Pull-Out Strength of 0°/30° Kirschner Wire Syringe External Fixators With and Without Polymer Augmentation: A Biomechanical Study

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Background: *Hand external fixators are in use worldwide and insulin syringes can generally be found in an operating room.*
Objective: *To compare the pull-out strength between degrees of Kirschner wire fixation (0° and 30°) and the effect of filling an insulin syringe with polymer.*
Material and Method: *Pull-out strength was compared between a syringe external fixator and a bone or plastic tube model. Fifty-two plastic tube models and 20 dry phalangeal bones were included. The syringe external fixator was attached via two Kirschner wires. Four variations were studied: 0° non-polymer, 0° with polymer augmentation, 30° non-polymer, and 30° with polymer augmentation. The pull-out strength was measured in each group.*
Results: *The strength of polymer augmentation was higher than non-polymer augmentation at 0° ($p = 0.0003$) and 30° ($p = 0.0002$). The Kirschner wire at 30° provided more pull-out strength than at 0° ($p = 0.0003$) using the syringe with no polymer. However, using the syringe with polymer augmentation, there was no significant difference ($p = 0.5136$).*
Conclusion: *Polymer augmentation significantly increases the pull-out strength at both degrees of fixation. The degree of fixation significantly increases the pull-out strength only in the non-polymer group, where pinning at 30° was superior to 0°.*

Keywords: *Biomechanical, Syringe external fixator, Pull-out strength, Degree of fixation, Polymer*

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Hand fractures represent approximately 30% of all fractures[1]. Although most hand injuries can be managed conservatively, complex fractures involving significant soft tissue injury require operative fixation. To avoid stiffness and extensive soft tissue dissection, external fixation is the appropriate option for these fractures[2,3]. External fixation can achieve rigid immobilization which facilitates bone healing while simultaneously allowing early motion at the adjacent joints[4]. Furthermore, removal of fixators can be accomplished under local anesthetic in the outpatient clinic[5].

There are many commercial hand external fixators available; however, fixators which provide adequate rigidity and also have a low profile can be created from materials generally found in an orthopedically equipped operating room. Advantages of those fixators over commercial devices include that they are radiolucent, allow for a multitude of different pin placements, have a low profile, and are less expensive. The complication risks and postoperative outcomes are comparable to other fixators[6].

At Chiang Mai University Hospital, the authors made an external fixator using a readily available and inexpensive insulin syringe as a rod. A small K-wire was connected between the bone and the insulin syringe. The result was good bone length preservation and maintenance of bony alignment. However, pulling of the K-wire from the rod as the result of unintentional external force was observed in some cases. A previous study found that the stability of a small external fixator increased with larger pin diameters, the number of pins on either side of the fracture, decreased distance of the side bar from the digit and decreased separation of the pins[7]. Nonparallel placement of pinning might also help stabilize the device. The addition of polymer, which is easily

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introduced into the syringe, might increase the pull-out strength after fixation. The purpose of the present study was to evaluate the effects of pin direction and the addition of polymer on the pull-out strength of the syringe external fixator to reduce the incidence of pulled out wires in complex hand fractures.

Material and Method

This biomechanical experiment was performed to assess pull-out strength of different systems. Syringe external fixators were attached to plastic tube models (insulin syringe one ml, Terumo®). A special resin-box template was used to guide the direction of the Kirschner wire fixation (0° parallel to vertical axis or 30° converging on the vertical axis). Two 1.6 mm K-wires with trochar tips were prepared to measure ultimate pull-out strength[8] and drilled to fix the syringe external fixators to the plastic tube models using the highest speed of an intraoperative minicompressed air drill (3,000 rpm). After that, all plastic tube models were filled with polymer (25 ml of unsaturated polyester resin mixed with six drops of catalyst). The syringe external fixators were adjusted according to the degree of K-wire fixation and polymer augmentation and were classified into four groups as follows.

In Group A, the plastic tube models were fixed with syringe external fixators without polymer at 0° of K-wire fixation parallel to the vertical axis (0° non-polymer). In Group B; syringe external fixators with polymer augmentation were attached to the plastic tube models at 0° parallel to the vertical axis (0° with polymer augmentation). In Group C, the fixation was performed at 30° converging on the vertical axis and there was no polymer augmentation in the syringe external fixators (30° non-polymer). In Group D, the syringe external fixators were augmented with polymer and were fixed to the models at 30° converging on the vertical axis (30° with polymer augmentation).

There were ten samples in each group (Fig. 1). Pull-out strength was evaluated using a tensile testing machine (Hounsfield® material testing machine H50K-S) with a custom holder provided by Rajamangala University of Technology Lanna Chiang Mai. The holder was attached to the midpoint of the syringe. The ultimate pull-out strength was evaluated using the QMAT Test Zone program (Fig. 2).

The insulin syringe external fixators were also used to test the pull-out strength of dry phalangeal bones (Fig. 2). The inclusion criterion was availability of both hands from one cadaver. Bones with previous fractures or other deformities were excluded. The protocol for the present research was approved by the Research Ethics Committee of the sponsoring institution.

The external fixators were attached at 30° converging on the vertical axis including seven samples with non-polymer syringes and seven samples with polymer-augmented syringes (Fig. 1). The results were compared to a group of plastic tube models also at 30° with polymer augmentation (Group D).

To determine the location of the failure junction, isolated pull-out strength was examined at the junction of the pin and the non-polymer insulin syringe, at the pin and the insulin syringe with polymer augmentation, and at the pin and the dry phalangeal bone. There were six samples in each group. Each sample was composed of a single K-wire with trochar tip fixed into the material (non-polymer insulin syringe, insulin syringe with polymer augmentation or dry phalangeal bone) (Fig. 3). The ultimate pull-out strength of each sample was measured using the same machine with the custom holder attached to the single pin at the midpoint of the syringe or bone.

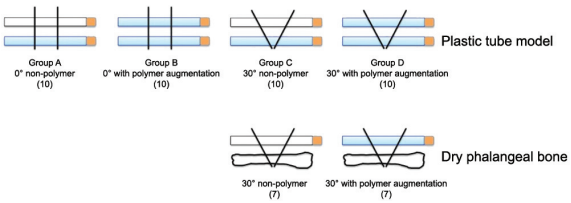

Fig. 1 The plastic tube models and dry phalangeal bone models (number of samples in each group).

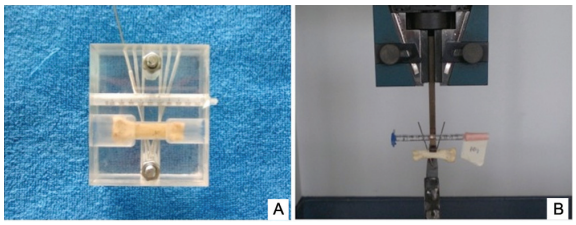

Fig. 2 (A) The special resin-box template used to guide direction of the Kirschner wire fixation. (B) The insulin syringe external fixator which was used to test the pull-out strength of dry phalangeal bones.

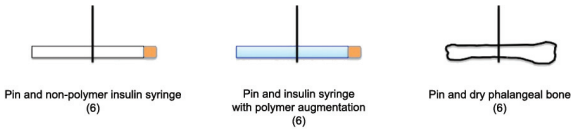

Fig. 3 The three groups of failure junction tests.

Statistical analysis

The pull-out strength studies were evaluated using the SPSS version 15.0 software program. The results were analyzed by non-parametric test (Mann-Whitney U test or Wilcoxon rank sum test when comparing two groups, and Kruskal-Wallis test when comparing three or more groups).

Results

One sample from Group B (0° with polymer augmentation) was excluded because of dilapidation. In the pull-out strength study, the mean ultimate pull-out strength of Group A (0° non-polymer), Group B (0° with polymer augmentation), Group C (30° non-polymer) and Group D (30° with polymer augmentation) were 14.7 N (6.9-28.2), 139.5 N (23.2-240), 32.1 N (26.5-50.3) and 151.7 N (72.8-193), respectively.

The failure points were located at the junction between the pin and the polymer-augmented syringe in the polymer augmentation, while the non-polymer group failure points were at the junction between the pin and the non-polymer syringe (Fig. 4).

Comparison of the effect of polymer augmentation at both 0° and 30° of fixation showed that polymer augmentation had a significantly higher pull-out strength than non-polymer augmentation in both Group A (0° non-polymer) versus Group B (0° with polymer augmentation) ($p = 0.0003$) as well as in Group C (30° non-polymer) versus Group D (30° with polymer augmentation) ($p = 0.0002$).

Comparison of the effect of the degree of fixation in the non-polymer syringe found that Group A (0° non-polymer) had a significantly lower pull-out strength than Group C (30° non-polymer) ($p = 0.0003$). No statistically significant difference was found between fixator angles with polymer augmentation at 0° (Group B) and at 30° (Group D) ($p = 0.5136$).

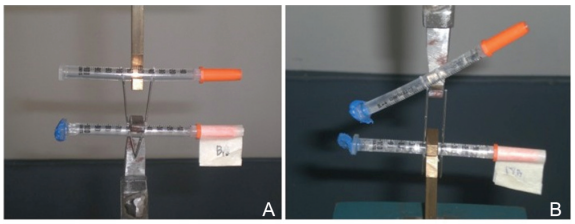

Fig. 4 Failure points in the pull-out strength models: (A) at the junction between the pin and the non-polymer syringe in the 30° non-polymer group, (B) at the junction between the pin and the polymer-augmented syringe in the 0° with polymer augmentation group.

In the syringe external fixator attached to the phalangeal bone models, the mean ultimate pull-out strengths at 30° for non-polymer and for polymer augmentation were 25.9 N (20.8-29.6) and 117.8 N (54.8-141.1), respectively. The failure point was always at the junction between the pin and the bone in the polymer augmentation groups, while failure in the non-polymer groups occurred at the junction between the pin and the non-polymer syringe. Comparison of the two groups showed that the polymer augmentation group had a significantly higher pull-out strength than the non-polymer group ($p = 0.0017$), which parallels the results of the syringe external fixator fixed to the plastic tube models.

No statistically significant difference in pull-out strength was found between the 30° with polymer augmentation group (Group D) and the dry phalangeal bone group ($p = 0.2367$).

In the junction failure study, the values for mean isolated pull-out strength of the pin and the non-polymer insulin syringe, of the insulin syringe

Table 1. Overall pull-out strength in each group

Attachment	Syringe external fixator model	Mean (N.)	Standard deviation
Syringe with polymer augmentation	Group A: 0° non-polymer (10)	14.7 (6.9-28.2)	6.5
	Group B: 0° with polymer augmentation (9)	139.5 (23.2-240.0)	64.0
	Group C: 30° non-polymer (10)	32.1 (26.5-50.3)	6.7
	Group D: 30° with polymer augmentation (10)	151.7 (72.8-193.0)	36.6
Dry phalangeal bone	30° non-polymer (7)	25.9 (20.8-29.6)	2.7
	30° with polymer augmentation (7)	117.8 (54.8-141.1)	30.1
Failure junction	Non-polymer (6)	10.3 (7.0-13.3)	2.5
	Polymer augmentation (6)	43.4 (34.7-53.3)	6.1
	Dry phalangeal bone (6)	47.6 (22.0-73.7)	20.1

N. = newton

with polymer augmentation and of the dry phalangeal bone were 10.3 N (7.0-13.3), 43.4 N (34.7-53.3) and 47.6 N (22.0-73.7), respectively. The isolated pull-out strength of the pin and non-polymer insulin syringe was significantly lower than the others ($p = 0.0018$). However, there was no statistically significant difference between the pin and insulin syringe with polymer augmentation and the pin and dry phalangeal bone ($p = 0.5000$).

Discussion

In 1974, Crockett[9] was the first investigator to describe the technique of external fixation using K-wires bonded with methyl methacrylate resin. Those early fixators lost popularity as they were cumber some and otherwise not ideal for hand fracture treatment. Many recent papers on external fixators in hands have reported good clinical outcomes using different external fixation materials[5,10-17]. However, there has been only limited supporting data from biomechanical studies.

The authors employed an insulin syringe, which is small in size, readily available and inexpensive, in treating complex hand injuries. Clinical outcomes following a period of follow-up were acceptable; however, it was anticipated that filling the syringe with unsaturated polyester resin and increasing the degree of Kirschner wire fixation might improve the stability of the syringe external fixator.

Namba et al[8] studied the pull-out strength of K-wire fixation in thirteen canine metacarpals and reported that a wire with a trochar tip configuration achieved the highest pull-out force. Based on that result, this study used the trochar tip configuration, but with a drilling speed of approximately 3,000 rpm, similar to that used in actual cases.

To overcome the potential impact of mismatches in size, density, and strength of the bones, the pull-out strength of plastic tube models was compared to dry phalangeal bones. The results showed no statistical significance between the groups. The junctional study of isolated pull-out strength confirmed those findings, demonstrating that the plastic tube models were a good representation of the phalangeal bones.

The addition of polymer augmentation resulted in a significantly increased pull-out strength with both 0° and 30° of fixation. These results are in agreement with the ultimate pull-out strength measurements which found that both the polymer augmentation model and the phalangeal bone model had a higher pull-out strength than the non-polymer model.

The present study shows that in situations where Kirschner wire fixation cannot be achieved in a converging direction due to the fracture configuration, a polymer augmented syringe can be used as an external fixator. In the absence of polymer augmentation of the syringe, it is crucial that convergent Kirschner wire fixation should be performed to increase the pull-out strength.

Conclusion

The present experimental study demonstrates that polymer augmentation increases pull-out strength in both degrees of fixation. The degree of fixation significantly increased the pull-out strength only in the non-polymer group, where pinning at 30° was superior to 0°.

Limitations

The present study was limited in that it did not examine other modes of pull-out strength. In addition, the number of samples in this study was limited. Cyclical loading experimental studies should also be undertaken.

What is already known on this topic?

There is an experimental study from Stuchin et al in 1984 found that the stability of a small external fixator increased with larger pin diameters, the number of pins on either side of the fracture, decreased distance of the side bar from the digit and decreased separation of the pins.

What this study adds?

The polymer augmentation increases the pull-out strength of the syringe external fixator in both 0 and 30 degrees of fixation. The degree of fixation significantly increased the pull-out strength only in the syringe external fixator without polymer, where pinning at 30° was superior to 0°.

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Potential conflicts of interest

None.

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แรงดึงถอนของอุปกรณ์ดามกระดูกจากภายนอกโดยใช้หลอดฉีดอินซูลินกับลวดโลหะในการยึดกระดูกมือในปัจจัยขององศาการยึดของลวดโลหะที่แตกต่างกันและผลของการเสริมโพลิเมอร์

พิชิตชัย อรรถโกมล, นพดล วังจิระพันธ์, ศุภชาติ กรุดทอง, จิรศักดิ์ ปัญญา, ศิริชัย ลือวิฑูรเวชกิจ, จิรชาติ ไกรศรินท์, คณิตศ์ สนั่นพานิช

ภูมิหลัง: *อุปกรณ์ดามกระดูกมือจากภายนอกมีใช้อย่างแพร่หลายและหลอดฉีดอินซูลินเป็นอุปกรณ์ที่หาง่าย*
วัตถุประสงค์: *เพื่อเปรียบเทียบแรงดึงถอนของอุปกรณ์ดามกระดูกจากภายนอกโดยใช้หลอดฉีดอินซูลินในการยึดที่องศาแตกต่างกันและผลของเสริมโพลิเมอร์*
วัสดุและวิธีการ: *ศึกษาแรงดึงถอนระหว่างอุปกรณ์ดามกระดูกจากภายนอกกับหลอดฉีดอินซูลินเสริมโพลิเมอร์ 52 ตัวอย่าง และกระดูกนิ้วมือ 20 ตัวอย่าง ในแง่ของปัจจัยจากการเสริมโพลิเมอร์และองศาการยึดลวดที่ 0 และ 30 องศา*
ผลการศึกษา: *การเสริมโพลิเมอร์เพิ่มแรงดึงถอนมากกว่ากลุ่มที่ไม่เสริมอย่างมีนัยสำคัญทางสถิติทั้ง 0 องศา ($p = 0.0003$) และ 30 องศา ($p = 0.0002$) ในส่วนของความแตกต่างขององศาการยึดลวดในกลุ่มที่ไม่เสริมโพลิเมอร์ที่ 30 องศา มีความแข็งแรงกว่า 0 องศา อย่างมีนัยสำคัญทางสถิติ ($p = 0.0003$) ในขณะที่กลุ่มเสริมโพลิเมอร์พบว่าไม่มีความแตกต่างกันที่ 0 และ 30 องศา ($p = 0.5136$)*
สรุป: *การเสริมโพลิเมอร์ช่วยเพิ่มแรงดึงถอนทั้งระบบในการยึดลวดที่ 30 และ 0 องศา ในขณะที่ปัจจัยด้านองศาการยึดลวดมีผลเฉพาะกลุ่มที่ไม่เสริมโพลิเมอร์เท่านั้นโดยการยึดลวดที่ 30 องศา มีความแข็งแรงกว่า 0 องศา*