

The effect of an additional core suture during Pulvertaft tendon repair: a fresh-frozen cadaver study

(Pulvertaft 腱縫合に追加した core suture の影響について)

千葉大学大学院医学薬学府

先端医学薬学専攻

(主任：大鳥精司教授)

戸口泰成

ABSTRACT

Purpose

Pulvertaft tendon repair is a strong suture technique; however, proper tendon tension is impaired by repair site elongation. Therefore, methods to reduce postoperative elongation are warranted. This study aimed to determine the effects of additional core sutures during Pulvertaft tendon repair on repair site elongation and rupture strength.

Methods

A total of 48 finger extensor tendons were harvested from fresh-frozen cadavers, and tendons with similar diameters were paired. The 24 pairs of tendons were divided into the following 4 groups: group I, 3 interlaced weaves only; group II, 3 interlaced weaves and 2 core suture strands with 4-0 nylon; group III, 3 interlaced weaves and 2 core suture strands with 4-0 FiberWire; and group IV, 4 interlaced weaves only. Each sutured tendon was placed in a Universal Testing Machine, and repair site elongation after repeated traction loads and rupture strength were measured.

Results

The mean elongation values were 2.74 ± 0.84 mm, 1.80 ± 0.16 mm, 1.60 ± 0.18 mm, and 1.92 ± 0.18 mm for groups I, II, III, and IV, respectively. The elongation values were significantly lower in groups II, III, and IV than in group I. The mean rupture strengths were 64.9 ± 16.0 N, 94.8 ± 17.2 N, 110.9 ± 21.3 N, and 104.9 ± 17.5 N for groups I, II, III, and IV, respectively. Rupture strengths were significantly higher for groups III and IV than for group I.

Conclusions

After adding core sutures during Pulvertaft tendon repair, the elongation amount decreased, and the rupture strength improved.

Clinical relevance

The study showed the effect of additional core sutures during Pulvertaft tendon repair, suggesting that it could be useful in reducing postoperative tendon elongation when extensor tendon transfers are performed.

Key words

Core suture, fresh-frozen cadaver, Pulvertaft tendon repair, rupture strength, suture elongation.

INTRODUCTION

Various suturing methods have been reported for tendon transfer and grafting for chronic tendon rupture and peripheral nerve palsy, including side-to-side sutures and the cow-hitch technique.^{1,2} Pulvertaft tendon repair is a strong tendon suture method that has shown good clinical results.³

Various biomechanical studies have compared the suture strength of a Pulvertaft tendon repair with that of other methods.⁴⁻⁹ Gabuzda et al⁴ performed a single traction test on the Pulvertaft tendon repairs of 1-5 weaves and demonstrated that the rupture strength increased with the number of weaves, up to 5 weaves. However, in clinical practice, the number of weaves cannot be increased because of the conditions of the surgical field and the limited lengths of donor and recipient tendons. Therefore, developing an auxiliary suture method or a modified method that increases repair strength even with a small number of weaves is desirable.

Although stable results have been achieved with tendon transfers of extensor tendons, no consensus has been reached on determining the tendon tension during suturing. However, when the wrist is moderately flexed, the fingers should be maintained in a completely extended position. When the wrist is moderately extended, the metacarpophalangeal (MP) joints should flex only 20 to 30°.¹⁰ Tada et al¹¹ stated that patients are more dissatisfied with postoperative flexion than with preoperative extension restrictions. Therefore, the tension of

the reconstructed tendon should be gauged with the carpal and MP joints in the neutral position. In addition, the extent to which the repair site, consisting of all weaves and sutures, elongates with postoperative rehabilitation is unclear. Thus, the determination of intraoperative tension at the repair site largely depends on the surgeon's experience, and repairs have been performed with slightly stronger tension to account for elongation.

Nishiura et al¹² performed a 2-weave Pulvertaft tendon repair with a 2-strand core suture using the Tsuge method and reported good results. However, the extent of improvements in rupture strength and prevention of repair site elongation compared with those of the usual Pulvertaft tendon repair are unclear. Van Royen et al¹³ added a 4-strand core suture using a running suture technique with a 4-0 Fiber-Wire during Pulvertaft tendon repair and reported a significant improvement in rupture strength. However, they did not evaluate the degree to which the elongation could be reduced. Therefore, we hypothesized that adding a core suture using the Tsuge method during Pulvertaft tendon repair would not only increase rupture strength but also decrease repair site elongation after repeated traction loading. The purpose of this study was to evaluate the effects of additional core sutures on repair site elongation and rupture strength.

MATERIALS AND METHODS

Experimental groups

We obtained 15 upper limbs from 8 fresh-frozen cadavers, including 6 men and 2 women with a mean age of 87.9 years (range, 74-103 years). This study was approved by the institutional review board of the authors' affiliated institutions. We excluded upper limbs damaged by injury or surgery and limbs paralyzed due to stroke or other neural dysfunctions. The upper limbs were thawed to room temperature (27 °C). The tendons of the extensor digitorum communis, extensor pollicis longus, extensor indicis, and extensor digiti minimi, were removed from the musculotendinous junction to the extensor hood. When all 105 tendons were collected and checked, some tendons were too thin, others consisted of several secondary tendons, and some had dried out during storage. After excluding tendons deemed unsuitable for experimentation, 48 tendons remained. Macroscopically, circular parts with nearly uniform diameters were used. The tendons were kept moist with saline mist during all procedures. Uniform tension at 5 N was applied to each tendon to remove slack. The circumference was measured with calipers by winding 1 round of number 3 silk thread around the tendon and then dividing the measurement by π to obtain the diameter. All tendons were paired (donor and recipient tendons) in ascending order of diameter, and the mean diameters of the donor and recipient tendons were calculated for each pair. Thereafter, the tendons were divided into the following 4 groups of 6 pairs each using a 1-way analysis of variance to ensure no significant differences in tendon diameters between the groups: group I, 3 interlaced weaves only; group II, 3 interlaced weaves and 2 core suture strands with 4-0

nylon; group III, 3 interlaced weaves and 2 core suture strands with 4-0 FiberWire (Arthrex, Inc); and group IV, 4 interlaced weaves only.

Pulvertaft tendon repair

All tendon sutures were performed by a single surgeon (Y.T.). The recipient tendon was placed on a traction table, and 5 N of tension was applied. Sutures were applied to both ends of the recipient tendon, and the tendons were placed on the traction table used in our previous study (Fig. 1).¹⁴ In that previous study, we investigated the relationship between tendon tension during suturing and the amount of repair site elongation after repeated traction tests. We found no significant differences in elongation above 5 N of tension. Therefore, we consistently applied 5 N of tension with weight during suturing. The first slit was made parallel to the recipient tendon fiber using a number 15 scalpel, and the donor tendon was passed through using forceps. To create each weave, the donor tendon was inserted at a 60° angle into the recipient tendon, referring to the guidelines on the traction table. The 5 N of tension was also applied to the donor tendon, and horizontal mattress sutures (2 sutures per weave) were performed with 4-0 nylon (Prolene; Ethicon Inc) according to the corner stitch shown by Tanaka et al.⁵ The second and subsequent weaves were sutured in the same way, with adjacent slits placed at 90° and the distance between slits set to 0 mm. After the final

weave, the tips of both tendons were cut off, leaving 5 mm, and the ends were left free without sutures.

Core suture

For the core suture in groups II and III, a 2-strand suture was used according to the Tsuge method, referring to the report by Nishiura et al.¹² We used 4-0 nylon (Tsuge Looped Suture; Crown Jun) or 4-0 FiberWire sutures. The suture was passed through both tendons from the recipient tendon, 5 mm proximal to the first weave, 5 mm distal to the final weave, and sutured under 5 N of tension (Fig. 2). Because the suture needle was short compared with the overlap distance of the tendons, the needle was moved out of the tendon once or twice and then reinserted into the tendon when passing through the overlap area of both the tendons. Using this procedure, we confirmed that there were no suture ruptures.

Biomechanical testing

All sutured tendons were subjected to mechanical testing using a Universal Testing Machine (AGXplus; Shimadzu Corporation). The sutured tendons were clamped at both ends at 1.5 cm and placed vertically on the mechanical testing machine. Doublesided sandpaper was used to

grip the tendons to prevent them from pulling out of the clamps. The lengths of the tendons were adjusted beforehand so that the distance between the upper and lower clamps was 10 cm. After applying a 2 N preload to the sutured tendon, repeated uniaxial traction of 5-15 N at a rate of 12.5 N/s was applied for 1000 cycles. The repair site elongation was measured (Fig. 3). Because the 5 N of tension was applied during tendon suturing, the repair site elongation after 1000 cycles was measured at 5 N of traction.

The sutured tendon was then pulled at a rate of 10 mm/s until rupture, and the rupture strength was measured (Fig. 4). This single traction test was videotaped to evaluate the failure mode. On the basis of the work of Tanaka et al,⁵ we classified the failure mode into the following 3 types: (1) suture failure, (2) pull-out of the tendon from the weave, and (3) intrasubstance rupture of the tendon. For groups II and III, the presence or absence of tears in the sutures used for the core suture was also recorded.

STATISTICAL ANALYSIS

The mean and SD of the tendon diameters, the elongations after repeated traction, and the rupture strengths obtained from the single traction test for each group were calculated. One-way analysis of variance followed by Tukey's *post hoc* analysis was used to determine statistical differences between groups. Bonferroni correction was not performed because of the small number of variables. *P* value of <.05 was considered significant.

RESULTS

Tendon diameter

The mean diameters of the tendons were 2.64 ± 0.24 mm, 2.59 ± 0.13 mm, 2.52 ± 0.21 mm, and 2.53 ± 0.24 mm for groups I, II, III, and IV, respectively.

Repair site elongation after repeated traction

The elongation data are shown in Figure 5. The mean elongation values were 2.74 ± 0.84 mm, 1.80 ± 0.16 mm, 1.60 ± 0.18 mm, and 1.92 ± 0.18 mm for groups I, II, III, and IV, respectively. The elongation values in groups II and III, in which core sutures were performed, and group IV were significantly lower than that in group I ($P = .016$, $P = .003$, and $P = .039$ for groups II, III, and IV, respectively) . Groups II and III exhibited the same amount of elongation as group IV.

Rupture strength

Rupture strength data are shown in Figure 6. The mean rupture strengths were 64.9 ± 16.0 N, 94.8 ± 17.2 N, 110.9 ± 21.3 N, and 104.9 ± 17.5 N for groups I, II, III, and IV, respectively.

The rupture strengths for groups III and IV were significantly higher than that for group I ($P < .05$), whereas groups III and IV exhibited similar rupture strengths.

Failure mode

Only 1 tendon in group I had a pull-out of the donor tendon because of a suture rupture in 1 of the 6 sutures for 3 weaves, which was determined to be a suture failure. All other ruptures were pull-out of the tendon from the weave. No intrasubstance rupture of the tendon was observed. Core suture rupture occurred in 4 of 6 tendons in group II but was not observed in group III.

DISCUSSION

The study showed that adding core sutures to Pulvertaft tendon repair using FiberWire significantly reduced elongation after repeated traction loading and significantly increased rupture strength. In clinical practice, the addition of a core suture to Pulvertaft tendon repair to improve rupture strength has been reported.¹² However, few studies have evaluated how it affects rupture strength or repair site elongation. Van Royen et al¹³ also showed increased rupture strength with an additional core suture using the running suture technique.

Nonetheless, we believe that our core suture using the Tsuge method may have an advantage in tendon gliding because the suture runs within the tendon.

The tension of 5-15 N in the repeated traction test in this study was set according to the tension required for hand MP joint extension.¹⁵ This test was designed to simulate early postoperative movements in clinical practice. Regarding the relationship between extensor tendon lengthening and MP joint extension lag, Strauch et al¹⁶ shortened the second and fifth metacarpals by osteotomy to create relative extensor tendon lengthening and measured the extension lag of the second and fifth MP joints, respectively, under a constant tension of 1.5 kg applied to the finger extensor muscles. They reported that for every 2 mm of bony shortening (2 mm of extensor tendon lengthening), the MP joint exhibited an extension lag of approximately 7°. In the current study, the additional core suture reduced elongation after the repeated traction load test by approximately 1 mm in groups II and III compared with that in group I. Therefore, we believe that the additional core suture can be expected to prevent an extension lag of 3.5° in the MP joint. Given that the MP joint has a reserve capacity for hyperextension, preventing the lag of the 3.5° MP joint extension in clinical practice is of little importance. However, we believe that the additional core suture improves rupture strength with fewer weaves, and this may be advantageous for tendon gliding because of the reduced number of weaves.

As for the mode of rupture, the donor tendon was generally pulled out, as shown in the report by Gabuzda et al,⁴ and only 1 case in group I showed suture failure with a suture tear in only 1 of the 6 sutures. In the core suture, the needle used in group II was an inverted triangular needle, and the needle used in group III was round. However, no suture tear was observed because of the core suture operation in either group, and no suture failure occurred during the rupture test. The possible damage to each suture may be further reduced by using a straight round needle when performing the core suture.

In the current study, there was a significant difference in rupture strength between the groups with 3 and 4 weaves. Gabuzda et al⁴ performed 1-5-weave Pulvertaft tendon repairs using mattress sutures and cross stitches. They showed that rupture strength increased with an increasing number of weaves, up to 5 weaves, but that intrasubstance rupture of the tendon occurred at higher weaves. Tanaka et al⁵ devised a corner stitch technique that preserves blood flow in the center of the tendon. This group showed that rupture strength was comparable to that of conventional cross stitch, and rupture strength increased with an increasing number of weaves, up to 3 weaves. Conversely, Choke et al¹⁷ conducted a study in which the number of sutures in Pulvertaft tendon repair was uniform, and the rupture strength was compared by increasing and decreasing the number of weaves. They found no significant differences in rupture strength above 2 weaves. In light of the reports by Gabuzda et al⁴ and Tanaka et al,⁵ the increased number of sutures associated with the increased number of

weaves may contribute more to improving repair site rupture strength than the increased number of tendon weaves. In the current study, we adopted corner stitch sutures for each weave and did not perform any suturing procedure on the tendon ends. We also did not evaluate core sutures using any suturing method other than the Tsuge method. Changing these suturing conditions may affect the rupture strength and elongation and should be investigated.

This study has limitations. First, the number of specimens was restricted to 6 per group because of the limited availability of cadaveric forearms. Because of this, we calculated the power of comparison as 0.75 for both repair site elongation and rupture strength, which did not meet the desired power analysis level of 0.80. However, a power of >0.75 is considered by many investigators as indicating a sufficient sample size for each study arm to provide conclusions. Second, given that this was an in vitro study, the effects of postoperative adhesion, friction, and healing between the tendon and surrounding tissues on the amount of elongation and rupture strength were not considered. Because these factors may be important, further research is warranted.

In conclusion, this study suggested that adding core sutures during Pulvertaft tendon repair using the Tsuge method can reduce elongation after repeated traction and increase rupture strength. We believe that the additional core suture may be an option for early and safe active exercise in clinical practice.

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FIGURE AND FIGURE LEGENDS

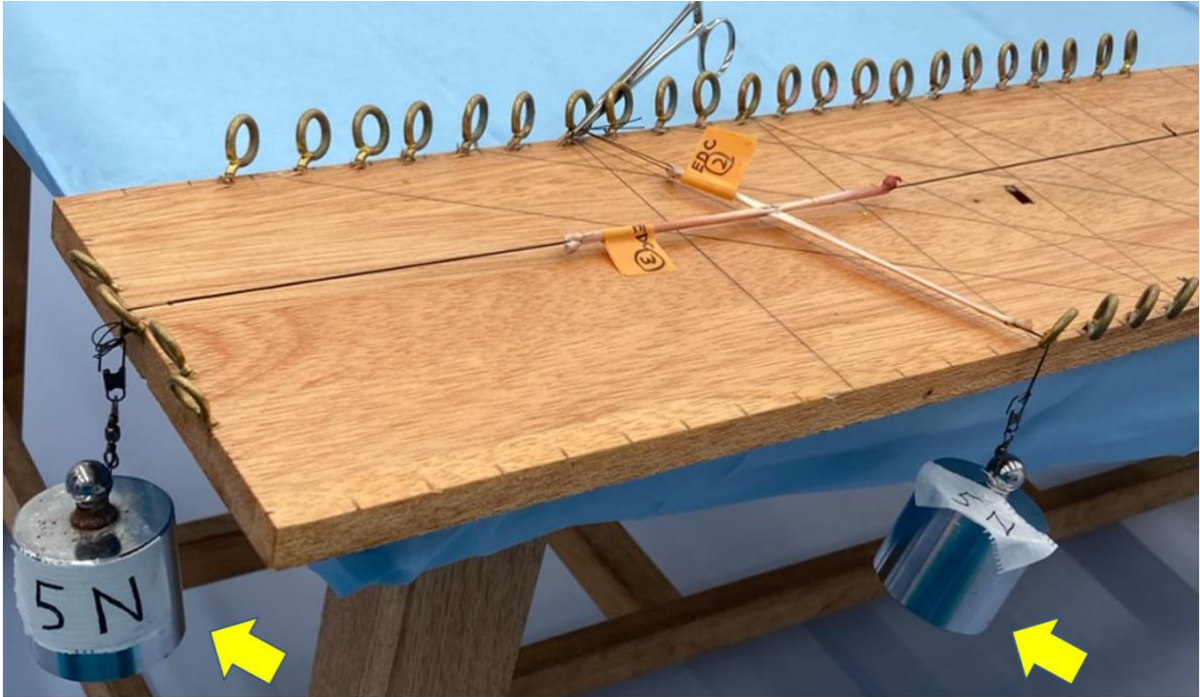


Figure 1: Traction table (arrows indicate 5 N weights).

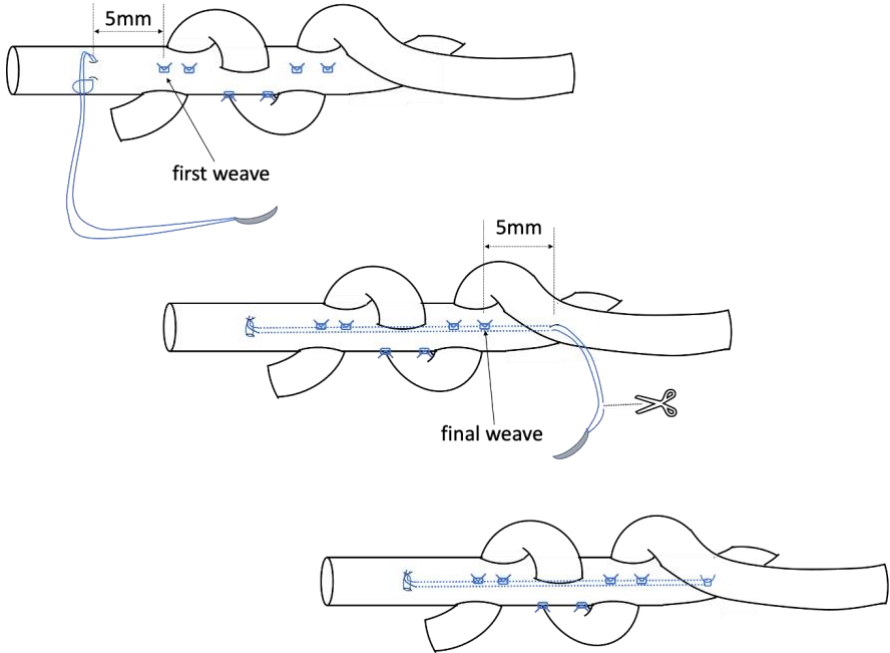


Figure 2: Additional core suture to the 3 interlaced weaves using the Tsuge method.

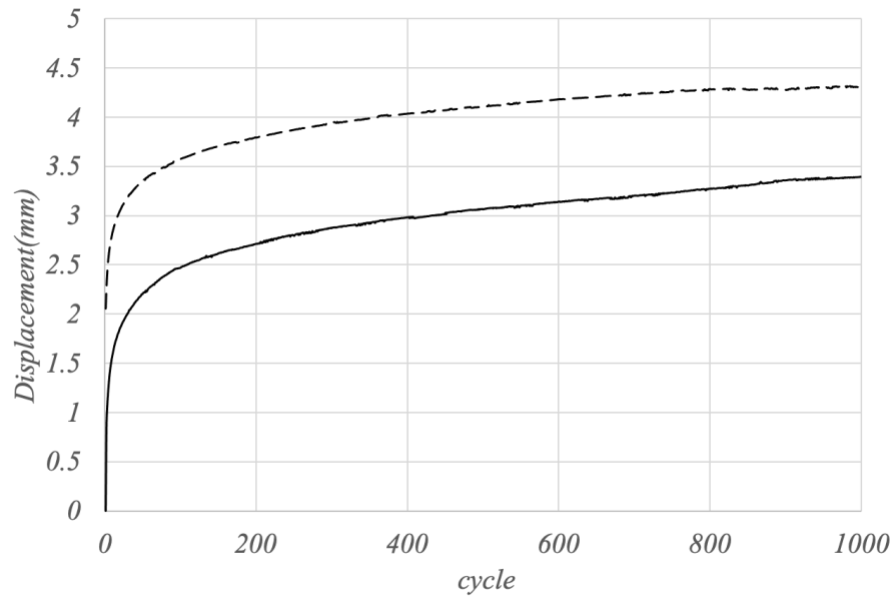


Figure 3: Displacement curve of repeated traction test for 1 case in group I. The solid line indicates displacement at 5 N (elongation), and the dashed line indicates displacement at 15 N.

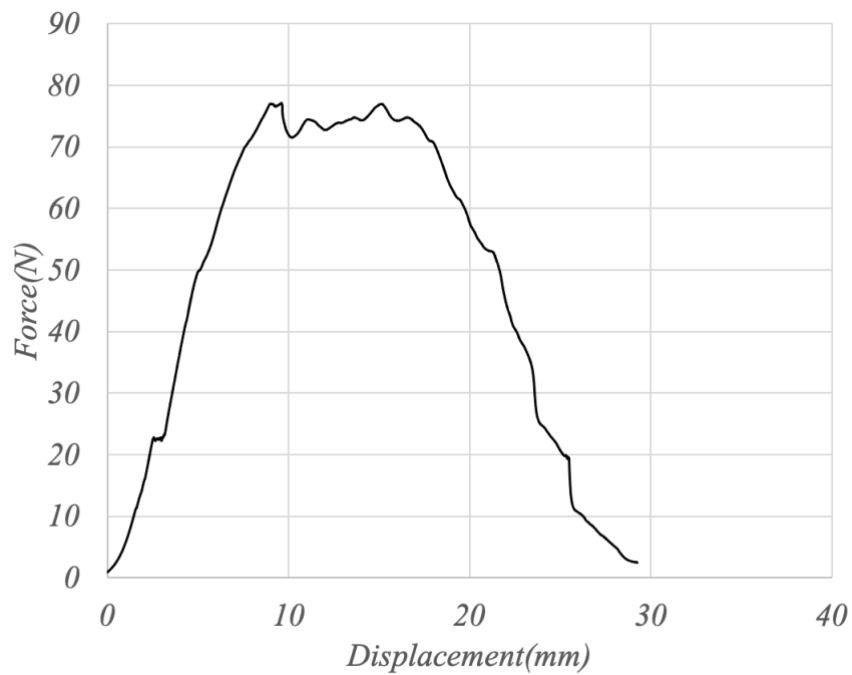


Figure 4: Force-displacement curve of single traction test for 1 case in group I.

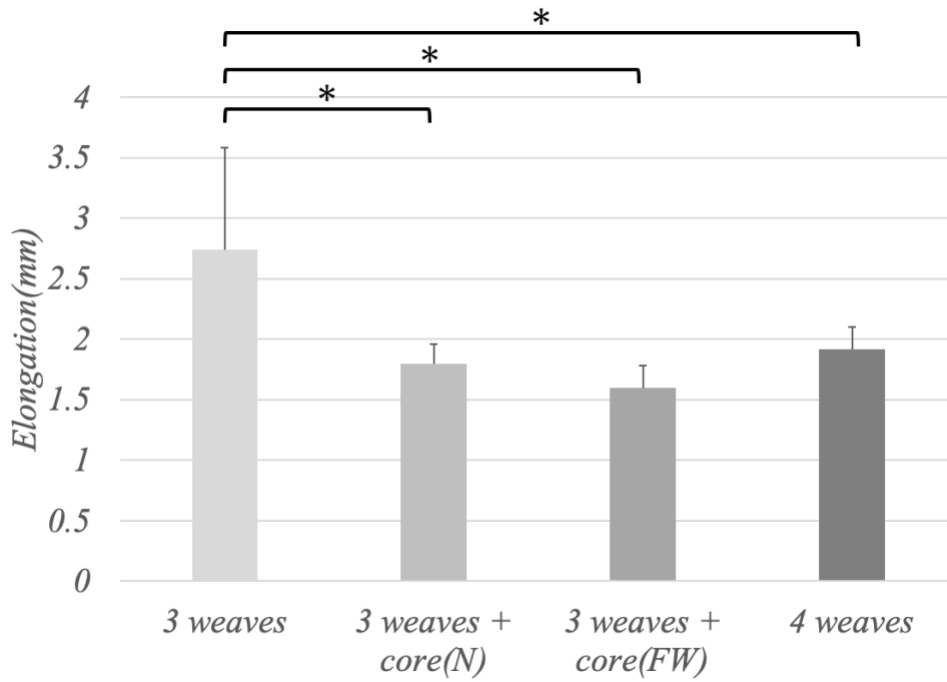


Figure 5: Elongation measurements for the 4 groups. Core (N) indicates core suture by nylon,

and core (FW) indicates core suture by FiberWire. The bars represent standard deviations.

The asterisks indicate statistically significant differences at a *P* value of <.05.

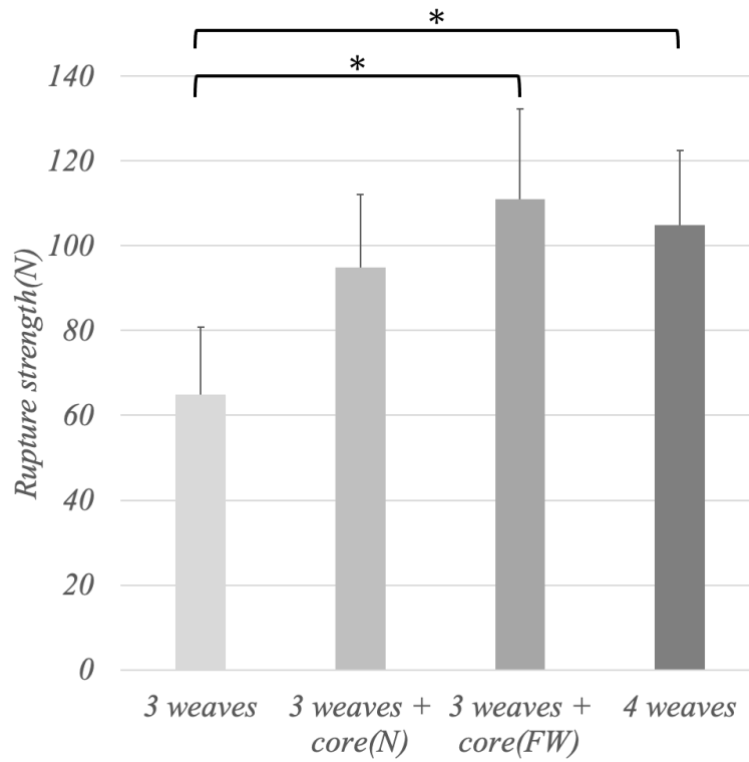


Figure 6: Rupture strength measurements for the 4 groups. Core (N) indicates core suture by nylon, and core (FW) indicates core suture by FiberWire. The bars represent standard deviations. The asterisks indicate statistically significant differences at a P value of $<.05$.

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