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Evaluation of Suture Elongation of Flexor Tendons using the Pulvertaft Method: a Biomechanical Study using Cadaveric Specimens

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SUMMARY

Background. Determining flexor tendon tension in Pulvertaft methods is challenging. The tendons are sutured slightly tightly in anticipation of a postoperative decrease in flexor tendon tension, but it is not possible to predict by how much the tension will decrease. The purpose of this study is to determine the flexor tendon stretch length after undergoing Pulvertaft repair using the cyclic loading test.

Methods. We obtained flexor tendons from fresh-frozen cadavers. We performed the flexor tendon suture using the Pulvertaft method from three to six weaves. We performed the cyclic loading tests to calculate suture stretch length. Next, we performed a single loading test to measure the failure load and record the mode of failure. We compared suture stretch length, failure load, and failure mode between the numbers of suture weaves.

Results. The stretched lengths of the woven tendons in the 3-, 4-, 5-, and 6-weave groups were 2.99 ± 0.33 mm, 2.60 ± 0.25 mm, 3.48 ± 0.30 mm, and 3.04 ± 0.21 mm in the cyclic loading test, respectively. The mean failure load values of the woven tendons were 115.8 ± 8.9 N, 162.8 ± 18.5 N, 226.4 ± 24.7 N, 306.7 ± 36.0 N, respectively, with a significant difference between the groups

Conclusions. Our study suggests that the use of the Pulvertaft method results in a stretch length of the sutured tendon by approximately 3 mm during rehabilitation. By performing the procedure while considering the postoperative stretching effect, it can be expected that better results will be obtained.

KEY WORDS

Interlacing suture; Pulvertaft method; biomechanical study; flexor tendons; cadaver specimen .

INTRODUCTION

Tendon reconstruction is necessary for tendon rupture, such as in rheumatoid arthritis and osteoarthritis, and for paralysis resulting from peripheral nerve disorder. Most tendon rupture cases present with defects. Therefore, tendon transfer and/or tendon graft surgery are often required. Although various suture methods, such as side to side (1), wraparound (2), and step cut (3, 4), have been reported, the Pulvertaft method is widely used.

Tension adjustment during surgery is very important in tendon reconstruction. Previous studies have reported that the Pulvertaft method can be used to easily adjust the degree of tension during surgery (5, 6). Loose tension at suturing results in a shortage of the active range of motion of the joint after the operation. Conversely, if the tension is too strong, the joint's range of motion will be limited.

Tension during the operation can be determined by estimating the graft length in an anesthetized patient via the relaxed position of the fingers with the wrist in a neutral position. Each finger should fall into semiflexion, which is slightly less flexed than its ulnar neighbor or more flexed than its adjacent radial finger (7). However, the tension of the tendon is often reduced after the Pulvertaft procedure, resulting in insufficient flexion of the hand

A lack of joint flexion may occur to some extent due to loosening of the weave of the tendon during the postoperative course. However, it is not clear to what extent the woven portion of the tendon will loosen. Using biomechanical tests, previous studies have proved that Pulvertaft methods have sufficient rupture strength to allow rehabilitation (8-11). These studies were single-traction tests, and the tension and length at which sutures break have been studied. However, no studies have examined the stretch effect of the intact tendon after repeated cyclic traction tests.

We hypothesized that if the degree of tendon stretch after the Pulvertaft procedure can be predicted, postoperative dysfunction can be reduced by suturing the tendon as tightly as per the prediction. The purpose of this study was to evaluate the stretching by repeated cyclic loading test assuming postoperative rehabilitation of the tendon and determine the rupture strength by single loading test after performing the Pulvertaft procedure in fresh-frozen cadavers.

MATERIALS AND METHODS

Tendon preparation

We obtained 6 upper limbs from 3 fresh-frozen cadavers (1 woman and 2 men with a mean age of 79.7 years [range: 74–85 years]). This research was approved by the Institutional Review Board of the authors' affiliated institutions (Graduate School of Medicine Chiba University Ethics Review Committee). Helsinki Protocol was followed. We excluded upper limbs damaged by injury or surgery and paralyzed due to stroke or other neural dysfunctions. The cadavers were not paralyzed. Immediately before the test, the harvested tendon was thawed and used at room temperature (27 °C) (12), and the specimens were kept moist with saline mist during all procedures. We used the flexor digitorum profundus tendons of the index, middle, ring, and small fingers (24 tendons); the flexor digitorum superficialis tendons of the index, middle, ring, and small fingers (23 tendons); and the flexor pollicis longus tendons (3 tendons). We removed the muscle-tendon transitions and parts of the chiasma. Macroscopically, a circular part with nearly uniform diameter was used. Moreover, we removed the lumbrical muscles and subsynovial connective tissues. To measure the circumference of both ends of the tendon of the part to be used, we used Nylon thread. We measured the circumference of the tendons by winding 6-0 Nylon around the tendon, cutting one place, and measuring it with a digital caliper (**figure 1**). From this value, we obtained the diameter using the circumference ratio. In addition, we obtained the average of both ends as the diameter of the tendon. We divided the specimens into 4 groups so that the diameter of the tendon was not significantly different between groups. We set the number of each weave to 3, 4, 5, and 6. The number of each sample was 5.

Figure 1. To measure the tendons, we wound 6-0 Nylon around the tendon, cut it one place, and measured it with a digital caliper.

Suture technique

The Pulvertaft technique was used to suture each tendon specimen. One surgeon performed all tendon sutures. We made a dedicated jig for suturing (**figure 2**). One tendon was tensioned with 5 N, and a small incision was made parallel to the fiber direction at the center of the tendon with a scalpel. The other tendon was passed to achieve a 60° angle between the tendons, and we used 2 sutures while applying a tension of 5 N to this tendon (**figure 3**). Suturing was carried out with a corner stitch by Tanaka *et al.* (13) using 4-0 Nylon (**figure 4**). In the next weave, a small incision was made toward the direction orthogonal to the small incision that was opened during the initial eave, and adjacent to each other in the longitudinal direction of the tendon. Furthermore, the tendon was passed through and sutured. This suture was repeated 3–6 times. In the original method of Pulvertaft, one end of the tendon is shaped like a fish mouth and the other tendon is embedded when suturing. However, we did not use these methods in this study. The end of the tendon was cut with a scalpel, leaving 5 mm from the last sewn part.

Figure 2. Creation of a dedicated jig for suturing.

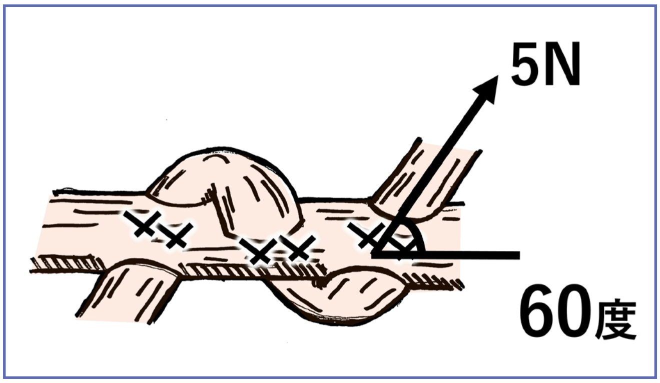

Figure 3. The other tendon was passed to achieve a 60° angle between the tendons, and 2 sutures were used while applying a tension of 5 N to this tendon.

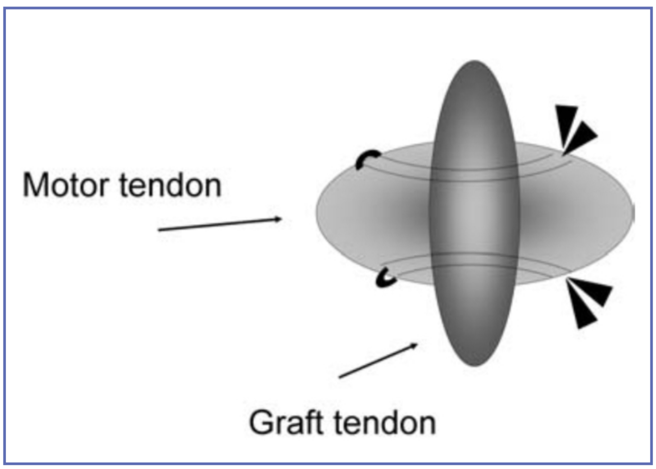

Figure 4. Corner-stitch repair technique. The central portions of the motor and graft tendons are not crossed by the sutures (from the article by Tanaka *et al.* (13)).

We subjected all sutured tendons to a cyclic loading test at room temperature using a tensile testing machine (AG-Xplus; SHIMADZU Corporation, Kyoto, Japan; **figure 5**). The specimens were clamped in the vertical distance between the clamps held at 100 mm. To avoid slipping, the tendon was gripped through the sandpaper to the testing machine. The sutured tendons were prepared with a preload of 1 N and cyclic load of 5–30 N for 1000 cycles at a frequency of 0.25 Hz. We chose these load levels to represent loads experienced during active finger fle - ion (14). We recorded the displacement after 1000 cycles and considered it as tendon stretched. Suture stretch was compared between the numbers of suture weaves. Moreover, for comparison, tendons that did not undergo the Pulvertaft procedure were also subjected to the same cyclic loading test and tendon stretching was measured.

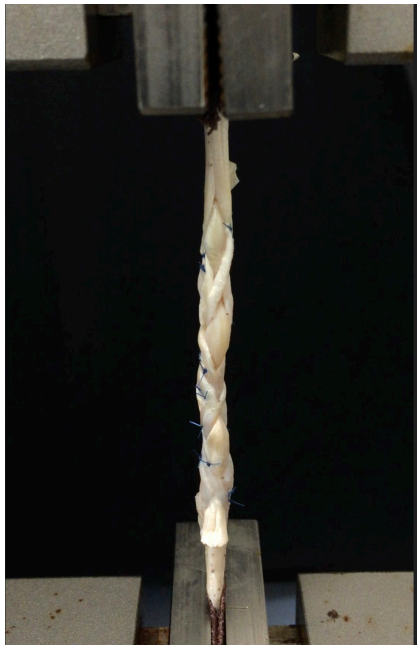

Figure 5. All sutured tendons were subjected to cyclic loading test using a tensile testing machine (AG-Xplus; SHIMADZU Corporation, Japan).

Single loading test

Tendons were loaded at a rate of 10 mm/min until the repair was completely ruptured, and the failure load was recorded. We observed the failure mode of the specimens. Based on the work of Tanaka *et al.* (13), we classified the failure mode into three types: 1) suture failure (thread breaks and sutures break), 2) suture pullout (tendons are torn by threads, pulled out, and broken), and 3) tendon rupture (**figure 6**). We compared the failure load and mode between the numbers of suture weaves.

Figure 6. Tendon rupture.

Statistical analysis

To compare the mean values, we performed statistical analysis using the Kruskal–Wallis H test and Student–Newman–Keuls test. P-values of < 0.05 were considered statistically significant

RESULTS

Tendon diameter

The mean diameters of the tendons in the 3-, 4-, 5-, and 6-weave groups were 3.82 ± 0.09 mm, 3.71 ± 0.14 mm, 3.73 ± 0.08 mm, and 3.74 ± 0.08 mm, respectively. No significant differences were observed between the 4 groups (p = .864).

Cyclic loading test

The tendon stretch lengths of the woven tendons in the 3-, 4-, 5-, and 6-weave groups were 2.99 ± 0.33 mm, 2.60 ± 0.25 mm, 3.48 ± 0.30 mm, and 3.04 ± 0.21 mm, respectively. We observed no significant difference between the groups (p = 0.134) (**figure 7**). In addition, when the same cyclic loading test was carried out with only one native tendon without suture, the tendon stretch length was 0.32 mm.

Single loading test

The mean failure load values of the woven tendons in the 3-, 4-, 5-, and 6-weave groups were 115.8 ± 8.9 N, 162.8 ± 18.5 N, 226.4 ± 24.7 N, and 306.7 ± 36.0 N, respectively (**figure 8**). These values were significantly higher in the 5- and 6-weave groups than in the 3-weave group (p = .012; p = .018). Similarly, the 6-weave group had a significantly greater failure load value than the 4- and 5-weave groups. The failure mode is also presented in the table in **figure 9**. In the 3-, 4-, and 5-weave groups, many were suture pullouts, whereas tendon rupture was the failure mode in the 6-weave group.

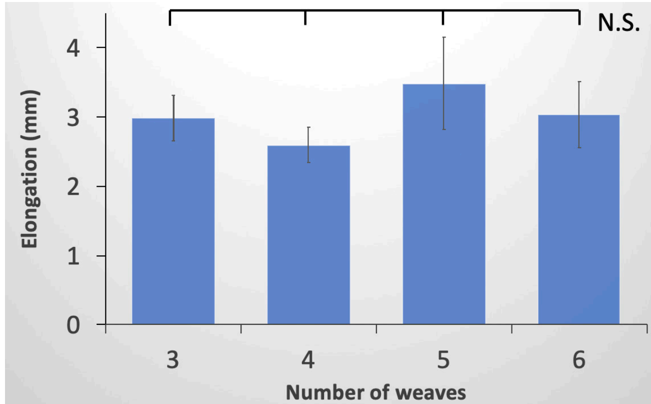

Figure 7. Tendon stretched lengths after the cyclic loading test in the 3-, 4-, 5-, and 6-weave groups.
No significant difference between-group was observed

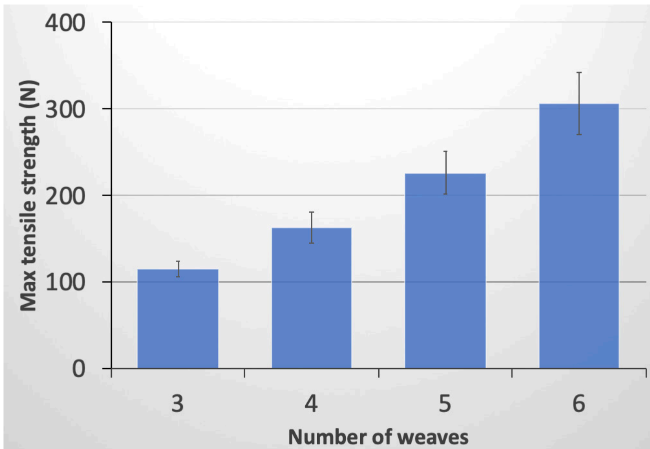

Figure 8. Failure load of tendons in the 3-, 4-, 5-, and 6-weave groups.

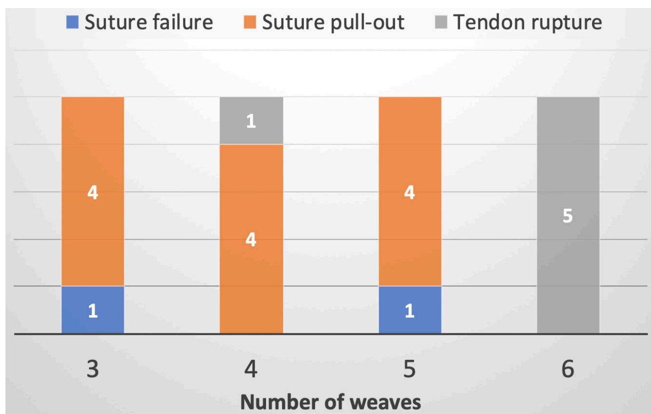

Figure 9. Failure mode for each weave group.

DISCUSSION

We found no significant differences in the cyclic loading test results in the 3- to 6-weaves group, and the sutured tendon elongated about 3 mm. This suggests that, in clinical practice, rehabilitation or repeated finger flexion can cause the tendon to stretch by approximately 3 mm at the point of suture of the Pulvertaft method. In other words, our results suggest that when performing the Pulvertaft procedure in clinical practice, tension should be increased by an equivalent of 3 mm, regardless of the number of weaves.

However, in clinical practice, the surgeon sutures the tendons while maintaining a slight tightness by considering factors such as 1) the length by which the sutured portion of the tendon is stretched, 2) the length by which the contracted muscle stretches, and 3) the degree of relaxation as the transferred tendon straightens. The length by which the contracted muscle stretches will be different for each case. As the transferred tendon straightens, the degree of relaxation can be reduced by keeping the tendon as straight as possible. Factors other than the stretch effect at the point of suture of the Pulvertaft method may also be considered when suturing.

The failure load of all specimens in this study was greater than 100 N. In past research, tension on the flexor tendons with moderate grip was reported to be about 30 N (1-8, 13). In this study, all weave numbers exceeded 30 N in the failure load of the specimens. Therefore, if patient compliance is good, 3 weaves may be sufficient, but adjustment is accordingly necessary. The failure loads between the 5- and 6-weave groups showed no significant difference, and the failure mode in the 6-weave group was tendon rupture; therefore, no further steps were needed. In the 6-weave group, breakage occurred at the portion passing through the tendon at the end of the suture part, that is, at the part where the thickness is half. In other words, when the failure load of the sewn portion exceeds a certain level, a tendon with half the thickness is considered unable to bear that load, which leads to tendon rupture.

The limitations of this research are described below. First, in this study, we did not consider the effects of the healing process because we used tendons taken from cadaver specimens. Therefore, we were not able to evaluate the effect of the healing process on the inhibition of tendon stretch. This study should be applied clinically, keeping in mind that it evaluated the stretching of tendons in the early postoperative period. Second, the number of samples in each group was small. Third, we did not consider the increase in resistance due to friction or adhesions between tendons and surrounding tissues and swelling. In reality, edema may occur immediately after surgery, and resistance may increase thereafter due to adhesion. Moreover, this can be different for each case.

CONCLUSIONS

Our study suggests that the use of the Pulvertaft method results in a stretch length of the sutured tendon by approximately 3 mm during rehabilitation. By performing the procedure while considering the postoperative stretching effect, it can be expected that better results will be obtained.

FUNDINGS

None.

DATA AVAILABILITY

Data are available under reasonable request to the corresponding author.

CONTRIBUTIONS

EO: principal investigator. YM: research supervision. TS: cadaver management. K.K: research advisor. SO: laboratory manager.

ACKNOWLEDGMENTS

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CONFLICT OF INTERESTS

The authors declare that they have no conflict of interests.

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