

EDITORIAL

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TRANSOSSEOUS OSTEOSYNTHESIS – THE ILIZAROV METHOD

TRANSOSEALNA OSTEOSINTEZA – ILIZAROVA METODA

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The Ilizarov method is a valuable alternative option to more conventional methods in the treatment of severe wound contamination and in cases of soft tissue or bone loss. Ilizarov named his method transosseous compression-distraction osteosynthesis and formulated its principles [1, 2]. Today it is simply called the Ilizarov method, although the method is a collective result of a large team of talented scientists, surgeons and engineers, he had gathered around him. It is a system of techniques that induce compression or distraction (or the combination of both) by moving bone fragments via transosseous wires with the adjustments of the external ring fixator for bone union, growth or spatial transformation that finally ends in osteosynthesis, consolidation and new bone remodeling. It is used for skeletal injuries, their complications, congenital disorders, degenerative diseases and tumors. The treatment of bone loss occurring as a result of acute trauma has traditionally been a complex surgical problem. In an attempt to avoid the problems associated with deficient graft materials and free tissue transfers, internal bone transport is a technique that has been a successful method for bony reconstruction in acute bone loss [1–3]. In addition, the Ilizarov apparatus may provide stability even in cases of bone comminution when internal fixation devices can do no better than tenuous fixation. Nonunion of long bones is often associated with a significant loss of function of the affected extremity, joint stiffness, muscular atrophy, diffuse osteopenia, and even an extremity amputation or systemic manifestations in the case of infection. Indications for appropriate treatment are often unclear [4]. In complex nonunion, intramedullary nailing is preferred, in delayed consolidation and hypertrophic nonunion without angular defects or hypometria, while the Ilizarov method is more often indicated in atrophic nonunion, and in hypertrophic nonunion with hypometria and angular defects [5]. The ring frame supports and stabilizes the underlying bone by means of transfixion wires and

half pins. The frame stability increases with the increasing wire diameter and tension, the use of more wires per ring, placing wires on opposite sides of the ring and inserting wires in different planes. Increasing crossing angles of wires to 90° provides maximal stability and crossing angles of less than 60° may allow the bone to slide along the wires requiring the use of opposing olive wires or the addition of a half



Figure 1. G. A. Ilizarov (1921 – 1992)
Slika 1. G. A. Ilizarov (1921–1992)

pin. Olive wires provide an important buttress effect in the correction of angular deformity [6].

Gavril Abramovich Ilizarov was born in Białowieża, Poland in 1921 (**Figure 1**). His father died when Gavril was very young. There was little support for Ilizarov to attend school and consequently, his formal education was delayed until the age of 11. By the age of 16, Ilizarov had completed the equivalent of ten years of education in five consecutive years. In the setting of the Second World War, Ilizarov was forcibly evacuated from Simferopol, Crimea, where he studied at the Simferopol Medical Institute. Finally, in 1943, he finished his studies in Kzyl–Orda, Kazakhstan and at the age of 22, he was awarded a medical degree. In 1944, Ilizarov returned to a rural setting when he was assigned to practice general medicine in Dolgovka, Siberia, a remote region that had previously been used for the exile of Tsars and their families [6]. Ilizarov came across a shaft–bow harness connecting a horse to its carriage through shafts. This served as an inspiration and he attempted to incorporate this mechanism into a prototype to repair fractures. Before ever testing on a living subject, Ilizarov first created an apparatus based on the shaft–bow harness to “treat” broken broomsticks. He made several rudimentary versions of the device, trying each time to further reduce mobility of the broken broomstick. Ilizarov would eventually seek help from a local metal–worker to fashion ring–shaped wires that would be suitable for use on human limbs. The Ilizarov apparatus became a system of external fixators consisting of stainless steel rods, rings, and Kirschner wires. The method was distinct from conventional external fixators in that the apparatus encased the limb and formed an external cylinder around it (**Figure 2**). The circular construction afforded early weight bearing for patients since it provided greater support than monolateral fixators. A key biophysical element was that the superior rings of the apparatus allowed force to be transferred from the bone distal to the fracture site, through the external frame (bypassing the fracture site), directly to the bone proximal to the fracture. Although its initial application was to effectively stabilize severe fractures for healing, Ilizarov realized that the apparatus could also be used to lengthen a limb. The Ilizarov external fixator apparatus’ use for this purpose relied on the principle of distraction osteogenesis; when two ends of a bone are distracted but the periosteum remains intact, new bone is laid down to fill the space. This regeneration of bone was applied to correct limb length discrepancies [7]. Ilizarov’s studies proved that the ideal setting for new bone formation consisted of a low–energy osteotomy followed by one week of latency and a distraction of the bone at a rate of one mm/day in four divided increments [8].

In 1950, G. A. Ilizarov moved to Kurgan, Siberia. Practicing in this larger center allowed Ilizarov to develop his apparatus and broaden its scope. Though formally trained in general medicine, Ilizarov was promoted to Director of the Kurgan Research Institute for Experimental Orthopaedics and Traumatology because of his experience with his innovative apparatus. He chose former Russian soldiers in the Second

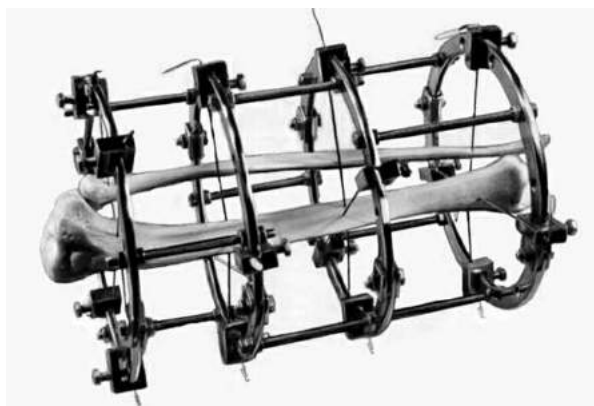


Figure 2. Model of Ilizarov apparatus
Slika 2. Model Ilizarovog aparata

World War as his initial patients. Ilizarov was disheartened by the time required for severe fractures to heal and wished to use his technique in an effort to repay veterans for their service. In 1964, Soviet high jumper and Olympic champion, Valery Brumel, found his career cut short after a severe automobile accident. Brumel sustained comminuted fractures resulting in the near complete loss of the use of both legs. In desperation, Brumel sought help from Ilizarov and was successfully treated in 1967. By 1981, a group of Italian orthopedic surgeons learned of his technique, mastered it and subsequently published it in didactic textbooks. In order to disseminate the device and the technique, these Italian orthopedic surgeons organized national societies throughout the world called the Association for the Study and Application of the Methods of Ilizarov. More recently, the method was introduced in North America, where it has been adopted primarily by pediatric orthopedic surgeons for limb lengthening. Some American orthopedic surgeons have expanded their practice to include the Ilizarov method for adults with severe deformities such as nonunions and bone deficiencies from trauma, infections, and tumors. Many research centers have utilized the method to study bone formation. Coincidentally, these efforts corroborated Ilizarov’s own research and in part extended insights into the regeneration of both bone and soft tissues under mechanical distraction. Ilizarov first introduced this method both experimentally and clinically over his 40-year career in Siberia. The University of Toronto orthopedic surgery resident, Dr. Paley, was motivated to learn of this new technique and bring its benefits to North America. But during the tensions in the Cold War era, Soviet Union made it extremely difficult for people from the Western World to gain access to this “closed” Soviet city. In 1986, Ilizarov and other Soviet–based surgeons hosted an International Conference on Transosseous Osteosynthesis, giving Paley the perfect justification to visit Kurgan. Ilizarov felt it was important to disseminate his method to American audience but was simultaneously wary of not receiving credit from American scientists and clinicians, especially given the air of secrecy between the two nations. Paley helped to assuage these tensions

by being able to communicate with Ilizarov in Russian. Since Ilizarov was more willing to share the confidential details on the use of his apparatus in the absence of an intermediary translator, Paley enjoyed greater access to the intricate details of mastering the technique. Also, being from Canada, as opposed to the United States, made him less threatening. For Paley, learning Russian provided an opportunity to make sense of many of Ilizarov's original documents [4]. The Ilizarov procedure of transosseous osteosynthesis was alive and well by the late 1980s [8]. When Ilizarov eventually went to Rome in 1982 to lecture on his innovation, the Ilizarov apparatus had already begun to acquire global fame. Italian surgeons dubbed Ilizarov "The Michelangelo of Orthopedics" [9, 10].

In the Republic of Serbia, this method has been successfully applied at the Institute for Orthopedic Surgical Diseases "Banjica" - Belgrade for 35 years, and at the Clinic for Orthopedic Surgery and Traumatology in Novi Sad in the last 15 years. The leading surgeons of these institutions were also educated at the World Science Center in Kurgan. Their papers were presented in domestic and foreign books and journals [11–14].

Ilizarov had been bestowed the rare honour of Hero of Socialist Labour in 1981, and became a member of the Russian Academy of Sciences ten years later. He was awarded the Lenin Prize in 1979. In 1992, Ilizarov died of heart failure at the age of 71 in his hometown of Kurgan. The Ilizarov Centre for Orthopedic Surgery in Kurgan has been repurposed to focus on the surgical correction of congenital limb abnormalities (**Figure 3**). A scientific journal "Orthopaedic Genius" ("Genii Orthopedii") was created shortly after his death in honour of Ilizarov [10].

The basic principle of Ilizarov technique is the use of a percutaneous corticotomy that minimizes trauma to the periosteum and preserves the blood supply of the bone marrow and periosteum [15]. The use of a corticotomy instead of osteotomy emphasizes the importance of the blood supply to osteogenesis. Both the periosteal and medullary blood supply can be preserved by cutting only the cortex. Significant retardation of osteogenesis has been observed in animal studies with damage to the intramedullary nutrient vessels in osteotomized bones. Ilizarov's experiments with distraction osteogenesis made it clear that both rate and rhythm of distraction affect the quality of the regenerate [1, 15, 16]. Ilizarov performed his experiments in canine tibiae. He found that 0.5 mm of distraction per day often resulted in premature consolidation of the regenerate, while 2 mm of distraction per day produced a poor regenerate often with intervening fibrous tissue [15, 17].

The biomechanical goals of external fixation in bone transport are threefold: to maintain the bone ends in stable alignment, to control the movement of the bone projectile, and to allow compression of the bone in the target zone [18, 19]. Stable fixation of the bone fragments is one of the most important principles in the Ilizarov technique [15]. A stable frame permits full weight bearing, does not restrict the function of adjacent joints, and permits physiologic func-

tion of the entire limb, ensuring optimal mechanical and biologic conditions [15]. Secure fixation limits translational micro motion between the bone fragments. Weight bearing and active muscle function enhance local circulation and shorten the period required for osseous callus formation and remodelling [15]. The degree of stability of the apparatus depends on multiple factors. The number of and tension on the wires influences the stability of the construct. In addition, the angles between the wires can affect stability. Optimal stability with two transfixation wires is obtained when the wires are perpendicular to each other. When anatomic and functional constraints prevent perpendicular wire placement, supplementary wires may be required [15, 17]. Stability also depends on the number and size of the rings in the apparatus and the rigidity of the fixator construct. The amount of compression or distraction incorporated into the configuration can also contribute to the stability. The shape, cross-sectional area, and the density of the bone fragments, as well as the shape, location, and plane of the fracture or osteotomy relative to the longitudinal axis of the bone, are also important determinants of the stability of the construct.

Distraction osteogenesis has been applied in the treatment of a wide variety of problems including severe limb length discrepancy, acquired and congenital deformities, fracture nonunion, and osteomyelitis [1, 17, 20]. Regardless of the reason, the general technique remains unchanged: bone division, stable fixation of the fragments, a 7 to 14 day latency period, distraction, consolidation, assessment of regenerate bone, and removal of the frame [16, 21–24]. Care must be taken to allow for at least 2 to 3 days of consolidation for each day of distraction. Prior to removal of the frame, a careful assessment of the regenerate and docking site, if present, is required. Similarly, this technique may also be applied in acute limb shortening followed by limb lengthening [21, 25–27]. The theoretical advantage of this technique is that it allows faster healing of a traumatic defect as it does not require waiting until docking is achieved to begin callous healing. Shortening assists with the closure of soft tissue defects, though it may result in soft tissue redundancy and swelling. These techniques can be readily applied to the treatment of various types of nonunions. Atrophic nonunions may be treated with bifocal osteosynthesis, which involves resection of the nonunion site, compression at the nonunion site, and bone lengthening at an osteotomy site remote to the nonunion site [22, 28]. This technique also allows alignment if deformity is also present. Hypertrophic nonunions have traditionally been treated by revision to rigid fixation. These fractures have a vital blood supply from each bone end and a dense collagenous interface. These characteristics allow the nonunion to be treated by stimulating bone formation with primary distraction and realignment when necessary. Nonunions with bone loss can be transported with bone transport or shortening distraction [22, 29]. Infected nonunions require resection of the focus of infection, with removal of all necrotic and poorly-vascularized tissues [22]. The

remaining osseous segments must have an adequate blood supply to promote bone formation at its trailing end and healing at its leading end [19]. Bone transport can then subsequently be used to eliminate the residual defect. When compared to treatment with bone grafts, antibiotic beads, and vascularized bone grafts, patients who are treated with bone transport experience similar rates of healing, duration of treatment, final deformity, complication rates, and total number of operative procedures [22, 30, 31]. However, patients who undergo bone transport end up with improved limb length discrepancy, decreased cost of treatment, and shorter duration of disability than those treated with bone graft, antibiotic beads, and vascularized bone graft [22, 32]. The benefits of treating nonunions with bone transport include the ability to achieve regeneration of living bone with the same strength and width as that of native bone [22]. In addition, this technique can be used to treat very large defects, up to 30 cm, in both children and adults [32]. Moreover, it allows simultaneous deformity correction as well as treatment of concomitant soft tissue problems. Unfortunately, bone transport is not the answer for all nonunions. Its use requires specialized training and equipment. Frequently, bone transport requires a long treatment duration during which numerous complications may occur.

The technique of transformational osteogenesis is also described by Ilizarov, which involves the mechanical stimulation of pathologic bony interfaces through variations in compression and distraction to induce osteogenesis and regenerate normal bony continuity [15, 33, 34]. He recommended this technique for the treatment of nonunions. Transformational osteogenesis is less well documented histologically than distraction osteogenesis. Success of the technique depends on the stability and composition of the pathologic interface. Ilizarov argued that a stiff, fibrous nonunion should be treated with initial distraction [34]. Tension is applied across the nonunion site using the Ilizarov device to induce distraction osteogenesis. Once new bone formation is visualized radiographically, the bone ends can then be compressed to transform the osteogenic bridge into a solid cylinder of bone [18, 34]. Transformational osteogenesis can be used similarly to treat a site of mobile pseudoarthrosis. The site must first be compressed progressively at a rate of 1 mm per day for 10 to 15 days [16]. Compressive forces induce local necrosis and subsequent neovascularization of the cartilaginous interface. When local resorption occurs, distraction of the site then renews osteoneogenesis. Following

the induction of local osteogenesis, compression can then be reapplied to successfully unite the bone ends.

Early complications are pain, bleeding that can result in hematoma or compartment syndrome, deep vein thrombosis and pulmonary embolism, and nerve injury as a result of stretching. Immediate complications involve direct damage to neurovascular structures. Infection, especially of the pin sites, has been reported to be as high as 95%; however, with local pin care, with or without oral administration of antibiotics for 5 days, 97% of these resolved [35]. Soft tissue contractures, subluxation, and contracture of the joint are more serious complications. They can, however, be minimised with pre-operative planning, including protection against subluxation by spanning of the joint with the fixator and with intensive therapy and splinting during the fixation period [36]. Late complications include chronic recurrent pin-site infections, osteomyelitis, premature union if distraction is too slow or delayed or nonunion, hardware failure, reflex sympathetic dystrophy, late bowing and fracture. The rate of complications decreases substantially as the experience of the surgeon increases. In one study, major complications followed 69% of Ilizarov lengthening procedure performed in the first 6-month period of experience, but only 35% in the third 6-month period [37]. The rate of minor complications remained constant and independent of the experience of the surgeon and type of a fixator.

Ilizarov frames provide a versatile fixation system that gives stability, soft tissue preservation, adjustability and functionality. All these factors are vital for bone to realise its full osteogenic potential. A preoperative plan is essential with careful selection of patients who will be able to adhere to strict post-operative regimen of lengthening, and angular correction to avoid late complications.

Russian studies of the Ilizarov method (Popova and Khodesecich, 1984) as cited by (Ilizarov & Rozbruch, 2007) showed that the use of this method significantly reduced the time and cost of treatment, and disability payments. When used for the treatment of fractures and post traumatic nonunions, primary disability was decreased by 3–5 times, and 8-fold compared with traditional treatments in the case of open fractures. This meant that more patients were able to return to work sooner, which is advantageous for the economy of the country. Extensive knowledge of human anatomy is essential, in order to reduce the risk of nerve or vascular damage. It takes a vast amount of time to acquire the necessary knowledge and there are few surgeons adequately trained to perform this technique.

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