The Ilizarov paradigm: thirty years with the Ilizarov method, current concerns and future research

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Abstract The Ilizarov method of bone lengthening, reconstruction and osteosynthesis has developed immensely since its introduction by G.A. Ilizarov in the Soviet Union in the 1960s and in the Western countries in the early 1980s. It has become an integral part of the arsenal used by the orthopaedic community worldwide. The evolutionary development of the method and its current role has considerably improved the quality of life for millions of people around the whole world. Despite the great versatility of its possible applications for bone injuries and diseases, the Ilizarov method could not and cannot be the alternative to a range of other methods that are applied for some specific bone conditions, but rather is a method of choice. Its combination with the current methods of internal fixation or the means of internal fixation that use the biological principles that were laid down by G.A. Ilizarov have demonstrated the importance of tension stress, blood supply, functional loading, and fragment control during bone treatment. The objective of this study was to present an overview of the current state and concerns in the application of the Ilizarov method and define the prospective research trends aimed at regeneration stimulation, better control of treatment, infection barriers and patient comfort.

Introduction

The Ilizarov method has established itself as a powerful technology for the management of a great variety of bone diseases and conditions. It is considered by us as a system that is based on biological laws and technological philosophy.

The following basic principles of this philosophy were stated by the founder of the method [1–3]:

- Tension stress effect that stimulates the biosynthetic activity in tissues
- Adequacy of blood supply and loading
- Gradual lengthening and correction
- Possibility of full-time control of callus formation
- Early limb functioning and loading

The surgical interventions applying the Ilizarov techniques are not aggressive, spare tissues and involve little blood loss. They do not require massive intensive care measures postoperatively. The essential factors of treatment are rigid circular external fixation, control of fragment position, bone transport, and monitoring of bone regeneration allowing for possible corrections during the course of treatment limb weight-bearing and maintenance of joint motion [3–6].

The external apparatus for bone fragment fixation and control that was invented by the author of the method in the early 1950s is a remarkable device that was later perfected and brought him to the discovery of those laws (Figs. 1 and 2). It may be considered the best instrument that is able to realise the principles of the philosophy of this method [7]. Bringing the system for fixation and control of bone fragments out of the human body was a colossal stimulus for scientific search and perfection of osteosynthesis devices. As any other device, the Ilizarov apparatus cannot be the only feature of the method but its invention and application has resulted in the “arms race” or competition for better constructions both for external and internal fixation of bones that has advanced bone treatment and osteosynthesis. External monolateral fixators, intramedullary kinetic distractors, automated external distractors, external minifixators for the hand, the Taylor spatial frame, Orthofix ring and hybrid fixators, locked intramedullary nails and plates, as well as guided growth plate systems are the most noteworthy and apply the Ilizarov laws [8–18]. There is an opinion that the Ilizarov

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Fig. 1 Diagram of the apparatus for fracture repair (Ilizarov application for invention dated 9 June 1952, courtesy of the Centre's museum)

method is limited by the use of the circular fixator. However, the method has outgrown its instrumentation that was considered its historical driver. The biological principles and technical guidelines that were proposed by the Ilizarov method developers have been considered and interpreted by other technologies for bone reconstruction and osteosynthesis. The Ilizarov method philosophy has harmoniously integrated with intramedullary nailing and plating yielding good results and more comfort for patients [19–22]. Guided growth systems using dynamic intramedullary nails or lateral plates use its biological principles of gradual and guided distraction. Distraction osteogenesis has been adapted to the maxillo-mandibular, midface and cranium surgery that applies both internal and external devices to implement bone transport or distraction [23]. Transosseous osteosynthesis is applied in spinal surgery and employs many technical solutions that are similar to the approaches of external fixation.

The aim of this study was to emphasise the current concerns in the application of the Ilizarov method and its integration

Fig. 2 The earliest Ilizarov apparatus construction available (1960s, courtesy of the Centre's museum)

with other technologies, and to define the prospective trends to overcome obstacles and obtain regeneration stimulation, more control during the treatment process and further improve patient comfort.

Concerns and future research

The first reports that cited the use of the Ilizarov techniques in the peer-reviewed orthopaedic journals appeared 30 years ago [24, 25]. The peak of the distribution and application of the Ilizarov method outside Russia was in the 1990s [26], with the peak of the published studies of its use in the same period according to the PubMed database. Since then, the number of reported studies on the method in highly cited medical journals has been in the range of 60–90 articles each year illustrating that the method remains one of the key technologies of bone repair and reconstruction [27–29]. A number of pathological bone conditions can be solved mainly with the conventional Ilizarov method as it offers an alternative to amputation and limb salvage (Fig. 3) [30–36]. It has been adopted in a great number of countries in spite of its long learning curve and a great degree of expertise needed to perform it successfully.

Our centre is a specialised clinical and research institution that has been using and developing the Ilizarov method since 1971. It has accumulated thousands of historical cases of bone disorders that were completely cured or improved using the method (Table 1). The concerns and tasks in the development of the Ilizarov method deduced from the reported sources and our institutional experience can be focused on the following trends aimed at better control of bone fragments and infection during the treatment process, regeneration stimulation, reduction of the treatment period and patient comfort.

Control

Control is the key concept and means of treatment in the Ilizarov method philosophy that implies management of bone fragments and maintenance of joint motion combined with an obligatory feedback or control (checkup) of the process. The primary issues of future research should be the necessary level and duration of the control. In other words, the studies should define differentiated indications for the necessity and the means of this control as well as the indications for using hybrid technologies. The combination of the technologies of external and internal fixation is undoubtedly the main direction that can solve their eternal conflict. Internal fixation is unable to correct complex multiplanar deformities as their management requires an accurate control of bone fragment transport while external fixation foresees the need for a prolonged treatment period that involves highly-qualified personnel, economic expenditure

Fig. 3 Limb salvage with the technique of sequential multilevel lengthening to manage a 20-cm tibial defect after failed treatment of an open comminuted fracture with plating that had resulted in osteomyelitis and multiple sequestrectomies. Gradual transport of the osteotomised proximal and distal fragments was used. When the total gain of the regenerated bone was 16 cm an additional corticotomy of the distal fragment and fibular osteotomy were performed in order to compensate leg-length discrepancy. Total distraction took 219 days. Adaptation at the docking site was open. Foot malposition was corrected simultaneously

Table 1 Pathologies and patients treated with the Ilizarov techniques in 1971–2012 (according to Centre's archive files)

Conditions treated	Description	Number of patients (<i>N</i> = 77,372)	% patients treated	Age range (years)
Bone injuries and their consequences	Severe open and closed fractures including gunshot fractures, pelvic injuries, intraarticular fractures, spine injuries, delayed unions, non-unions	27,080	35 %	6–89
Bone diseases	Achondroplasia, congenital and acquired limb discrepancy, bone defects, congenital pseudoarthrosis, valgus and varus long bone deformities, congenital and pathological hip dislocation, Perthes' disease, deforming arthrosis, unicameral bone cysts, bone fibrous dysplasia, benign bone tumours, congenital finger shortening and stumps, syndactyly, congenital and acquired foot deformities (clubfoot, etc.), shin and foot stumps, poliomyelitis consequences, osteomyelitis, cranial defects, scoliosis	50,292	65 %	1–69
Total		77,372	100 %	

and lowered quality of patient's life due to high costs of treatment and inconvenience due to the application of the external fixator [15–20, 37–40].

Despite the fact that 30 years have passed since the start of the use of the programmed automated distractor at our centre, another direction for research would be the application of automated distraction and new technical designs for its implementation. The experimental trials and clinical use of high frequency distraction for limb lengthening were effective. Their results have shown that it caused less joint stiffness and the overall treatment period was shorter [41–43]. The research may focus on the electronic feedback systems for managing automated high frequency distraction in order to bring the growth process by means of distraction osteogenesis closer to the natural system. The quality of manipulations should be the primary focus in such developments. The use of software and internet communication could provide outpatient control, without any detriment to the volume and quality of rehabilitation measures. New designs of fixation devices, units, half-pins, screws, and wires will also be required for implementation of the control.

Barrier

Soft tissue and septic bone conditions are the most challenging concerns in orthopaedic practice. Therefore studies that direct their efforts to the elimination of infection are of great importance. This direction should be based on the concept of the natural bactericidal ability of tissues under tension stress due to the activated biosynthetic processes that may be used instead of massive and continuous antibacterial therapy in the postoperative period [3, 44]. It seems difficult to maintain the therapeutic doses of effective antibiotics in the compromised tissues because of their impaired local rheology. Toxic and allergic side-effects from prolonged administration of antibiotics and the bacterial resistance to them arising from prolonged use are the other concerns [45]. In spite of the fact that the majority of authors and various statistical findings indicate that wire tract infection does not affect the final outcome, the discussion of this issue continues to be of concern as the penetration of infection through wire or pin tracts has been considered one of the weak points of external fixation [39, 46–48].

The pioneers of the Ilizarov method developed and described the ways to minimise the intraoperative trauma to soft and bone tissues such as the rules for performing osteotomy and drilling [3, 6, 49–51]. They designed wire sharpening types, assessed adequate wire tensioning and the ways of checking fragment stability. However, it is well known that some patients can tolerate the external fixator without any medical care for long periods. Therefore, it is very important to understand the essence of the barriers to

infection: whether they result from technical specifications of wires and half-pins, local microflora of the skin in the area of external fixators, individual immunity, blood supply, or from a multifactorial combination. May we find out the risk factors and formulate the rules to avoid infection for specific conditions? The same can also be referred to internal techniques. Novel wire or half-pin coatings and dressings could minimise the need for frequent outpatient visits for pin tract care and would help to control or eliminate the infection process.

The infection barriers developed might be applicable to improve the quality of biocompatible implants being designed nowadays. Creation of distal implantable working limb prostheses seems to be a prospect but inability to provide a barrier to infection in the contact areas of patient's soft tissues and an implant appears to be an unsolved problem to date.

Stimulation

Poor regeneration or nonunion can be caused by a complexity of factors. The major factors contributing to regeneration delay or nonunion are specific features of some pathological conditions as well as technical and tactical errors during treatment. Autologous bone grafting continues to be a favoured means to enhance regeneration in the problematic area among surgeons [52, 53]. Trials evaluating the outcomes of ultrasound, electrical and electromagnetic fields for stimulation suggest that they are suitable for fracture healing [54].

Recently, a great amount of fundamental research has been conducted in order to study the stimulating effects of various biological substances such as blood plasma, aspirates of bone marrow cells or osteoprogenitor cells, growth factors, and bone morphogenic proteins [54–56]. The key problems of their possible use seem to be the pathways of their transportation into the area of impaired regeneration as well as their effects on tissues, cells and the human system as a whole. It is obvious that the opposite side of their influence could be the danger of adverse events or toxicity [57–60]. However, the impacts of such modalities remain unknown due to the lack of clinical research available.

Meanwhile, the best way would be to find out viable alternatives of achieving the correct level for the factors that affect the normal regeneration course during bone lengthening and consolidation [52, 61–64]. A variety of mechanical ways have been proposed by clinicians to stimulate osteogenesis during the procedures with the Ilizarov apparatus, e.g. dosed decrease of distraction forces in the frame in order to compact the weak regeneration site, sequential removal of wires, additional osteotomy in the lengthened segment followed by retrograde transport of the new fragment, mechanical perforation of the regenerated

bone with wires, etc. But there is little available literature that describes clinical outcomes or series of patients to justify their wide use. Nevertheless, a better bone regeneration capacity has been proven using high frequency distraction which may be applicable mostly for lengthening procedures in an automated mode [65, 66]. Osteogenesis stimulation and development of the means for bone strengthening in fighting systemic skeletal diseases such as osteogenesis imperfecta, phosphate diabetes, and osteoporosis of various origins remain important directions for research [67].

Comfort

The issues of the patients' quality of life during the treatment with the Ilizarov method are closely interrelated with the previously described concerns. The improvement of control, regeneration stimulation and barriers to infection will ultimately result in better patient comfort and rehabilitation. As far as the final goal of any treatment is our patients' satisfaction, the research and technical solutions should be directed towards combined or sequential use of various fixation systems [68], minimally aggressive interventions, reduction of the treatment period, lighter weight and smaller sizes of external fixators, less painful postoperative manipulations and faster joint recovery. Our patients will also benefit from early robotised physical therapy, simpler postoperative care of wires or half-pins with novel dressings for better personal hygiene, and from the creation of psychological training programs that can strengthen their self-motivation to recovery during a long and difficult treatment.

Conclusion

Control and guidance of the bone shape-forming process remain the basis of the Ilizarov method and its evolution. Following the Ilizarov principles and integrating them with innovative solutions for management of bone pathologies ensures their maintenance and harmonic use in the future. Further research in limb reconstruction and tissue regeneration will undoubtedly improve efficiency in clinical practice.

Conflict of interest None.

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