



Impact of the Ilizarov apparatus on external fixation: Current modifications of the 75-year-old orthopedic tool

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Abstract

The Ilizarov apparatus was designed by its author 75 years ago and addresses a wide range of orthopedic conditions. Its classical assemblies are still self-sufficient and versatile. However, certain clinical scenarios require a more specialized approach, and some groups of patients may benefit from customized Ilizarov constructs. Engineering science has designed various external fixators for orthopedic purposes, and some of those have become the gold standard for specific clinical tasks. We aimed to determine the current state and novel modifications of specialized external fixators for specific clinical situations which are based on the principles of the Ilizarov method. They are half-pin-based fixators for temporal fracture fixation, ring or hybrid devices for gradual deformity correction, and compression-distraction devices tailored for definite limb segments. Gradual correction of deformities can be achieved with external hexapods incorporating universal reduction units. Alternatively, external fixators with special connection mechanisms are able to provide independent movement of the rings in six degrees of freedom. Deformity correction can be performed with combined or sequential use of external and internal fixators. Special devices were developed for moving the split fragment for revascularization of the tibia. The units of external frames on the foot were modified to consider its complex anatomy and the clinical needs ranging from correction of multi-plane deformities, joint arthrodesis to distraction arthroplasty. Mini-fixators are compact external fixators for small bones of the hand and foot. The varieties of external fixators based on the Ilizarov principles have been designed to fulfill an ultimate goal of improving treatment outcomes.

Key Words: Ilizarov apparatus; External fixation; Distraction osteogenesis; Bone lengthening; Bone deformity; Hexapod frame; Mini-fixator

Core Tip: The Ilizarov apparatus was designed 75 years ago and addresses a wide range of orthopedic conditions. Its classical assemblies are still self-sufficient. However, certain clinical scenarios require a more specialized approach, and some groups of patients benefit from customized or modified Ilizarov constructs. They are half-pin hexapod or hybrid fixators for gradual deformity correction, and compression-distraction fixators for definite limb segments. Special devices were developed for moving the split fragment for tibial revascularization. The external frames for the foot and hand were modified to consider their complex anatomy and implement lengthening, correction of multi-plane deformities, and web-space soft-tissue growing.

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INTRODUCTION

The Ilizarov apparatus or the Ilizarov circular (ring) external fixator is almost 75 years old and is still one of the most popular tools currently employed by orthopedic surgeons for bone reconstruction worldwide[1,2]. It was designed by its author, Gavriil Ilizarov, in 1951 and was claimed for patenting in Russia in June 1952 (Figure 1). The first presentation of the outcomes in 43 patients treated in 1951-1953 with the original version of the apparatus for several orthopedic conditions including bone lengthening, nonunion and delayed consolidation was published in the collected works on medical studies of the Kurgan regional scientific medical society in 1954 (Figure 2).

Since then, the design of the Ilizarov fixator has changed greatly as the solutions of orthopedic problems required introduction of new elements, units, hinges, connection plates and threaded parts. Currently, it is a set of stainless-steel parts (rings, half-rings, wires, posts, threaded rods, connection plates and other elements of different sizes) that can be assembled into personalized constructs to solve specific orthopedic tasks. Its established assemblies and customized frames are able to address a wide range of orthopedic conditions, the main of which are temporary and definite fixation of fractures, bone lengthening and deformity correction, management of bone defect and nonunion, both post-traumatic and infected[3].

The key biological phenomenon of the Ilizarov method technical solutions for bone healing and reconstruction is the generation of viable new bone tissue *via* distraction osteogenesis triggered by tension stress in the external frame applied to a limb that yields high union rates and the functional weight-bearing during the treatment process[3,4].

Professor Ilizarov GA not only developed his circular fixator for new bone formation, but also was the first to conduct research on distraction osteogenesis with his team and publish the findings both in the domestic and international journals[5-7]. In the 1980s, the phenomenon of distraction osteogenesis was deeply investigated in experimental and radiographic clinical studies and was estimated by the USSR science as a discovery on the law of tension stress[7].

The classical Ilizarov techniques and frame assemblies for different pathological conditions are still self-sufficient and versatile. However, certain clinical scenarios require a more specialized approach[8]. Some groups of patients may benefit from customized Ilizarov constructs, especially in such conditions as bone deformities in the foot, hand, pelvis and lower/upper limbs in several systemic or congenital diseases such as osteogenesis imperfecta, achondroplasia or tibial hemimelia.

It should be clearly distinguished that the Ilizarov apparatus is a tool of the techniques applied to bone and soft tissues based on the Ilizarov principles of distraction and/or compression discovered by this outstanding orthopedic surgeon and his team in the 1970s and 1980s such as the rules of osteotomy (corticotomy) performance, distraction rates for large and small bone generation, weight-bearing and fixation rigidity. These principles are implemented by a variety of other devices and combined modifications that evolved thereafter[1,3,8].

We aimed to study the current state and novel modifications in external fixation for specific clinical situations which are based on the principles of the Ilizarov method.

LITERATURE SEARCH

We performed a comprehensive search in the available Internet platforms (PubMed, Scopus) that index medical studies to identify recent clinical studies and literature reviews on the advances of external fixation techniques and the Ilizarov method modifications using the terms “Ilizarov method”, “external fixation”, “modifications of the Ilizarov method”, “novel external fixation devices”, “bone lengthening”, “deformity correction”, “bone nonunion and defects”, “mini-fixators”, “fracture repair”, “joint arthrodesis” published within the period from 2020 throughout 2024. Literature reviews and clinical full-text studies in English and Russian (including case series or reports) were screened and those that reported on advances and modifications of external fixation techniques for specific clinical scenarios (limb

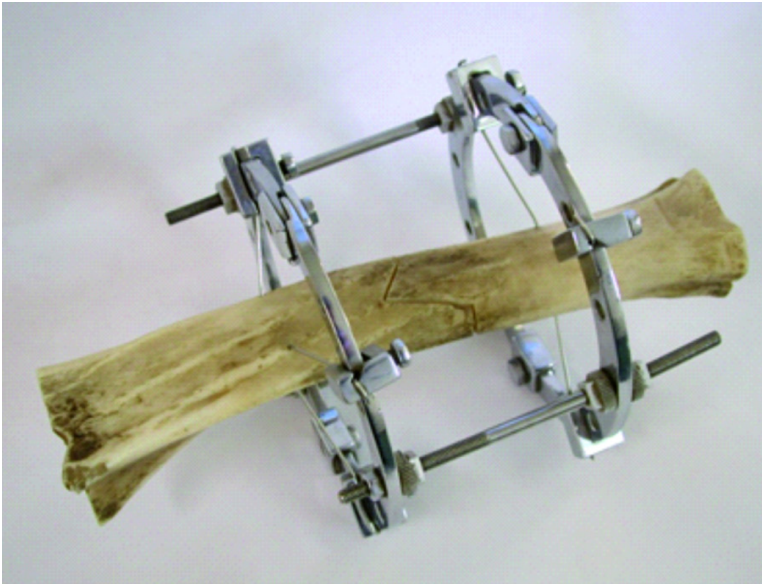


Figure 1 The first version of the Ilizarov apparatus (courtesy of the Kurgan Ilizarov Center Museum).

lengthening, deformity correction, nonunion/ defects, joint arthrodesis, foot and hand pathology) or customized Ilizarov frame application were chosen. Thirty-four studies that met the criteria were included (Table 1)[8-41]. Experimental studies and literature in other languages were excluded.

SPECIALIZED APPROACHES IN EXTERNAL FIXATION AND ITS CURRENT MODIFICATIONS FOR SPECIFIC PURPOSES

Surgical techniques, external fixator systems, and materials for managing bone pathology have made a continuous advance[3]. The benefits of traditional external fixation have been enhanced in recent years with innovative configurations, ring and pin modifications such as carbon rings, double telescopic rods for lengthening and bioactive pin coating aimed at frame weight and infection rate reduction or bone healing acceleration[9,42]. Chinese and Indian scholars are among the leading Ilizarov philosophy followers[9-11]. They developed some special treatment methods, made many modifications to the Ilizarov external fixator, developed a number of external fixators for special purposes and published a great number of papers in the international journals being the most active researchers and users of the Ilizarov method and its modifications nowadays according to the published studies[9]. It is noteworthy, that external fixation used in China differs from the one in Russia and the Western world, especially in the instruments and techniques that are aimed to use minimum components for maximal efficiency[9].

Bone lengthening and deformity correction

Currently, the original techniques of bone lengthening and deformity correction have been utilized alongside with 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[1,3]. Engineering science has designed various external fixators for orthopedic purposes, and some of those have become the gold standard for specific clinical tasks. The introduction of the Taylor spatial frame (TSF) in 1997 was the most remarkable change in external fixation[43]. This hexapod fixator based on the use of software is a more complex device but gained the world market of hexapod fixators that many companies develop. Its new version, the Smart TSF, was introduced in Baltimore in 2021[12]. The introduction of intramedullary lengthening nails at the beginning of the 2000s and their wide dissemination that started approximately in 2013 made external fixation more applicable for certain more complex indications[3,13]. External fixators still play an important role in tibial lengthening, especially in young children with open physis and small bone diameter that prevent insertion of a rigid nail. One of the recent advancements of internal lengthening enables to perform internal lengthening both intramedullary and extramedullary. Extramedullary internal lengthening is a new technique and was described for fibular hemimelia that uses an implantable nail attached to the bone like an internal-external fixator[14].

Though the Ilizarov apparatus is the most commonly used fixator to address deformities and limb lengthening, gradual correction of deformities can be achieved with number of modified techniques and modified fixators[9,15-17,44]. Thus, the strategy of intramedullary flexible nailing combined with external fixation ensured a reduction in external fixation time and high accuracy of alignment. Intramedullary nails are left in situ and prevent deformity recurrence in dysplastic or abnormal bone zones[17,44]. External hexapods incorporate universal reduction units to perform correction and lengthening[43]. The newer six-axis devices such as the Ortho-SUV can greatly aid in deformity correction[18]. External hexapods are universal reduction devices that can provide any type of movement but independent movements

Table 1 Summary of external fixation modifications discussed in the recent literature

Limb lengthening and deformity correction	Bone defects and nonunion	Foot and ankle pathology	Small bone foot and hand pathology	Fracture repair	Rare application
Flexible intramedullary nailing + external fixation in children with metabolic bone disorders, skeletal dysplasias with compromised bone tissue development, femoral deficiency and fibular hemimelia, polyostotic fibrous dysplasia	Novel technique of three-ring Ilizarov fixator frame in gap non-union of tibia	Universal external configuration for correction of foot and ankle deformities	Enlargement of the great toe by applying transverse distraction with a mini-fixator of the original type for future finger transposition	Definitive circular external fixation for acute tibial fracture-related infection	Lengthening after limb replantation
Intramedullary telescopic nailing used in combination with a reduced Ilizarov frame in children with osteogenesis imperfecta	Post-traumatic infected non-union of the humerus managed by hybrid ring fixators	Calcaneal lengthening using a specialized Ilizarov external fixator assembly in posttraumatic shortening	Metacarpal lengthening for thumb reconstruction with special mini-ring fixators	Closed reduction and Ilizarov/hybrid fixator application for complex proximal tibia fractures	Modified hip reconstruction surgery
External fixation and extramedullary intramedullary nailing for lengthening and deformity correction in fibular hemimelia	Internal cable as a guide to transport the fragment with a unilateral fixator	Transverse tibia distraction for the treatment of diabetic foot ulcer complicated with chronic osteomyelitis	First web-space plasty with the Ilizarov mini-fixator for functional and esthetic improvement	Treatment of intra-articular calcaneal fractures with Polish modification of the Ilizarov external fixator	
Bone lengthening and deformity correction with Smart Taylor spatial frame	Hexapod system with a computer program for combined soft-tissue and osseous defects	Technique of hindfoot reconstruction in chronic calcaneal osteomyelitis	Ilizarov mini-fixator for the purpose of interdigital widening and elongation of the flap		
Bone lengthening with motorized intramedullary nail in posttraumatic length discrepancies	Hybrid techniques (external fixators with internal implants)	Use of tibial bone transport for treatment of massively infected hindfoot defects to salvage it	Treatment of chronic Monteggia fracture-dislocations in children with Ilizarov mini-fixator		
Modifications on Ilizarov fixation for flexed knee deformity and double telescope rods design for limb lengthening	Integrating three-dimensional-printed customized guides with hemicorticotomy bone transport	Closed arthrodesis in infected neuropathic ankles using Ilizarov ring fixation			
Minimally invasive osteotomy and simple circular fixation for adolescent late-onset tibia vara	Transverse tibial transport in thromboangiitis obliterans and mini-transverse tibial transport	Distraction arthroplasty in the treatment of moderate-to-severe ankle arthritis			
Personalized assemblies constructed from the Ilizarov apparatus sets for complex congenital deformities					
Management of complex knee deformity using Ortho-SUV					

are impossible because of hexapod construction. All reductional maneuvers are made by simultaneous compression/distraction forces in all struts of the hexapod. Alternatively, external fixators with special connection mechanisms are able to provide independent movements of the rings in six degrees of freedom[45-47]. Devices of this type have advantage in gradual reduction and treatment of nonunion by compression-distraction method due to their ability to produce separate movements of bone fragments in any direction (Figure 3)[46,47]. Another advantage of such devices is unnecessary software in the treatment process.

It is noteworthy to stress that complex deformities involving congenital conditions and several joints are better addressed with specific personalized assemblies constructed from the Ilizarov apparatus sets like in the study that presented eight pediatric cases of previously non-ambulatory children in which deformities were corrected gradually with construction of individual Ilizarov frames and additional soft-tissue releases in three knees[16]. Despite that minor recurrence of deformity is expected in such cases, all patients became ambulatory aided with braces and supports.

Intramedullary telescopic nailing used in combination with a reduced Ilizarov frame in children with osteogenesis imperfecta was another modification for such specific cases of deformity correction in the femur and tibia in 12 children in the age up to 13 years[19]. Reduced external fixation enabled to overcome the limitations of telescopic systems to provide longitudinal and rotational stability. Children were able to walk weight-bearing in the postoperative period because of external fixation that lasted 35.8 ± 13.2 days in average. Telescopic gain related to spontaneous growth assessed at one-year follow-up control was 13.7 mm in the tibia and 15.9 mm in the femur. There were no deep infection or neurologic complications. Gait and joint problems resolved after one year.

Новый принцип остеосинтеза с применением перекрещивающихся спиц и колец

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Для целей репозиции костей, их сращения и удлинения конечностей нами был сконструирован аппарат, применение которого было апробировано решением Министерства здравоохранения СССР от 14 сентября 1953 года.

Конструкция разработанного аппарата позволяет осуществлять:

- закрытую репозицию и фиксацию отломков костей при переломах;
- взаимную фиксацию бедренной и большеберцовой костей после операции резекции и артротомии коленного сустава;
- остеосинтез при ложных суставах;
- удлинение конечности.

Аппаратом обеспечивается прочная фиксация отломков без наложения гипсовых повязок и без выключения функции смежных суставов.

Отсутствие необходимости фиксации суставов полностью исключает причину возникновения контрактур, позволяет рано начать функциональное лечение без риска смещения отломков. Больные становятся мобильными уже с первых дней лечения.

Применение аппарата дает возможность осуществлять дозированное постепенное растяжение сегмента конечности с одновременной фиксацией фрагментов кости при оперативном удлинении конечности без приковывания больного к постели.

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Принцип репозиции и фиксации отломков кости указанным аппаратом заключается в следующем: через каждый костный фрагмент вблизи места перелома (на расстоянии 3—6 см.) проводится в плоскости поперечного сечения по две взаимоперекрещивающиеся спицы. Каждая пара перекрещивающихся спиц фиксируется в натянутом виде к собранному из двух половинок металлическому кольцу или сегментам его в виде дуг. Поскольку взаимный перекрест спиц не дает возможности смещаться отломку по отношению к кольцу, создается полная возможность взаимным перемещением колец под контролем рентгенооскопии закрытым путем сопоставить отломки в правильном положении, после чего с помощью 3—4 металлических стержней с винтовой нарезкой на концах и гаек достигается прочная взаимная фиксация колец, а следовательно, и отломков.

Общий вид аппарата и принцип его действия представлен на приводимых фотографиях (рис. № 1 и № 2).

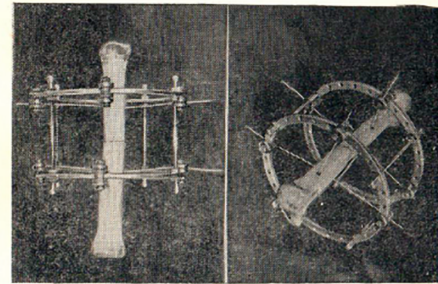


Рис. № 1 и № 2. Схема аппарата.

Методика проведения спиц через отломки ничем не отличается от техники проведения при осуществлении скелетного вытяжения. К отломкам спицы подводятся путем вкола, затем они дрелью проводятся через кость, после чего внутренние их концы выводятся наружу. От-

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Figure 2 The first page of the report “New principles of osteosynthesis employing crossed wires and rings” published by Ilizarov GA in 1954 (courtesy of the Kurgan Ilizarov Center scientific library).

Thus, hybrid techniques (external fixation + intramedullary nailing) have become suitable in difficult scenarios (big lengthening magnitude or deficient bone) and may have sequential or simultaneous protocols[3,17].

Bone defects and nonunion

The Ilizarov bone transport is the most used technique for bone defect management, especially in the tibia[48]. Today, newer methods of bone transport have been described using a hexapod system with a computer program to move the ring fixator[20], or unilateral fixation and an internal cable as a guide to transport the fragment[48]. Multiple osteotomy techniques, such as tandem, trifocal, tetra-focal and penta-focal transport techniques, were reported in the literature with successful reduction of the transport time[49]. However, monorail systems for infected and non-infected nonunion of the tibia had similar functional results as the Ilizarov fixator but lower external fixation time[50].

Hybrid techniques may combine the advantages of external fixators with internal implants. They allow early removal of the external fixator after the transport phase is over, thus shortening the external fixation time by several folds[21,22]. Also, internal implants can maintain bony alignment and stability, protect the distraction callus and the docking site from fracture and deformity. Hybrid techniques may be sequential internal fixation after bone transport or simultaneous internal fixation along with bone transport.

The Ilizarov bone transport, based on the principle of distraction osteogenesis, has demonstrated remarkable success in treating chronic osteomyelitis with associated bone loss, achieving infection control rates of up to 95% in some series[23]. Modified techniques such as hemicorticotomy for bone transport have been proposed in recent years. This approach involves partial osteotomy and transport of a vascularized bone flap rather than complete segmental resection. Three-dimensional (3D)-printed customized guides offer the potential for a more precise osteotomy site, optimized frame configuration, and improved overall surgical accuracy[23]. Another modified technique for treatment of bone defects is cable-assisted bone transport that was compared with the established Ilizarov bone transport[48]. It allows bone transport for defects greater than 10 cm in the presence of compromised soft tissues, while the patient continues to weight-bear as tolerated. The transport strut is designed to provide a stable and efficient motor for the cable performing the bone transport. However, the technique is complex technically. If required, customized Ilizarov external frames can be designed for special conditions, as in a case report after a failed treatment of infected nonunion in an obese patient[51].

Revascularization of the tibia and diabetic foot

Transverse tibia transport, once used by the Ilizarov team, was further developed by Chinese orthopedic surgeons to use it for thromboangiitis obliterans and diabetic foot with remarkable treatment outcomes[24,25]. Various fixators and instruments for transverse tibia transport were invented and applied in recent years[9]. Their main features are com-



Figure 3 Compression-distraction apparatus for external fixation featuring six degrees of freedom[47]. Citation: Matsukatov FA. Compression-distraction apparatus for external fixation and method of closed reduction of bone and bone fragments. Euroasian patent register. <https://old.eapo.org/en/patents/reestr/patent.php?id=45163>. Copyright© The Author(s) 2023 (Supplementary material).

pactness and simplification of transverse bone transport process by turning only one mechanism.

Foot and ankle applications

The units of external frames on the foot were modified to consider its complex anatomy and the clinical needs ranging from correction of multi-plane deformities, lengthening, joint arthrodesis or distraction arthroplasty[9,26,52]. Ilizarov or hexapod circular fixators are also utilized for recurrent clubfoot according to surgeon's preference. Fixator configurations, acute and gradual correction techniques, and case examples have been well described[52,53]. The construction of classical Ilizarov fixator for foot and ankle surgery has been improved for better patient's comfort by designing pads for floor contact or a modular U-shaped foot frame and forefoot frame modifications[9]. The transverse tibia distraction was found effective for the treatment of diabetic foot ulcer complicated by chronic osteomyelitis[27]. Calcaneal lengthening using a specialized Ilizarov external fixator assembly was a technique to restore the length and height of the calcaneus in three cases of posttraumatic shortening[26]. Individual osteotomies and personalized Ilizarov frames were constructed to fix the tibia, calcaneus, talus, and forefoot and start distraction after a latency period of 7 days that achieved satisfactory foot function[26]. A modified technique of hindfoot reconstruction in chronic calcaneal osteomyelitis was very effective to recover the shape of the segment[28]. The new surgical procedure was reported with the use of the Ilizarov apparatus for partial or total calcaneal osteomyelitis that was aimed to preserve the hindfoot[29].

Ankle arthrodesis and distraction arthroplasty

Ankle fusion with the Ilizarov fixator has become an established practice as the rates of success are very high[54,55]. It is seen as a salvage procedure in septic cases and previous failures with internal techniques[55]. Ankle arthrodesis was done in a closed manner using the Ilizarov ring fixator, without surgical preparation of the joint surfaces by cartilaginous debridement, in Charcot joint, Charcot-Maire-Tooth disease, and post-traumatic arthritis and showed comparable results to open methods[30,56]. An interesting practice was shown by a study that demonstrated a special fixator assembly that achieved high clinical efficacy in distraction arthroplasty for treating moderate-to-severe ankle arthritis in a young and elderly people groups at a rather long follow-up proven with visual analysis scale and American Orthopaedic Foot and

Ankle Society ankle-hindfoot scores[31].

External fixation for upper limb pathology

The use of external fixators in the upper limb remains more limited than their application in the lower limbs due to the spread of new systems of plates and screws and intramedullary lengthening nails that are more comfortable for patients [57]. The indications about when to use external fixation remain open. However, monolateral or circular frames for humeral lengthening and correction of forearm deformities in multiple hereditary exostoses disease or radial longitudinal deficiency sequelae is a common practice[58]. Monoaxial fixators retain a prominent role for skeletal lengthening in the upper limb, including an Orthofix® monolateral fixator[58,59]. However, multiaxial external fixators are used efficiently for humeral lengthening and angular and rotational deformity correction. Circular fixators may be preferred in cases of severe deformity. Thus, hexapod systems are likely to represent the future for the correction of multiplanar forearm deformities[59]. Lengthening of the humeri improves the overall proportion in achondroplasia[59,60]. It is supposed that the role of external fixators could be outclassed by motorized intramedullary nails, especially for humeral lengthening [57].

Mini-fixators

Mini-fixators are compact external fixators for small bones of the hand and foot. The one that was designed in the 1980s by the Ilizarov team[61] has been still used for finger, toe, metacarpal and metatarsal bone and soft-tissue problems[32,62-65]. Enlargement of the great toe by applying transverse distraction with a mini-fixator of the original type for future finger transposition was presented as a modified technology of transverse distraction implemented with the Ilizarov technique[33]. Multiple tissues of the great toe regenerated, including bone, nail, and plantar skin, and more tissues were preserved after toe-to-hand transfer. This is a novel method to enlarge the donor site for finger reconstruction. Mini-ring external fixators were designed in several sizes for specific tasks such as metacarpal lengthening for thumb reconstruction [34]. Such device was used with a groin flap for single-stage lengthening of the injured thumb with bone exposure. The first web-space plasty was achievable with the Ilizarov mini-fixator to improve esthetics and function in complex injuries of the hand[35]. The Ilizarov mini-fixator was found less invasive than plate fixation for the treatment of chronic Monteggia fracture-dislocations in children[36].

Fracture repair

Nowadays, the dominant external fixation technique used for bone injuries is application of monolateral fixators for temporary stabilization in polytrauma and soft tissue management in open fractures or compromised skin conditions followed by definite fixation. Among most common external fixators are a unilateral spanning external fixator for tibial plateau fractures[66] and a delta-frame for comminuted pilon fractures[67]. However, external fixation as a definitive treatment for fractures also remains popular, especially for tibial plateau and pilon fractures[37-39,67,68]. A hybrid type of half-pin and wire external fixator is used for these fractures. The common construct of the external fixator for pilon fractures is generally the same as the Ilizarov-type external fixator[66].

The main merit of fracture treatment using external fixators is their technical capabilities. Unilateral external fixators can only temporarily stabilize fragments, maintaining the axis, length, and rotation of the segment. They do not allow for reduction. On the other hand, ring fixation devices such as the Ilizarov fixator are capable of performing reduction maneuvers by moving the olive wires or rings using hinges[38,39]. The most modern and promising type of a ring fixator for shaft fractures would be the one that allows for six degrees of freedom (Figure 3), as it is time-saving and causes less trauma during reduction[45,47]. Reduction of spiral fractures with this type of fixator was more accurate and the fixation term with the frame on was much shorter than the one performed with the Ilizarov fixator[45].

Fixation of intra-articular fractures remains a weak point of the Ilizarov fixator and its modifications, due to the difficulty in achieving closed anatomical reduction[39]. On the other hand, hinged external fixators are essential for injuries to the elbow, such as the terrible triad[69]. They may be combined with open reduction and internal fixation (Figure 4).

Definitive circular external fixation for acute tibial fracture-related infection with either the Ilizarov or hexapod fixators was efficient in a comparative study that showed their high union rate and infection control. Nevertheless, the hexapod fixation resulted in less residual coronal translation deformity and better callus quality[37]. On the other hand, a comparative study of the time to frame removal for tibia fractures treated with hexapod and Ilizarov circular frames found that there was a significant difference between Ilizarov and hexapod frames in favor of the Ilizarov fixator, especially in metaphyseal fractures the proportion of which was larger in that study[70]. Another study investigated the utility and outcomes of the Ilizarov circular external fixation in the management of failed internal fixation of tibial fractures. It yielded limb salvage in complex infected and non-infected cases with a high union rate (100%) and minimal major complications[71].

A remarkable experience was presented in the use of microsurgery combined with the Ilizarov technique in limb amputation[40]. Limb salvage and reconstruction was performed after replantation with the use of internal and external step-by-step combined fixation, one-stage shortening and two-stage limb lengthening in 44 patients with mostly good functional results.

The minimally invasive modified Ilizarov hip reconstruction surgery was proposed as an alternative for hip replacement surgery in young population with developmental dysplasia of the hip, congenital hip deformity or femur head necrosis with satisfactory clinical outcomes[41]. There were few complications compared to the conventional pelvis support surgery.

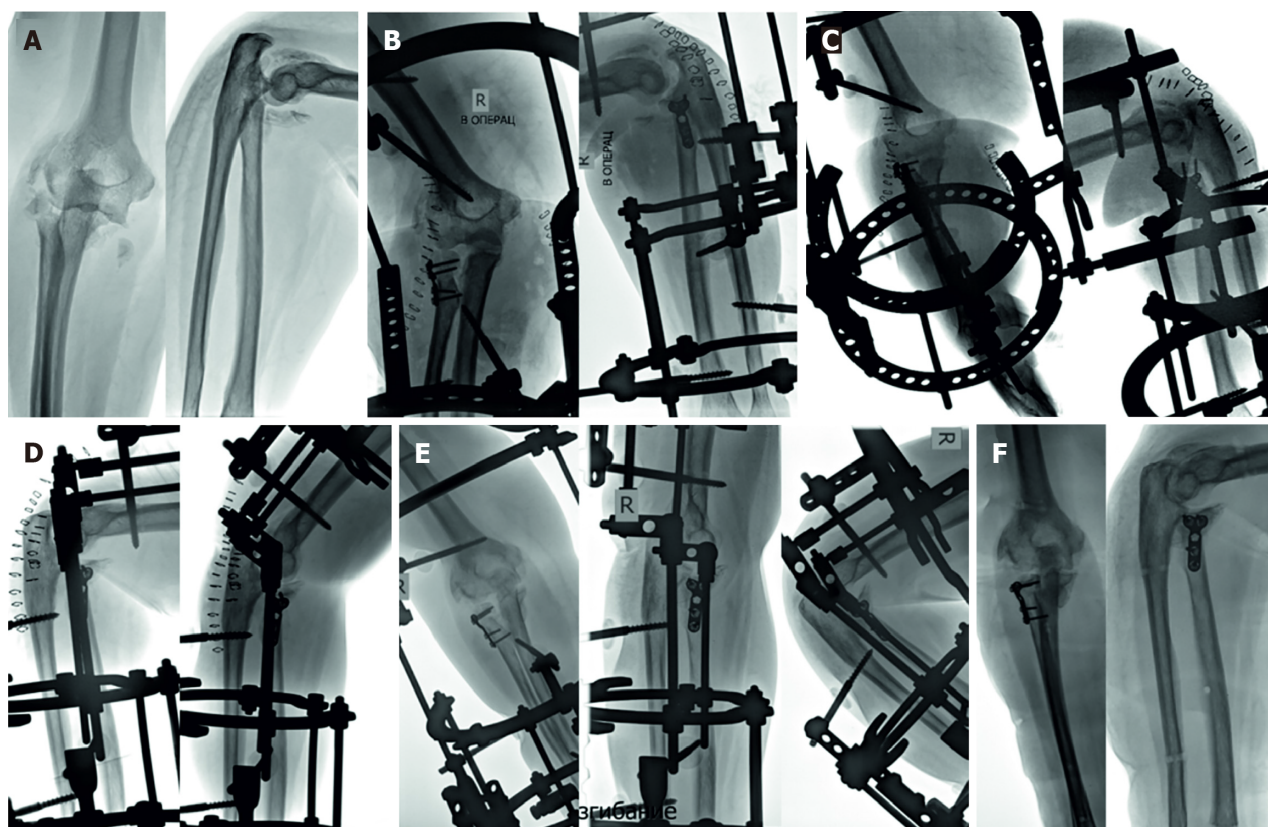


Figure 4 Customized external fixation with the Ilizarov frame combined with open reduction and internal fixation after failed closed reduction and cast immobilization of the forearm injury for 1.5 months in a 66-year-old patient. A: Terrible triad: Mal-alignment of the right forearm with posterolateral dislocation, radial head nonunion, coronoid process malunion, heterotopic ossification; B: Open reduction and internal fixation of the radial head and fixation of the elbow joint with the Ilizarov fixator; C: Gradual reduction of the forearm bones for 8 days; D: Placement of hinges in the axis of the elbow joint upon completion of reduction for active range of motion (ROM); E: Due to obvious ROM limitation, a distraction rod system was attached on the anterior part of the Ilizarov fixator and active ROM continued for 12 days to restore the function of the elbow joint; F: Outcome at 2 months after surgery upon removal of the Ilizarov fixator, bone union and functional recovery.

Summary

Thus, the evolution of external fixation for bone pathology has made a long way and has not stopped yet[72,73]. However, a number of biomechanically proven and clinically approved external fixators, modifications of their configurations and techniques have established their role in the contemporary orthopedics in the past decades. Advancement of newer robotic technologies that could motorize and control the process of distraction osteogenesis and 3D accuracy of reduction would be a great step forward in future, if they are commercially available[72].

Until now, the Ilizarov fixator remains a versatile and affordable orthopedic instrument. It can be fabricated at the national level and most of its components are reusable what is important for the developing countries[74,75]. The collection of recent reports of its application to be considered for reviewing is enormous according to the PubMed database diagram that indicates that within the period of 2020 throughout 2024 more than 130 articles related to the Ilizarov method have been published each year in the prominent orthopedic journals worldwide.

Data relevant to Ilizarov technologies from 1994 to 2023 were collected, studied and presented early in 2025[76]. The methodology used identified that the peak of publications occurred in 2020, with 141 articles published. There are a number of previous reviews on the topic of the Ilizarov method and external fixation advances[1-3,76]. They discuss some history of the method and its basic principles[1], advances in bone lengthening[3], international spread of the method on the basis of publications[2,76], and innovations of in the field made by Chinese researchers[9]. Advancements in the external fixation focus on several key areas that include optimization of Ilizarov external fixator assemblies or innovative designs that could increase precision of manipulations with the fixator, reduce the risk of complications, and improve its use by both patients and surgeons. Personalized treatment plans and patient comfort in every case remain the main concerns in the customized approach and external fixator choice. Our mini-review is aimed to focus on recent specific applications and modifications in the Ilizarov method for certain clinical scenarios that require a more specialized approach that are summarized in Table 1[8-41].

CONCLUSION

The classical Ilizarov ring fixator is still the tool and the Ilizarov principles are the method of choice for complex

reconstruction of the injured or deformed bone in adults and in pediatric population. It is crucial to possess a precise comprehension of the Ilizarov principles in order to effectively utilize and modify this method and fixation system. A great variety of external, hybrid and internal fixators based on the Ilizarov principles have been designed lately to generate new bone tissue or repair it and fulfill an ultimate goal of improving treatment outcomes in orthopedic injuries and diseases. This fact reflects the impact of the Ilizarov philosophy of bone regeneration and repair on the contemporary orthopedic clinical science and practice. In 2026, the Ilizarov apparatus will be 75 years old. Millions of patients in the world are thankful to this old orthopedic tool that has improved their quality of life or salvage their lives while orthopedic surgeons worldwide praise this invention for its great utility.

FOOTNOTES

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