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

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MJM 2017 16(2)

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. 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, open reduction and internal fixation, volar plate arthroplasty, static or dynamic external fixation, 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.

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. performed a biomechanical analysis of the frame described by Suzuki et al. 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, and one that uses the recoil force of a wire without elastics. 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. 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 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).
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 ≤ 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 ± 0.43 N of resistance. The 3E group had 9.16 ± 0.32 N of distraction, while the 5E had 15.26 ± 0.51 N of distraction (Figure 2).

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 ± 18%; lateral: 93 ± 27%); 5E (AP: 117 ± 3%; lateral: 100 ± 17%); and the two-pin model (2P) (AP: 141 ± 15%; lateral: 83 ± 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.

**Acknowledgements**

We give special thanks the 3M Canada Company for donating the elastics necessary to carry the project. We also thank Dr. Eugene Daniels, Dr. Geoffrey Noël, Mr. Robert L’Hereux, and Mr. Jamie Brisebois from McGill’s Anatomy department. As well, we thank Dr. Lawerence Stein, Dr. Brian Lee and Mrs. Dawn Starker for their time and the use of their radiology equipment.

**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 ownership/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.

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