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Development of a new suturing technique for tendon graft preparation: An animal cadaver study

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ABSTRACT

Background: This study should analyze ten different suturing techniques for tendon graft preparation to allow the development of an entirely new suturing technique.
Methods: Extensor tendon grafts of fattening bulls' forelegs were sutured with Ethibond Excel size three (six metric) fibers (Ethicon, Somerville, New York, USA). The tendon/suture complexes were biomechanically tested with a hydraulic testing machine applying traction according to a standardized protocol. The testing was observed to find out why the failure at the maximum traction load occurred. The mean values for the maximum tension and extension stiffness were recorded for each suturing technique.
Findings: An entirely new suturing technique was developed based on the observations and biomechanical results. The newly developed suture was also tested and provided a higher traction stability than the other ten techniques that had been evaluated. Compared to the other ten techniques the new technique was ranked 3rd in terms of extension stiffness and reached 10.3 N/mm.
Interpretation: The new technique evolved in the course of this study provided promising results. Therefore this study provides initial evidence that this technique could be useful in clinical routine.

1. Introduction

Several biomechanical evaluations of suturing techniques for tendon graft preparation have been published. Jassem et al. reported on the effect of varying the suture pitch using the technique according to Krackow (Jassem et al., 2001; Krackow et al., 1986). Krappinger et al. compared a modified Prusik knot with a whipstitch technique (Krappinger et al., 2007). Sakaguchi et al. assessed the biomechanical differences of the techniques according to Krackow, a whipstitch technique, and a so-called baseball stitch (Sakaguchi et al., 2012). These studies provide results for a maximum of three different suturing techniques. Furthermore, these reviews varied in their methodology and therefore it is difficult to really compare the respective techniques. Yamagami et al. provided an important biomechanical evaluation by comparing four different suture techniques together with four different suture materials resulting in 16 combinations of methods (Yamagami et al., 2006). Braided polyblend polyethylene together with a single locking technique provided the highest antigap strength (Yamagami et al., 2006). The study clearly showed that the biomechanical characteristics of suturing techniques strongly depend on the suture material and size. Therefore it is crucial to use the same suture material and size for comparison and evaluation regarding the development of a new suturing technique. Yotsumoto et al. compared different suturing techniques regarding tensile strength and were able to draw conclusions from their testing (Yotsumoto et al., 2010). This study demonstrated that the evaluation of techniques regarding tensile strength possibly allows to draw conclusions regarding the characteristics of techniques (Yotsumoto et al., 2010).

The literature shows that analyzing several existing techniques with similar methodology could contribute valuable information for the development of a new technique.

The aim of this study was to biomechanically test ten different suturing techniques for tendon graft preparation and to analyze the failure mode, i.e. where and why suture failure occurred. Out of these observations a new suturing technique should be developed and tested in terms of traction stability and extension stiffness.

2. Methods

2.1. Anatomical specimen/tendon grafts

From a local abattoir 55 fresh bovine extensor tendon grafts, originating from Simmental Fleckvieh cattle were harvested from the forelimbs. The calves aged around two years, weighing approximately

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800 kg. The terminal branches of the common digital extensor tendons of digits III and IV were cut right above the extensor process of the coffin bone (hoof) and below the bifurcation. The average diameter of the tendons was 4.7 ± 0.3 mm. The tendons were cut to a length of 10 mm. The distal end of the tendon branches was used for suturing. This study was reviewed and approved by the IRB.

2.2. Suture

2.2.1. Suture materials

For the testing of the techniques Ethibond Excel size 3 (6 metric) fibers (Ethicon, Somerville, New Jersey, USA) were used. In order to acquire reference values, the doubled suture material Ethibond Excel 3 was also tested without tendon involvement.

2.2.2. Terms and definitions

The tendon end, which was clamped in jaws, was defined as the proximal end and the tendon end used for suturing was defined as the distal end. The suture pitch presents the distance between two adjacent stitches (Fig. 1). It was generally 5 mm in our study. The distance between the most distal stitch and the tendon end was defined to be 5 mm (Fig. 1).

2.2.3. General description of suture course

The tendon was clamped using special jaws (see 2.4 Biomechanical traction testing) with low pressure. The distal tendon end was hanging over the edge of the table. The suture length was calculated by multiplying the number of throws by 5 mm and marked onto the tendon with a water-resistant pen. Suturing was then started at this proximal mark. Right after stitching on the right side of the tendon, the corresponding stitch on the left side was performed. After the most distal stitch, the fiber was either carried forward into the tendon (e.g. using the technique according to Bunnell or the newly developed technique) or outside the tendon (e.g. using the technique according to Bauer or Krackow).

2.3. Suturing techniques

Ten different suturing techniques were evaluated in this study for the development of a new suturing technique (Fig. 2). Detailed photos of the techniques in plane view, side view and bottom view are supported online in the supplementary data section.

Whip4_Rowden has already been described in the literature (Rowden et al., 1997). Whip4_modified differed in the most proximal stitch from Whip4_Rowden. Whip4_crossed differed in the way that the suture ran within the tendon, but from the outside the seam construction diagram did not look different. Whip4_shifted was characterized by shifted stitches in the tendon. Whip6 showed the same proximal seam construction diagram as Whip4_Rowden, but had two more throws.

Furthermore a modified version of the technique according to Strobel was included: six throws were used for Strobel_modified, while originally five throws were published (Strobel, 1998). The technique according to Krackow (Krackow et al., 1986, 1988), the suturing technique according to Bauer (Bauer et al., 1995) and the technique according to Bunnell (Bunnell, 1928) were also evaluated. In addition Bunnell_modified was tested. This technique had an additional backstitch compared to the original technique according to Bunnell.

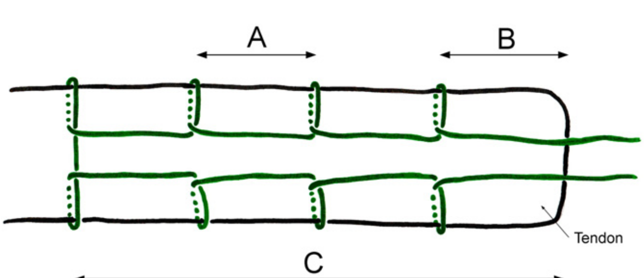

Fig. 1. Suture sketch. The sketch explains terms and definitions, exemplary for the suturing technique according to Bauer: A = suture pitch; B = distance between the most distal stitch and the tendon end; C = effective length for force transmission.

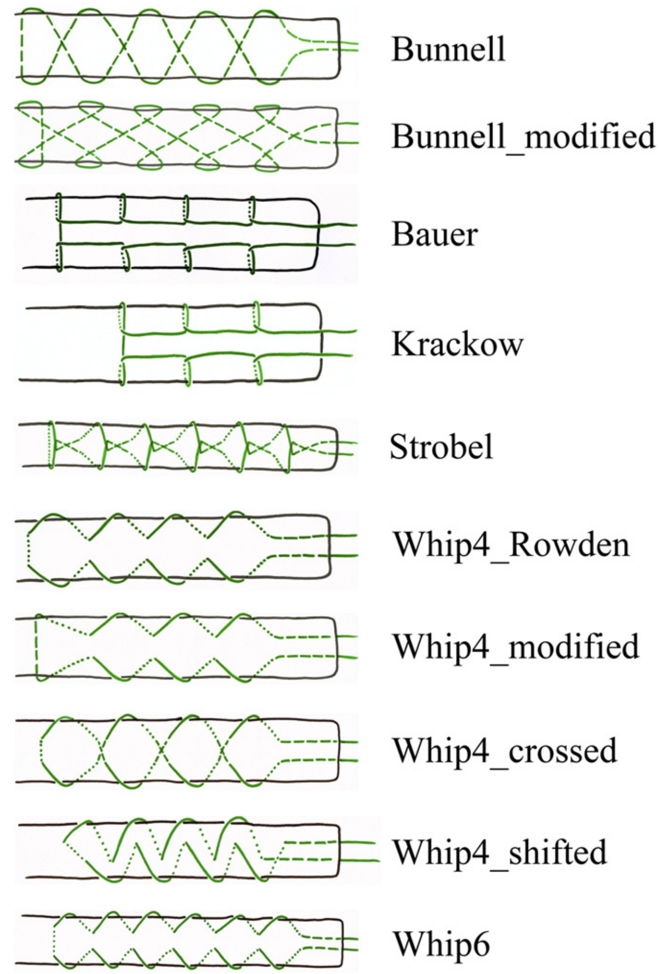

Fig. 2. Overview of the ten evaluated suturing techniques. Detailed pictures of the techniques are provided in the supporting information section. The suture pitch ("A" according to Fig. 1) and the distance between the most distal stitch and the tendon ("B" according to Fig. 1) were both 5 mm for all techniques in this study. The effective length for force transmission was 15 mm for the technique according to Krackow, 20 mm for the technique according to Bauer, 25 mm for all Whip4 techniques and both Bunnell techniques, 30 mm for the technique according to Strobel and 35 mm for the Whip6 technique.

2.4. Biomechanical traction testing

The tendons were clamped right at the proximal end of the suture. To avoid damage to the tendon caused by pinching it with the clamps and to reduce the risk of a possible tendon tear, special jaws with increased friction were developed for the used tendons. The principle had already been used by Wilhelm et al. for biomechanical testing of the Achilles tendon (Wilhelm et al., 1973) but has already been used for hamstring tendons as well (Jagodzinski et al., 2004). This principle was adapted and jaws with hemicycles of 5 mm in diameter were manufactured for tendon clamping in regard to the diameter of the used tendons. The suture material was clamped between two planar clamp jaws (Teflon plates with 3 mm thickness). Traction was generated by a hydraulic testing machine (Z010/TN2A, Zwick/Roell, Ulm, Germany).