Biomechanical Analysis of a New Eight-Strand Suture for Flexor Tendon Repair

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Abstract

Background The placement of multistrand sutures during flexor tendon repair requires complicated surgical skills; such suturing is difficult. We developed a new, simpler eight-strand suture, which we term the Yoshizu cross-lock. This reduces the numbers of suture passages through the tendons, as well as the numbers of knots.

Methods Fourteen porcine flexor tendons were transected and repaired using the Yoshizu cross-lock system; no peripheral sutures were placed. Our system is a modification of the published, exposed cross-lock repair method that employs a 4–0 monofilament nylon two-strand line and two needles. The repaired tendons were subjected to linear, noncyclic load-to-failure tensile testing. The initial gap, the 2-mm gap force, and the ultimate strength were measured.

Results The initial gap force was 12.6 ± 5.6 Newtons (N), the 2-mm gap force was 33.9 ± 10.9 N, and the ultimate strength was 70.1 ± 17.0 N. All tendons subjected to Yoshizu cross-lock repair failed due to suture rupture rather than pullout.

Conclusions Our biomechanical study revealed that Yoshizu cross-lock repair had sufficient tensile strength but was associated with wide variation in the 2-mm gap load (standard deviation = 10.9 N). This study is clinically relevant, showing that the Yoshizu cross-lock repair combined with peripheral suturing may allow a repaired flexor tendon to withstand the stresses encountered during early active mobilization. This simple eight-strand technique will be particularly useful to surgeons who commonly employ the cross-lock stitch for primary flexor tendon repair following early mobilization.

Keywords
- ► cross-locking
- ► eight-strand
- ► flexor tendon repair

Introduction

Restoration of tendon gliding is the goal when repairing flexor tendon injuries. The tendon forces experienced during postoperative, active flexion exercises are significantly larger than the tendon forces experienced by patients engaging in only passive flexion.[1] Multistrand sutures (typically four- or six-strand repairs) may withstand much greater tension than conventional two-strand sutures during early active mobilization.[2–4] However, multistrand (particularly eight-strand) repair requires complicated surgical skills; such repair is difficult. Here, we present a new eight-strand suture for flexor tendon repair that features fewer passages through the tendons and fewer knots than existing approaches; it affords the necessary tensile strength to prevent both gap formation and ultimate failure. We term the new suture the “Yoshizu cross-lock” because we employ the “Yoshizu needle” that consists of two monofilament nylon strands and two needles

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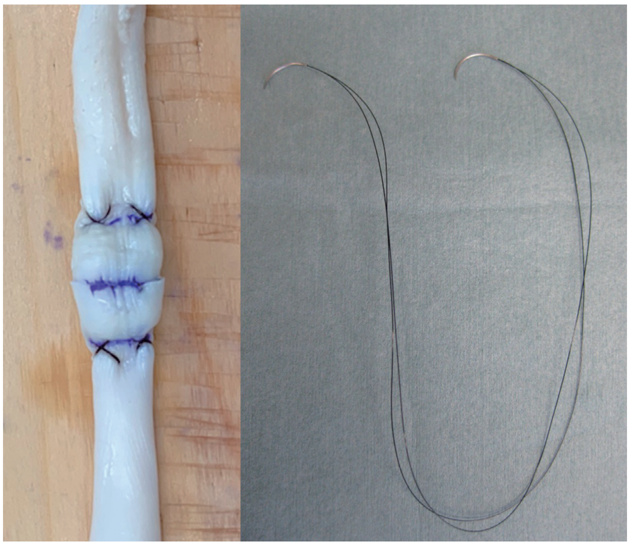

Fig. 1 The Yoshizu cross-lock repair technique and Yoshizu needle.

(►**Fig. 1**).[5] The purpose of this study is to introduce our Yoshizu cross-lock repair technique and evaluate its tensile properties.

Materials and Methods

We evaluated the mechanical properties of tendons subjected to Yoshizu cross-lock repair (without peripheral epitendinous suturing); we performed linear loading tests. We employed porcine flexor tendons with structures and diameters similar to human flexor tendons. Fourteen porcine flexor digitorum profundus tendons (mean length, 141.9 ± 3.9 mm) were harvested from the second and third toes in the hind feet of adult pigs, then stored at –20°C; they were thawed to room temperature for 7 hours prior to testing. All tendons were harvested and repaired by the lead author (K.M.), who has considerable experience in flexor tendon surgery (level 4 expertise).[6]

Operative Technique

The proximal excesses of all tendons were removed; all tendons were 100 mm in length. The tendons were mid-transected; structurally, this zone corresponds to the human flexor tendon zone 2. At this level, the mean porcine flexor digitorum profundus tendon width was 8.3 ± 0.5 mm. The Yoshizu cross-lock repair technique employs two cross-lock suture grasps placed on either side of the repair site; two knots are embedded in the repair site of the tendon (►**Fig. 2**).

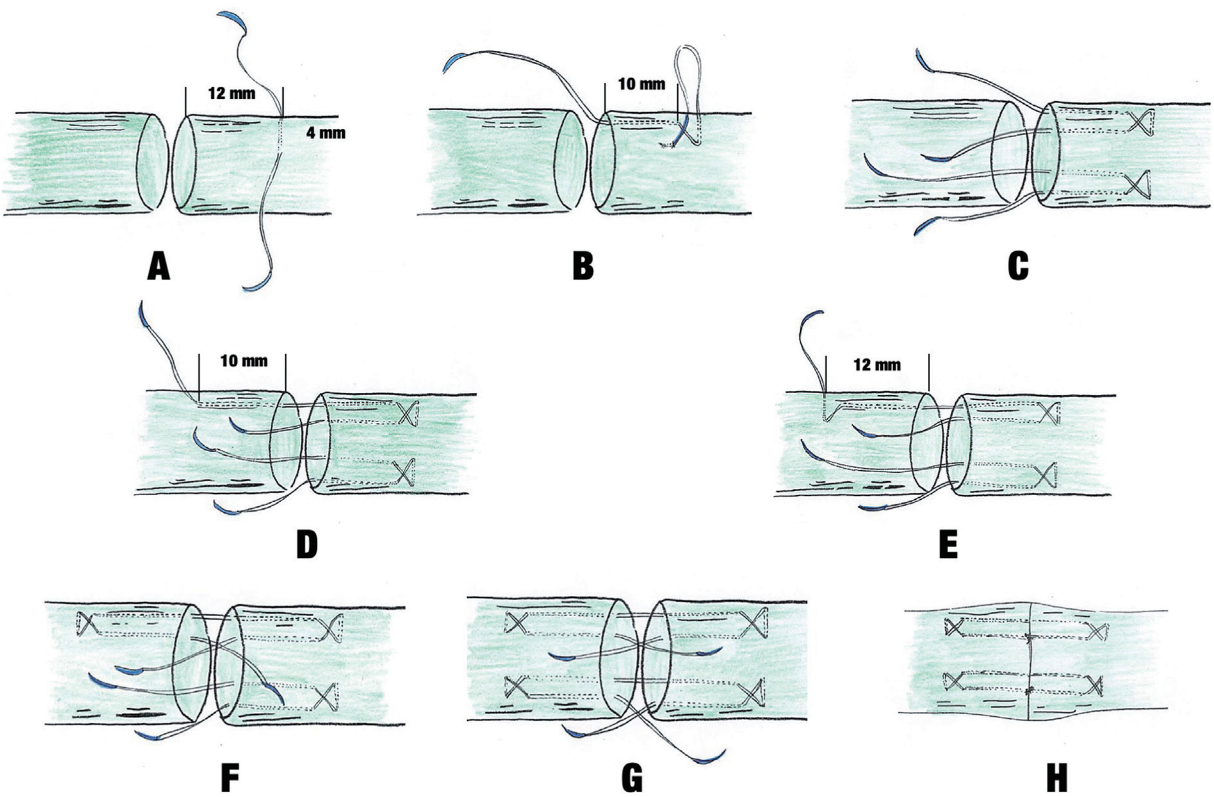

Fig. 2 The Yoshizu cross-lock repair. (**A**) First, a superficial 4-mm transverse tendon bite was performed in the far volar quadrant of the tendon, 12 mm from the end of the cut. (**B**) Two needles were inserted at 10 mm apart from the tendon end and out the end to complete the single-cross grasp, taking a deeper, longitudinal bite of the tendon, running parallel to the length of the tendon fibers. (**C**) A similar, initial, single-cross grasp suture was placed in the close volar quadrant of the tendon. (**D**) Next, one of the two needles was passed longitudinally through the cut surface to the other side of the cut, exiting 10 mm from the tendon end. (**E**) A superficial, 4-mm, tendon transverse bite was created in the far volar quadrant of the tendon, 12 mm from the end of the cut. (**F**) The needle was then passed longitudinally 10 mm distant from the tendon end and out through the cut surface. (**G**) This procedure was repeated at the close volar tendon side. (**H**) Each thread of the far and close sides was tied under the tension that reduced the length of the encompassed tendon segments by 10%.

We used a 4–0 monofilament nylon double strand with two needles (Bear Medic Corp., Ichikawa, Japan). The core suture purchase length was 10 mm, the lock width was 4 mm, and all lock depths within the tendon were approximately 2 mm. The core sutures were placed under tension to shorten the tendon segment encompassed within the core suture strands by 10%.[7] All sutures were knotted using double throws, followed by two single (square) throws. No peripheral sutures were placed to rule out any influence of variations therein.

Biomechanical Testing

Repaired tendons were moistened with wet gauze prior to testing; all were subjected to linear load-to-failure testing using a tensile test machine (AG-I 10kN; Shimadzu Corp., Kyoto, Japan) (►**Fig. 3**). The force transducer of the machine was connected to the upper clamp. The force was recorded with a specialized software program (TRAPEZIUM; Shimadzu Corp., Kyoto, Japan). The tendon ends were tightly gripped in the upper and lower clamps. The initial distance between the clamps was 5 cm. A preload of 1 Newton (N) was applied before loading evaluation. The overhead crossbar connected to the upper clamp was advanced at a constant speed of 25 mm/min. The preload and the tendon pull rate simulated the loading of a tendon during active finger flexion.[8] The distance between the stumps was monitored by a video camera that had been vertically mounted at the level of the tendon repair site. The pulling force was continuously recorded. Any force that produced gaps evident on the monitor was recorded on the display board; each such force was considered an initial gap force. Any force separating the tendon stumps by 2 mm was recorded as a 2-mm gap formation force. An external observer recorded the initial and 2-mm gap forces. The tendons were pulled until complete pullout or rupture of the sutures occurred. The ultimate strength of the repair was the peak force recorded during the test.

Results

Under linear loading conditions, the mean initial gap force was 12.6 N (range: 3.3–22.5 N), the mean 2-mm gap formation force was 33.9 N (range: 15.6–54.1 N), and the mean ultimate strength was 70.1 N (range: 42.3–93.5 N). All tendons subjected to Yoshizu cross-lock repair failed due to suture rupture rather than pullout.

Discussion

Previous studies have reported that the transverse components of core sutures reduce the tensile strengths of two-, four-, and six-strand tendon repairs.[9–11] If different suture configurations are used during the same repair, ultimate repair strength is compromised by the noncumulative load, attributable to the dissimilar stiffnesses of the various repair components.[4] The Yoshizu cross-lock repair does not use a transverse core suture component; instead, there are two identical cross-locking passes. Thus, this technique may improve mechanical performance of the core suture.

The cross-locking configuration strengthens the repaired tendon.[4,12,13] Several repair techniques applying this locking component at the tendon–suture junction have been proposed, including exposed cross-lock repair (four-stand),[13] the modified Savage technique (six-strand),[4] and eight-strand cross-locked cruciate repair[14] (►**Fig. 4**). Yoshizu cross-lock repair is a modification of the four-strand exposed cross-lock repair method of Xie and Tang[13] using double-stranded nylon suture material instead of a single-stranded suture. Although it is similar to eight-strand cross-lock repair, our technique uses only a longitudinal component, whereas the eight-strand cross-locked cruciate repair has two oblique strands. Clinical feasibility is important for strong tendon sutures. A cross-lock theoretically requires more suture passes compared with other locking configurations, such as the Tsuge and modified

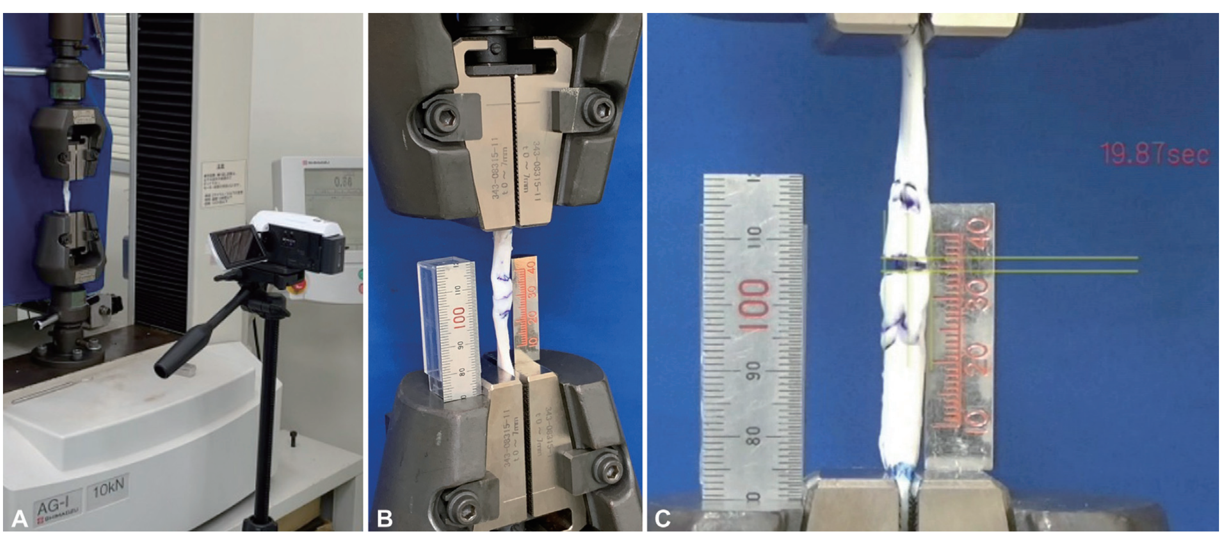

Fig. 3 The experimental setup. Stump separation and repair failure were monitored using a high-resolution video camera (**A**) that recorded vertical tendon views at the repair sites. The gap sizes were measured using a scale (**B**) placed adjacent to the tendons on still images (**C**) from the videos; these measurements were performed using a computer software program (Adobe Premiere Elements; Adobe Inc., San Jose, California, United States).

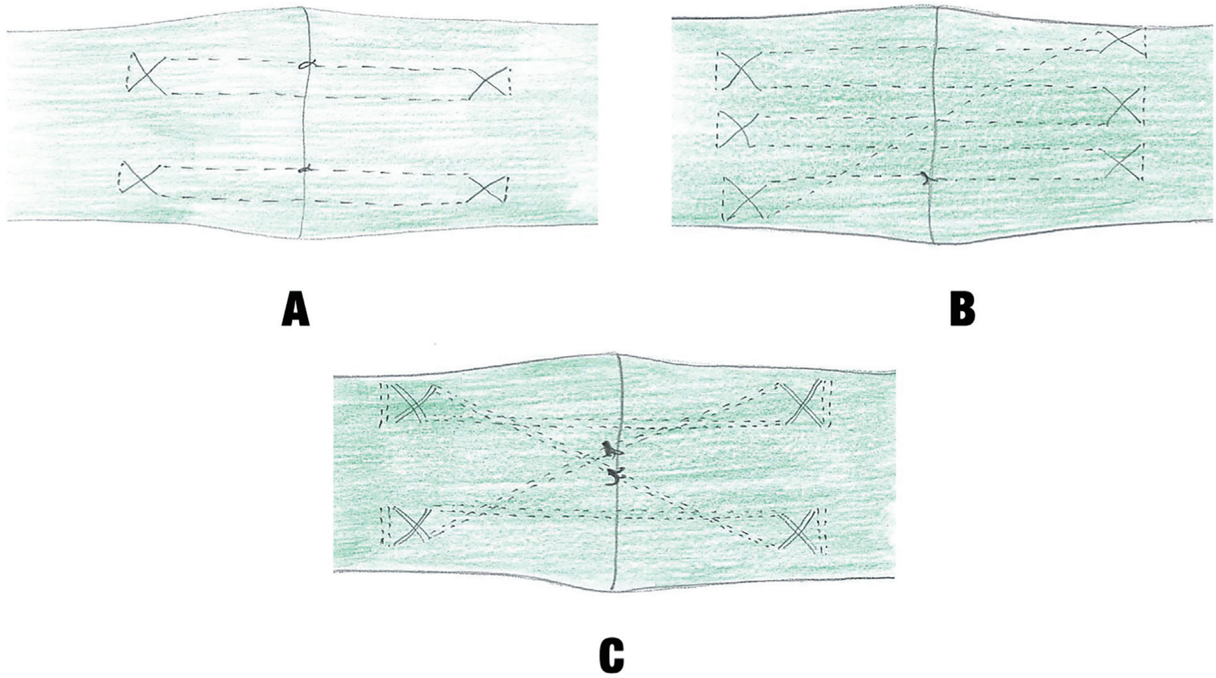

Fig. 4 Various cross-lock repair techniques. (**A**) Exposed cross-lock repair, (**B**) modified Savage technique, and (**C**) eight-strand cross-locked cruciate repair.

Kessler configurations.[15,16] When limited to a multistrand technique using cross-lock configurations, eight-strand cross-locked cruciate repair requires 12 suture passes for the complete suture,[14] compared with 18 suture passes with the six-strand-based modified Savage technique.[4] The Yoshizu cross-lock suture is an eight-strand suture; however, there are only two grasps on either side. Importantly, 12 suture passes are required for complete tenorrhaphy, which equates to eight-strand cross-locked cruciate repair. Yoshizu cross-lock repair can be performed using a 4–0 caliber looped suture if the needle is initially inserted into the end of the tendon; however, the Yoshizu needle, which is commonly used for flexor tendon repair in Japan, facilitates tenorrhaphy because it obviates the need to reverse the needle during passage of the longitudinal suture. Such needle reversal is technically difficult. The six-strand modified Savage technique and eight-strand cross-locked cruciate repair require more needle reversal than Yoshizu cross-lock repair.[4,14]

The load to a 2-mm gap is used to measure clinical failure because gaps larger than 2 mm have been associated with significant deteriorations in patient outcomes (caused by adhesions).[17,18] Urbaniak et al reported that active flexion under mild resistance can impart a force of 10 N; this increases to 17 N when resistance is moderate.[19] Schuind et al found that a mean flexor digitorum profundus force of 19 N was generated during active (unresisted) flexion of an uninjured tendon.[20] We found that the mean 2-mm gap-formation force after Yoshizu cross-lock repair was 33.9 N in the absence of peripheral sutures; this allows gentle or moderate active motion. In this way, peripheral stitches may be unnecessary because of the strong multistrand core suture.[21,22] However, the Yoshizu cross-lock repair is associated with wide variation in the 2-mm gap load (standard deviation = 10.9 N). As the minimum load is 15.6 N, Yoshizu cross-lock repair without peripheral sutures does not always enable early active mobilization. We concluded that peripheral sutures are thus required (in combination with the Yoshizu cross-lock repair) because tendon strength does not increase in the initial 2 to 3 weeks after surgery; only the baseline surgical repair maintains the alignment of tendon ends during this time.

Our work had several limitations. First, we used porcine tendons, rather than human cadaveric tendons. Second, we conducted a static test with a linear distraction force. This test did not consider cycling conditions during repetitive passive or light active motion activities. Experiments involving cadaveric fingers, with cyclic testing of repaired tendons, are needed to overcome these limitations. Third, this study was limited to time-0 properties without considering the healing process. Fourth, no biomechanical test was conducted to compare tensile strength to that of other multistrand repair techniques. Thus, further studies are necessary to demonstrate whether our technique is superior to others. In addition, an eight-strand method including our technique is too bulky for extremely small tendons, such as extensor tendons; thus, the use of our technique may be limited to flexor tendons. Tendon nutrition and vascularity may also be affected by the many suture passes.

Conclusion

Yoshizu cross-lock repair afforded sufficient tensile strength to counter the 2-mm gap formation force. The clinical relevance of this study lies in the fact that Yoshizu cross-lock repair (with peripheral sutures) may allow the repaired flexor tendon to withstand the stresses encountered during early active mobilization. This simple eight-strand technique will be particularly useful to surgeons who commonly employ the cross-lock stitch for primary flexor tendon repair following early mobilization.

Ethical Approval Declaration

The local ethics committee approved this study [R3–4]. The study was conducted according to the World Medical Association Declaration of Helsinki.

Authors' Contributions

KM conceptualized, collected, and interpreted the experimental data, and wrote the manuscript. YM, HK, and NT interpreted the experimental data, and revised the manuscript critically for important content. All authors read and approved the final manuscript.

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Conflicts of Interest

All named authors hereby declare that they have no conflicts of interest to disclose.

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