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Original article

Optimum locations of the locking loop and knot in tendon sutures based on the locking Kessler method

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Abstract
Background. We investigated the factors that influence tensile strength and resistance to gap formation at the repair site of tendon suture (stiffness) by comparing (1) the location of the locking loops and (2) the location of the knot.
Methods. Transected bovine tendons of the medial gastrocnemius (9–11 × 14–16mm diameter) were sutured with a modified locking Kessler method with a USP (United States Pharmacopeial convention) 2 polyester multifilament suture (0.500–0.599mm) and loaded to failure using an Instron 5565 tensiometer. The locking loops were located on either the upper surface facing the operator or on side portions of the tendon. The knot was positioned either close to or far from the tendon stump.
Results. The locations of the locking loops did not influence the tensile strength; however, the stiffness of the side loop suture (5.70 ± 0.09N/mm) was significantly higher than that of the upper surface loop suture (5.17 ± 0.10N/mm). Regarding the knot location, the tensile strength with the knot far from the tendon stump (195.1 ± 4.8N) was significantly higher than that with the knot close to the tendon stump (169.0 ± 3.6N), although the stiffness was unchanged by differences in knot location.
Conclusions. These data suggested that a greater tensile strength with less of a gap is obtained by (1) forming locking loops in the side portion of the tendon, and (2) forming knots far from the tendon stump.

Introduction

Increasing tensile strength of the tendon suture and eliminating the gap at the suture site are important factors when repairing the lacerated tendon and initiating an early mobilization program.[1–5] Hotokezaka et al. proved the effectiveness of the locking Kessler suture with locking loops at distal and proximal sites, which provided strong tensile strength and antigap resistivity.[6–8] They also reported that the tensile strength was greater when the knot was located outside the repair site than inside the repair site.[9] However, differences of the location of knots outside the repair site had not yet been investigated.

We hypothesized that subtle differences in the location of the knot results in differences in tensile strength and mode of failure when the knot is located outside the repair site. We investigated the effect of the knot location in the single locking Kessler method by observing the tensile strength, mode of failure, and resistance to repair site gap formation (stiffness) using a thick bovine tendon. In addition, we tried to conceive a practical suturing technique, comparing two locations of loops in the single locking suture.

Materials and methods

Materials

Bovine tendons of the medial heads of the gastrocnemius were removed from beef cattle (male Japanese black cattle 24 months old and weighing 450–550kg) immediately after butchering for edible meat. Tendons with diameters of 15–16 × 9–10mm were stored at –20°C and thawed at 4°C immediately prior to use. The tensile strength of all the intact tendons was greater than 3000N. The tendons were transected into two pieces and then sutured end-to-end using USP (United States Pharmacopeial convention) 2 (diameter 0.500–0.599mm) polyester multifilament suture (Ethibond; Ethicon, Somerville, NJ, USA).

Suture methods

The locking loops were applied at two locations. One was in the upper surface portion of the tendon that

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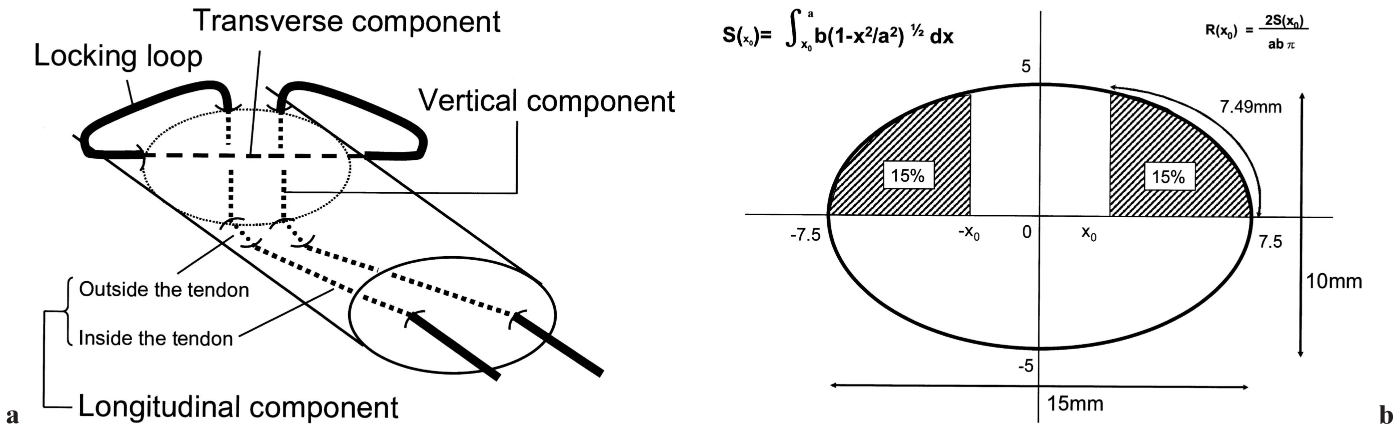

Fig. 1. **a** Structure of "locking Kessler suture" modified by Hatanaka et al. **b** Elliptical section view of the tendon with the upper surface loop method (locking Kessler suture). The suture captured both sides of the tendon by 15%, with a total of 30%. From Hatanaka et al.,[10] with permission

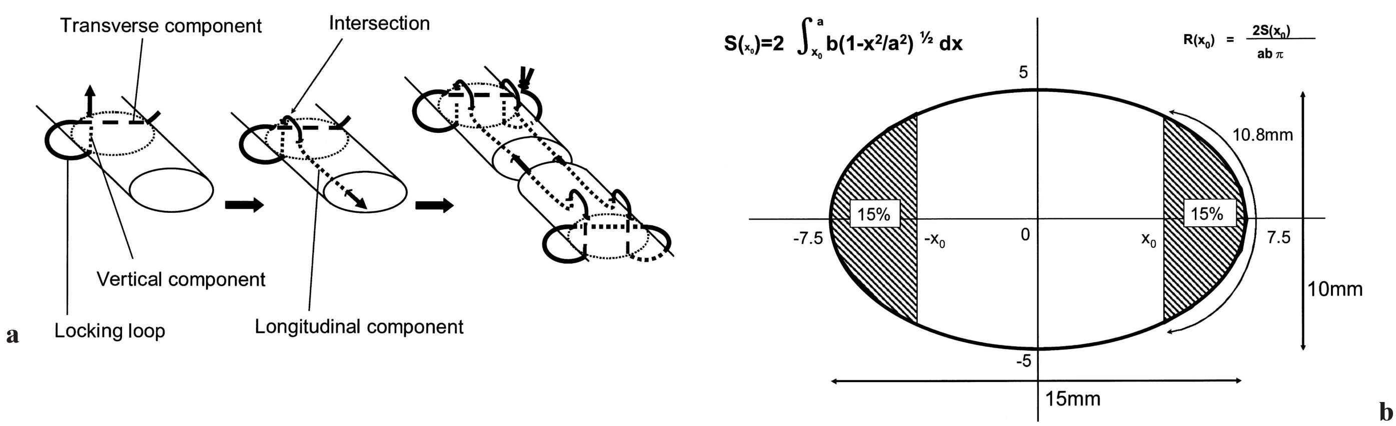

Fig. 2. **a** Procedure of modified locking Kessler suture (side loop method). After the transverse component of the suture is placed, the loop is made in the side of the tendon. Then the vertical component of the suture penetrates the tendon from the back to the front, slightly distal from the transverse component; thus, the locking configuration can be easily seen from the operator. **b** Elliptical section view of the tendon with the side loop method. The suture captured both sides of the tendon by 15%, with a total of 30%

facing the operator based on the locking Kessler suture that Hatanaka and Manske[10] reported after modifying the conventional Kessler method[11] in which the suture thread penetrated the tendon to ensure that the locking loops are on the upper surface of the tendon. Herein, we refer to this method as the "upper surface loop" (Fig. 1a). The other location was the side portion of the tendon. Herein, we refer to this method as the "side loop" (Fig. 2a). At the time of suturing, a custom-made, elliptically shaped tendon fixation unit (Fig. 3) was used to measure the area of the locking loop, encompassing 30% of the entire cross-sectional area of the tendon (Figs. 1b, 2b).[10] Each locking loop was made at a point 20 mm distant from the tendon stump (Fig. 4).

Knots were applied at two locations: close to or far from the stump. All knots were formed outside of the

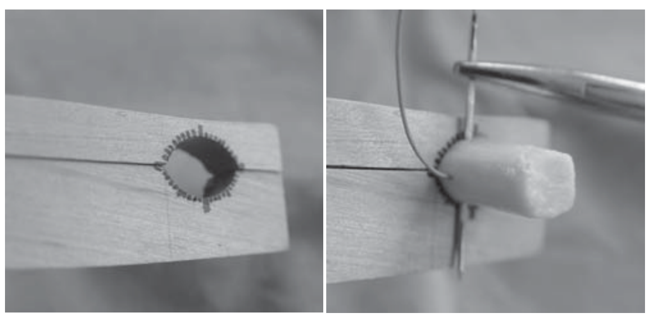

Fig. 3. Custom-made tendon fixation unit: accurate measurement of the elliptical shape

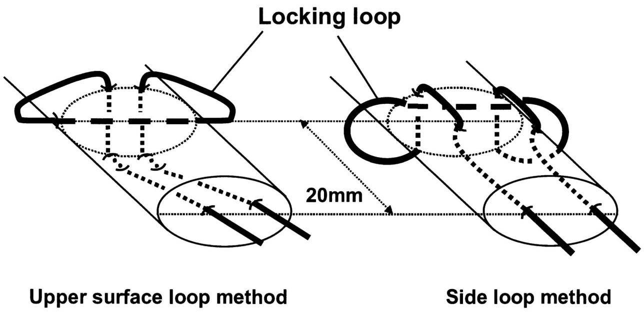

Fig. 4. Location of locking loops. Each locking loop was made at a point 20 mm distant from the tendon stump

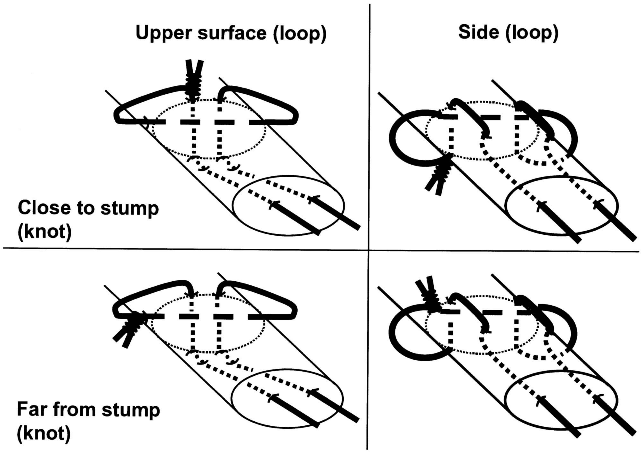

Fig. 5. Location of knots in the upper surface loop method and the side loop method. *Top left* Upper surface loop method with a knot close to the tendon stump. *Top right* Side loop method with a knot close to the tendon stump, *Bottom left* Upper surface loop method with a knot far from the tendon stump. *Bottom right* Side loop method with a knot far from the tendon stump

repair site (i.e., in the locking loop on the surface of the tendon) by differentiating the knot location as being close to or far from the stump. Thus, four suture techniques were applied (10 samples in each technique): an upper surface loop with a knot close to the tendon stump; an upper surface loop with a knot far from the tendon stump; a side loop with a knot close to the tendon stump; and a side loop with a knot far from the tendon stump. All of them were based on the single locking Kessler method. For convenience, we herein refer the two loop locations as either "upper surface" or "side" and the knot location as "close to stump" or "far from stump" (Fig. 5).

Test procedure

To measure the tensile strength of the sutured tendons, lacerated tendons were fixed by touching the ends together in custom-made clamps on a loading cell of the Instron 5565 tensiometer (Instron, Canton, MA, USA) (accuracy is ±1%). A saline drip was used to keep the specimens moist during the suturing and testing procedure. After suturing, the knot was fastened by squeezing the locking site tightly. Specimens were loaded until failure occurred with a crosshead speed of 20 mm/min in the Instron apparatus. Values of loading and elongation of all specimens were registered in an x-y recorder. The loading values, movements of the knot, and formation of the gap length (which occurred at the maximum tensile strength before suture failure) were measured. Migration of the suture lines was recorded using a digital video camera (NV-MX2500; Panasonic, Osaka, Japan). A preload value of 2 N was used to normalize the data of all specimens. After the tests, the suture lines were removed from the tendons and observed to determine the modes of failure of the specimens. Stiffness (N/mm) was determined by calculating the ultimate failure force divided by the gap length.

Statistical analysis

Comparisons of two groups were performed: between the upper surface loop and the side loop and between knots close to the stump and knots far from the stump. The uniformity of the dispersion of values was statistically analyzed with the Bartlett test. Two-factor factorial analysis of variance (ANOVA) was applied to assess fluctuations of tensile strength and stiffness, thereby examining the effects of the locations of locking loops and knots. Values were represented as the mean ± standard deviation; and $P < 0.05$ was defined as being significant.

Results

While applying the loading cell of the Instron tensiometer, the tensile strength gradually increased and a gap was formed between the sutured tendon stumps, in accordance with the increased elongation of the sutured tendon (Figs. 6, 7). With both upper surface loop methods, a transient tensile decrease (dip) occurred, which resulted in an increased gap length of about 3 mm, whereas such tensile dips were not observed with the two side loop methods (Figs. 6, 7). The tensile dips occurred when the suture thread was drawn into the tendon in all cases ($n = 20$) using the upper surface loop methods (Fig. 8). Most of the tensile dips occurred four times (15/20 cases), except in some (5/20 cases) that had the dips three times. The three dips in the tensile strength–gap curve were "pull-in" of the suture thread into the tendon fibers, which the recorded videotapes revealed had happened at two sites simultaneously — thus, the three dips observed on the tensile strength–gap curve.

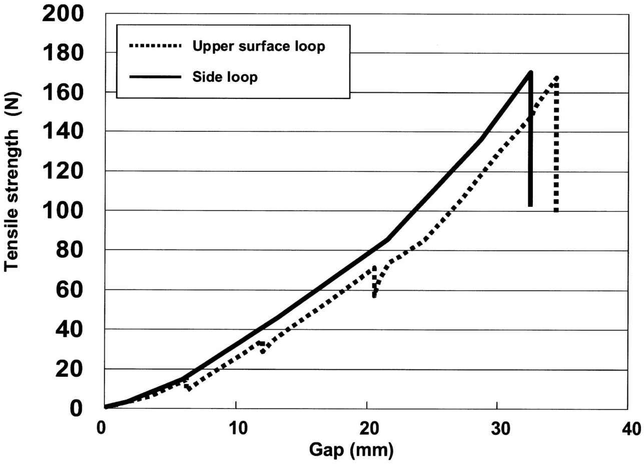

Fig. 6. Tensile strength–gap curve when knots located close to the tendon stump. Transient tensile dips occurred four times in upper surface loop methods, resulting in a longer gap length than side loop methods by approximately 3 mm

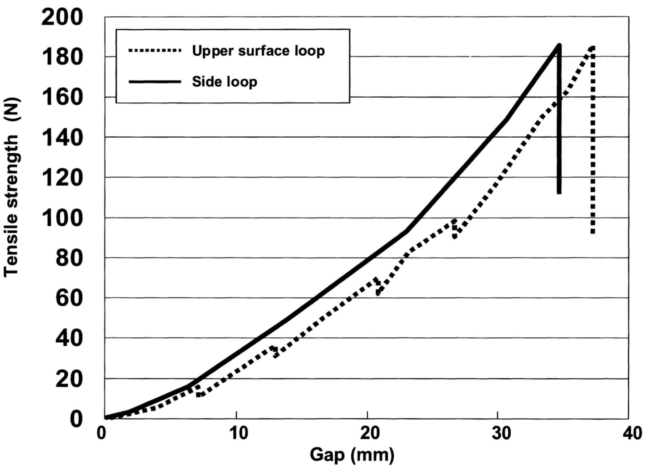

Fig. 7. Tensile strength–gap curve when knots were located far from the tendon stump. Transient tensile dips occurred four times in upper surface loop methods, resulting in a longer gap length than side loop methods by approximately 3 mm

The mode of failure in all groups was rupture of the suture thread close to the knot. There were no samples that failed because of suture slippage at the knot or suture migration to the tendon stump by tearing the tendon fiber with the suture thread. The tensile strength immediately before suture rupture was measured as the tensile strength. The gap length was also measured immediately before suture rupture.

Tensile strength

The tensile strength of the upper surface loop method with a knot close to the tendon stump was 169.0 ± 3.6 N; the upper surface loop method with a knot far from the tendon stump was 195.1 ± 4.8 N; the side loop method with a knot close to the tendon stump was 171.8 ± 4.6 N; and the side loop method with a knot far from the tendon stump was 196.6 ± 2.8 N (Figs. 6, 7; Table 1). Statistical analysis showed that the tensile strength was not influenced by the locking loop location ($P = 0.5972$), although it was influenced by the knot location. That is, the tensile strength was greater when the knot was located far from, rather than close to, the tendon stump in both the upper surface loop group and the side loop group ($P < 0.0001$). No interactions were found between the locations of the locking loops and the knots ($P = 0.8638$) (Table 1).

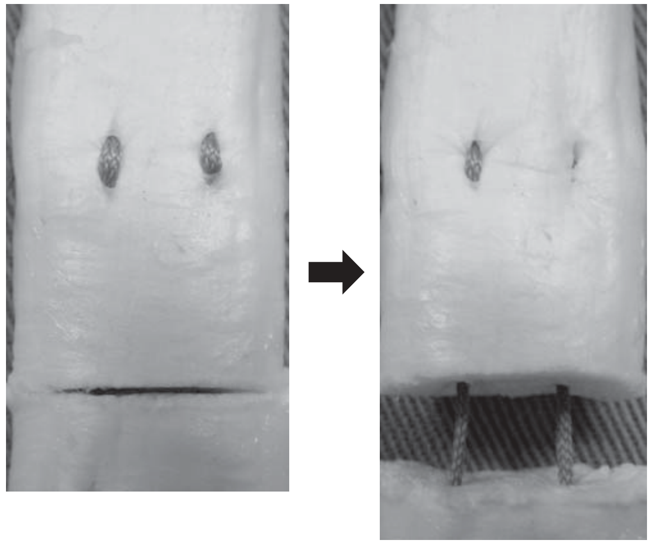

Fig. 8. Suture thread being drawn into the tendon. Movement of the suture thread outside the tendon was observed at the time of tensile dips in the tensile strength–gap curve (Figs. 6 and 7).

Table 1. Tensile strength of the sutured site

Location of knots	Tensile strength (N), by location of loops	
	Upper surface	Side
Close to stump	169.0 ± 3.6	171.8 ± 4.6 ┐ *
Far from stump	195.1 ± 4.8	196.6 ± 2.8 ┘
	NS	

Two-factor factorial analysis of variance (ANOVA) was applied to examine the effects from location of locking loops and knots
Values are expressed as the mean ± SD
*$P < 0.0001$
There was no interaction between the two factors ($P = 0.8638$)

Table 2. Stiffness of the sutured site

Location of knots	Stiffness (N/mm), by location of loops: Upper surface	Side
Close to stump	5.18 ± 0.09	5.68 ± 0.14 (NS)
Far from stump	5.17 ± 0.10	5.70 ± 0.09 (NS)
	* (Upper surface vs Side)	

Two-factor factorial ANOVA was applied to examine the effects from location of locking loops and knots
Values are expressed as the mean ± SD
$^{*}P < 0.0001$
There was no interaction between the two factors ($P = 0.8772$)

Gap between tendon stumps

The gap between the tendon stumps was 32.6 ± 0.7 mm for the upper surface loop method with a knot close to the tendon stump, 37.6 ± 0.4 mm for the upper surface loop method with a knot far from the tendon stump, 30.2 ± 0.6 mm for the side loop method with a knot close to the tendon stump, and 34.5 ± 0.4 mm for the side loop method with a knot far from the tendon stump. Thus, when the tensile strength was greater, a larger gap was formed (Figs. 6, 7).

Stiffness

Stiffness of the suture was 5.18 ± 0.09 N/mm for the upper surface loop method with a knot close to the tendon stump, 5.17 ± 0.10 N/mm for the upper surface loop method with a knot far from the tendon stump, 5.68 ± 0.14 N/mm for the side loop method with a knot close to the tendon stump, and 5.70 ± 0.09 N/mm for the side loop method with a knot far from the tendon stump (Table 2). The tensile strength–gap curve showed transient tensile dips with the upper surface loop methods, resulting in reduced stiffness. The stiffness was not influenced by the location of the knot ($P = 0.9664$), but it was influenced by the location of the locking loop in both the close knot group and the far knot group ($P < 0.0001$). No interactions were found between the locations of the loops and the locations of the knot ($P = 0.8772$) (Table 2).

Discussion

In our study, the tensile strength was greater when the knot was located far from the stump. However, the location of the locking loops did not influence the tensile strength. Our finding that the tensile strength differed even when the knot was located in the limited area outside the repair site has not been reported elsewhere. This finding is explained by the fact that the knot has the weakest resistivity in the entire length of the suture.[7,9] The tension of the suture thread in the tendon is more effectively minimized, especially at sites far from the stump, because of the frictional resistance between the suture thread and the tendon fibers.[9] Therefore, it is thought that when the knot is located far from the tendon stump the sutured tendon could bear strong tension.

The stiffness depended on the location of the loops, irrespective of the location of the knot. Although the tension continuously increased in the side loop method, it showed a transient decrease (dip) three or four times with the upper surface loop method, resulting in decreased stiffness. This sudden decrease in tension was due to the reduced strain of the suture thread when the longitudinal component assumed a straight shape; the longitudinal portion outside the tendon tore the tendon fiber and drew in the tendon. Such reduced suture stiffness might result in delayed healing after treatment owing to an enlarged gap between the stumps.[12] Also, the torn tendon surface caused by the longitudinal component of the suture is indicative not only of the enlarged gap but also of the damaged minute vessels inside the tendon.

A different outcome is possible when applying our method on variously sized tendons and suture threads. For example, tendons thinner than those in our study may yield smaller differences in tensile strength even with different locations of the knot. However, such a small difference would be regarded as significant because the tensile strength itself is low when using a thin suture thread. When suturing a thin tendon, although the gap size should be small because of its small tensile dips, the small difference of a gap is critical for a thin tendon. When using a thick suture thread, the increase in strength may be regarded as less significant. Although the tensile strength itself is great with a thick thread, the sizes of the (total) gap and dips remain almost the same. Hence, our findings can be applied for thicker suture thread in terms of preventing a gap. In our study, we sutured bovine tendon of about 15 × 10 mm diameter using a USP 2 (diameter 0.500–0.599 mm) suture thread, the ratio of which is considered equivalent to suturing the flexor tendon of the hand using a USP 4-0 thread.

We believe that the side loop with a knot far from the tendon stump is an excellent suture method based on the experimental results of tensile strength and stiffness. It is therefore recommended for its certainty and simplicity of technique. In clinical practice, first, we need to make a locking suture. It is relatively easy to confirm the locking with the side loop method because we can observe the intersection of the transverse and vertical components on the tendon during operation. On the other hand, with the upper surface loop method, we cannot visually confirm the locking because the intersection is inside the tendon. Second, we need to form the knot as far as possible from the tendon stump. With the side loop method, when placing a knot on the upper surface of the tendon (facing the operator) the knot can be formed at a site far from the tendon stump without too much care. In contrast, with the upper surface loop method, the knot on the upper surface of the tendon is located at a site close to the stump. Although strong tensile strength may be obtained when locating the knot far from the stump with the upper surface loop method, it requires a special attention; it is relatively difficult to form the knot on the side to bottom portion of the tendon. Therefore, we believe that the side loop method with a knot far from the tendon stump is the most effective locking suture method in terms of certainty and simplicity in clinical practice.

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