

Original Research

A comparative cadaveric biomechanical analysis of the differences between dynamic external traction devices for PIP joint fracture dislocation

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Abstract

Introduction: No study in the literature has compared different external distractors for proximal interphalangeal joint (PIPJ) injury. We compared an elastic based device described by Suzuki et al. to a 2-pin model described by Hynes and Giddins in non-injured cadaveric fingers. The main outcome measures were articular space and PIPJ flexion resistance.

Methods: Thirty-two Thiel embalmed fingers were used. The elastic based model was performed with 3 and 5 elastics per side (3E and 5E), while the 2-pin model (2P) used no elastics. Articular distraction of each device was measured using x-ray imaging. The force required to flex the PIP joint to 45° and 90° in each group was measured with a dynamometer.

Results: The articular distraction was statistically significant for all groups ($p < 0.01$). The difference in articular distraction was significant in the antero-posterior (AP) view between groups 3E and 2P, and 5E and 2P ($p < 0.05$). Flexion forces were only significantly different between the elastic and non-elastic at 90° flexion ($p < 0.05$). Group 2P was more difficult to engage and often disengaged in flexion compared to groups 3E and 5E.

Discussion: All devices achieved significant articular distraction (>99% in AP). However, optimal distraction has not been clinically determined, and may depend on each unique fracture. This suggests that a variable distraction device may be optimal. The present study found that the elastic based model was superior to the non-elastic model because it was more reliable and had less joint motion resistance. Additionally, the force required to reduce the fracture could be easily adjusted by changing the number of elastics.

► Dynamic external distractor; Suzuki frame; PIP joint fracture; biomechanical analysis; cadaveric model; pin and rubber traction system.

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Introduction

Injuries to the hand and wrist account for 29% of visits to emergency departments. Of these injuries, 52-62% involve the phalanges of which 7-12% are fractures^(1,2). Fracture-dislocations of the proximal interphalangeal joint (PIPJ), often mistakenly dismissed as a simple 'jammed finger', require prompt recognition and treatment to optimize outcomes. Treatment goals include restoration of joint congruity and early PIPJ range of motion (ROM).

Fracture dislocations of the PIPJ involving more than 40% of the articular surface at the base of the middle phalanx are typically unstable. Treatment options for unstable PIPJ fracture dislocations include extension block pinning^(3,4), open reduction and internal fixation⁽⁵⁻⁹⁾, volar plate arthroplasty^(6,10,11), static⁽¹²⁾ or dynamic external fixation⁽¹³⁻²⁶⁾, and hemihamate arthroplasty. Due to poor outcomes of conservative treatment and technical difficulty of open treatment, dynamic external fixation has gained a leading role in fracture management. In a recent review, patients treated with traction had superior ROM in the involved digit compared to treatment options with no traction⁽²⁷⁾.

Many different dynamic external fixators have been described, yet the biomechanical differences between these devices must be defined. This will provide a clearer understanding of the variables that may contribute to different clinical outcomes in PIPJ injuries. For example, knowing which frame provides the least resistance to joint flexion may allow for easier joint rehabilitation.

In our review of the literature there were no published biomechanical studies comparing distraction frames in neither laboratory nor clinical setting. There is little information on the effect of these distraction devices on intra-articular width and on the quantitative resistance to flexion of the phalanx with the device in place. Kneser et al.⁽²⁸⁾ performed a biomechanical analysis of the frame described by Suzuki et al.⁽²⁴⁾ and demonstrated increased force of flexion with application of the device. However, in their study, there was no statistically significant difference between elastic types and distraction.

In order to have a better understanding of the clinical impact these devices may have, it is important to understand their effect on joint anatomy. In this study, we compare two devices frequently used at our institution (McGill University Hospital Center, MUHC); one that uses rubber bands^(14, 15, 21, 28-35), and one

that uses the recoil force of a wire without elastics^(26, 36-39). In addition, we quantify the resistance to joint flexion with the device in place.

Methods

The study was approved by the McGill University institutional review board.

Specimen Preparation

The digits of four cadavers (eight hands) were used for the study. Cadavers were Thiel embalmed in order to preserve soft tissue suppleness and best approximate live tissue biomechanics. Fingers were isolated by disarticulation at the carpometacarpal joint. Flexor and extensor tendons for each finger were isolated. All pulleys were preserved. The thirty-two fingers were labeled by cadaver number (C1-4), right or left hand (R, L), and digit number (2-5), (e.g. C1R4; 1st cadaver, right hand, 4th finger). The specimens were randomized into two groups (group 1 - pins and rubber system, and group 2 - no rubber system). Each set of four fingers from the same hand were allocated to one group, while the fingers from the contralateral hand were assigned to the other group. Hence, group 1 had C1R, C2R, C3L, C4L; and group 2 had C1L, C2L, C3R, and C4R.

Device Material and Frame Preparation

All specimens had two 1.2 mm diameter Kirshner wires inserted under fluoroscopic guidance by the senior author. One pin was placed through the axis of rotation of the proximal phalangeal head and a second pin through the middle phalanx. The position was confirmed under fluoroscopy. Group 1 had an additional dorsal blocking pin inserted in the mid-diaphysis of the middle phalanx to prevent dorsal subluxation and maintain the wire construct on the same plane.

Group 1: The technique employed by the senior author is similar to the frame described by Suzuki *et al.*⁽⁴⁰⁾. In brief, the proximal and distal wires were bent 5 mm from the skin surface. The wires were bent such that a distance of 2 cm was left between the ends of the distal and proximal wire. *3M Unitek* orthodontic elastics of medium strength (*Louie 404-546*) were used to span this distance (Figure 1). Group 1 was further subdivided in group 3E (3 elastics per side) and 5E (5 elastics per side).

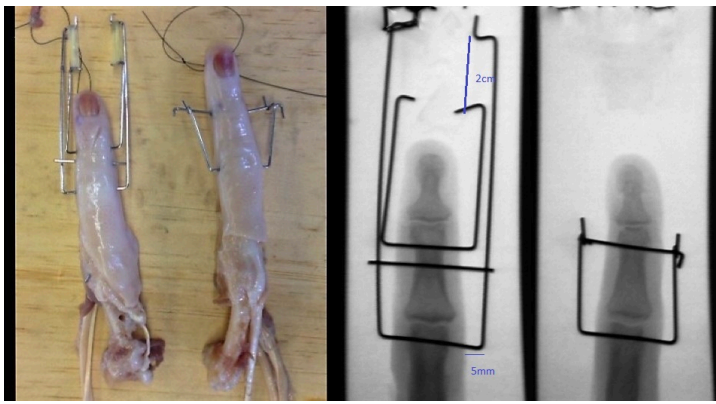


Figure 1- Gross and radiographic imaging of the two models. Distances labeled in blue.

Group 2: We followed the technique described by Hynes and Giddins(26). In brief, the proximal wire was bent 5 mm from the skin and the wire hook was shaped by bending the wire 3 mm from its overlap with the distal pin. The distal pin was bent 2 cm from the skin surface for the hook to not slide past the wire (Figure 1).

Articular Space

Fluoroscopy was used to obtain antero-posterior (AP) and lateral views of the digits before and after placement of the distraction device. A metal object of known length was used for size calibration of all images.

Force for Flexion

The digits were stabilized with pinning onto a wooden board for all measurements. A protractor was centered at the axis of rotation of the proximal phalangeal head. A digital dynamometer with precision up to 5G differences was used. The dynamometer was secured to the Flexor Digitorum Profundus (FDP) of each digit. Flexion of the digit was achieved by pull of the dynamometer/FDP tendon until the middle phalanx reached 45° and 90°. The force required for flexion was recorded at each angle, with the distractor frame disengaged and engaged. One digit (C4L5) was excluded in the calculations as there was a pre-existing 45° flexion contracture of the PIP joint.

Force of Distraction

The independent distraction force provided by the elastics was measured with the same dynamometer by pulling the elastic until they reached a length of 2 cm (the length that the elastic was stressed to in the distraction devices). This was performed with 2, 4, 6, 8, 10 and 12 elastics.

Statistical Analysis

Statistical analysis and graphic representations were performed using Microsoft Excel 2011. The graphical representations were scatter plots and bar graphs. Descriptive statistics performed included linear regression, mean, standard deviation, confidence interval, and student t-test. The student t-test was considered statistically significant when $p \leq 0.05$. Digits from the same hand were treated as independent outcomes because each digit may have different biomechanical properties despite belonging to the same hand.

Results

Independent Elastic Resistance

The resistance to distraction of each pair of elastics outside of a wire frame increased linearly as a function of the number of elastics ($r=0.997$; $p<0.001$). Each elastic added an average of $1.53 \pm 0.43N$ of resistance. The 3E group had $9.16 \pm 0.32N$ of distraction, while the 5E had $15.26 \pm 0.51N$ of distraction (Figure 2).

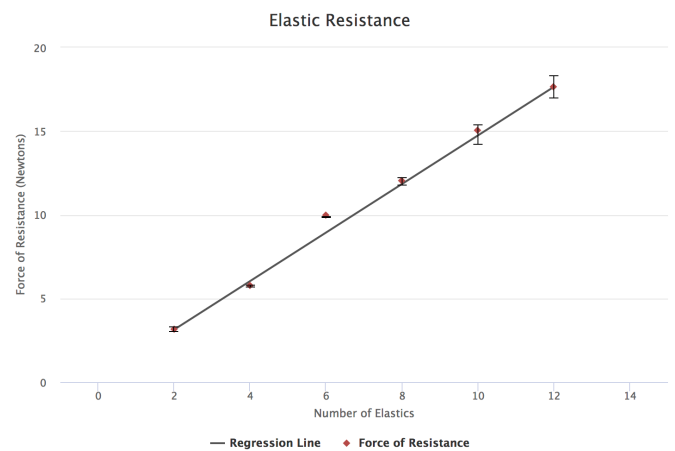


Figure 2 - Graphic showing the linear relationship between the number of elastics and the force needed to distract them at 2 cm.

Articular Space

The articular space before and after distraction was measured in AP and lateral x-ray views (mm). The articular space before and after distraction was significantly different in all groups ($p<0.01$). Intra-articular spaces were described as percentage increase from the original space as follows: 3E ((mean±SD) AP: $99 \pm 18\%$; lateral: $93 \pm 27\%$); 5E (AP: $117 \pm 3\%$; lateral: $100 \pm 17\%$); and the two-pin model (2P) (AP: $141 \pm 15\%$; lateral: $83 \pm 28\%$) (Figure 3). The percent increase in the articular width was found to be statistically significant in the AP view between the 3E and 5E (mean difference 17.75%; 95% CI 8.42-27.09;

$p < 0.01$), 3E and 2P group (mean difference 41%; 95%CI 29.36-53.11; $p < 0.01$), and 5E and 2P group (mean difference 24%; 95%CI 16.55-31.81; $p < 0.01$). However, no statistically significant differences were observed in the lateral view. Articular space in mm and percent increase in articular width were both directly correlated with the number of elastics ($r = 0.9934$; $p < 0.001$) for all groups within the studied range of distraction forces.

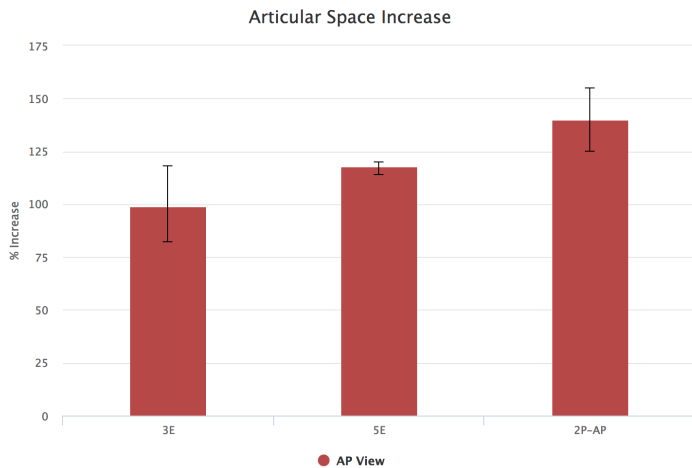


Figure 3. Bar graph illustrating the articular space increase in each experimental group.

Flexion Force

The flexion force was measured at 45° and 90° of PIPJ flexion. There were no significant force differences between the groups at 45° degrees ((mean±SD) 3E: 4.02±2.29N; 5E: 4.43±1.94N; 2P: 5.00±3.97N). There was a statistically significant difference at 90° demonstrating that 3E and 5E were easier to flex than 2P devices ($p < 0.05$) ((mean±SD) 3E: 12.37N±5.41; 5E: 10.40N±5.09; 2P: 15.03N±6.11) (Figure 4).

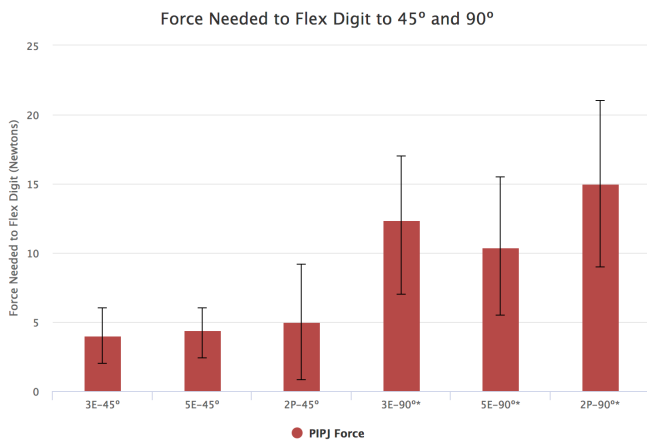


Figure 4. Bar graph illustrating the force needed to flex the PIPJ to 45° and 90° in each experimental group. 3E: 3 elastics per side. 5E: 5 elastics per side. 2P: 2 pin model (no elastics). * $p < 0.05$.

Discussion

Pilon fractures of the PIPJ have significant failure rates after conservative treatment such as splinting. Possible complications from conservative treatments include phalangeal fracture malunion, instability, stiffness with gross reduction of motion and deformities (e.g. flexion, boutonniere, pseudoboutonniere, swan neck deformities and persistent subluxation)(41). Open treatment techniques can be technically difficult, especially in cases of significant comminution, and do not necessarily improve functional outcomes(42). Recent studies report 40% reoperation rates and argue that percutaneous pins may achieve equivalent results to Open Reduction and Internal Fixation with significantly less difficulty(43, 44). Due to the limitations of conservative and open treatment techniques, dynamic external fixation has gained a leading role in fracture management.

Dynamic external fixators allow joint mobilization while maintaining reduction of the fracture dislocation via the principle of ligamentotaxis. The early active and passive ROM provided by these devices prevents contractures and adhesions of the collateral ligaments, volar plate, and extensor and flexor tendons by allowing tendon gliding. Additionally, articular cartilage healing and regeneration have been shown to improve with passive motion(45). These properties have translated into acceptable functional results(21-23, 28, 46, 47). At our institution, two types of distraction devices are routinely used for unstable fracture dislocations of the PIPJ, one system made with 3 pins and rubber(24) and the second made with two-pins(26). Due to lack of a gold standard for the best distraction device in the literature, we performed a biomechanical analysis comparing these two devices. Unlike the biomechanical study performed by Kneser *et al.*(28) on the three-pin and rubber device, we varied the number of elastics rather than change the type of elastic. Clinically, this translates into less patient confusion and easier articular distraction control.

We studied the resistance force of elastics at a constant distraction (2 cm). Each elastic added to group 1 resulted in 1.53N increase in distraction force. Based on this we can express distraction force in Newtons or number of elastics, interchangeably. Also, it is much easier to bend the wires to a constant distraction distance and vary the distraction force by changing the number of elastics than varying the distraction distance.

We observed, to a maximum of 12 elastics, a linear relation between articular space and number of elastics. It is important to note that this relation most likely will plateau if the joint capsule was fully stretched had more elastics been tested. Contrary to Kneser *et al.*(28), who compared 3 rubber strengths and did not find a significant effect on the distraction of the PIP joint, our study found a difference. An important limitation to our study was the lack of reliable measurements of the articular distraction on the lateral view. The AP view was easy to measure the articular space since we were not seeing across two condyles. The lateral view was unreliable because it was very challenging to determine the true articular space given the obliquity of the view relative to the two overlapping condyles; this was particularly difficult given the osteopenia of the cadaveric fingers. This measurement error may explain, in part, the lack of statistically different distraction in the lateral view.

In this study, we observed that the non-elastic device (group 2) required higher forces than group 1 to flex the PIPJ to 45° and 90°. This was only significant at 90°. Resistance to flexion may be an undesirable characteristic that may further limit joint mobilization and thus post-operative results.

We observed that the two-pin system was markedly more difficult to engage than the elastic system. In the two-pin system it was technically more challenging to precisely bend the curved wire to engage the horizontal pin with equal force on each side of the digit. In the elastic model, individual elastics could easily be placed one at a time. Additionally, the two-pin system frequently disengaged when flexing the finger as opposed to the elastic system.

Attention to detail and surgical technique may also explain different biomechanical results as well as clinical outcome. Debus *et al.*(48) reviewed their post-operative outcomes and outlined important pitfalls such as pins not centered in the axis of rotation of the proximal phalanx and persistent dorsal subluxation. Over-distraction on one side of the joint may also lead to clinodactyly.

This study has limitations. First, although we minimized measurement error by eliminating inter-observer variability through using the same measuring device and clinician for all fingers, intra-observer measurement errors may have been introduced into our sample. Second, as mentioned previously, the lateral view x-ray measurements were difficult and unreliable as demonstrated by the lack of consistency

compared to the AP view. Third, although the purpose of these devices is for injured PIPJs, we thought it would be important to first determine the impact of these devices on a non-traumatized finger. Indeed, the effect of these devices may behave differently on a traumatized finger. Finally, it is difficult to control the fracture pattern of the PIPJ. Future studies should include a greater number of digits with a fracture model of the PIPJ.

Conclusion

The ideal dynamic external device should provide sufficient and adjustable distraction (observed in an increased articular space and the fracture reduction), while allowing for normal flexion biomechanics (the least added resistance to PIPJ flexion).

With these characteristics in mind, both distractor devices in our biomechanical analysis provided significant joint distraction and thus we could not establish the superiority of one device. In terms of ease of application, we favor group 1 (elastic distractor) given that 3E and 5E distraction force is easily controlled by varying the number of elastics. Group 1 had the lowest increase in resistance to flexion, and could be easily engaged. Future clinical studies are required to translate these biomechanical differences into clinical outcomes.

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Conflicts of Interest

Material support was provided by 3M Canada Company in the form of a box of orthodontic elastics. The support did not include contractual or implied restriction on utilization or publication of the data and/or review of the data prior to publication

Authors have no form of association or financial involvement (i.e. consultancies/advisory board, stock ownerships/options, equity interest, patents received or pending, royalties/honorary) with any organization or commercial entity having a financial interest in or financial conflict with the subject matter or research presented in the manuscript.

Human and Animal Rights

No live humans nor animals were used in this research. Models were cadaveric human fingers. The research protocol of this manuscript was reviewed and approved by the McGill University's Institutional Review Board. The research presented meets ethical standards.

Statement of Informed Consent

Not applicable to this research. No live humans were part of this study.

References

1. Larsen CF, Mulder S, Johansen AM, Stam C. The epidemiology of hand injuries in The Netherlands and Denmark. *Eur J Epidemiol.* 2004;19(4):323-7.
2. Angermann P, Lohmann M. Injuries to the hand and wrist. A study of 50,272 injuries. *Journal of hand surgery (Edinburgh, Scotland).* 1993;18(5):642-4.
3. McElfresh EC, Dobyms JH, O'Brien ET. Management of fracture-dislocation of the proximal interphalangeal joints by extension-block splinting. *The Journal of bone and joint surgery American volume.* 1972;54(8):1705-11.
4. Twyman R, David H. The door stop procedure. A technique for treating unstable fracture dislocations of the proximal interphalangeal joint. *J Hand Surg Am.* 1993;18(6):714-5.
5. Stern PJ, Wieser MJ, Reilly DG. Complications of plate fixation in the hand skeleton. *Clinical orthopaedics and related research.* 1987(214):59-65.
6. Deitch MA, Kiefhaber TR, Comisar BR, Stern PJ. Dorsal fracture dislocations of the proximal interphalangeal joint: surgical complications and long-term results. *The Journal of hand surgery.* 1999;24(5):914-23.
7. Freeland A, Benoist L. Open reduction and internal fixation method for fractures at the proximal interphalangeal joint. *Hand Clin.* 1994;10(2):239-50.
8. Green A, Smith J, Redding M, Akelman E. Acute open reduction and rigid internal fixation of proximal interphalangeal joint fracture dislocation. *The Journal of hand surgery.* 1992;17(3):512-7.
9. Wolfe SW, Katz LD. Intra-articular impaction fractures of the phalanges. *The Journal of hand surgery.* 1995;20(2):327-33.
10. Durham-Smith G, McCarten GM. Volar plate arthroplasty for closed proximal interphalangeal joint injuries. *Journal of hand surgery (Edinburgh, Scotland).* 1992;17(4):422-8.
11. Malerich MM, Eaton RG. The volar plate reconstruction for fracture-dislocation of the proximal interphalangeal joint. *Hand Clin.* 1994;10(2):251-60.
12. Stark RH. Treatment of difficult PIP joint fractures with a mini-external fixation device. *Orthop Rev.* 1993;22(5):609-15.
13. Morgan JP, Gordon DA, Klug MS, Perry PE, Barre PS. Dynamic digital traction for unstable comminuted intra-articular fracture-dislocations of the proximal interphalangeal joint. *The Journal of hand surgery.* 1995;20(4):565-73.
14. Robertson RC, Cawley JJ, Jr., Faris AM. Treatment of fracture-dislocation of the interphalangeal joints of the hand.

The Journal of bone and joint surgery American volume. 1946;28(28):68-70.

15. Schenck RR. The dynamic traction method. Combining movement and traction for intra-articular fractures of the phalanges. *Hand Clin.* 1994;10(2):187-98.
16. Stassen LP, Logghe R, van Riet YE, van der Werken C. Dynamic circle traction for severely comminuted intra-articular finger fractures. *Injury.* 1994;25(3):159-63.
17. Deshmukh SC, Kumar D, Mathur K, Thomas B. Complex fracture-dislocation of the proximal interphalangeal joint of the hand. Results of a modified pins and rubbers traction system. *J Bone Joint Surg Br.* 2004;86(3):406-12.
18. Duteille F, Pasquier P, Lim A, Dautel G. Treatment of complex interphalangeal joint fractures with dynamic external traction: a series of 20 cases. *Plast Reconstr Surg.* 2003;111(5):1623-9.
19. Fahmy NR, Kenny N, Kehoe N. Chronic fracture dislocations of the proximal interphalangeal joint. Treatment by the "S" Quattro. *Journal of hand surgery (Edinburgh, Scotland).* 1994;19(6):783-7.
20. Fahmy NR. The Stockport Serpentine Spring System for the treatment of displaced comminuted intra-articular phalangeal fractures. *Journal of hand surgery (Edinburgh, Scotland).* 1990;15(3):303-11.
21. Gaul JJ, Rosenberg S. Fracture-dislocation of the middle phalanx at the proximal interphalangeal joint: Repair with a simple intradigital traction-fixation device. *Am J Orthop.* 1998;27(10):682-8.
22. Inanami H, Ninomiya S, Okutsu I, Tarui T. Dynamic external finger fixator for fracture dislocation of the proximal interphalangeal joint. *The Journal of hand surgery.* 1993;18(1):160-4.
23. Krakauer JD, Stern PJ. Hinged device for fractures involving the proximal interphalangeal joint. *Clinical orthopaedics and related research.* 1996(327):29-37.
24. Suzuki Y., Matsunaga T., Sato S., Yokoi T. The pins and rubbers traction system for treatment of comminuted intra-articular fractures and fracture-dislocations in the hand. *J Hand Surg.* 1994;19(1):98-107.
25. Syed A, Agarwal M, R. B. Dynamic external fixator for pilon fractures of the proximal interphalangeal joints: A simple fixator for a complex fracture. *J Hand Surg* 2003;28(2):137-41.
26. Hynes MC, Giddins GE. Dynamic external fixation for pilon fractures of the interphalangeal joints. *Journal of hand surgery (Edinburgh, Scotland).* 2001;26(2):122-4.
27. O'Brien LJ, Simm AT, Loh IW, Griffiths KM. Swing traction versus no-traction for complex intra-articular proximal inter-phalangeal fractures. *J Hand Ther.* 2014;27(4):309-16.
28. Kneser U, Goldberg E, Polykandriotis E, Loos B, Unglaub F, Bach A, et al. Biomechanical and functional analysis of the pins and rubbers tractions system for treatment of proximal interphalangeal joint fracture dislocations. *Arch Orthop Trauma Surg.* 2009;129(1):29-37.
29. Ellis SJ, Cheng R, Prokopis P, Chetboun A, Wolfe SW, Athanasian EA, et al. Treatment of proximal interphalangeal dorsal fracture-dislocation injuries with dynamic external fixation: a pins and rubber band system. *J Hand Surg [Am].* 2007;32(8):1242-50.
30. Keramidis E, Solomos M, Page RE, Miller G. The Suzuki frame for complex intra-articular fractures of the proximal interphalangeal joint of the fingers. *Ann Plast Surg.* 2007;58(5):484-8.

31. Keramidas EG, Miller G. The Suzuki frame for complex intraarticular fractures of the thumb. *Plast Reconstr Surg.* 2005;116(5):1326-31.
32. Nam SM, Park ES, Shin H, Jung SG, Kim YB. Interphalangeal traction for comminuted fracture of middle phalanx fingers: case report. *J Hand Surg Am.* 2010;35(8):1282-5.
33. Rawes ML, Oni OO. Swan-neck deformity as a complication of the Agee technique. *J Hand Surg Br.* 1995;20(2):255-7.
34. Ruland RT, Hogan CJ, Cannon DL, Slade JF. Use of dynamic distraction external fixation for unstable fracture-dislocations of the proximal interphalangeal joint. *J Hand Surg Am.* 2008;33(1):19-25.
35. Skoff HD. A proximal interphalangeal joint fracture-dislocation treated by limited open (percutaneous) reduction and dynamic external fixation. *Plast Reconstr Surg.* 1997;99(2):587-9.
36. Theivendran K, Pollock J, Rajaratnam V. Proximal interphalangeal joint fractures of the hand: treatment with an external dynamic traction device. *Ann Plast Surg.* 2007;58(6):625-9.
37. Cheema M, Mangat K, Holbrook N, Rajaratnam V. A biomechanical analysis of distraction force in modified hynes-Giddins dynamic external fixator. *Ann Plast Surg.* 2007;59(3):300-1.
38. Borgohain B, Borgohain N, Tittal P. Double parabolic Kirschner-wires as dynamic distractor for treatment of unstable intraarticular phalangeal fractures of hand. *Indian journal of orthopaedics.* 2012;46(6):680-4.
39. Badia A, Riano F, Ravikoff J, Khouri R, Gonzalez-Hernandez E, Orbay JL. Dynamic intradigital external fixation for proximal interphalangeal joint fracture dislocations. *The Journal of hand surgery.* 2005;30(1):154-60.
40. Suzuki Y, Matsunaga T, Sato S, Yokoi T. The pins and rubbers traction system for treatment of comminuted intraarticular fractures and fracture-dislocations in the hand.[Erratum appears in *J Hand Surg [Br]* 1994 Jun;19(3):408]. *J Hand Surg [Br].* 1994;19(1):98-107.
41. Thomas L, Mehlhoff C, Crouch C, Bennett J. *Injuries of the hand.* Philadelphia: W.B. Saunders; 2001.
42. Stern PJ, Roman RJ, Kiefhaber TR, McDonough JJ. Pilon fractures of the proximal interphalangeal joint. *The Journal of hand surgery.* 1991;16(5):844-50.
43. Aladin A, Davis TR. Dorsal fracture-dislocation of the proximal interphalangeal joint: a comparative study of percutaneous Kirschner wire fixation versus open reduction and internal fixation. *Journal of hand surgery (Edinburgh, Scotland).* 2005;30(2):120-8.
44. Giugale JM, Wang J, Kaufmann RA, Fowler JR. Mid-Term Outcomes After Open Reduction Internal Fixation of Proximal Interphalangeal Joint Dorsal Fracture-Dislocations Through a Volar, Shotgun Approach and a Review of the Literature. *The open orthopaedics journal.* 2017;30(11):1073-80.
45. Salter RB. The physiologic basis of continuous passive motion for articular cartilage healing and regeneration. *Hand Clin.* 1994;10(2):211-9.
46. Bain GI, Mehta JA, Heptinstall RJ, Bria M. Dynamic external fixation for injuries of the proximal interphalangeal joint. *J Bone Joint Surg Br.* 1998;80(6):1014-9.
47. Johnson D, Tiernan E, Richards AM, Cole RP. Dynamic external fixation for complex intraarticular phalangeal fractures. *Journal of hand surgery (Edinburgh, Scotland).* 2004;29(1):76-81.
48. Debus G, Courvoisier A, Wimsey S, Pradel P, Moutet F. Pins and rubber traction system for intra-articular proximal interphalangeal joint fractures revisited. *The Journal of hand surgery, European volume.* 2010;35(5):396-401.