Acta of Bioengineering and Biomechanics
Vol. 19, No. 1, 2017

Original paper
DOI: 10.5277/ABB-00521-2015-03

Biomechanical properties of alternative suture technique for flexor tendon repair

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Purpose: Flexor injuries are most common in the hand and require special attention and experience from the surgeon. Both quality and technique affect the stability of the suture. The selection of the optimum method will influence the process of rehabilitation. The aim of this study was to compare three different suture techniques based on the strength, depending on the method of breakage, i.e., axial or pulley load. *Methods*: The study was divided into six sessions. The research material was dissected deep flexor porcine tendons. Three types of stitches were used: the modified Kessler suture with an additional running suture, the cruciate four-strand suture with an additional running suture and the multistrand running suture. We obtained 120 sutures, 40 for each technique. Breaking strength was assessed using a tensile machine in two ways, i.e., axial or pulley load, with 20 sutures per group. *Results*: The strongest suture for both axial and pulley load was the cruciate four-strand suture. Between the multistrand running suture and the modified Kessler suture, there was no statistically significant difference in the strength of breaking for both axial and pulley load. Comparing the two ways of breaking, there was no statistically significant difference in the strength of the suture. *Conclusions*: The multistrand running locking suture is a good alternative to widely used core sutures. It not only provides the same strength as other techniques examined by us but also reduces the procedure time and trauma to the tips of the tendon.

Key words: *flexor injuries, multistrand running suture, modified Kessler suture, suture breaking strength*

1. Introduction

Flexor injuries are most common in the hand and require special attention and experience from the surgeon [1]. These are often multiple and time-consuming procedures [2], and the result has to be resistant to early mobilization protocols [3]. Among the various suture techniques, the surgeon has to select the most optimal one, i.e., which is the best for union and most resistant to early rehabilitation [4], [5].

Most of these techniques are based on the seam or seam core, which may be accompanied by a running suture [6]. Biomechanical testing of the breaking strength of sutures has shown that the strength increases with the number of core stitches [7]. Running sutures reduce the risk of cracks. Correct alignment is the most important factor affecting the prognosis after broken tendon fixation [8].

The technique becomes more difficult and complicated depending on the number of stitches, both core and running [7]. Our study is based on the Strickland

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Received: November 25th, 2015
Accepted for publication: May 31st, 2016

criteria that an ideal suture also takes into account the ease of suturing [9]. It has been shown that a greater number of core sutures in the fusion area significantly increases its strength [7]. The Department of Traumatology, Orthopedics and Hand Surgery at the Medical University in Poznań developed the single running locking suture. This solution aims to eliminate the core suture and strengthen the running suture. Our aim was to compare the most commonly used methods with an accompanying running suture, namely the modified Kessler suture and cruciate suture, with the running locking suture. We investigated the strength of the anastomosis and the duration of the procedure.

2. Materials and methods

Preparation of samples

The research material was dissected porcine tendons of the deep flexor muscle branch to fingers II and V (tendo musculus flexoris digitorum profundus ramus ad digitorium II et V) from the domestic pig (Sus scrofa f. domestica). Tendons were obtained from slaughtered 10–12 month old piglets. After slaughter, anatomical specimens were taken. Two tendons were obtained from each pig foot. During the study, all the rights of animals were retained and the study was approved by the Bioethics University of Medical Sciences in Poznań.

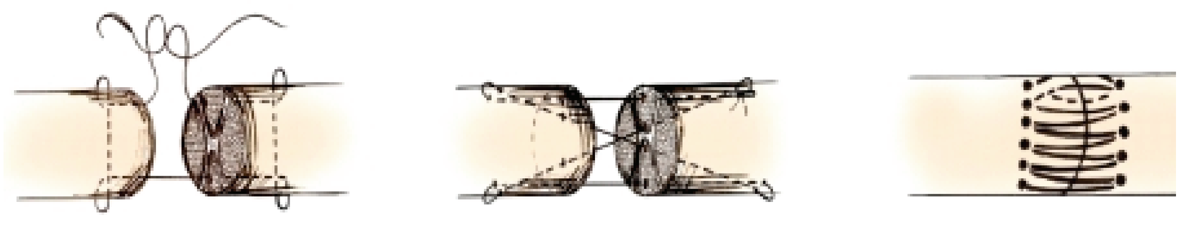
Description of the procedure

A longitudinal incision of the skin and subcutaneous tissue was performed at the midline on the plantar side of each foot, followed by dissection and identification of the deep flexor tendon II and finger V. Tendon cuts were made at the height of metatarsophalangeal joints and tarsometatarsal joints to provide approximately 7 cm long samples.

The study was conducted in six sessions in weekly intervals. During each session, 40 tendons were dissected, obtaining a total of 240 tendons. After dissection, the tendons were stitched using a modified Kessler (Fig. 1a) or cruciate (Fig. 1b) suture or the running locking suture developed by the authors (Fig. 1c, Fig. 2). Each tendon group was sutured together by four experienced operators, all of whom performed the same number of anastomoses of each type. In the end, there were 120 anastomoses, 40 for each method. To perform every stitch and the running locking suture, ATRAMAT (non-absorbable multifilament polyester) USP 3-0/ EP 2 5-0/EP 1 thread was used with a 1/2 circle R 26 mm needle. To complete each running suture, ATRAMAT CE 1245-N (non-absorbable monofilament nylon) 5-0 thread was used with a 3/8 circle R 12 mm needle. Standard needles were used in similar studies [7], [10]. Each procedure was done in a specific period of time. Time was measured for each suture separately with the use of stopwatch. Until breaking strength was assessed, tendons were stored in saline at 5 °C for not longer than 48 hours.

Running locking suture technique

After installing the first suture covering both ends of the tendon cut, a thread was introduced superficially on the opposite side (Fig. 1). Then, the tendon was introduced, without changing the direction, solely by the outer peritendineum and isolated superficial fibers lying below. Afterwards the thread was led out at 90° angle and re-introduced to the same depth (Fig. 2). The needle was introduced into the created loop, resulting in a knot, which was tightened such that the ends of the tendon were close to each other and slightly creased (Fig. 3). Each of the carried threads was anchored within the superficial fibers (up to about 1 mm in depth) using a tendon loop. Threads were carried in and out between the two ends of the tendon 13 to 15 times.



(a) (b) (c)

Fig. 1. Sutures compared in the study: (a) modified Kessler suture with an additional running suture; (b) cruciate four-strand suture with an additional running suture, and (c) multistrand running suture

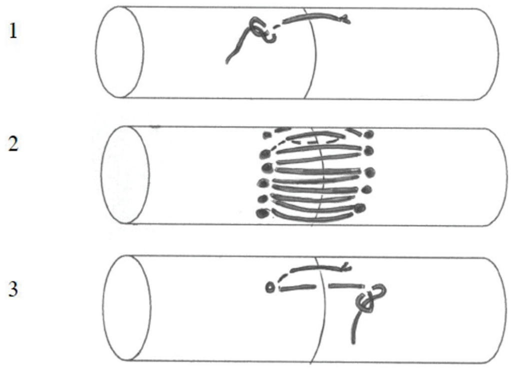


Fig. 2. Multistrand running suture technique

Biomechanical testing

Sutured tendons were examined using a Universal Testing Machine (Instron Model 4481) at the Department of Plastics (Poznań University of Technology). Each sample was mounted and stabilized in the respective holders of the machine (Fig. 3a). During each of the six sessions, 20 samples were examined. Ten samples were mounted along the axis of the load. The axis of symmetry coincides with the axis of the device. Another 10 samples were clamped using a block specifically designed for the analysis (Fig. 3b). This procedure provided a 90° angle of breakage [11]. All samples were subjected to a tensile speed of 5 mm/minute until a 2 mm space appeared.

Most studies assessing strength of tendon sutures are based on linear breaking, but in rehabilitation protocols and in the tasks of daily living or working, flexor tendons are subjected to stresses at different angles. To maximize the research conditions, and to approximate the working conditions of a tendon in vivo, a special block (Fig. 3b) was designed. Thus, the samples were subjected to an angular breaking force. The block was placed on a wooden board, with the ability to firmly secure the tendon to the pads, and the whole block was attached to the arm of the testing machine. The other end of the tendon was attached directly to the machine arm and the point of anastomosis of the tendon was placed at the location where the tendon bent over the pad at an angle of 90°.

Statistical methods

Collected data were analyzed using Statsoft Statistica 7.1. Descriptive statistics were subjected to the ANOVA Kruskal–Wallis test and the corresponding Mann–Whitney test to determine differences between individual groups. Statistical significance was defined as $p < 0.05$.

3. Results

In total, 120 anastomoses were performed, and 113 of them were examined. Specimen loss resulted from the technical limitations of the machine, as it required a sample of sufficient length.

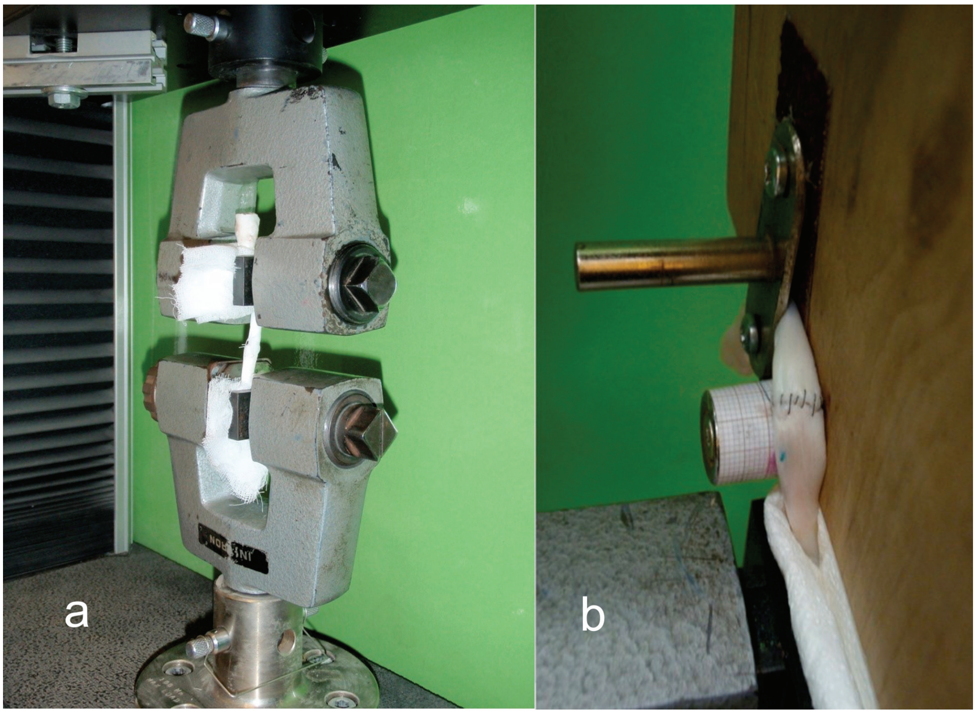


Fig. 3. Biomechanical testing set-up for: (a) linear, and (b) angular analysis of breaking force

Table 1. Mean and standard deviation of the linear and angular breaking force of each suture

Suture	*n*	Linear force [N]	*n*	Angular force [N]	Mann–Whitney test
Modified Kessler suture with additional running suture	18	36.11 ± 17.2	20	36 ± 13.53	0.68
Cruciate four-strand suture with additional running suture	20	49.25 ± 14.86	19	48.95 ± 15.95	0.9
Multistrand running suture	17	32.65 ± 17.51	19	35.56 ± 21.91	0.76
ANOVA test		0.0052		0.0201	

Table 1 shows the average breaking force and standard deviation (SD) for each fixation method, depending on the method of breakage.

There was a significant difference in the breaking strengths between the types of sutures (Kruskal–Wallis test: $p = 0.0052$). The cruciate suture proved to be the strongest. In the pulley angular load test, there was a statistically significant difference in the strength of the sutures (Kruskal–Wallis test: $p = 0.0201$). Similarly, in the pulley angular load test, the cruciate suture was the strongest. There was no significant difference in linear or pulley angular breakage between the running locking suture and the modified Kessler suture.

There were no significant differences between linear and pulley angular load tests for sutures of the same technique.

The suture time differs among groups (Kruskal–Wallis $p = 0.030$). Modified Kessler was significantly faster (610 ± 63 s) than the two others. Time of cruciate (747 ± 126 s) was similar to the running locking suture (745 ± 163 s).

4. Discussion

The biomechanical properties of porcine tendons are considered similar to those of human tendons and have been used previously in similar studies [3], [12]–[14]. They are readily available and recommended for anatomical studies. They are commonly used in biomechanical tests to assess suturing of the flexor tendon [14].

Reconstruction and the restoration of continuity in tendons provides a swift return to active movement in the joints of the hand [15]. A perfectly sutured tendon allows smooth movement, both active and passive within the tendon sheaths in the hand. The suture should be easy to place and durable enough to allow active hand movements [6].

Another important element in the repair of flexor tendons is tensile demand. Tensile demand in the normal finger flexor has been reported: 5 N for passive motion, 15 N for a light grip, 50 N for a strong grip and 90 N for tip-pinch with the index flexor digitorum profundus [16], [17].

Currently used tendon suturing techniques use both core and running sutures. Running sutures were initially used for aesthetical reasons, but proved to be an important part of biomechanical fixation. The running suture, responsible for the approximation and tightness of fusion, affects strength during the formation of the gap. This procedure provides up to 50% of the load distribution [18]. All these features justify its use, particularly for patients who want to achieve early mobilization [18].

The running suture has a significant impact on the stability of the fusion, while the core suture guarantees high tensile demand and high resistance to the formation of a gap in the first stages of wound healing [8]. Previous studies examining the importance of the core suture have demonstrated its necessity [19].

However, the running suture remains an underrated component of fusion [20], [21]. Originally described as an epitenon repair, the importance of a suture passing through the tendon fibers has been described [22]. Therefore, it is closer to the truth to describe it as a “running component of the suture” than a “running suture” [23]. It has been shown to be important in preventing the formation of a gap, and provides 50% of the total strength of the fusion [18].

According to Strickland, a properly placed four-strand cruciate core suture with an additional running suture is capable of withstanding the load of a gentle hand grip during the healing period [9]. Biomechanical studies of flexor tendon repairs have shown that the strength of fixation increases with the number of core strands [20]. The addition of a running suture results in increased strength of the repair and reduces the formation of a gap [18].

The difficulty of the procedure increases with the number of core sutures and the technique of the running epitenon suture [7]. Sometimes, an inexperienced surgeon manipulates the ends of the tendons in an indelicate way, increasing trauma to the tendon. Pinching and grasping of uninjured surfaces should be avoided, because this can contribute to the formation of adhesions. A greater number of core sutures increases the bulk of the repair and is associated with more friction between the tendon and the sheath [24].

Our study shows that, among the sutures examined, the strongest was the cruciate four-strand suture with an additional running suture. However, all techniques tested can be considered effective. The continuity of the tendon is restored, and in addition to this, we showed that a 2 mm wide gap arises only at loads greater than those permitting the application of early motion stress. The strength of the repair is most important and indicates good reconstruction of the tendon. The restoration of continuity of the tendon allows for a return to active movement in the hand joints. A well-repaired tendon allows both active and passive smooth movement in the tendon sheaths. The repairing suture should be easy to place and strong enough during active hand movements [16].

When choosing a tendon repair technique, other parameters should be considered. In addition to adequate strength of the suture, gentle handling of the ends is also important to optimize tendon healing. The running locking suture developed in our department does not require a core suture. A multistrand core suture is considered to be the basis for maintaining the strength of the repair, but it involves undesirable consequences and extends the time of the procedure. The argument against a core suture is that, to place a parallel strands, it is necessary to stabilize the injured ends. This involves further trauma, since even the most delicate grasping of the ends by the tool is associated with end compression. This makes it difficult to obtain circular, symmetrical surfaces ideal for core sutures. This study examining the importance of core sutures does not undermine the legitimacy of their application. However, the running suture remains an underrated compound of tendon repair [18].

An additional advantage of the running locking suture is the significantly shorter procedure time, while providing similar strength to the modified Kessler suture. When restoring the continuity and durability of a tendon, we must also bear in mind the thickness of the repair, which affects friction in the tendon sheath during rehabilitation [24]. However, due to the aim and nature of this study, we were unable to assess this parameter.

In summary, it can be concluded that a core suture is not necessary to provide effective tensile strength repair.

5. Conclusions

The multistrand running locking suture performed by us provides the same strength as the other repair techniques examined. This suture does not contain core sutures, which decreases the bulk of the repair site, causes less trauma to the tendon ends and decreases the time of repair. Therefore, the running locking suture is a good alternative to the already widely used core sutures.

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