

REVIEW ARTICLE

The Ilizarov Technique: A Dynamic Solution for Orthopaedic Challenges

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The Ilizarov technique is one of the most important tools that is currently employed in bone reconstruction surgeries. Its inception dates back to the mid-20th century and involves various bone reconstruction methodologies implemented using a circular external fixator system devised by G. A. Ilizarov. The key advantages of this approach include the generation of viable new bone via distraction osteogenesis, high union rates, and the functional utilization of the limb during the treatment process. The exploration of distraction osteogenesis phenomenon triggered by tensile stress with the Ilizarov device served as a catalyst for progress in bone reconstruction surgery. Subsequently, the original technique has been utilized alongside several adaptations resulting from the introduction of novel fixation tools and methods of their application, such as hexapod external fixators and motorized intramedullary lengthening nails. It is crucial to possess a precise comprehension of the Ilizarov principles of deformity correction in order to effectively utilize this fixation system. In this article, we will discuss the history of Ilizarov frame, the basic sciences behind it, the mechanical principles governing its use, and the clinical application of the fixation system in our daily practice.

Key words: Deformity Correction; Ilizarov Frame; Ilizarov Method

Introduction

The Ilizarov technique was first developed by G. A. Ilizarov in 1951 in the former Soviet Union.¹ Professor Ilizarov (Figure 1) and his team were searching for solutions to develop external fixation techniques to treat the pathology of long and short bones of both upper and lower limbs, skull, pelvis, and spine, and joint disorders in Kurgan in 1971.^{1–4} In 1954, he successfully treated his first patient—a factory worker who suffered from tibial non-union with this novel technique.

The Ilizarov frame/apparatus utilizes external supports of metal rings and wires that are drilled trans-osseously and operated with threaded units, enabling the generation of multiplanar movements on the bone fragments. The technique involves the application of compression or distraction forces to bone fragments to achieve bone consolidation, axial alignment, or the formation of new bone. This process is facilitated by the phenomenon called distraction osteogenesis, which is induced by tensile stress applied with the Ilizarov apparatus. The distraction

osteogenesis principle was practiced for the next 20 years in Kurgan before its introduction to the Western world. In 1980, Ilizarov presented his findings at an AO conference in Bellagio, Italy and subsequently introduced his findings to the United States in 1987. This novel and effective technique has been widely adopted by surgeons around the world since the early 1990s.

Principle of Distraction Osteogenesis

Distraction osteogenesis techniques include osteotomy/surgical phase, latency period, distraction phase, and consolidation phase. Previous experiments⁵ showed that ideal conditions included stable fixation, a low energy osteotomy followed by 5–7-day latency, and a distraction rate of 1 mm/day in three or four divided increments.²

During the period of distraction, there is a development of regenerated bone within the complete cross-sections of each bone surface that is being distracted, characterized by the presence of a central radiolucent fibrous interzone

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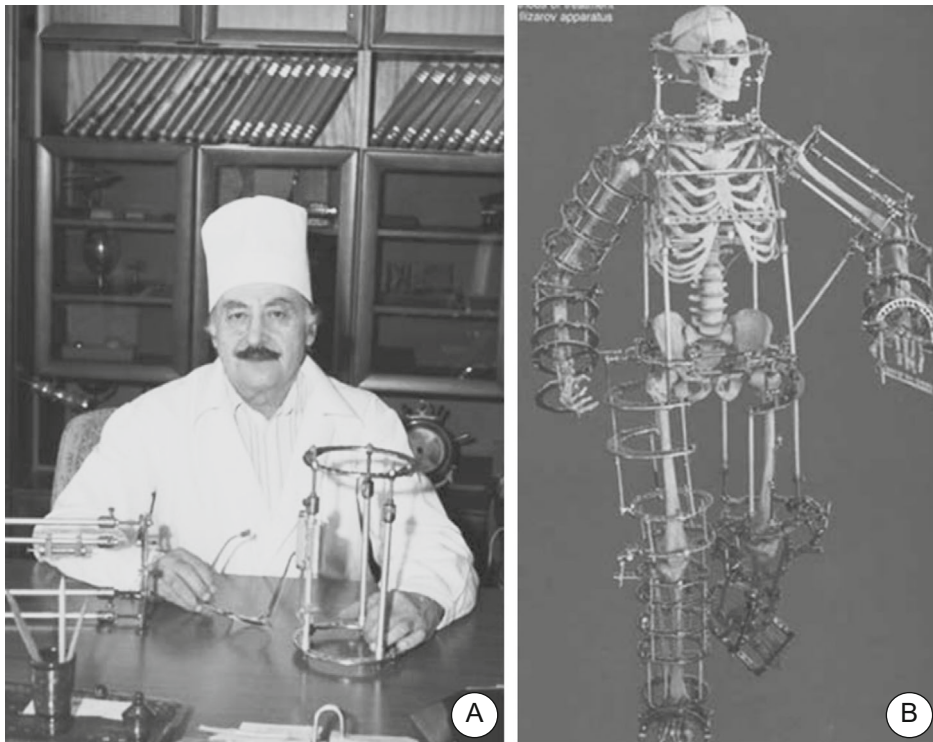


FIGURE 1 A, Professor Gavriil Ilizarov in his office in Kurgan, Russia. B. The “Ilizarov Man” was part of the traveling “Glasnost” exhibits of the early 1990s. Reproduced with permission from the Ilizarov Institute, Kurgan, Russia.

consisting mainly of type I collagen. The emergence of new bone trabeculae occurs directly from this central collagen zone, extending towards both surfaces of the bone.⁶ This formation is aligned in a parallel orientation to the distraction force and is encompassed by a network of blood vessels. Subsequent to the distraction phase, these microcolumns amalgamate and undergo prompt restructuring to establish a configuration resembling that of the original bone, a phenomenon referred to as consolidation. Up to 10% lengthening is well-tolerated by muscle, but substantial histopathological changes occur after lengthening of 30%. Eight to 10 nerves, arteries, and veins had histological evidence of temporary degenerative changes, but these disappeared 2 months after lengthening.^{7,8}

Ilizarov Frame/Fixator

The Ilizarov frame consists of multiple elements, with rings and connecting rods being the primary components. The inclusion of full rings offers maximum rigidity, while partial rings and arches are beneficial for tasks in close proximity to joints, facilitating necessary wound access post injury. Stability is the absolute key to the success of the frame and it is achieved by employing two rings per bone segment, thereby controlling both the proximal and distal ends of each bone segment.⁹ A minimum of four connecting rods connecting the rings and a minimum of two fixation points or wires per ring are deemed necessary.¹⁰ In instances of atrophic non-unions, double ring blocks are utilized to enhance construct stability. Conversely, in hypertrophic non-unions, one

ring block per segment is considered adequate unless deformity correction is required. Lengthening frames typically benefit from and sustain increased stability from distraction forces necessary to surpass the soft tissue envelope; hence, one ring per segment with multiple wires in various planes is utilized. The ring frame provides support and stabilization to the underlying bone by utilizing transfixion wires and half pins. Frame stability escalates with an increase in wire diameter and tension, a higher number of wires per ring, placement of wires on opposing sides of the ring, and insertion of wires in diverse planes. Elevating the crossing angles of wires to 90° yields optimal stability, while angles below 60° may permit bone sliding along the wires, necessitating the deployment of opposing olive wires or the addition of a half pin. Olive wires play a crucial role in bolstering the correction of angular deformity. An in-depth understanding of the cross-sectional anatomy of the extremity is imperative to prevent neurovascular damage. If the patient is under general anesthesia, administration of paralytic agents should be avoided to prevent obscuring vital signs like muscle flickering in response to motor nerve irritation. Minimizing the heat produced during wire drilling is crucial to avert bone and soft tissue necrosis. Wire tension significantly boosts wire rigidity and frame stability. Typically, smooth wires are tensioned up to 130 Nm, as exceeding 155 Nm can lead to wire stretching and plastic deformity.¹¹ Wires intersecting at angles below 60° should be tensioned simultaneously to ensure uniform tension distribution across both wires.¹² Comparative analyses between wire-only frames and combination half-pin

frames have indicated that the incorporation of half-pins augments the bending and torsional stiffness of the frame.

The Ilizarov Techniques in Today's Clinical Practice

Despite the old circular frame, in the past 20–30 years, computerized circular fixators (hybrid and hexapod external fixators, the Orthofix limb reconstruction system, the Taylor Spatial Frame) and motorized intramedullary lengthening nails, which ensure distraction osteogenesis, have made a grand entrance to orthopaedic practice around the world. Nevertheless, the basic principles remain the same—a thorough understanding of deformity is a must. Deformity evaluation requires a comprehensive understanding of typical anatomical alignment and rotational aspects. Usually, the unaffected limb can serve as a point of comparison, and a full-length, weight-bearing, anteroposterior X-ray of both lower extremities, with the use of blocks beneath the shorter limb to align the pelvis, is conducted. Radiographs services a pivotal role in directing the treatment approach and establishing a framework for preoperative strategizing.

Fracture Management

The Ilizarov techniques have evolved over the years to specify the types of fractures in which the Ilizarov external frames demonstrate greater efficacy. Primarily, these encompass complex open and closed comminuted fractures that are not suitable for traditional methods such as open reduction and internal fixation or cast immobilization. Indications for the implementation of Ilizarov techniques involve pediatric juxta-articular distal radial, distal femoral, distal humeral, and distal tibial fractures that exhibit comminution, complexity, and/or openness.¹³ The fundamental principles of Ilizarov fixation for pediatric fracture management prioritize the avoidance of growth plate damage using K-wires, precise reduction without interfragmentary compression, maintenance of anatomic alignment and fracture stability, preservation of periosteal blood supply, and facilitation of joint mobility and early weight-bearing. The utilization of the Ilizarov fixator in the treatment of complex pediatric tibial fractures, particularly those with open wounds, bone defects, or soft-tissue compromise, has been demonstrated to be safe, effective, and dependable, resulting in favorable functional outcomes and improvements in health-related quality of life throughout the treatment process. The Ilizarov frames were also used in elderly patients for tibia plateau fractures, pilon fractures, ankle fusions, non-unions, deformity correction.^{14,15} For diabetic patients who suffered from tibial fracture, the concept of bone transport is often used. It helps patients to achieve early mobilization, restoration of the normal lower extremity alignment, versatility, and improved union rate with decrease of wound complications.

Limb Length Discrepancy and Deformity Correction

Limb deformity remains a main issue of bone reconstruction in orthopaedics and its correction is a necessity for a variety of conditions. The classical Ilizarov method emphasized the significance of the protocol for qualitative distraction

osteogenesis.¹⁶ It is recommended to adhere to the standard 1-mm daily lengthening rate, as validated in the earlier studies conducted by Ilizarov's group,⁴ when utilizing any fixator. However, adjustments may be necessary if complications arise to ensure a consistent bone healing process.¹⁷ The focus primarily lies on the state of the regenerate and its consolidation to facilitate complete weight-bearing.

The concept of center of rotation and angulation (CORA) was introduced, and corrective osteotomy is performed, gradual correction is followed.¹⁸ During this process, both bone and soft tissue are incrementally distracted at a consistent rate of 1 mm/day, divided into four increments. The area of bone growth within the distraction gap is commonly referred to as regenerate. The period between the osteotomy procedure and the commencement of lengthening is termed the latency phase, typically lasting 7–10 days. The stage involving the correction and lengthening itself is denoted as the distraction phase. Following the conclusion of distraction, the duration until bony union is achieved is defined as the consolidation phase. Techniques that involve bone separation and lead to disruption of the periosteum, such as widely displaced corticotomies or osteotomies, may result in a reduction of osteogenesis.¹⁹

With the introduction of Taylor Spatial Frame with computer guidance for long-bone lengthening and deformity correction. Following external fixation was supplemented by internal fixation with a nail. The combined modifications used currently are lengthening over nail and lengthening and then nailing techniques.²⁰ One more combined technology is the use of flexible intramedullary HA-coated wires along with the Ilizarov apparatus.²¹ These user techniques lead us to a new path of limb lengthening and deformity correction.

Foot and Ankle Deformities

The Ilizarov methodologies involve gradual correction in multicomponent foot deformities and gradual soft tissue distraction alongside open releases and/or bony procedures, resulting in the achievement of a pain-free and plantigrade foot.^{22–24} The application of an Ilizarov-type frame on the foot and its subsequent adjustments necessitates the expertise of a proficient surgeon and the cooperation of a motivated patient. However, these techniques effectively realize the objectives in terms of both bone reconstruction and enhancement of foot functionality. In instances of intricate conditions, distraction osteogenesis should be considered as a last-resort option and ought to be carried out at specialized medical facilities. Various modifications to the frame, such as hexapod external fixators, are employed in the implementation of foot pathology techniques. These techniques are often considered as salvage procedures in scenarios like neglected adult clubfoot, challenging ulcerations, and ankle joint arthrodesis for addressing Charcot neuroarthropathy, despite the associated complications.²⁵ Consequently, a combined approach involving circular external fixation and an intramedullary nail coated with antibiotic cement has proven successful in preserving lower limbs for the majority of patients, resulting in a functional and clinically stable foot in

cases of infected neuropathic ankles. Infected ankles have also been effectively managed using the Ilizarov method.²⁶ The reconstruction of the hind foot and ankle, coupled with concurrent lengthening through a distal tibial corticotomy utilizing the Ilizarov frame, has demonstrated comparability to alternative treatment options. Furthermore, modifications have been suggested for addressing rare congenital foot malformations like brachymetatarsia and cleft foot. A classification of different foot and ankle frame assemblies into several standard hexapod configurations has been proposed, showcasing various strategies for foot treatment.²⁷

Complications

Intraoperative complications involve direct neurovascular damage, pain, bleeding, and nerve injury resulting from stretching. Pin sites infection has been reported to be as high as 90%, but with proper postoperative care, at least 95% of these resolved with or without oral antibiotics.²⁸ Soft tissue and joint contracture can be serious complications, but with better preoperative planning, careful surgical technique spanning of the joint combined with postoperative physical therapy, contractures can be managed.²⁹ Chronic complications including osteomyelitis, non-union, malunion, and hardware failure often need to be surgically addressed.³⁰ The rate of complication decreases as surgeons' experience increases, but

the rate of intraoperative complications remain constantly independent of the experience of the surgeon.

Conclusion

The Ilizarov techniques/frames have stood the test of time and are a gift to the orthopaedic community from G. A. Ilizarov. It is a versatile fixation system that gives stability, soft tissue preservation, adjustability, and functionality. With careful preoperative planning, postoperative complications are minimized. We should all achieve the desired surgical outcome as G. A. Ilizarov intended 70 years ago.

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Conflict of Interest Statement

The authors declare that they have no competing interests or personal relationships that could have appeared to influence the work reported in this article.

Author Contributions

Shengsheng Guan and Hui Du prepared the manuscript. Yong Wu and Sihe Qin revised the manuscript. All authors read the manuscript and approved the submission.

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