RESEARCH ARTICLE

Treatment of Fracture-Dislocations of Proximal Interphalangeal Joint by Applying of Dynamic Mini External Fixator: Clinical and Radiographic Results

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Abstract

Background: Fracture-dislocations of the proximal interphalangeal joint of fingers are believed to be challenging injuries that usually lead to residual pain and stiffness. To date, several treatment options have been applied. Dynamic traction-external fixation is a safe and easy technique offering good results in many works of literature. The dynamic mini external fixator using K-wires and mini rods provide sufficient dynamic traction and facilitate early mobilization of the injured joint. The present study was conducted to evaluate the results of a dynamic mini external fixator for the treatment of those lesions.

Methods: In total, 40 patients who suffered from proximal interphalangeal fracture-dislocations were treated at our institution between November 2017 and November 2019. Dynamic mini external fixator device was utilized for their treatment. Clinical and radiographic parameters were evaluated at 2, 4, 6, 12, and 24 weeks after surgery.

Results: This study included 30 (75%) males and 10 (25%) females with a mean age of 38.7±9.9 years. In total, 6 (15%) patients had concomitant fractures or fractures in their hands. All the fractures, including 27 (67.5%) dorsal fracture-dislocations and 13 (32.5%) Pilon fractures, were united without the occurrence of any malunion or major residual subluxation. One Pilon fracture needed to be realigned by reassembling the device at the second week of follow-up. Furthermore, 36 (90%) patients achieved full range of joint motion, and 4 (10%) patients had mild loss of motion arc. In addition, 8 (20%) patients developed mild pin site infection treated with oral antibiotics without device removal. Following six months, one (2.5%) patient mentioned minimal residual pain.

Conclusion: The dynamic mini external fixator was found to be a safe and applicable technique to manage proximal interphalangeal fracture-dislocations. To obtain significantly accurate results, regular follow-up and accurate device care are of great necessity.

Level of evidence: IV

Keywords: Articular, Early ambulation and range of motion, External fixators, Finger joint, Fracture dislocation

Introduction

Proximal interphalangeal joint (PIPJ) of the fingers plays an undeniable role in the function of hands (1). In comparison with other hand joints, PIPJ has the greatest arc of motion and is responsible for up to 85% of the total encompassment during grasp (2). Therefore, it can be stated that PIPJ is the anatomical and functional locus of finger function (3). The PIPJ is a hinge joint normally stabilized by a complex of soft tissues, including collateral ligaments, volar plate, and central extensor slip. If any disruption occurs in these elements, whether as a rupture or as a bony avulsion, subluxation or dislocation of the joint are not inevitable and may occur in volar, dorsal, or lateral direction, while

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dorsal dislocation is the most common type of PIPJ dislocation (4).

Fracture-dislocation of the PIPJ is considered a prevalent injury, classified by Seno et al. into five types (5). In types 1 and 2, the fracture is on the palmar and dorsal sides, respectively. In type 3, also named as PIPJ pilon fracture, both volar and dorsal buttresses are involved, and the central part is usually depressed, which is usually associated with the worst outcome. Type 4 is an extraarticular fracture, and type 5 occurs on the sagittal plane. Significant finger stiffness, loss of function, and residual pain are the most disabling complications of PIPJ fracture-dislocations (6). The outcome of these injuries depends on the amount of articular surface of the base of the middle phalanx and the maintenance of a congruent reduction of the joint with the most respect to adjacent soft tissues (7).

Evaluation of stability is the most essential step to plan for the treatment of PIPJ fracture-dislocations. Nonsurgical management is used for stable fractures. Nondisplaced or minimally displaced fractures with congruent joint and less than 40% involvement of articular surface of base of middle phalanx without subluxation are considered to be stable and are amenable to healing by various fashions of splinting (8).

If a PIP fracture is grossly displaced, the joint is subluxated or the articular damage of the base of the middle phalanx is over 40% or over 30-degree flexion of the joint is needed to obtain a congruent and non-subluxated joint. As the fracture is considered unstable, many investigators have recommended the management of these fractures via surgical interventions since nonsurgical treatment usually results in malunion, joint stiffness, or joint subluxation (9). Different kinds of surgical procedures are applied to treat the unstable fracture-dislocations of PIPJ. Surgical options comprise pinning of the joint, dorsal block pinning, open reduction and internal fixation, external fixation, volar plate arthroplasty, and osteochondral arthroplasty (10).

Most PIP fracture-dislocations are dorsal and have volar fragments or fragments with thin bones that make the fragments incapable to accept screws. More aggressive incisions of the soft tissues in open procedures result in the development of adhesions and undesirable post-operative complications leading the joint to not mobilize easily, whereas a more important aspect of treatment is to have a well-functioning hand rather than an achievement of accurate anatomic reduced fracture associated with a restricted arc of motion (11). External fixation-dynamic traction finds the place of a suitable option to treat PIPJ fractures as it is a closed treatment and results in less postoperative edema and adhesion and permits the joint for early and full mobilization.

Many frames of external fixation-dynamic traction have been developed for surgical management of PIPJ fracture-dislocations (12-19). Loss of fixation, being cumbersome and not suitable for probably required adjustment, is a certain disadvantage of these frames. To address these problems, a dynamic mini external fixator was designed. The current study aimed to retrospectively review the clinical and radiographic results of applying a dynamic mini external fixator to treat unstable PIPJ fracture-dislocations.

Methods

This cross-sectional study was approved by the institutional review board and ethics committee (IR.BMSU.REC.1399.486). Written informed consent was obtained from each patient prior to taking part in the study. In total, 40 patients (30 males and 10 females), who sustained unstable PIPJ fracture-dislocations, were treated with dynamic mini external fixators between November 2017 and November 2019. The indication was explained for the application of the device as an intra-articular acute fracture at the base of the distal phalanx of the thumb and middle phalanx of the other fingers associated with subluxation or dislocation. Subluxation radiographically was also defined as the presence of a V-sign in the true lateral view of a plain radiograph of the finger (4). The exclusion criteria included chronic lesion (more than three weeks interval from injury to procedure), concomitant tendon or neurovascular injuries, patients with an underlying disease or other conditions that restrict rehabilitation care, and preexisting limited range of motion of the injured finger. Demographic characteristics, type of fracture (Pilon versus dorsal fracture-dislocation), and the presence of another concomitant hand fracture were recorded at the time of patient selection.

All patients were visited 2, 4, 6, 12, and 24 weeks following the surgery. In each follow-up visit, the patients described their level of pain using the Numeric pain Rating Scale. In this scale, the most severe pain is scored 10 and a pain-free patient obtains a zero score. The patient chooses a number between zero and 10 for his/her pain based on the pain severity. The symptoms and signs of pin site infection, including inflammation marginal or substantial, induration, tenderness, surrounding erythema, and drainage (serous or purulent), were evaluated and documented in combination with radiographic findings of infection, including osteolysis at near or far cortices, sequestrum, and medullary abscess. Grading the pin tract infection was performed using Dahl classification (21). In this classification, the absence of symptoms and signs of infection is classified to be 0. The presence of only marginal inflammation without the presence of any discharge or radiographic change is classified as grade 1.

The presence of a substantial inflammation and serous discharge without any radiographic evidence of infection makes a grade 2 of infection. If a patient suffers from a substantial inflammation and purulent drainage without any radiographic change for infection, his/her grade of infection is 3; however, if his/her radiographs indicate cortical osteolysis or sequestrum and medullary abscess, the grade of infection is 4 or 5, respectively. Joints motion was measured with a finger goniometer and the total arc motion of a metacarpophalangeal joint, and interphalangeal joints were documented and classified based on American society for surgery of the hand (ASSH) classification (22). This classification is based on the comparison of total arc motion (TAM) between the affected finger and the contralateral finger. TAM is calculated as the total active flexion of metacarpophalangeal, proximal interphalangeal, and distal interphalangeal joints minus the total extension deficit of these fingers. If the affected finger has a similar

TAM to that of the contralateral finger, the ASSH class will be excellent. TAM comparisons of over 75%, between 50% and 75%, less than 50%, and less than pre-operative TAM are classified as good, fair, poor, and worse classes, respectively. Plain radiographs were obtained in each visit to evaluate construct and reduction stability, alignment of the fractured segments, congruency of the joint, any evidence of fracture healing, and any probable findings of infection. Finally, any relationships between the variables were analyzed utilizing SPSS software (version 16). The Chi-square, Fischer's exact, and Pearson correlation tests were employed for the investigation of the statistical relationships.

Dynamic Mini External Fixator

The apparatus employed in this study was originally made and developed by the senior author (Parviz Ahangar) and named "P-frame". The dynamic mini external fixator is composed of K-wires, mini rods, and mini-screws [Figure 1]. K-wires are 1.5 mm in diameter. Initially, the mini rods made of a different material (copper) were used. These are radio-opaque and once the lateral radiographs of the finger were obtained, the details became obscure. Therefore, the mini rod was designed with polyoxymethylene, an engineering thermoplastic material [Figure 2].

Mini rod is a cylinder with outer and inner diameters of 5 mm and one 1.6 mm transfer hole in the proximal end and three 1.6 mm holes in distal, respectively, and is designed to take in the K-wires. K wires were affixed by 1.4 mm self-tapping steel screws to the rod via 1-mm holes, perpendicular to 1.6 mm holes of the rod. Subsequently, mini-screws firmly attached the K-wires into the mini rods. Two mini rods were used in both the radial and ulnar sides of the finger.

Figure1. The dynamic mini fixator.

Figure2. Former and new designs of mini rods and screws.

Surgical technique

After the application of regional anesthesia and administration of intravenous prophylactic antibiotics, the affected finger was prepped and draped in a sterile fashion. In cases with a central depression of the articular surface of the base of the middle phalanx, the percutaneous intra focal pinning technique was used to reduce the articular fragment. Afterward, the first or "proximal" 1.5 mm pin was inserted at the center of the head of proximal phalanx (center of rotation of PIPJ), and the pin crossed the far cortex and advanced the skin until the adequate length of K-wire was obtained. The adequate length of the wire in both radial and ulnar sides of the finger is the minimum length of the wire which the mini rod is assembled on a wire at 5 to 7 mm distance from the finger skin. A mini rod was then assembled on the radial or ulnar side of the pin without screw insertion. After applying longitudinal traction to the finger, as the same rule for proximal pin insertion, the second or "distal" 1.5-mm pin was entered through one of the distal holes of the mini rod, advanced in the diaphysis of the middle phalanx and far skin to achieve an "adequate length" of the wire. Subsequently, the second mini rod was assembled on the contralateral side of the pins. Both proximal and distal pins were parallel to the PIPJ line and perpendicular to anatomical axes of the proximal and middle phalanx. For an accurate and precise surgical procedure, K-wires were inserted under the guidance of fluoroscopy. Ultimately, the pins were affixed by 1.4-mm self-tapping screws to the mini rods, within almost 5 mm of the skin and cut 1-2 mm out of the mini rods [Figures 3, 4, and 5].

Since the main goal of this procedure is applying dynamic traction, it is not important to affix mini rod or mini rods to the first pin prior to or after the insertion of the second pin, and/or insertion of the second mini rod or mini rods prior to the insertion of the second pin.

However, it was found that the technical steps explained above were easier and faster than other methods of frame application. In certain circumstances, such as osteoporosis, dislocation, or severely comminuted fractures, two K-wires in a distal portion of the frame were used to make a stiffer construct. On a number of occasions, extra pins are required to achieve the appropriate reduction. These pins could be linked to the frame or left unattached. If the attempts to achieve closed reduction were unsuccessful, open reduction was performed via volar or dorsolateral approach.

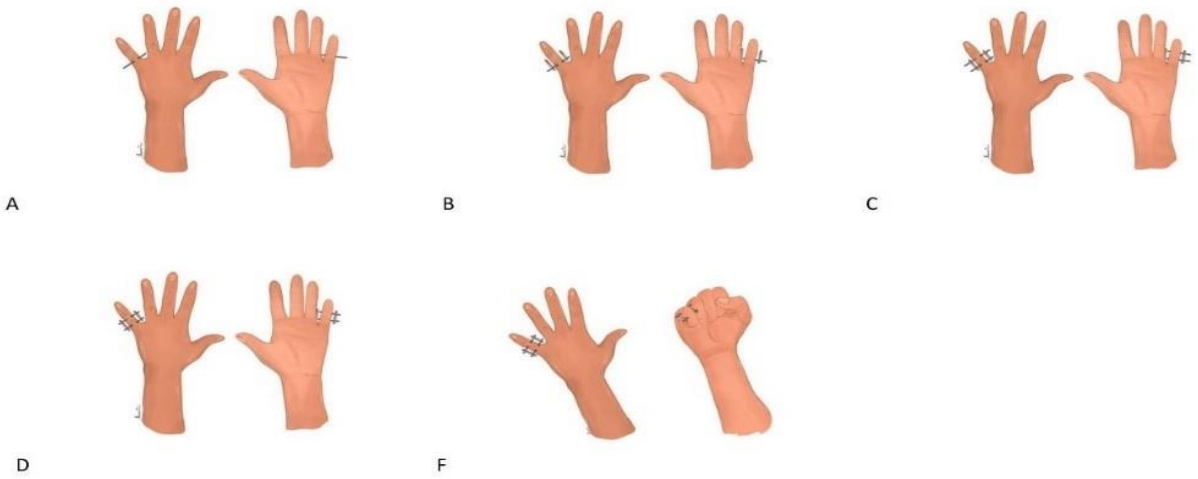

Figure3. Schematic illustration of the surgical technique: A: The proximal pin inserted into the center of rotation of P1. B: Proximal pin affixed to mini rods. C: The second pin was inserted into the mini rods and the diaphysis of P2 and affixed to mini rods. D: The pins are cut. E: Arc of PIPJ motion is controlled.

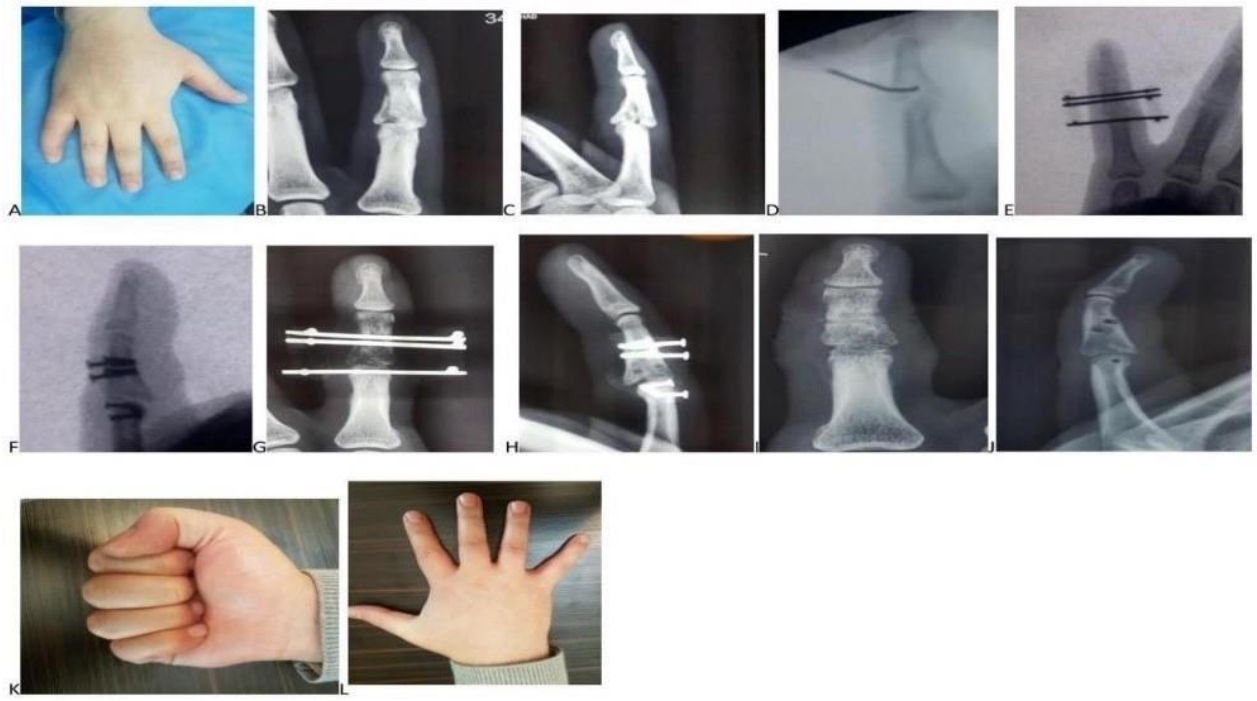

Figure4. A: An injured little finger with obvious clinical deformity. B: AP radiograph of the finger. C: Lateral radiograph of the finger. D: Intrafocal pining for the correction of articular depression. E: AP radiograph after the application of dynamic mini external fixator with fluoroscopy. F: Lateral radiograph after the application of dynamic mini external fixator with fluoroscopy. G: AP radiograph after six weeks. H: Lateral radiographs after six weeks. I: AP radiograph of the finger after device removal. J: Lateral radiograph after device removal. K: Fisted hand. L: Extended hand.

Figure5. A: The first pin was inserted in the center of the proximal phalanx head and cut with adequate length at both radial and ulnar sides of the finger. B: After assembling the ulnar-side mini rod, the second pin advanced through the distal hole of the mini rod to the shaft of the middle phalanx and exited from the contralateral skin of the finger. C: The second- radial side mini rod was assembled, and with the application of sufficient traction, pins were affixed to the mini rods by mini-screws. D: Flexed affected finger after the application of P-frame.

Post-operative management

The patients were educated and encouraged for active and passive mobilization of the joint from the day after surgery. The frame was removed six weeks following surgery, and the patients were referred to a physiotherapist until a plateau in ROM was reached. Pin sites were kept clean with daily swabs of peroxidase.

Results

In total, 30 (75%) males and 10 (25%) females with the mean age of 38.7±9.9 (age range: 22-66) years were treated utilizing a dynamic mini external fixator. A total of 6 (15%) patients had concomitant hand fractures, who were treated with appropriate options. Most of the fractures were in the ring and little fingers [Table 1]. All the fractures, including 27 (67.5%) dorsal fracture-dislocations and 13 (32.5%) Pilon fractures were united without the occurrence of malunion or residual subluxation. One Pilon fracture needed to be realigned by reassembling the device at the second week of the follow-up visits due to an apex volar angular deformity.

Pain assessment was carried out during periodical follow-up visits [Table 2]. Two and four weeks after surgery, all patients suffered from pain. At week 6 after surgery, 24 patients were pain-free, and eight and one patients mentioned minimal residual pain following 12 and 24 weeks after surgery, respectively.

At week 24, the final ROM was measured, and no extension lags were detected. Furthermore, 36 (90%) patients gained full TAM of the finger joints, and 4 (10%) patients reached less than 260 degrees of the total arc motion (214°, 227°, 232°, and 245°). In addition, 32 (80%) patients did not have symptoms of pin tract infection (grade 0 in Dahl classification). The remaining 8 (20%) patients had grade 1 of Dahl classification and were treated with oral antibiotics without device removal.

It is noteworthy that a meaningful correlation (P=0.012) existed between the severity of pain at the beginning of the study and the final follow-up. Moreover, there were no significant relationships between the severity of pain at follow-up visits and the final ROM. A meaningful relationship seems to exist between the presence of concomitant fracture of the hand, residual pain, infection, and the final ROM (P=0.015, P=0.48, and P=0.04 respectively). Furthermore, there was a significant relationship between the severity of pain at week 24 of the follow-up visits and getting infected (P=0.04). Eventually, there was a meaningful association between the occurrence of malalignment after the establishment of the frame and loss of detected ROM (P=0.02).

Table 1. Frequency of interphalangeal joint fracture-dislocations

Affected finger	Case frequency	Case percentage (%)	Frequency of Pilon fracture	Frequency of dorsal fracture-dislocation
Thumb	2	5	2	0
Index	5	12.5	4	1
Middle	2	5	0	2
Ring	12	30	4	8
Little	19	47.5	3	16

Table 2. Description of pain assessment during periodical follow up visits

Pain at follow-up visit	Mean±SD	Range	Mode
Week 2	5.45±0.63	3-7	5
Week 4	1.80±0.85	1-4	1
Week 6	0.40±0.59	0-2	1
Week 12	0.20±0.40	0-1	0
Week 24	0.25±0.15	0-1	0

Discussion

The present study found the fractures healed without the occurrence of any malunions or major residual subluxations. Only one patient had minimal residual pain after six months. In total, 90% of our subjects achieved full ROM indicating that based on ASSH classification, their arc of motion was in the excellent group. Furthermore, 10% of the patients finally had a non-complete arc of motion; however, since all of them were more than 195° (75% of normal total arc of motion), they were placed in the "good" group of ASSH classification. In addition, 80% of them had no pin tract infections, while the others manifested a mild pin site infection. Treatment of unstable fracture-dislocations of the proximal interphalangeal joint remains a conundrum for hand surgeons. Theoretically, appropriate treatment should make a stable environment for fracture healing while facilitating the joint to mobilize easily. The multiplicity of the constructs for external fixation-dynamic traction implies no consensus to manage these fractures by a device of choice (23).

A dynamic mini external fixator is a stiff, simple, small, and inexpensive construct which allows early mobilization of the PIPJ without concern of fixation loss. The learning curve of the surgical procedure is fast, and post-operative cares are convenient and easy to learn. Perfect results were obtained concerning fracture union applying our apparatus. It is comparable to other studies. Additionally, excellent to good results of joint motion were detected, which was almost superior to previous investigations (19, 24). The rate of infection was 20%, and low-grade pin site infections were documented, which were not obviously different from similar published literature (24, 25). The presence of concomitant hand fracture was related to the occurrence of infection. This finding can be explained by mentioning that other fractures were treated with percutaneous pinning which made the finger prone to more penetrated barriers, microorganisms' colonization, and suboptimal wound care. In addition, the proximal pin rotates in the bone and interferes with the healing of stabbed wounds adjacent to the pin and is more vulnerable to infections. However, it is believed that not inserting screws in the proximal arm of the mini rods results in obtaining movements from the pin-mini rod interface and may reduce the mechanical stress in the proximal phalanx.

One patient suffered from residual pain 24 weeks after surgery. It was found that more severe pain at early visits after the surgery could follow more pain at the next visits. Additionally, it was observed that the concomitance of other fractures in the affected hand and the development of pin tract infection put patients at risk of experiencing pain six months after surgery. There are no previous studies for or against this finding. One reason is the possibility of developing further edema due to the above-mentioned factors in the affected finger, which leads to the persistence of prolonged pain. However, the exact reason could not be found.

Moreover, a meaningful correlation was noted between the occurrence of concomitant fracture and final ROM. It could be the result of more pain, more development of pin site infection, and more swelling due to the presence of other fractures that may prevent patients from having more accurate and active rehabilitation plans. One patient who underwent realignment procedure and construct correction suffered from loss of fixation. The ultimate ROM decreased (TAM: 214°), and statistical analysis revealed a significant relationship between finger stiffness and the presence of ipsilateral concomitant hand fracture. This correlation cannot be explained; however, it is assumed that more severe pain and excessive edema might inhibit the appropriate rehabilitation of the hand.

The enrolled patients in our study mostly had fractured little and ring fingers. This distribution is favorably comparable to that of previous studies (17, 19, 24). In addition, it was recognized that most fractures were fracture-dislocation rather than Pilon fracture. This finding is in agreement with that of some recently-published studies (26). Furthermore, PIPJs of the thumb and index finger was injured as Pilon fractures. However, published literature has not mentioned this finding. It is thought that more flexed joints of the ring and little fingers predispose them to injury by a compound mechanism of axial loading and bending force, leading to the occurrence of fracture-dislocation rather than Pilon fracture. Nevertheless, an accurate conclusion cannot be obtained. The limitations of this study were the short follow-up period which precluded the detection of osteoarthritis of the affected joint, lack of validated criteria, and limited objective criteria, including no measurement of grip and pinch strength or assessment of the probability of returning to work or being capable of handling other activities.

Conclusion

The dynamic mini external fixator was found to be a safe and applicable construct to treat proximal interphalangeal fracture-dislocations. Suitable pain management and prevention of pin tract infection are substantial keys to achieve the best results. In order to obtain excellent results, regular follow-up and accurate device care are of great necessity.

Informed Consent: Written informed consent was obtained from each patient prior to taking part in the study.

Conflict of Interest: The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

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