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ARTICLE

Technique and biomechanical properties of the side-to-side Z-lengthening in spasticity-correcting surgery- a study on porcine tendons

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ABSTRACT

Spasticity-correcting surgery in patients with injuries to upper motor neurons include various techniques, including tenotomies and lengthening of tendons of spastic muscles. Early mobilization including active loading of a lengthened tendon is essential to prevent adhesion formation, which necessitates a lengthening technique that resists the forces produced by the involved muscles. This study on animal tendons reports the biomechanical properties in regards to elongation and load to failure in porcine tendons lengthened by either a 3 or 5 cm overlap and tested in a simple force rig. The lengthening technique used in these tendons is described in step-by-step detail. The mean elongation of 20 lengthened tendons at 100 N was 10 mm for tendons with a 3 cm overlap and 6 mm for tendons with a 5 cm overlap. The mean peak load at failure of the construct was 138 N for lenghened tendons with a 3 cm overlap and 201 N for tendons with a 5 cm overlap. The results of this study indicate that a tendon lengthened by the described technique with a mere overlap of three cm will withstand the estimated forces elicited by muscles in the forearm immediately after surgery.

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Introduction

Spasticity after brain or spinal cord injuries, e.g. stroke, cerebral palsy or traumatic injury, may cause pain, contractures, deformities and impaired hygiene [1]. In addition to pharmacological treatment, surgery is a treatment option [2] to alleviate symptoms of hypertonus and includes various techniques such as tenotomies, fractional lengthening at the musculotendinous junction and z-lengthening of tendons [3–5]. The specific technique of the Z-lengthening tenodesis in the upper extremity is not, contrary to the procedure in the Achilles tendon [6], well described, even in systematic reviews [7]. Furthermore, rehabilitation after spasticity-correcting surgery is essential and at our unit we have published a protocol for early active mobilization within 24 h after surgery [8]. A 1-year follow-up of 30 patients operated with the technique described below and with this rehabilitation protocol showed significantly reduced spasticity and pain and improved hand activities [9].

Even though the rupture rate in lengthened tendons exposed to immediate loading have been less than one percent in our clinic over the years, the evidence is scarce regarding the biomechanical strength of the sutured construct with the exception of a recent study which compared two different lengthening techniques [10]. However, the tendons in this study were sutured with only one or two sutures, which we assume is much less than what is regularly used in clinical practice.

The rationale for this study was to investigate the biomechanical properties of the lengthening tenodesis regarding elongation during loading and load to failure in a porcine model.

Material and methods

Forty fresh Flexor digitorum profundus (FDP) tendons from the two central rays in 1-year old pigs were obtained from a local butchery. No ethical approval was needed. All three authors, who are highly specialized surgeons in this field, performed the lengthening procedures. A Z-lengthening was performed in the central portion of each tendon, and twenty tendons were sutured with an overlap of 3 cm (Figure 1) and the other twenty tendons with an overlap of 5 cm as described in detail in Figure 2. The shorter overlap was sutured by five cross-stich running sutures using 4–0 braided polyester suture (Ti-Cron, Medtronic, Minnesota, USA), and the longer overlap by eight sutures.

A simple force rig was constructed using a reversed clamp (Quick Clamp QCB600/200 kgs force, Bahco, SNA Europe, Cergy Pontoise, France) to produce gradual tension. A calibrated Kern hanging scale dynamometer (KHCB 50 kg/20 g, Kern & sohn GmbH, Balingen, Germany) was placed between the static part of the Quick Clamp and the force-generating part. The dynamometer was set to record the maximum force that the tested tendons would withstand.

The lengthened tendons were secured in both ends with clamps in the force rig, and in order to measure elongation sutures were placed at both ends of the overlap in the tendon and the distance was measured by manual calipers before loading (Figure 1). The tension was increased to 100 N, and the elongation of the tendon was recorded by measuring the distance between the sutures and subtracting the distance recorded before any force was applied. The force was then increased gradually until

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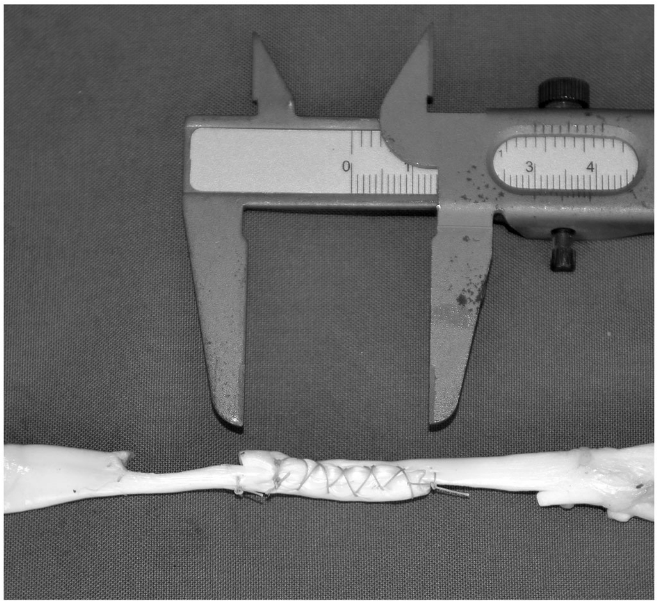

Figure 1. A porcine FDP tendon lengthened with a 3 cm overlap prior to load testing. The single sutures at the ends were used to measure the lengthening of the construct at 100 N.

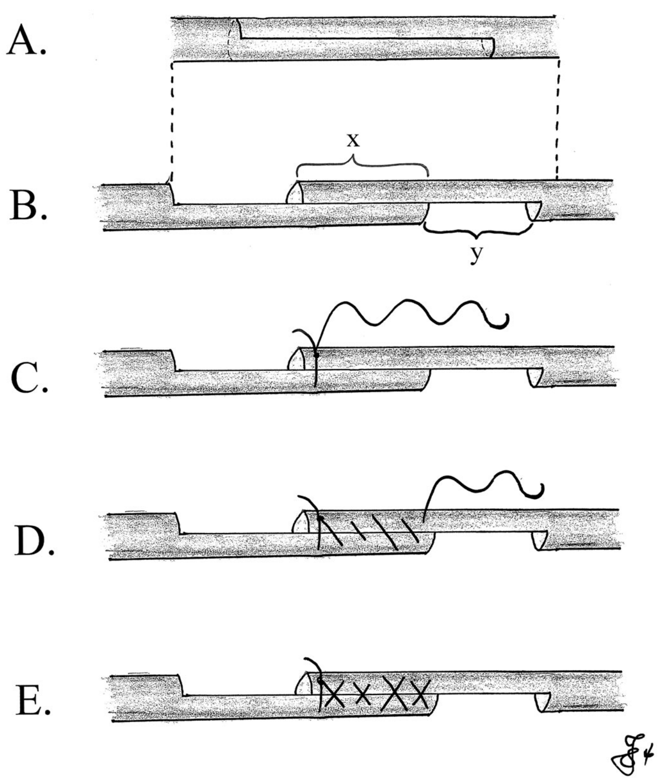

Figure 2. Schematic illustration of the lengthening procedure. (A) A Z-incision was made in which the length of the legs should be made as long as possible to maximize the overlap. (B) The legs of the tendon were distracted and × denotes the overlap, which were 3 and 5 cm, respectively. (C) Using a braided polyester suture (4–0), an anchoring single suture was placed at one side of the overlap. The end of the suture was used to tie the knot at the end of the procedure. (D) The placing of the sutures was varied as the suture was continued in order to prevent splitting of the fibers of the tendon. The suture turned at the end of the overlap. (E) An uneven cross-stitch pattern develops as the suture was returned and finally tied to the anchoring suture.

the construct failed, and the peak load of the dynamometer was recorded.

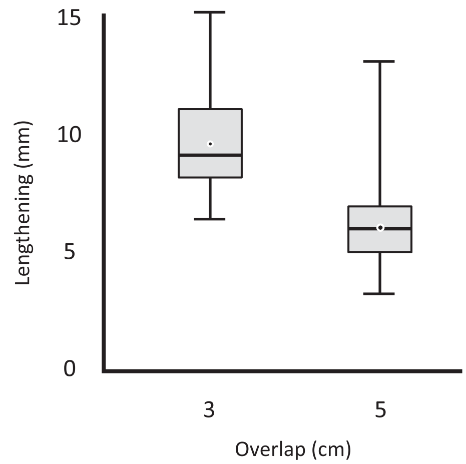

Figure 3. Elongation at 100 N. Twenty tendons were operated with an overlap of 3 cm, and another twenty with an overlap of 5 cm. Bars represent medians, dots means, boxes the interquartile range and whiskers the minimum and maximum loads.

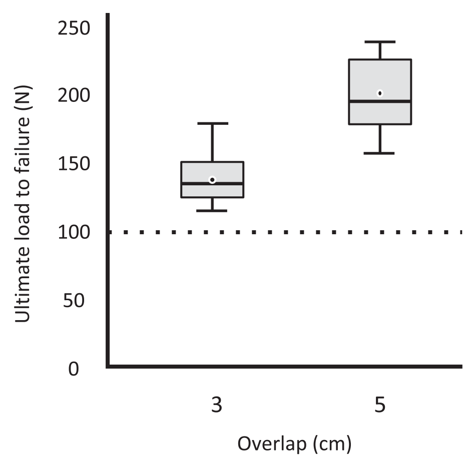

Figure 4. Ultimate load to failure. Twenty tendons were operated with an overlap of 3 cm, and another twenty with an overlap of 5 cm. Bars represent medians, dots means, boxes the interquartile range and whiskers the minimum and maximum loads. The dotted line represents the highest maximum force generated by forearm muscles.

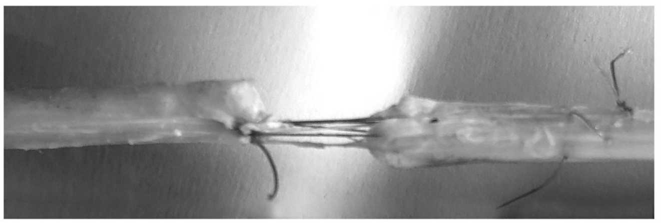

Figure 5. All forty lengthened tendons failed by shearing of the sutures through the tendon tissue.

Results

The mean elongation of the lengthened tendons at 100 N was 10 mm for tendons with a 3 cm overlap and 6 mm for tendons with a 5 cm overlap (Figure 3). The mean peak load at failure of the construct was 138 N for lengthened tendons with a 3 cm overlap and 201 N for tendons with a 5 cm overlap (Figure 4). Failure occurred when the sutures sheared through the tendons (Figure 5), no suture breakage or other cause of failure was registered.

Discussion

This limited study on porcine tendons tested in a simple force rig showed that even a short overlap provides substantial tensile strength in a lengthened tendon. It has been reported that the median flexor digitorum profundus force is 24 N and median flexor digitorum superficialis force is 13 N during active flexion [11]. Furthermore, it has been stated that the maximum tensile strength of any muscle in the forearm is 100 N [12]. Given this, the security margin of this technique seems to be adequate to allow immediate active mobilization postoperatively which is consistent with our clinical experience. An overlap of 5 cm instead of 3 cm yields an even higher security margin, and is usually possible to perform in most tendons in the forearm. The lengthening of the construct is probably clinically insignificant, since elongation less than 15 mm usually is compatible with excellent function [13]. Furthermore, the mode of failure in all tendons indicates that the tendon tissue, not the sutures, was the limiting factor and these results are consistent with the results of a recently published study [14].

One limitation of this study was the use of non-human tendons, but the porcine FDP model is an established method used in other biomechanical studies on tendons [14–16]. Moreover, the tensile testing in this study was not as sophisticated as in these studies, e.g. the tension was not increased with a specified velocity and the transverse size of the tendons was not measured. Even though the dynamometer was certified, the elongation of the tendons at 100 N was measured manually. However, the focus of the study in regard to the clinical use was to investigate if tendons lengthened with this technique could withstand the maximum force produced by muscles in the forearm (100 N) in order to allow immediate loading, which all tendons did.

When performing several tendon lengthenings simultaneously early mobilization is important to prevent adhesion formation [8] and the results from this study confirms that the hand therapists can rely on the suture strength when training the patient.

We conclude that this z-lengthening technique is robust, safe and allows early mobilization.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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