Application of Mini Ilizarov for the Management of Hand Injuries and Deformities

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INTRODUCTION

The Mini Ilizarov is an external fixator that is useful for treating various hand injuries. Its modern development began in the 1990s at the Ilizarov Institute in Russia and has several benefits. It is used for fracture management and can also be used for releasing joint contractures, bone lengthening, and correcting congenital malformations. It is favored for its ease of use, small size, and strong holding power. The device can be customized for different types of fractures, deformities, and soft tissue damage, and can be used on multiple bones simultaneously, reducing the number of interventions and treatment time. Despite its popularity globally and among hand surgeons, it is not widely used in Pakistan. This review aims to encourage young surgeons to use this technique and to inspire further clinical applications in the future.

Keywords: Mini Ilizarov, Ilizarov, Hand Injury, Hand deformity correction.

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HISTORICAL ASPECTS

The Ilizarov apparatus, a revolutionary breakthrough in external fixation, was first developed in the 1950s. However, it was not until 1966 that G.A. Ilizarov created the first external apparatus specifically for the hand. Over the years, the mini-fixator underwent various improvements. In 1983, G.A. Ilizarov proposed a compression-distraction apparatus to increase the longitudinal dimensions of hand pathologies, such as post-traumatic finger stumps, ectrodactyly, and brachydactyly. In the following years, the indications for the device were expanded to include its use in different surgical conditions. In 1984, it was used to treat hypoplasia and congenital absence of fingers. In 1986, it was used to manage flexion contractures of the hand, and in 1987, it was used for separate lengthening of the bones of the hand. In 1989, Ilizarov registered a patent for the "Method for the treatment of syndactyly". In 1991, wires were fixed on a common bar on each side of the digit with rods on hinged connections between the bars. Since 1998, cantilever wires with bends have been fixed on rods, which reduces the weight and dimensions of the apparatus.[1,2]

BIOMECHANICAL PROPERTIES

Stiffness is a key characteristic to measure for external fixators because the device must be able to withstand bending forces and maintain alignment after the removal of stress, without deforming or destroying the apparatus. The ideal fixator should have enough stiffness to heal the fracture without impeding movement, even if early motion is performed. However, it is currently unclear what level of stiffness is required for effective bone healing. Factors such as the thickness of the pins, the number of pins used, and the location of the fracture all affect the stiffness of the fixator. Increasing the

diameter of the pin increases the rigidity of the fixator by the fourth power but the thickness of the pin should be less than 1/3 of the diameter of the bone which it is inserted into. The reason behind this is the increased risk of iatrogenic fractures. A 2.0 mm pin may be too thick in adults with small hands and children as the width of the middle phalanx in the coronal plane of the diaphysis in adults is less than 10 mm and the width of the sagittal plane of the base is less than 7 mm. Regarding the number of pins that are adequate for fixation, A study compared the effectiveness of using 6 pins versus 4 pins for fixation and found that the 4-pin group had lower resistance to axial load and bending, but there was no significant difference in resistance to torsion between the two groups. Additionally, the fixation stiffness required for bone healing can vary depending on factors such as the location of the fracture, blood supply, load on the affected limb, and bone quality. In clinical situations, various factors such as bone fragment contact, scars, callus formation at the fracture site, and soft tissue tension around the fracture can impact the amount of load placed on the external fixator. Studies have shown that metacarpals consolidate at a faster rate compared to phalanges, taking only half the time to reach healing. This difference in healing rate may be due to the increased vascularity in the metacarpals, which is provided by the surrounding muscles, compared to the phalanges. In cases where bone lengthening is required, the mini Ilizarov is still stiff enough to follow the principle of gradual distraction through an area of healing fracture callus, as described by Ilizarov's "law of tension stress" which induces the formation of new bone in the distracted gap.[3]

INDICATIONS AND CONTRAINDICATIONS

The Ilizarov mini fixator is a versatile device that can be used to treat a wide range of hand and finger conditions, including fractures, non-unions, malunions, and congenital anomalies. It is particularly useful in cases where lengthening is required such as in post-traumatic stumps, in hypoplastic and congenital conditions, as it can achieve this through the use of gradual distraction and the formation of new bone in the distracted gap. It can also be used for expanding the skin in conditions such as syndactyly, and hand contractures. However, it is not suitable for use in certain conditions such as widespread pyoderma or vascular conditions, and patient compliance is also an important factor in determining whether or not to use the device.[4]

DESIGN AND CONFIGURATION

The mini-Ilizarov fixator components and surgical instruments are both uncomplicated and inexpensive. While the conventional axial system is straightforward to operate, it has limitations that hinder its adaptability. The mini Ilizarov procedure involves the insertion of simple, cross-positioned K wires that are perpendicular to the segment axis and on the same plane. This method provides stronger fixation, resolving the issue of fragment size. These Kirschner wires are appropriate for both pediatric and adult hand bones and feature three sharpened end facets that facilitate bone penetration. The Ilizarov mini-fixator typically consists of three 1.5mm stainless steel pins connected by a 3mm diameter rod. The pins are attached to slotted washers and secured with a fixation nut. The device also includes a bolt with a perpendicular threaded rod that passes through an axial hole and is held in place with a fixation nut. By turning the nuts on either side of the bolt, distraction or compression along the threaded rod can be achieved. Depending on the treatment indication, the configuration can be altered, such as using a larger rod (4mm diameter) for the treatment of hand contractures. There are several variations of the mini Ilizarov, including the LAKI fixator, which features two or more "V" shaped clamps that are positioned perpendicular to the bone's axis, allowing for the insertion of K wires. Typically, K wires ranging from 1.2 to 1.6mm in diameter are used and can be crossed at an angle of 60-120°. The clamps are joined by a standard threaded bar.[4-6]

SURGICAL TECHNIQUE

To begin the procedure, two or three k wires with the desired thickness are initially placed in a proximal location. These wires are drilled at a 90° angle to each other on the dorsolateral part of the bone. It's important that the same set of wires are parallel to one another. The wires should go through both cortices, but their exit from the bone should not extend more than 1 or 2 millimeters beyond the distal cortex. It's important to safeguard the "tendons and ligaments" during the procedure, which can be checked by passively moving the affected finger. If the wire has penetrated the ligament, there will be a noticeable resistance felt during the finger's movement. Afterward, the wires are bent to fit the

support unit, which should be positioned approximately 3 or 4 millimeters away from the skin. The wires are then secured to the support unit using slotted washers. Finally, the wires are fixed to the proximal fixation unit in a parallel orientation to the bone. To continue the procedure, a distraction rod is inserted through the proximal wire fixation unit. The distal end of the bone is then drilled and fixed in the same manner as the proximal end, before being secured to the distal wire fixation unit by bending the wire. It's important to ensure that the locking screws of both the proximal and distal units are positioned at a 90° angle to each other.

The flat surface of the rod should be perpendicular to the locking screw of the bolt in the distal support, with the screw locking the distal assembly in place on the flat surface. The locking screw of the proximal support should be firmly tightened to the threaded rod using the bolt. If an osteotomy is required, the locking screw of the distal part must be released. A dorsolateral skin incision is typically used for percutaneous osteotomy to minimize soft tissue damage. Once compression has been achieved and confirmed using a c-arm, the distal unit is locked again.[6-8]

TREATMENT OF HAND FRACTURES

As previously mentioned, the mini fixator is recommended for treating closed and open fractures of the metacarpals and phalanges, as well as intra-articular fractures involving small bone fragments in these areas. The wires are placed at an angle to the bone fragment fixation sites to account for the angular displacement. However, once connected to the core, the wires will become parallel and reposition the hand bone's axis. In cases of oblique fractures of the Phalanx, the wires are inserted either parallel or at a 45° angle to the palm plane, and the bending angle and external fixator should be adjusted to align with the central force line. In cases where the bone fragment requiring fixation is small, fewer pins may be used, and a configuration of two pins fixed per unit can be employed. For comminuted or wedge-shaped fractures, fracture reduction should be performed before fixing the fracture fragments with wires, simplifying the fracture structure. The fixed wire is then bent and secured to the external fixator, providing both support for the reduction and aiding in stabilizing the fracture. For traumatic amputations of the fingers, the initial stage of treatment involves the restoration of all soft tissues through the use of microsurgical techniques. In the final stage, osteosynthesis is performed using a mini-fixator, which offers strong support for the affected finger(s) and promotes circulation, ultimately enhancing the effectiveness of restorative treatment.[1,4,5]

BONE MALUNIONS IN THE HAND

Malunions typically involve a combination of angular, rotational, and shortening deformities, which can be corrected through various types of osteotomies, such as closing-wedge and opening-wedge osteotomies performed at the fracture site. While a corrective osteotomy can achieve anatomical correction, it can also result in range of motion limitations and stiffness due to the development of additional adhesions between tendons and soft tissue. An alternative method for correcting malunions involves correcting the deformity at an unaffected site. For instance, in the case of a phalanx malunion, correction can be done at the base of the metacarpal. This approach provides rotational correction without the potential for developing adhesions, although it may not be as effective for correcting angulation deformities that accompany malrotation. The corrective procedure can be performed under digital block anesthesia, and after the osteotomy is completed, full finger flexion can help ensure proper correction of the phalanx malunion. In cases where shortening of the phalanx is present, simultaneous lengthening can be achieved using an external fixator. Prior to performing the osteotomy, wires are inserted above and below the deformity, oriented perpendicular to the longitudinal axis, with the knots placed opposite to the angle of the deformity. After making a 5-mm incision on the concave aspect of the bone, an osteotomy is performed, followed by osteoclasis to correct the axis. A triangular defect is then created on the concave side of the bone, and bracing wires are placed parallel to each other before a connecting hinge is attached at the center, following which the wires are secured to the rod. The duration of bracing required after the corrective procedure depends on the severity of the deformity angle and can range from 30-45 days. The length of time required for bracing is also dependent on the size of the defect following axial correction and the formation of regenerate bone. Malunions that involve segment shortening and tissue adhesions can be treated with a corrective osteotomy followed by gradual distraction over time.[4,8]

DISTRACTION LENGTHENING

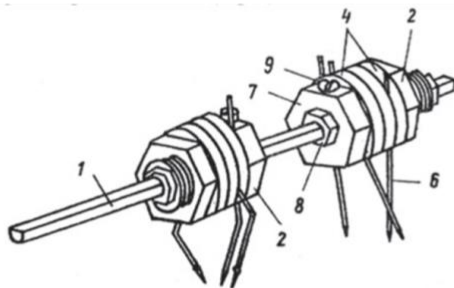
Distraction osteogenesis using the mini-Ilizarov fixator can be used to improve function in individuals with congenital anomalies or shortened amputated stumps. The goal of this treatment is to restore basic hand function, such as the ability to perform plucking-like actions, as well as to improve overall hand strength. When deciding the site of osteotomy it is important that it be made on the area of normal bone as the site of osteotomy helps in healing. Before undergoing any lengthening procedure, all options for soft tissue reconstruction should be considered to restore the integrity and prehensile function of the hand. During the lengthening process, it is important to keep in mind that a slow rate of distraction allows for earlier union, while an increased rate of distraction can lead to poor consolidation. Typically, the maximum amount of lengthening that should be obtained at a single osteotomy is 1 to 2 cm on average, followed by fixation of the lengthening for 4 to 8 weeks depending on the quality of regeneration and the amount of lengthening. If the segment to be lengthened is less than 3 cm, bridging of the proximal joint should be considered, while those longer than 3 cm do not require spanning of the joint. Following an osteotomy, a period of 5-7 days is required to allow for the formation of a hematoma and the recruitment of inflammatory and mesenchymal stem cells before distraction can begin. The recommended distraction rate is 0.5 mm/day to ensure sufficient time for both soft tissue and hematoma lengthening, without compromising the strength of the regenerate. In cases where the regenerate is poor or an hourglass-shaped distraction callus forms, the distraction rate may need to be reduced or stopped temporarily to facilitate the healing process. The consolidation period should be three times longer than the lengthening period to ensure adequate time for bone regeneration and remodeling.

To ensure proper bone strength and prevent angulation of the lengthened bone, it is important to allow sufficient time for consolidation after the lengthening process has begun. Previous studies have suggested that bone grafting should be performed in individuals over 20 years old who require more than 3cm of lengthening, as spontaneous consolidation is unlikely. Additionally, an intramedullary K-wire can be used during the consolidation phase and removed once consolidation is complete. This will help to ensure optimal bone strength and prevent angulation.

To perform lengthening on stumps that are less than 2 cm in length, a technique called "Spiral Oblique Osteotomy" is used. This involves the insertion of two wires into the proximal segment of the stump, followed by the placement of an S-shaped wire through the distal segment, which is slung over the nearby joint and then fixed to a support. This allows for lengthening of the stump. In the case of lengthening of the metacarpals, elongation of the 1st-3rd metacarpals can be performed to improve hand function. This can also involve deepening of the interdigital cleft.[4,6,7]

CONGENITAL ANOMALIES OF THE HAND

The Ilizarov mini-fixator has proven to be a valuable tool in the functional and cosmetic improvement of various congenital anomalies of the hand. Examples of these conditions include syndactyly, brachydactyly, clinodactyly, ectrodactyly, and hypoplastic hand conditions. Clinodactyly can be corrected by lengthening the affected phalanx to restore the finger axis and the length ratio of the fingers. The mini-fixator can be utilized in hypoplastic conditions to lengthen the affected segment, which can improve the cosmetic appearance of the affected area. To correct Syndactyly, the Ilizarov mini-fixator is used by inserting two wires with corkscrew stoppers into the proximal and distal metaphyses of each involved phalanx, as well as into the distal ends of the metacarpals.



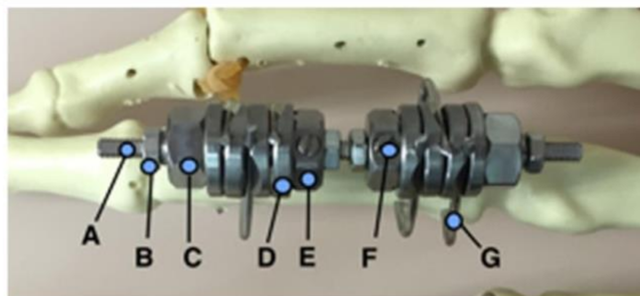


Fig. 1: Threaded rod (1), nuts (2) and wire-fixation unit. Composed of slotted washers (4) and space washer (4), bolt (9) with an axial hole and perpendicular threaded hole in its head, locking screw (9), fixation nut (8).

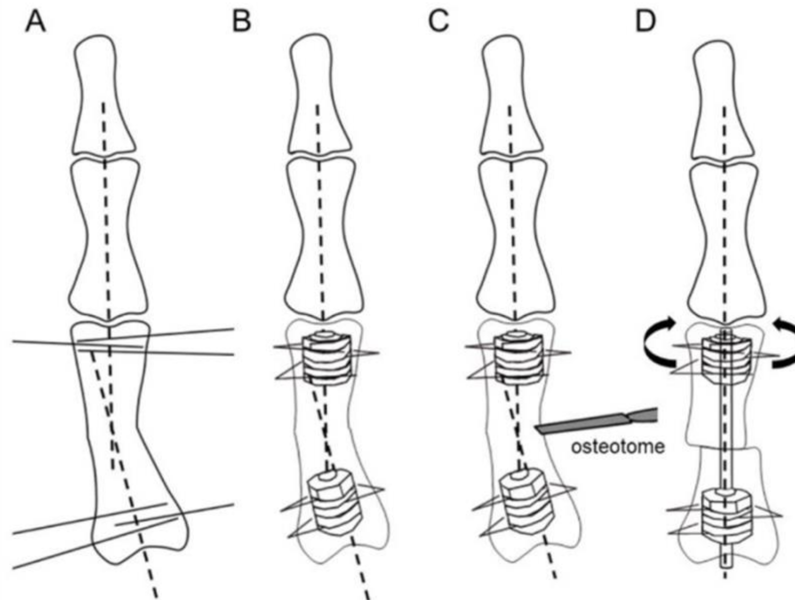


Fig. 2: Placement of wires for different fracture configurations

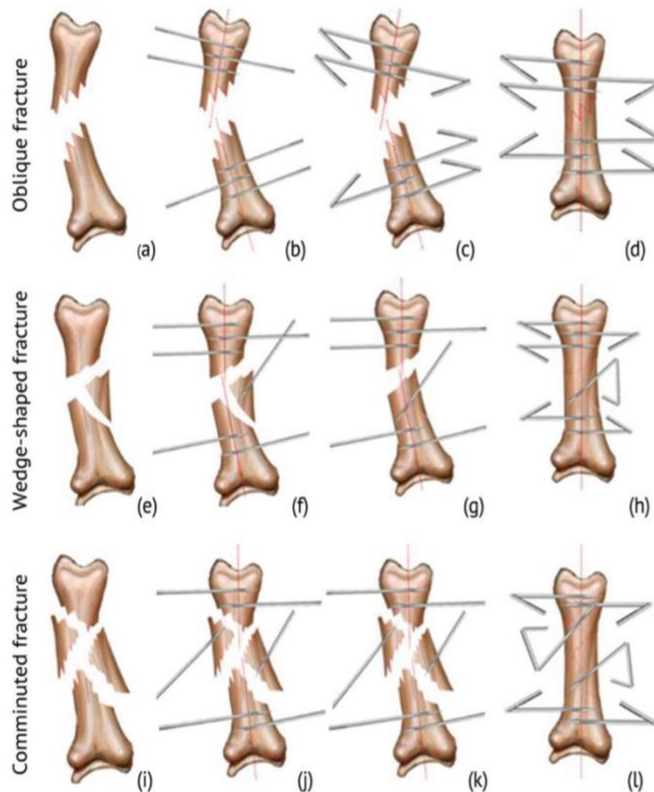


Fig. 3: Corrective Osteotomy for angular deformities

The wires are then passed through a phalanx from the palmar surface outward and fixed along the longitudinal axis of the fingers on the dorsal surface of the hand. Two transversely distracting rods are

used to interconnect the rod ends. Distraction is started at a rate of 0.25 mm twice a day on the 3rd post-op day, with the distal rod being distracted four times a day for the first 15-20 days and then two to three times a day. Distraction is carried out for 30-45 days, followed by fixation for 12-15 days. Once there is sufficient skin abundance, the device is removed and plastic surgery is performed.[4,6]

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