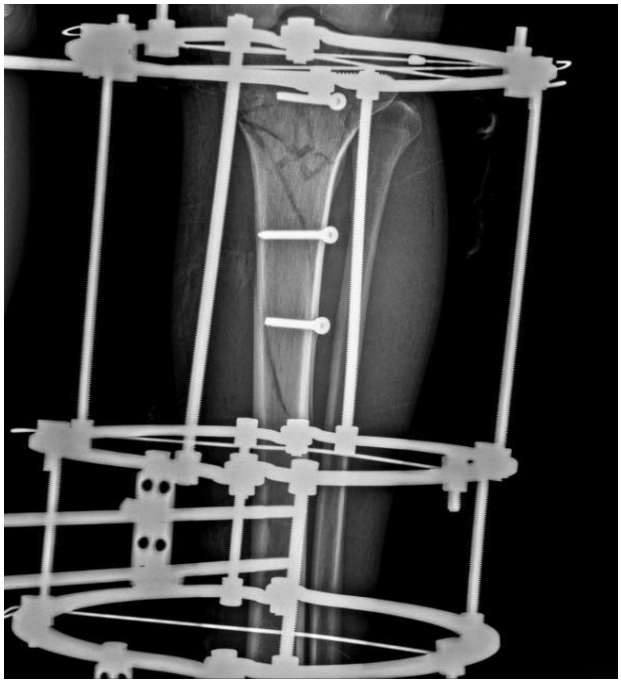

Figure (3): Postoperative X-ray of the knee joint with Ilizarov.

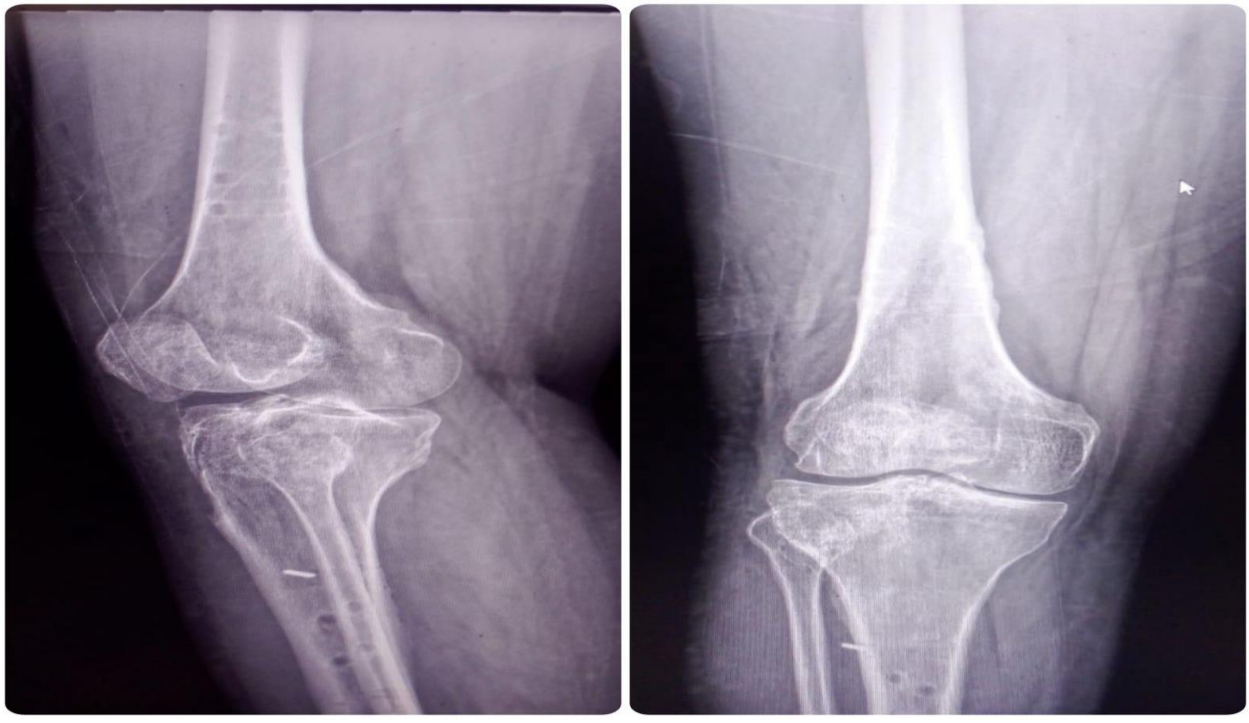

Figure (4): Knee joint X-rays postremoval showing healed fracture.

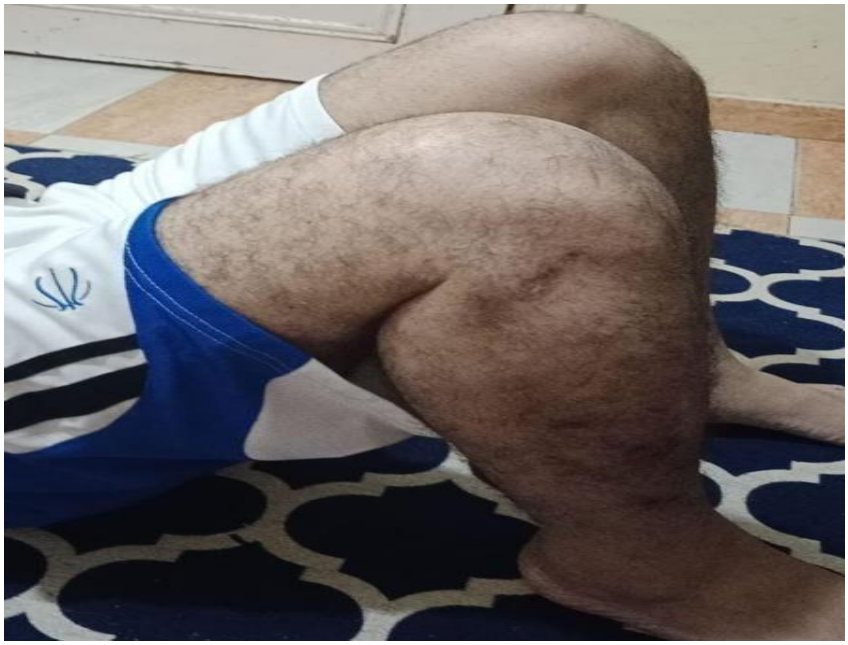

Figure (5): Image demonstrating range of motion of a patient without Ilizarov fixator.

Advantages of Ilizarov External Fixation:

1. **Minimally Invasive Approach**:

o 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 and wound dehiscence **(24, 25)**.

2. **Early Weight Bearing and Mobilization**:

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

3. **Adjustable and Dynamic Fixation**:

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

4. **Biological Favorability**:

o The technique promotes biological healing by maintaining micromovements at the fracture site, which stimulates callus formation and bone healing. The preservation of periosteal blood supply is another significant advantage, as it enhances the biological environment for bone repair.

5. **Versatility**:

o 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**:

o Compared to internal fixation methods, the risk of deep infection is lower with external fixation. The pins and wires are outside the zone of injury, and their placement is less likely to compromise the local blood

supply. ***Parameswaran et al.*** **(26)** 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**:

o By avoiding extensive dissection and exposure of the fracture site, the Ilizarov method reduces the risk of additional soft tissue injury, which is especially important in fractures with compromised surrounding tissues. ***Debnath et al.*** **(7)**, ***Gill and Raza*** **(27)**, believe that the Ilizarov technique is better for the management of complex tibial plateau fractures, which have extensive comminution with compromise of soft tissue and should be preferred over other methods.

Advantages with Minimal Internal Fixation

1. **Enhanced Stability**:

o 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 **(20)**.

2. **Improved Reduction**:

o 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**:

o The 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**:

o 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.

Reduced Need for Secondary Procedures:

o 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.

5. **Flexibility in Management**:

o 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)**.

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 **(28)**.

- A contracture arises when the muscle length becomes relatively short compared to that of the bone. Another etiologic consideration is transfixion of muscles or tendons by the pins of the 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 hypervascularity 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 the 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 and unsatisfactory cosmetic appearance can develop **(28)**.

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 micromotion 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 the site of bone loss or fracture gap without additional bone grafting. Rotational and translational deformities can be corrected as consolidation progresses.

Careful management of the soft tissue injury is vital, and the use of the Ilizarov system facilitates this. The 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 increase the 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 the complication, ***Kataria et al.*** **(29)** recommend placing wires at least 15 mm away from the joint surface, monitoring the status of pin sites (especially at juxta-articular locations), and removing any pin revealing features of infection **(30)**.

References:

1. Ahmed A-SAJTEOJ. Management of open complex tibial plateau fractures by Ilizarov fixator: average follow-up of 8.5 years. The Egyptian Orthopaedic Journal,2019;54(1):72-8
2. Malkova TA, Borzunov DY. International recognition of the Ilizarov bonereconstruction techniques: Current practice and research (dedicated to 100th birthday of GA Ilizarov). World Journal of Orthopedics. 2021;12(8):515.
3. Hosny GA. Limb lengthening history, evolution, complications and current concepts. Journal of Orthopaedics and Traumatology. 2020;21(1):3
4. Kotb, A., S. Samir, and K.A. Alghafar, Management of bicondylar tibial plateau fractures with severe articular comminution by ligamentotaxis with biplanar spanning external fixation. Current orthopaedic practice, 2018. 29(1): p. 42-48
5. Nishimura R, Ogino N, Miyawaki T, Matsuura S, Fujii M, Akaishi W, et al. A Biomechanical Study Comparing Different Configurations of the Ilizarov Minifixator and Plate Fixation. Journal of Plastic and Reconstructive Surgery. 2022;1(2):35-43.
6. Najim AA, Hamandi SJ, Alzubaidi A. Enhancing the Ilizarov Apparatus: Mechanical Stiffness. Al-Nahrain Journal for Engineering Sciences. 2024;27(1):25-31.
7. Debnath UK, Jha DK, Pujari PK, trauma. Results of ring (Ilizarov) fixator in high energy Schatzker type VI fractures of proximal tibia. Journal of clinical orthopaedics and trauma, 2018;9(2):186-91
8. Abdel-Wahed M, Abdalbary S, Amr S, Seifeldin A, Saied A, Mansour A. Two Versus Four Ilizarov Rings in All Schanz Screw Fixation for Fractures of the Tibia: Experimental Mechanical Testing. Orthopedics. 2023;46(3):152-7
9. Guan S, Du H, Wu Y, Qin S. The Ilizarov Technique: A Dynamic Solution for Orthopaedic Challenges. Orthopaedic Surgery.

10. Ghongade N, Bhokare N, Gardas BB. Analysis of K-Wire and Olive Wire in Ilizarov Apparatus: A Comparative Study. Indian Journal of Orthopaedics. 2024:1-11
11. Messner J, Prior CP, Pincher B, Britten S, Harwood PJ, Foster PA. Ilizarov method for acute paediatric tibial fractures. Strategies in Trauma and Limb Reconstruction. 2021;16(1):46.
12. Qin S, Zang J, Jiao S, Pan Q, Shi L, Zhu Y, et al. Application of the Ilizarov Technique. Lower Limb Deformities: Deformity Correction and Function Reconstruction: Springer; 2020. p. 67-110.
13. Lineham B, Stewart T, Ward J, Harwood P. Measurement of wire deflection on loading may indicate union in ilizarov constructs: a pilot study. Strategies inTrauma and Limb Reconstruction. 2021;16(3):132.
14. Grubor P, Borrelli J. Biomechanics of External Fixators for Fracture Fixation: Uniplanar, Multiplanar, and Circular Frames. Essential Biomechanics for Orthopedic Trauma: A Case-Based Guide, 2020:45-59
15. Naik P, McMillan LE, Narayan B, Iyengar KP. Use of External Fixation in Primary management of fractures. Handbook of Orthopaedic Trauma.: Springer; 2023. p. 307-24
16. KOUASSI KJ-E. Locally-developed external fixators and their impact on the stability of long bone diaphyseal fractures after osteosynthesis: UCL-Université Catholique de Louvain; 2021
17. ORTHOPAEDICS MOSI. A Comparative Study of Functional and Radiological Outcome in Management of Open Tibial Fractures by Ao External Fixator and Ilizarov External Fixator: RAJIV GANDHI UNIVERSITY OF HEALTH SCIENCES; 2020.
18. Nirdesh H. Evaluation of Acute Complex Tibial Fractures Treated with Primary Ilizarov External Fixator: Rajiv Gandhi University of Health Sciences (India); 2017.
19. Malkova TA, Borzunov D. International recognition of the Ilizarov bone reconstruction techniques: Current practice and research (dedicated to 100th birthday of GA Ilizarov). World Journal of Orthopedics, 2021;12(8):515.
20. Erdem M, Gulabi D, Tuncay I, Uzer G, Erdil M, Kuyucu E, et al. Treatment of intraarticular joint fractures of the lower extremity with external fixators. Basic Techniques for Extremity Reconstruction: External Fixator Applications According to Ilizarov Principles: Springer; 2018. p. 129-65.
21. Pawson JR, Church D, Fletcher J, Wood RA, Hilton C, Lloyd J, et al. Rehabilitation Techniques for Adults Undergoing External Fixation Treatment for Lower Limb Reconstruction: A Systematic Review. Strategies in Trauma and Limb Reconstruction, 2024;19(1):45.
22. Herbert C. Design and development of an adaptive external bone fracture fixation system. 2019.
23. Baloch SR, Rafi MS, Junaid J, Shah M, Siddiq F, Ata-ur-Rahman S, et al. Ilizarov fixation method of tibia plateau fractures: a prospective observational study. Cureus, 2020;12(10).
24. Abd Aziz AU, Wahab AHA, Rahim RAA, Kadir MRA, Ramlee MHJI. A finite element study: finding the best configuration between unilateral, hybrid, and ilizarov in terms of biomechanical point of view. Injury, 2020;51(11):2474-8.
25. Widanage KN, De Silva MJ, Lalitharatne TD, Bull AM, Gopura R. Developments in circular external fixators: A review. Injury, 2023;54(12):111157. 87.Jeremic D, Grubor N, Bascarevic Z, Slavkovic N, Krivokapic B, Vukomanovic B, et al. Comparative Analysis of Complication Rates in Tibial Shaft Fractures: Intramedullary Nail vs. Ilizarov External Fixation Method. Journal of Clinical Medicine, 2024;13(7):2034
26. Parameswaran AD, Roberts CS, Seligson D, Voor MJ. Pin tract infection with contemporary external fixation: how much of a problem? Journal of orthopaedic trauma, 2003;17(7):503-7

27. Gill UN, Raza MA. Functional outcome of the proximal tibial fractures using Ilizarov external fixator. Journal of Pakistan Orthopaedic Association, 2019;31(02):53-6.

28. Mahgoub MEH, Hefny A-SM, Nahla AM, Gaber AM. Complications of Ilizarov Technique. Tobacco Regulatory Science (TRS). 2023:320-31

29. Kataria H, Sharma N, Kanojia RJ. Small wire external fixation for high-energy tibial plateau fractures. Journal of Orthopaedic Surgery, 2007;15(2):137-43.

30. Rahman MJ. An Outcome of Ligamentotaxis and Stabilization by Ilizarov External Ring Fixator in Tibial Plateau Schatzker Type V Fracture. SAS J Surg, 2021;3:112-7.