ABSTRACT

Purposes. To assess the tensile strength of the modified 4-strand cruciate technique for obliquely lacerated tendons, and to compare the findings with the strength of transversely lacerated tendons repaired at various grasping depths.

Methods. 60 porcine front foot tendons were evenly divided into 4 groups. In groups 1 to 3, tendons were transversely lacerated and repaired with grasping points at both ends away from the laceration by 5 mm, 10 mm, and 15 mm respectively. In group 4, tendons were obliquely lacerated and repaired with a grasping point 5 mm away from the laceration on one end and 15 mm on the other. All tendons were repaired with a modified 4-strand core suture and continuous epitendinous suture, and then tested to failure in a tensile machine.

Results. The tensile strength in group 1 was significantly lower than that in the other 3 groups (p<0.005). The tensile strength in group 4 was not significantly different from groups 2 and 3.

Conclusion. The tensile strength of modified 4-strand cruciate repair configuration is not weakened in obliquely lacerated tendons; the grasping point at one end of the tendon being 15 mm away from laceration provides sufficient strength to compensate for the relatively weak 5-mm end. So long as one grasping point is away from the laceration site by 10 mm, the ultimate tensile strength of the transversely lacerated tendons appears acceptable. The modified 4-strand cruciate repair is safe to use for repairing obliquely lacerated tendons.

Key words: animals; biomechanics; suture techniques; tendon injuries; tensile strength

INTRODUCTION

Hand injuries in the forms of bone fractures, tendons injuries, neurovascular injuries, or a combination of all these are commonly seen. The reported incidence of hand injuries in Hong Kong was 600 per 100 000 annually, accounting for 3.2% of all accident and emergency attendance. Other countries reported such injuries ranging from 3.7 per 100 000 annually in Denmark, 475 per 100 000 annually in the United Kingdom, to 1981 per 100 000 annually in Russia. Tendons used to be considered avascular
structures and primary flexor tendon repair was abandoned. In recent years, studies on tendon healing and physiology have led to many advances in their treatment and rehabilitation. Primary flexor tendon repair followed by early tendon movement is now considered standard, though the strength of such rectified tendons needs to be increased.

Numerous in vivo and in vitro studies have examined the effect of different suture techniques. A flexor tendon repair technique should satisfy 6 criteria prior to clinical application. They are: (1) easy placement of sutures in the tendon, (2) secure suture knots, (3) smooth junction of tendon ends, (4) minimal gap formation at the repair site, (5) minimal interference with tendon vascularity, and (6) sufficient strength throughout the healing to allow application of early motion stress to the tendon. Although many repair techniques have been proposed, few satisfy all 6 criteria.

The cruciate 4-strand flexor tendon repair technique showed a significantly stronger repair than the Kessler, Strickland, or Savage repairs, whilst providing better ultimate tensile strength and being easy to perform. It conferred the ease and speed of a 2-strand technique and the tensile strength that exceeded other 4-strand techniques.

Most flexor tendon repair techniques were based on studies that used transversely lacerated tendons. Tendon lacerations can be oblique or incomplete. Few publications on the tensile strength of the tendon repair techniques were based on obliquely lacerated tendons.

The direction of tendon lacerations affected the strength of certain repair configurations. The non-locking modified Kessler or the 4-strand cruciate tendon repairs were weakened considerably when the tendon was obliquely lacerated. Nonetheless, re-orienting the repair strands to lie parallel to the laceration strengthened their mechanical performance.

The tensile properties of oblique partial tendon lacerations and the effects of peripheral sutures on their strength were evaluated. Obliquity of the laceration affected the strength of partially lacerated tendons. Tendons with 45° or 60° oblique lacerations had significantly lower ultimate strengths than those with transverse, or 15° or 30° oblique lacerations. Running peripheral sutures significantly increased both the gap formation forces and the ultimate strength of the tendons with oblique partial lacerations.

Elongating the repairs improved the strength in obliquely lacerated tendons. When the grasping point was moved farther away from the level of the laceration, the suture-tendon interface and grasping power of the sutures on the collagen bundles increased.

We assessed the tensile strengths of the modified 4-strand cruciate technique for obliquely lacerated tendons, and compared the findings with the strength of transversely lacerated tendons repaired at various grasping depths (ranging from 5 mm to 15 mm).

**MATERIALS AND METHODS**

60 flexor tendons of 30 adult pig front feet were harvested for the experiment. Such tendons are readily available, easy to handle, long enough for fixation in clamps for mechanical testing, and have a similar structure to human tendons. The 6-cm long flexor profundus tendons were exposed completely through an incision at the metatarsophalangeal joint. The site of transection was marked, so were the sites at 5 mm, 10 mm and 15 mm away from the transection site of both ends. The tendons were then transected either transversely or obliquely (45°).

A single surgeon performed all tendon repairs using the modified 4-strand cruciate technique, with the suture knot being placed between the 2 cut ends of tendon (Fig. 1). All tendons were repaired with 4-O non-absorbable suture (Ethilon W1620; Ethicon, St-Stevens-Woluwe, Belgium) and a circumferential running suture with 6-O non-absorbable material (Ethilon W1610; Ethicon, St-Stevens-Woluwe, Belgium).

The 60 tendons were evenly divided into 4 groups. In groups 1 to 3, tendons were transversely lacerated and repaired with grasping points at both ends away from the laceration by 5 mm, 10 mm, and 15 mm,
respectively. In group 4, tendons were obliquely lacerated and repaired with a grasping point 5 mm away from the laceration on one end and 15 mm on the other (Fig. 2).

Immediately after repair, the tendons were tested to failure in a tensile machine (MTS 858 Mini Bionix, MTS System Corporation, Eden Prairie, USA). Both tendon ends were mounted on round wire end caps, with the upper clamp connected to a force transducer (Fig. 3). The tendon was then distracted at a rate of 25 mm/min until complete pullout or suture rupture. Time, force, and displacement were recorded simultaneously during the test. A one-way ANOVA was used for data analysis. Levene’s test was used to test for homogeneity of variance. The Tukey Honestly Significantly Different post hoc test was used for pairwise multiple comparisons. P values of <0.05 were considered significant. Data were presented as mean (standard error of mean [SEM]).

RESULTS

The respective mean ultimate tensile strengths of groups 1 to 4 were 33.8 (SEM, 1.2; range, 23.9–41.8) N, 46.3 (SEM, 1.2; range, 38.4–52.4) N, 45.1 (SEM, 0.9; range, 40.4–54.2) N, and 45.5 (SEM, 1.7; range, 31.9–53.9) N; the overall mean was 42.7 N. The Levene statistic was 2.229 (p=0.095); the F value was 21.41 (p<0.005). The ultimate tensile strength in group 1 was significantly lower than that in the other 3 groups (p<0.005), and in group 4 it was not significantly different from groups 2 and 3 (Table).

The circumferential suture provided around 35% extra strength to the core suture in transversely lacerated tendons, whereas in obliquely lacerated tendons it provided only around 11% extra strength to the core suture (Fig. 4). When the tendon was

Table

<table>
<thead>
<tr>
<th>Tendon No.</th>
<th>Failure force (N)</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Group 1</td>
</tr>
<tr>
<td>1</td>
<td>23.90</td>
</tr>
<tr>
<td>2</td>
<td>38.49</td>
</tr>
<tr>
<td>3</td>
<td>30.70</td>
</tr>
<tr>
<td>4</td>
<td>34.35</td>
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<td>5</td>
<td>40.11</td>
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<tr>
<td>6</td>
<td>31.39</td>
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<tr>
<td>7</td>
<td>28.63</td>
</tr>
<tr>
<td>8</td>
<td>34.90</td>
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<tr>
<td>9</td>
<td>34.66</td>
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<tr>
<td>10</td>
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<td>11</td>
<td>32.15</td>
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<td>13</td>
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<tr>
<td>14</td>
<td>29.63</td>
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<tr>
<td>15</td>
<td>38.14</td>
</tr>
<tr>
<td>Mean</td>
<td>33.81*</td>
</tr>
<tr>
<td>(SE)</td>
<td>(1.22)</td>
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</tbody>
</table>

* Significantly lower than other groups (p<0.005)
distracted, tension gradually increased and reached the first peak while both the core and circumferential sutures were intact. The circumferential suture failed first and the core suture remained, making the second rise in tension until the core suture failed giving the second peak (Fig. 4).

**DISCUSSION**

Moving the grasping point away from the lacerated site up to 10 mm improved the ultimate tensile strength of the transversely lacerated tendons, as it increased the suture-tendon interface and provided greater grasping power on the collagen bundles. However, this could only improve the pull-out strength, not the tensile properties of the suture material. When the tension exceeded the ultimate tensile strength of the suture material, the suture broke. The mode of failure in suture with farther grasping point may be due to suture breakage, whereas in nearer grasping point, it may be due to cut out of the suture from the tendon.

The suture usually failed near the knot, as the knot produced a stress riser and concentrated the stress on the knot. Maintaining a distance between the grasping point and the laceration (e.g. 10 mm) twice the diameter of the tendon (e.g. 5 mm) may provide the optimal strength. However, we did not record the diameter of each tendon. Therefore, no concrete conclusion could be drawn in this aspect.

In the present study, the ultimate tensile strengths of the obliquely or transversely lacerated tendons were comparable, as the grasping point at one end of the obliquely lacerated tendon being 15 mm away from laceration provided sufficient strength to compensate the relatively weak 5-mm end. However, weaker ultimate tensile strength in obliquely lacerated tendons has been reported, in which McLarney’s cruciate 4-strand technique was used. The difference in knot location could affect the ultimate tensile strength. Theoretically, knots located outside of the repair site may interfere with tendon gliding and increase adhesions, whereas knots located within the repair site may compromise tendon healing. An *in vitro* study concluded that the number of knots in a repair should be minimised and preferentially be placed outside of the tendon repair site. However, an *in vivo* canine study concluded that placing a knot within the repair site did not negatively impact tensile strength and may actually stimulate tendon healing. A knots-outside suture had greater initial tensile strength, but the knots-inside suture showed a statistically significant increase in tensile strength at 6 weeks.

The gap formation force was not studied, as we did not have the proper equipment to measure the gap distance during distraction. Gap formation weakened the strength and stiffness of a repair and was associated with increased adhesions and impaired tendon gliding. Gaps of >2 mm were associated with increased adhesion and poorer clinical results. Therefore, minimising gap formation may improve the ultimate tensile strength. The ideal ratio of the length of the longitudinal strands to the tendon diameter was not studied as well.

**CONCLUSION**

The modified 4-strand cruciate technique is safe to use for repairing obliquely lacerated tendons. Moving the grasping point further away from the laceration site (up to 10 mm) appears to improve the ultimate tensile strength of transversely lacerated tendons. Further studies are needed to define the ideal ratio of the distance of grasping point to tendon diameter and to measure the 2-mm gap formation force.

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REFERENCES