A Biomechanical Evaluation of Various Double Krackow Suture Techniques for Soft-Tissue Graft Fixation

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Purpose: The purpose of this study was to compare the biomechanical properties among the different double Krackow suture techniques for tendon graft fixation. **Methods:** Thirty porcine flexor profundus tendons were randomly divided into 3 groups of 10 specimens each. Three different double Krackow suture techniques were evaluated, namely, the McKeon's double Krackow (MDK) suture, Wilson's double Krackow (WDK) suture, and Ostrander's modified Krackow (OMK) suture. All suture configurations were completed with a braided nonabsorbable suture. Each suture-tendon construct was pretensioned to 100 N for 3 cycles, cyclically loaded from 50 to 200 N for 200 cycles, and then finally loaded to failure. Elongation after cyclic loading, ultimate load to failure, and the mode of failure were recorded for each specimen. **Results:** There were significant differences in elongation after cyclic loading among the MDK suture (7.9 ± 3.6 mm, 14% ± 6%), WDK suture (11.6 ± 2.2 mm, 22% ± 3%), and OMK suture (9.6 ± 3.3 mm, 17% ± 6%; $P = .018$). In addition, although the post hoc analysis showed that elongation after cyclic loading in the MDK suture was significantly less than the WDK suture ($P = .004$), ultimate failure load and cross-sectional area were not significantly different across the 3 groups. **Conclusions:** In this porcine in vitro biomechanical study, the MDK suture had significantly smaller elongation after cyclic loading than the WDK suture; however, high elongation values may have a potential for risk of clinical laxity. The ultimate failure load was not different across the MDK, WDK, and OMK sutures. **Clinical Relevance:** Smaller elongation during cyclic loading in a suture-tendon construct represents a lower possibility of tendon graft loosening after ligament reconstruction surgery. The double Krackow suture techniques are attractive options for tendon graft fixation in ligament reconstruction, and the MDK suture could possibly be the optimal choice among the double Krackow suture techniques.

A secure suture-tendon construct is important in ligament reconstruction surgeries. A strong fixation strength that can withstand the inherent mechanical loading would allow for early rehabilitation before the completion of biologic healing in the graft tunnel.[1-5] Numerous suture techniques have been described for fixing tendon grafts,[1,2,4,6-12] and the Krackow suture, first proposed in 1986, is a common technique.[8]

Various biomechanical characteristics affect the fixation strength of graft fixation,[4,13,14] and the number of sutures is one of them.[4] McKeon et al.[4] biomechanically evaluated the fixation strength of the Krackow suture with respect to different numbers of sutures and suture loops. Their results revealed that adding a second Krackow suture interlocked at 90° with the first suture increased the ultimate failure load of the suture-tendon construct.[4] Based on their experimental findings, the authors suggested that the optimal Krackow suture configuration would be composed of 2 interlocking sutures at 90° that have 2 locking loops on each side.[4]

In 2014, Wilson et al.[11] proposed another double suture technique for tendon graft fixation. In their technique, a total of 4 pairs of suture loops are placed along both sides of the tendon; the first and third suture

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loops are created by the first suture, while the second and fourth suture loops are achieved by the second suture.[11] They also biomechanically evaluated the fixation strength between the double Krackow suture and 3-loop pulley suture in a canine gastronemius tendon avulsion model.[11] Their results suggested that the double Krackow suture had superior biomechanical properties to the 3-loop pulley suture; therefore, the authors strongly suggested applying the double Krackow suture in clinical practice.[11]

In 2016, Ostrander et al.[15] demonstrated the so-called modified Krackow stitches with a pair of sutures. Ostrander's modified Krackow (OMK) suture is composed of 4 pairs of suture loops; the first and third pairs of suture loops are completed with one suture, while the second and fourth suture loops are accomplished with another.[15] Differing from the technique proposed by Wilson et al., the tendon is flipped after one set of sutures is completed.[15] Ostrander et al.[15] also reported that the OMK suture had similar elongation after cyclic loading and significantly greater load to failure compared with the modified locking SpeedWhip stitch.

Although previous studies[4,11,15] have recommended the double Krackow suture with 2 pairs of suture loops in each suture for soft-tissue graft fixation, little was known about the biomechanical properties between the different double Krackow suture techniques. The purpose of this study was to compare the biomechanical properties among the different double Krackow suture techniques for tendon graft fixation. Our hypothesis was that there would be no differences in elongation and load to failure among the 3 different double Krackow suture techniques.

Methods

This study was granted an exemption from the Institutional Review Board at National Cheng Kung University Hospital, Tainan, Taiwan. Porcine flexor profundus tendons acquired from fresh adult male porcine (mean age, 2 years) hindleg trotters were used, and a total of 30 tendons of equal length (18 cm) were excised. The hindleg trotters, stored at −20°C, were thawed to room temperature, after which the entire flexor profundus tendon was dissected. Upon inspection, it was agreed that none showed any degenerative or pathologic changes. The attached soft tissue, including the synovial sheath, was removed from the distal part of the tendons. A transverse section 5 to 6 mm in thickness was then acquired from the distal end of each tendon. With the use of a calibration scale, an 8.9-megapixel digital camera (EOS 60D; Canon, Tokyo, Japan), and image analysis software (SigmaScan Pro 5.0; Systat Software Inc, San Jose, CA), the cross-sectional area of each tendon section was calculated.

The tendons were randomly divided into 3 groups of 10 specimens each, with each group randomly assigned to receive one of the 3 kinds of suture configuration, namely, the McKeon's double Krackow (MDK) suture,[4] Wilson's double Krackow (WDK) suture,[11] or Ostrander's modified Krackow (OMK) suture.[15] A 0.9% saline solution was sprayed on the tendons to keep them moist during preparation and testing. A no. 2 HI-FI high-strength suture (CONMED, Largo, FL) was used for all samples.

The MDK suture technique began at 1 cm from the distal end of the tendon. The first set of the Krackow stitch with 2 throws along each side of the tendon was performed, with the interval between the throws being 5 mm. After rotating the tendon 90° in the clockwise direction, a second suture was applied to perform another set of the Krackow stitch, also with 2 throws along each side of the tendon (Fig 1A). Similarly, the WDK suture technique started at 1 cm from the distal end of the tendon. The first set of the Krackow stitch was conducted along the tendon with 2 throws on each side; the 2 throws of the WDK suture were located 1 cm and 2 cm, respectively, from the distal tendon end. Another suture was used to perform the second set of the Krackow stitch, 2 throws of which were located 1.5 cm and 2.5 cm from the distal tendon end (Fig 1B). The OMK suture technique started 1 cm from the distal end of the tendon. The first half of the steps in the OMK technique were the same as those in the WDK suture technique; however, after completing the first 2 pairs of throws with one suture, respectively located 1 cm and 2 cm from the distal tendon end, the tendon was flipped. The second 2 pairs of throws, respectively located at 1.5 cm and 2.5 cm from the distal tendon end, were then completed with another suture (Fig 1C).

Biomechanical Testing

Each suture-tendon construct was mounted on a universal material testing system (AG-X; Shimadzu, Tokyo, Japan). A sinusoid mechanical clamp was used to fix the proximal end of the tendons, allowing an equal length (9 cm) of free tendon (Fig 2). The ends of the sutures were knotted together and looped over a post on the adapter of the material testing machine.

Each tendon was pretensioned to 100 N at a rate of 100 mm per minute for 3 cycles and then preloaded to 50 N for 1 minute. Next, each suture-tendon construct was cyclically loaded between 50 N and 200 N for 200 cycles at a rate of 200 mm per minute. The above-mentioned parameters were set based on previous studies.[2,5,14,16-19] A blue line and 2 blue marks, respectively, marked on the tendon at a point 5 cm from the distal end of the tendon and on both suture limbs where they extended from the tendon were created as indicators for measuring the elongation of each suture-tendon construct. The elongation after