SCIENTIFIC ARTICLE

Influence of Locking Stitch Size in a Four-Strand Cross-Locked Cruciate Flexor Tendon Repair

Tim S. Peltz, MD, Roger Haddad, MBBS, Peter J. Scougall, MBBS, Sean Nicklin, MBChB, Mark P. Gianoutsos, MD, William R. Walsh, PhD

Purpose The 4-strand cross-locked cruciate technique (Adelaide technique) for repairing flexor tendons in zone II is a favorable method in terms of strength and simplicity. The purpose of this study was to investigate the effects of varying the cross-lock stitch size in this repair technique. Outcomes measured were load to failure and gap formation.

Methods We harvested 22 deep flexor tendons from adult pig forelimbs and randomly allocated them into 2 groups. After cutting the tendons at a standard point, we performed a 4-strand cross-locked cruciate repair using 3-0 braided polyester with either 2-mm cross-locks (n = 11) or 4-mm cross-locks (n = 11). All repairs were completed with a simple running peripheral suture using 6-0 polypropylene. Repaired tendons were loaded to failure and the mechanism of failure, load to failure, stiffness, and load to 2-mm gap formation were determined.

Results All repairs failed by suture breakage; we noted no suture pullout. There was no difference in load to failure (71.7–71.1 N; $p = .89$) or stiffness (4.1–4.6 N/mm; $p = .23$) between the 2-mm cross-lock and the 4-mm cross-lock groups. There was a trend toward higher resistance to 2-mm gap formation with the 4-mm cross-locks (55–62.2 N; $p = .07$).

Conclusions Four-strand cross-locked cruciate repairs with cross-lock sizes of 2 and 4 mm provide high tensile strength and are resistant to pullout. Repairs with 4-mm cross-locks tend to provide a more central load distribution and better gapping resistance than repairs with 2-mm cross-locks. *(J Hand Surg 2011;36A:450–455. Copyright © 2011 by the American Society for Surgery of the Hand. All rights reserved.)*

Key words Flexor tendon, gap formation, mechanical testing, tendon repair, locking stitch.

THE IDEAL FLEXOR tendon repair should be easy to reproduce and add as little bulk as possible. It should possess a high tensile strength to safely allow early mobilization, and be resistant to gap formation to facilitate healing with minimal scarring. Various repair techniques have been described that differ in their ability to meet these aims.

Repair strength relates to several factors including suture material[1–4] and size,[5] suture configuration,[6–9] and the number of suture strands crossing the repair site.[10] Yet the complexity of achieving a 6- or even 8-strand repair has limited practical application. Potential pitfalls with using more than 4 strands include the surgeon's technical ability, an increase in surgical time, tissue handling, repair bulk, and injury to tendon vascularity. Four-strand techniques may provide a good compromise between minimizing complexity and adequate performance.

Sandow and McMahon[11] first reported the cross-locked cruciate repair as a 4-strand modification of the Savage 6-strand repair technique using 2 single cross-

From the Surgical and Orthopaedic Research Laboratories, University of New South Wales, Prince of Wales Hospital, Sydney; and the Department for Hand Surgery, Sydney Hospital, Sydney, New South Wales, Australia.

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Corresponding author: William R. Walsh, PhD, Surgical and Orthopaedic Research Laboratories, Prince of Wales Hospital, Randwick, 2031, Sydney, Australia; e-mail: w.walsh@unsw.edu.au.

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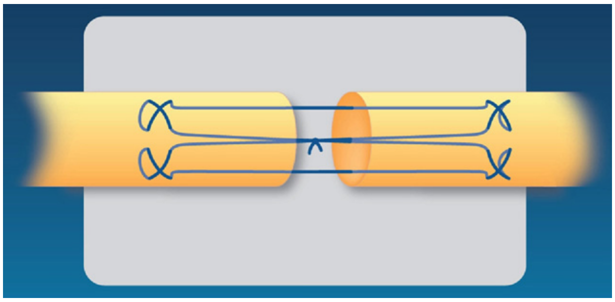

FIGURE 1: Schematic drawing of the cross-locked cruciate repair technique (Adelaide repair).

locks to grasp the tendon ends on each side[8,12] (Fig. 1). This repair technique is also known as the Adelaide repair technique. Current literature suggests that this cross-locked cruciate repair is not only stronger than other 4-strand techniques but also is a favorable repair in terms of gap formation and simplicity.[13–17] However, the optimum size of the cross-locks in this specific repair technique has not been investigated, or indeed whether the size of the locking stitch effects the repair strength or gapping behavior. The purpose of this article was to address this question in an *ex vivo* porcine model.

MATERIALS AND METHODS

Many *ex vivo* animal models use porcine deep flexor tendons to investigate tendon repair constructs.[2,7,16–22] Although previous investigators confirmed the resemblance of diameters and arrangement of flexor tendons in pig toes with those of human digits,[23,24] we felt the need to define an exact point of dissection to reliably mimic a zone II laceration in humans. Therefore, we dissected 6 forelimbs from adult pigs and re-examined the anatomy of the deep flexor apparatus. The A1 to A4 pulleys and the vinculum longum were identified (Fig. 2A). We used clamps to mark the interval between the vinculum and A1 pulley and took x-rays of the specimen. (Fig. 2B). We found a consistent relationship between this interval and the underlying phalangeal bones, corresponding to zone II in humans. Based on this examination, we chose a standard point 5 mm distal to the A1 pulley as the site for tendon transection and repair.

We harvested 22 deep flexor tendons from the forelimbs of adult pigs and randomly allocated them into 2 repair groups of 11 each. We used a less than 5% partial laceration to mark the planned transection point at time of harvest. Tendons were individually wrapped in saline-soaked gauze and deep-frozen at –18°C until the day of experimentation.

On the day of mechanical testing, each tendon was thawed to room temperature immediately before transection and repair. We took care to minimize tensile strengthening of the tendon resulting from saline soaking.[25,26] A sharp transverse laceration of the tendon was performed at the premarked site using a number 22 scalpel blade. All tendons were then repaired with a 4-strand cross-locked cruciate suture technique (Fig. 1). The repairs were performed using 3-0 silicone-coated braided polyester sutures (Ticron; Tyco, Lane Cove, NSW, Australia) and each repair was accomplished by the same surgeon (TP) using ×3.2 loupe magnification. The cross-locks were uniformly set 10 mm from the line of tendon division. We used a cross-lock width of 2 mm for group 1 (n = 11) compared with a width of 4 mm for group 2 (n = 11) (Fig. 3). All repairs were completed with a 6-0 polypropylene (Prolene; Ethicon, Somerville, NJ) simple running peripheral suture with 16 loops and 2-mm purchase. We used a digital caliper (Mitutoyo CD-6–inch CS; Absolute Digimatic, Tokyo, Japan) during surgery to determine exact measurements of distances and lengths.

We mechanically tested repaired tendons in a uniaxial manner using an MTS 858 Mini Bionix materials testing machine (MTS Systems Corp., Eden Prairie, MN). Tendons were gripped in grooved pneumatic clamps with a gripping pressure of 60 psi. Gauge length was standardized at 40 mm. Samples were preloaded to 1.5 N, then tested to failure at a relative slow distraction rate of 10 mm/min. Load, displacement, and time were continuously recorded at 100 Hz. We used data to generate load-displacement graphs for each tendon. In addition, we placed a digital caliper fixed at 2.0 mm adjacent to the repair site as a reference. The repair site was continuously filmed during testing using a high-definition Sony Handycam camcorder (Sony Corp., Tokyo, Japan) to monitor gap formation. The timing of the video was coupled with the data recorded by the testing machine. This method allowed an exact visual and biomechanical correlation of 2-mm gapping.

We determined load to failure (N), load to 2-mm gap formation (N), stiffness (N/mm), and mechanism of failure for all samples. The video and mechanical data were correlated after each test to determine the load to first point of 2-mm gapping. Stiffness was defined from the tangent of the linear middle third of the load-displacement curve. We recorded the mechanism of failure as suture breakage at the knot, suture breakage away from the knot, or suture pullout.

Data are presented as means (± standard deviation) and were analyzed using SPSS version 17.0 (SPSS Inc., Chicago, IL). We used independent *t*-tests assuming