

Metacarpal fractures fixation with four knots, two lateral intraosseous wire loops fixation: a biomechanical study

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Objective : *To compare the strength of fixation between new technique of metacarpal fixation by four knots, two lateral intraosseous wire loop fixation with standard technique.*

Research design : *Experimental study.*

Material and Methods : *An experimental study about strength under four point bending stress of two bony fixation techniques which were 1.) four knots, two parallel lateral intraosseous wire loops fixation; and 2.) four knots, two crossed lateral intraosseous wire loops fixation compared with a standard technique (90-90 intraosseous wire loops fixation) in 39 embalmed human metacarpal specimens.*

Results : *Results showed that four knots, two parallel lateral intraosseous wire loops fixation gave higher bending stiffness and yield load higher than the standard technique ($p = 0.0001$ and 0.001 respectively) whereas four knots, two crossed lateral intraosseous wire loops fixation gave lower bending stiffness and yield load lower than the standard technique ($p=0.613$ and 6.7×10^{-6} respectively).*

การศึกษากลไกการยึดของลวดลูปแบบใหม่ที่ใช้ในการยึดกระดูกฝ่ามือและกระดูกนิ้ว
ด้วยลวดลูปแบบใหม่ที่ใช้ในการยึดกระดูกฝ่ามือและกระดูกนิ้ว
ด้วยลวดลูปแบบใหม่ที่ใช้ในการยึดกระดูกฝ่ามือและกระดูกนิ้ว

Conclusion : We concluded that the four knots, two parallel lateral intraosseous wire loops fixation which was easier to make. It is a new technique that provides sufficient strength for fixation of metacarpal and phalangeal fractures.

Keywords : Metacarpal fracture, Wire loop fixation, Biomechanical study.

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บุญสมรงค์ สิทธิพงศ์, อติศร ภัทรธาตุลย์, ประวิทย์ กิตติดำรงสุข. การทดลองความแข็งแรงของการยึดตรึงกระดูกมือด้วยวิธีมัดห่วงลวดแนวด้านข้างสองเส้น. *จุฬาลงกรณ์เวชสาร* 2545 ๕.ค; 46(12): 953 - 62

วัตถุประสงค์ : เพื่อศึกษาความทนทานต่อการหักงอของวิธีการมัดลวดแนวด้านข้างสองเส้น ในการยึดตรึงกระดูกมือ เทียบกับวิธีมาตรฐาน

รูปแบบการวิจัย : การวิจัยเชิงการทดลอง

วัสดุและวิธีการ : การศึกษาทางกลศาสตร์เปรียบเทียบความแข็งแรงในการหักงอใน *Four point bending stress* ของการมัดลวดสองห่วงด้านข้างในแนวขนานกัน และกลุ่ม การมัดลวดสองห่วงด้านข้างในแนวไขว้ เปรียบเทียบกับวิธีการมัดลวดสองห่วง ในแนวตั้งฉากกัน ในกระดูก *Metacarpal* ของอาจารย์ใหญ่จำนวน 39 ชิ้น โดยทำการศึกษาในช่วงระหว่าง กรกฎาคม 2543 ถึง มีนาคม 2545

ผลการศึกษา : พบว่าการมัดลวดสองห่วงด้านข้างในแนวขนานกัน ให้ความแข็งแรงและใช้แรงที่ทำให้กระดูกเคลื่อนจากกันมากกว่าวิธีมัดลวดแบบสองห่วงตั้งฉากกัน ($p = 0.0001$ และ 0.001 ตามลำดับ) ส่วนวิธีมัดลวดสองห่วงด้านข้างในแนวไขว้ ให้ความแข็งแรงและใช้แรงที่ทำให้กระดูกเคลื่อนจากกันน้อยกว่าวิธีมัดลวดแบบสองห่วงตั้งฉากกัน ($p = 0.613$ และ 6.7×10^{-6} ตามลำดับ)

สรุป : สรุปได้ว่าการมัดลวดสองห่วงด้านข้างในแนวขนานกัน ซึ่งเป็นวิธีใหม่ที่น่าเสนอ ให้ความแข็งแรงในการยึดตรึงกระดูกมือ และนิ้วมือได้เพียงพอจน และสามารถทำได้ง่ายกว่าการมัดลวดแบบสองห่วงตั้งฉากกัน

According to Richard K. Vanik and Robert C. Weber et al.⁽¹⁾ in 1981, a biomechanical study of embalmed human specimens were stressed under apex dorsal bending. Results showed that dorsal plating gave the highest strength for fixation. While two 90-90 intraosseous wire loops fixation gave the highest strength in intraosseous wiring groups, comparable with dorsal plating group. In clinical practice, however soft tissue dissection prior to the application of intraosseous wiring is less than dorsal plating, and thus it gives less soft tissue injury. Furthermore, the intraosseous wiring uses smaller implant that interfere less with the gliding motion of the extensor tendons; it is also more economical and requires only the use of general instruments in its application. But in the 90-90 intraosseous wire loops, there is a difficulty to apply a dorsovolar wire loop while passing a wire loop to the volar side and the knot often interferes with the gliding of the extensor tendon.

We hereby propose a new wiring technique that has four knots, two lateral intraosseous wire loops fixation. The technique required less soft tissue

dissection, less interference with gliding of tendon motion. Therefore, we studied a biomechanical strength in comparison with the standard technique, 90-90 intraosseous wire loops fixation.

Materials and Methods

The second to the fifth metacarpal bones of forty embalmed human metacarpal specimens were selected. One specimen was excluded due to its fracture. The remaining thirty-nine specimens, nineteen specimens were from right hand side and twenty specimens from the left hand side. Twenty specimens were from males and nineteen from females. All specimens were cut in mid-length by a bone saw and divided into three groups with thirteen specimens in each group. Experimental groups were the first and the second groups while the third was a control. Age of cadavers were ranged between 65 to 70 years (67.95 ± 1.75 years). Their antero-posterior diameters ranged between 5.5 to 10.4 millimeters. (7.87 ± 1.08 mm) There were no different in age and sex distribution of each group ($p = 0.171$ and 0.194 see Table 1 and 2).

Table 1. Result data shows age, sex, antero-posterior diameters, stiffness, yield load and yield displacement from the experimental groups (group I and II) and the control group (group III).

| | Age | Sex | AP Diameter (mm) | Stiffness (N/mm) | Yield Load (N) | Yield Displacement (mm) |
|---------|-----|-----|------------------|------------------|----------------|-------------------------|
| Group I | 68 | M | 9.1 | 99.33 | 112.38 | 0.63 |
| | 68 | M | 9.1 | 173.40 | 182.89 | 3.49 |
| | 68 | M | 7.1 | 98.61 | 102.66 | 1.01 |
| | 68 | M | 7.1 | 142.74 | 103.79 | 1.01 |
| | 68 | M | 7.1 | 140.37 | 109.73 | 3.04 |
| | 68 | M | 7.9 | 125.96 | 141.07 | 1.04 |

Table 1. Continuous.

| Age | Sex | AP | Diameter (mm) | Stiffness (N/mm) | Yield Load (N) | Yield Displacement (mm) |
|------------------------|-----|----|------------------|---------------------|-------------------|----------------------------|
| | 68 | M | 7.9 | 251.48 | 127.05 | 1.02 |
| | 68 | M | 7.9 | 303.85 | 157.74 | 3.05 |
| | 70 | F | 7.7 | 59.66 | 97.23 | 0.75 |
| | 70 | F | 7.7 | 298.47 | 95.47 | 3.16 |
| | 65 | F | 8.9 | 154.83 | 153.85 | 1.12 |
| | 65 | F | 8.9 | 275.90 | 130.48 | 0.74 |
| | 65 | F | 8.9 | 315.54 | 138.84 | 3.43 |
| Group II | 68 | M | 7.2 | 26.22 | 14.64 | 2.04 |
| | 65 | F | 5.5 | 25.03 | 26.00 | 1.06 |
| | 68 | M | 6.5 | 73.50 | 26.84 | 1.11 |
| | 68 | F | 6.8 | 26.31 | 33.72 | 2.04 |
| | 68 | M | 10 | 66.11 | 33.82 | 1.03 |
| | 68 | F | 8.6 | 102.43 | 50.05 | 3.27 |
| | 68 | M | 6.5 | 51.00 | 50.15 | 1.03 |
| | 65 | F | 7.1 | 62.95 | 53.27 | 3.1 |
| | 68 | M | 6.8 | 24.56 | 53.34 | 1.01 |
| | 68 | M | 7.2 | 18.75 | 62.57 | 0.69 |
| | 68 | F | 10.4 | 62.90 | 62.69 | 2.18 |
| | 68 | M | 6.5 | 74.41 | 67.40 | 2.13 |
| | 68 | M | 9.1 | 82.91 | 82.44 | 1.71 |
| Group III (Control) | 68 | M | 6.5 | 74.20 | 91.67 | 0.53 |
| | 70 | F | 8.1 | 175.44 | 115.87 | 0.19 |
| | 70 | M | 8.1 | 85.78 | 108.78 | 0.41 |
| | 70 | F | 8.1 | 99.79 | 94.16 | 3.05 |
| | 70 | F | 9.1 | 106.99 | 108.78 | 1.18 |
| | 70 | M | 9.1 | 83.61 | 94.16 | 1.02 |
| | 70 | F | 9.1 | 90.40 | 115.87 | 3.04 |
| | 70 | F | 7.1 | 37.80 | 82.74 | 1.01 |
| | 70 | F | 7.1 | 45.59 | 60.62 | 1.02 |
| | 70 | F | 7.1 | 39.99 | 91.67 | 3.01 |
| | 65 | M | 8.1 | 67.40 | 74.37 | 1.32 |
| | 65 | F | 8.1 | 70.38 | 83.26 | 1.01 |
| | 65 | F | 8.1 | 99.87 | 108.78 | 3.28 |

Table 2. Results show comparison of mean data between experimental groups and control group.

| Groups | Age(year) | Sex | AP Diameter (mm) | Stiffness (N/mm) | Yield Load (N) | Yield Displacement (mm) |
|-------------------------------|--------------|----------------------|---------------------|------------------------|--------------------------|----------------------------|
| Group I | 67.61 ± 1.66 | 8 males | 8.1 ± 0.78 | 187.70 ± 89.18 | 127.16 ± 26.86 | 1.80 ± 1.18 |
| | (65-70) | 5 females | (7.1 - 9.1) | (59.66 - 315.54) | (95.47 - 182.89) | (0.63 - 3.49) |
| <i>p value</i> ⁽¹⁾ | | | | 0.0001 | 0.01 | |
| Group II | 67.53 ± 1.12 | 8 males | 7.28 ± 1.31 | 27.04 ± 7.50 | 47.45 ± 19.36 | 1.72 ± 0.82 |
| | (65 - 68) | 5 females | (5.5-10.4) | (18.75 - 102.43) | (14.64 - 82.44) | (0.69 -3.27) |
| <i>p value</i> ⁽²⁾ | | | | 0.613 | 6.7×10 ⁻⁶ | |
| Group III | 68.69 ± 2.17 | 4 males | 8.25 ± 0.89 | 35.96 ± 9.97 | 94.66 ± 16.72 | 1.54 ± 1.12 |
| (Control) | (65 - 70) | 9 females | (7.1-10.1) | (37.80 - 175.44) | (60.62 - 115.87) | (0.19 - 3.28) |
| | | Total 20 males | | | | |
| | | 19 females | | | | |
| <i>p value</i> ⁽³⁾ | 0.171 | 0.194 ⁽⁴⁾ | 0.143 | 1.8 × 10 ⁻⁶ | 1.39 × 10 ⁻¹⁰ | 0.812 |

⁽¹⁾ *p value* of ANOVA test in comparison between the first group and the third group

⁽²⁾ *p value* of ANOVA test in comparison between the second group and the third group

⁽³⁾ *p value* of ANOVA test in comparison between groups

⁽⁴⁾ *p value* of Chi-square test in comparison between groups

First Group: all specimens were drilled with 0.8 millimeters diameter Kirschner wire in horizontal plane, two holes on each side and 5 millimeters away from the cut surface. Two parallel intraosseous wire loops were made in horizontal plane with 24-gauge wire (0.6 mm diameter). Two knots were made in each wire loop. The wire loop was tightened on each side in the clockwise rotation until the wire did not move and the cutting surface was compressed together. (Figure 1A).

Second Group: holes were prepared and drilled like in the first group. A crossed lateral intraosseous wire loops was made. Each loop was cut and ended together before both ends were tightened in the clockwise rotation until the cutting

surface was compressed. (Figure 1B).

Third Group: holes of 0.8 mm diameter were drilled in the vertical and the horizontal planes in right angle position to each other. Each hole was 5 mm away from the cutting end. 90-90 wire loops were made with 24-gauge wire. Each loop had one knot. The cutting ends of the two wire loops were together twisted in the clockwise rotation until the wires were tensed and there was no more movement of the wire loops and the compressed surface (Figure 1C).

All the 39 specimens were stressed under four-point bending with Instron machine number 5583. The upper (volar side) contact distance was 16 mm and lower (dorsal side) contact distance was 32 mm. Cross head speed of the compression was constant



Figure 1. Antero-posterior and lateral views of experimental group A: Four knots, two parallel lateral intraosseous wire loop fixation; B: Four knots, two crossed lateral intraosseous wire loop fixation and C: Control group, 90-90 wire loops fixation.

at 0.5 mm. per minute (Figure 2). The end-points of compression were evidence by any bony separation of fixation. Recorded force (Newton) and displacement of bone end (millimeters). A load-deformation curve was made which graph slope in elastic phase represented stiffness (N/mm) and maximum force in elastic phase represented yield load (N) (Figure 3).

The mean data of stiffness and yield load of experimental groups (the first and the second groups) were compared to the control group (the third group).

We used one-way ANOVA test with significant level at 0.05 to compare difference of mean between groups (Table 2).

Results

After the specimens were stressed under load till failure of fixation, bone end were separated in vertical (dorso-volar) direction. There were plastic deformation of the wire loops but no wire loop rupture nor bone fracture was found.

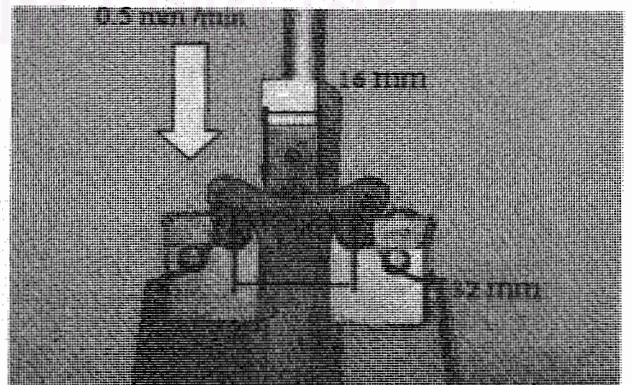
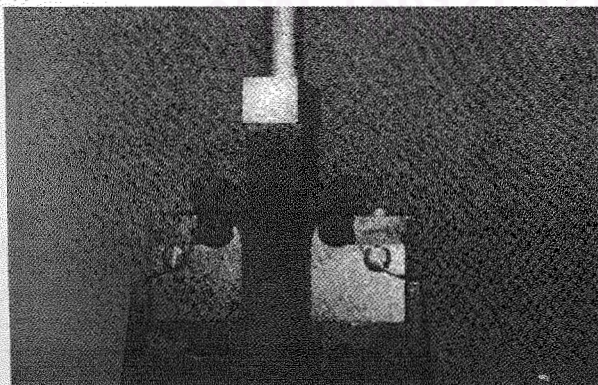


Figure 2. Specimen was stressed under four point bending by Instron machine.

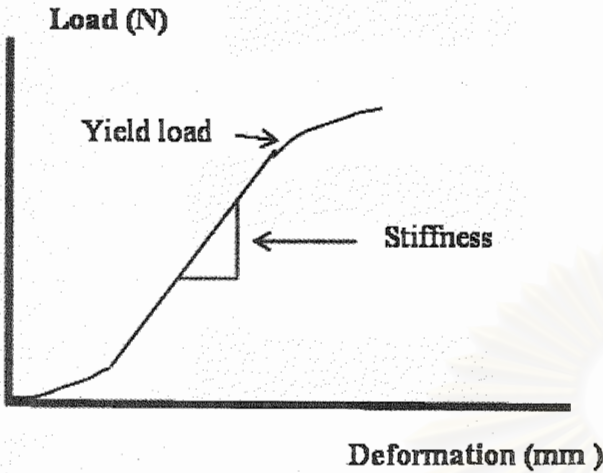


Figure 3. Load-deformation curve.

The mean antero-posterior diameter (mm) was 8.1 ± 0.78 in the first group; 7.55 ± 1.49 in the second group; and 7.97 ± 0.83 in the third group. The mean yield displacement (mm) at the failure point of fixation was 1.80 ± 1.18 in the first group; 1.72 ± 0.82 in the second group; and 1.54 ± 1.12 in the third group. There was no difference of mean antero-posterior

diameter ($p = 0.413$) and mean yield displacement ($p = 0.812$) between each group. The mean stiffness (N/mm) in the first group (187.70 ± 89.18) was higher than the control group (82.86 ± 35.96) ($p = 0.0001$). The mean stiffness in the second group (53.62 ± 27.04) was lower than the control group but without statistical significance ($p = 0.613$). The yield load (N) in the first group (127.16 ± 26.86) was higher than the control group (94.66 ± 16.72) ($p = 0.001$). The yield load of the second group (47.45 ± 19.36) was lower than the control group ($p = 6.7 \times 10^{-6}$). The first group represented four knots and two parallel lateral intraosseous wire loops fixation, the second group represented four knots and two crossed lateral intraosseous wire loops fixation. The control group (the third group) represented 90-90 wire loops fixation. All of the calculated data results were showed in Table 1 and 2, Figure 4.

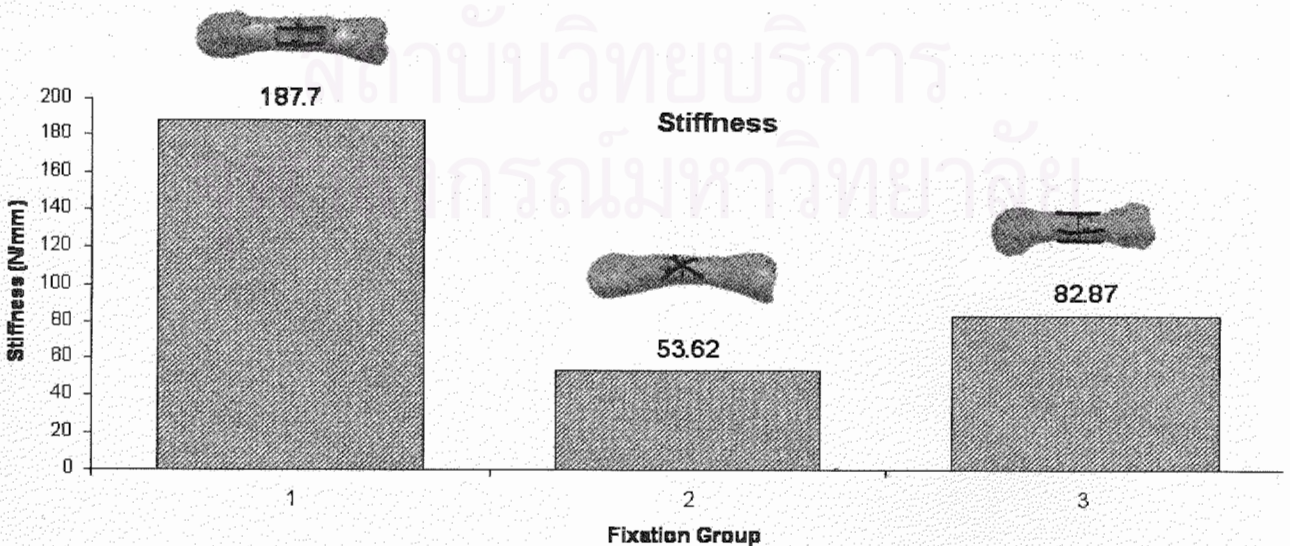


Figure 4. Graph shows average stiffness in each fixation group.

Discussion

In 1978, Graham Lister⁽²⁾ proposed his phalangeal fixation with intraosseous wiring. In 1981, Richard K. Vanik⁽¹⁾ studied the bending strength of metacarpal fixation. He stated that dorsal bone plating gave the highest bending strength. In intraosseous wiring group,⁽³⁻⁶⁾ 90-90 wire loops fixation gave the highest bending strength, comparable with dorsal bone plating.^(1,7-10) In clinical practice, dorsal bone plating requires more soft tissue dissection for plate application and the larger size than a wire, which may interfere with the gliding of the extensor tendon that can limit the full extension motion of the finger despite its postoperative rehabilitation.^(9,10) In the 90-90 wire loops fixation, dorsal wire knot often interfered with the gliding motion of the extensor tendon and it is difficult for the application of the vertical wire loop which requires a dissection of flexor tendon.

So we propose our new technique that made two parallel intraosseous wire loops in horizontal plane. Each wire loop was tightened on both sides, making totally four knots in two wire loops. Making wire loops in horizontal plane would irritate less degree to the gliding motion of both extensor and flexor tendons and requires less soft tissue dissection than the 90-90 wire loops fixation.

This study compared four-point bending strength in the vertical plane between two lateral wire loops fixation and the control group which were 90-90 wire loops fixation technique. We found that the two parallel lateral wire loops gave a higher bending strength than the control group as seen on bending stiffness ($p = 0.0001$) and yield load ($p = 0.001$). Although the two crossed lateral wire loops fixation gave lower bending stiffness than the control group

without statistical significance ($p = 0.613$) but the yield load was lower than the control group ($p = 6.7 \times 10^{-6}$). In this study, making lateral crossed wire loops was more difficult than parallel wire loops. The apposing bony surface usually slipped off while tightening the crossed wire loops. We thought that the technique of crossed lateral wire loops should not be used in clinical practice.

We concluded that the four knots, two parallel lateral intraosseous wire loops fixation gave higher biomechanical strength compared to the 90-90 wire loops fixation. The technique should be used in clinical practice. The wire knots were hidden on lateral side of bone not, interfered with the gliding motion of extensor tendon. It also provided appropriate mechanical strength for fixation to facilitated early motion exercise for hands and fingers.

However, the study also had a number of limitations. The size was too small, despite their statistical significant data. The biomechanical testing was performed only on vertical (dorso-volar) direction, which could not represent other directional forces like the lateral bending or the axial rotation. All specimens were taken from embalmed human specimens which might had different biomechanical properties compared to fresh bone specimens; additionally, all the surrounding soft tissue factors were not included into the study. Furthermore, this was the beginning study and had no supported clinical data which requires more research work in the future.

Conclusion

The four knots, two parallel lateral intraosseous wire loops fixation provides a rapid and rigid internal fixation of the digital skeleton and it gives a higher

bending strength than 90-90 wire loops fixation. This study proposes a technique which should be used in clinical practice.

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