Comparison of two different suture-passing techniques with different suture materials and thicknesses: Biomechanical study of flexor tendons for yield points, gap formation and early post-operative status

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ABSTRACT

Objective: The purpose of this study was to evaluate the biomechanical characteristics of two different suture-passing techniques with different suture materials and thicknesses and assess whether they could withstand passive and/or active mobilization in the very early post-operative period.

Materials and Method: 192 flexor digitorum profundus communis tendons of similar diameters were obtained from sheep front limbs. Each tendon was transected completely at a point 6 cm from the distal end and each repaired by one of the following suture materials: polyester suture (Ethilon 3.0 and 4.0 (Ethicon, U.S.)) and polypropylene monofilament (Polypropylene 3.0 and 4.0 (Ethicon, U.S.)). The repair of the tendons was performed through employing two different techniques with each suture material - the Bunnel and Modified Kessler. The primary outcome measures for each repair combination was suture material, suture-passing type and suture thickness. Regarding post-operative early motion, the yield point differences between the suture materials and techniques were compared.

Results: There was a statistically significant difference between suture materials used for the repair. Tendons repaired with Ethibond needed significantly greater amounts of force for rupture compared with tendons repaired with Polypropylene. There was a statistically significant difference between Ethibond and Prolene for all study groups.

Conclusion: The yield points with higher forces is expected to be preferred, but their thicknesses can be 3-0 or 4-0. Oblique suture passing should be preferred rather than longitudinal passing. Obviously, suture strengthening methods, like epitenodine running sutures and core sutures, should be used. Without these measures, even passive wrist motion can result in gap formation at the repair site. The results of this study showed that tensile properties of the repaired vary considerably with differences in suture material and design.

Key words: Biomechanical study, suture technique, tendon repair

Introduction

Restoration of hand function following division of a flexor tendon remains a significant challenge according to the literature [1, 2]. Thus, suture techniques and materials should be strong enough to resist forces during active and passive motion, especially in the very early post-operative period [3-5]. Unlike the rupture or suture pullout, gap formation, which can be the reason for adhesion and decreased excursion, may be developed with lesser forces [6]. Decreasing the failure rate secondary...
to gap, rupture or pullout has a direct relationship to the suture technique, suture material and suture strength.

There are numerous clinical and experimental studies in the literature related to biomechanical behavior of repaired tendons [7-9]. Most have focused primarily on stronger suture techniques rather than suture materials [8, 10, 11]. The other studies strictly focused on new suture techniques and their biomechanical behaviors without any analysis of the various available suture materials [12, 13]. Therefore, there is still debate in the literature on the most appropriate suture material, thickness and suture technique for early active and passive mobilization. The choice of the suture material and its thickness, important factors with respect to mechanical behavior, are usually based on the surgeon's individual experience rather than clear scientific evidence [14, 15]. Hence, the purpose of this study was to evaluate the biomechanical characteristics of the two different suture-passing techniques with a number of suture materials and thicknesses and analyze whether they could withstand passive and/or active mobilization in the very early post-operative period.

Materials and Methods

Study Groups

192 flexor digitorum profundus communis tendons of similar diameters were obtained from sheep front limbs [16]. The average age was 10 – 16 months. Tendons were kept moist with saline solution at – 26 0C. The tendons were divided randomly into eight groups with 24 tendons assigned to each group. Each tendon was transected completely at a point 6 cm from the distal end and each was repaired with one of the following suture materials: polyester suture (E3-Ethilon 3.0 and E4-Ethilon 4.0 (Ethicon, U.S.) and polypropylene monofilament (P3-Propilen 3.0 and P4-Propilen 4.0 (Ethicon, U.S.)).

The repair of the tendons was conducted with two different techniques with each suture material: the Bunnel (B-transverse and criss-cross passing with one knot) and the Modified Kessler (M-transverse and longitudinal passing with one knot) (Figure 1). The primary outcome measures for each repair combination was suture material, suture-passing type and suture thickness. In order to prevent any bias between experi-
Biomechanical study of tendon repair

E4M, E4B, P3M, P3B, P4M and P4B.

Biomechanical Testing

The testing of tensile properties of the tendons repaired with each suture material and each suture technique was performed until failure by an Instron machine (Shimadzu Co., Japan) at a constant speed of 20 mm/min. The initial distance between the clamps was set uniformly to 6 cm. Force/displacement and stress/strain graphics were recorded until the ultimate failure. Yield points were indicated on force-displacement curves as the peak point at the end of the initial linear slope. Yield point is defined as the stress at which a material begins to deform plastically. Prior to the yield point, the material will deform elastically and will return to its original shape when the applied stress is removed. Once the yield point is passed, a certain fraction of the deformation will be permanent and irreversible. So, the gap between the sutured ends will not close if the force applied during the post-operative rehabilitation period is large enough to induce plastic deformation. These yield points were all signaled on the force/displacement curves of each study group for statistical comparison. The results were analyzed by one way analysis of variance (ANOVA) and post-hoc Tukey honest significant difference (HSD) tests. Significance was considered when the probability values were less than 0.05 (p<0.05).

Results

Three kinds of failures were observed; suture rupture, suture pullout and knot loosening. The most and least commonly observed failure modes were suture rupture (113/192, 58.5%) and suture pullout (10/192, 5.2%), respectively. Knot loosening was observed in 69 out of 192 tendons (35.9%). The details of failures for each group are summarized in Figure 2. For each study group and each failure mode, the average force (in Newtons [N]) needed for ultimate failure and average displacement (in mms) when the failure occurred are also presented in Figure 2.
Suture Rupture

The force displacement curves for the study groups in regards to suture ruptures were presented in Figure 3. There was no statistically significant difference between suture thicknesses in terms of suture ruptures (p=0.345). This was also true for the suture technique. Neither the Bunnel nor Modified Kessler had a statistically significant effect on the force needed for suture ruptures (p=0.456). On the contrary, there was a statistically significant difference between Ethibond and Propilen for all study groups (p<0.05). Ethibond needed greater force for knot loosening. In terms of suture techniques, the study groups, E3M and E4M, needed significantly greater amounts of force for rupture compared to tendons repaired with Propilen (Figure 3).

Knot Loosening

The force displacement curves for the study groups with respect to knot loosening are presented in Figure 5. There was no statistically significant difference between suture thicknesses in regards to knot loosening (p=0.372). In contrast, there was a statistically significant difference between Ethibond and Propilen for all study groups (p<0.05). Ethibond needed greater force for knot loosening. In terms of suture techniques, the study groups, E3M and E4M, needed significantly greater amounts of force for knot loosening compared with the study groups, E3B and E4B. Dissimilarly, there was no statistically significant difference between the study groups for Propilen (P3M-P4M and P3B-P4B); i.e. regardless of suture thickness, using Ethibond with the Modified Kessler technique had a greater knot loosening strength compared with Propilen using the Bunnel technique (Figure 5).

The average yield points for tendon failure with knot loosening with respect to baseline forces previously defined by Schuind et al. are presented in Figure 4.
Pulling Out

The force displacement curves for study groups in regards to pulling out are presented in Figure 6.

There was no statistically significant difference between suture thicknesses in regards to pulling out (p=0.967); i.e. suture thickness (either 3.0 or 4.0) did not have a significant effect for pulling out. Contrarily, there was a statistically significant difference between Ethibond and Propilen for all study groups (p<0.05). Ethibond needed greater force for pulling out. With regards to suture techniques, for all study groups, there was a statistically significant difference between the Bunnel and Modified Kessler suture-passing techniques (p<0.05). Bunnel was found to endow greater strength versus the Modified Kessler (Figure 6).

The average yield points for the tendons that failed with suture pullouts in terms of baseline forces previously defined by Schuind et al. are presented in Figure 4.

Discussion

After the repair of the lacerated flexor tendons of the hand, early active and passive mobilization should be allowed to yield the best clinical outcomes [5, 14, 17]. Active and passive mobilization during protection is the most effective portion of the rehabilitation period in order to reduce adhesion between the flexor tendon repair site and the fibro-osseous canal, increasing excursion and inducing tenocyte proliferation and collagen synthesis [7, 14, 18]. However, early active and passive mobilization to prevent adhesion and associated stiffness may lead to a significant number of gap formations, suture ruptures, suture pull outs or knot loosening [7, 14, 19]. In the post-operative rehabilitation program, active and passive finger motions were used to obtain the most favorable results [19]. With increased healing, the load to the repaired site decreases. Thus, the most amount of stress loads to the suture, knot and suture-tendon junction is in the early post-operative period [20]. There are numerous studies that have concentrated on the forces of the flexor tendon during passive, active and against resistance active flexion. These forces have been noted to be in the range of 0.2-50 N [21]. Based on the literature, passive motion generates between 0.98 to 8.82 N of force at the repair site and active flexion against no resistance generates 8.82 to 28.4 N of force [7]. According to another investigation, passive motion of the fingers generates 1 to 9 N whereas active motion is responsible for between 1 to 29 N against no resistance and 15 to 50 N against moderate or maximum resistance [18]. In another study, the load during passive and active motion against resistance and no resistance were 2-4 N, 10 N, 17 N and 70 N, respectively [17]. Schuind et al. measured flexor tendon forces in vivo and found that the tensile force loading the flexor tendons during passive wrist mobilization was 0.1 - 0.6 kgf, 0.1 - 0.9 during passive motion, 3.5 kgf during active unresisted motion and 12 kgf during tip pinch [3].

Additionally, there are various results from the literature regarding gap formation that represents clinical failure. It generally appears to change from 1 to 3 mm [11]. In fact, persistent gap formation is plastic deformation and the yield point between the elastic and plastic deformation represents the lowest force leading to persistent deformation. The most important mechanical property of a tendon suture is the resistance to gap formation or plastic deformation [22]. Yield point forces determine the limits of forces during rehabilitation, especially in the very early post-operative period. As seen in the force/displacement curves, the forces generating 2 or 3 mm of displacement do not generate persistent deformation in all failure types. The persistent displacement values are seen to be between 3 and 10 mm. Although the forces generating a 2mm gap do not generate a persistent gap, passive finger and passive wrist motions during the post-operative period generate temporary displacement. This temporary motion at the repair site under low cyclical loads has been shown to lead to gap formation in human cadaveric tendon repairs [6]. Therefore, exaggerated frequency in passive motion forces not generating yield point displacement can lead to fatigue failure resulting with unsatisfactory clinical outcomes. Therefore, minimization of gap formation has become a critical consideration and should be avoided by avoiding excessive passive and active motions during the early post-operative period. There, suture strengthening methods should be implemented for post-operative early rehabilitation [23-28]. There are numerous methods to increase the strength of ten-
odon sutures [8,28,29]. As suture strength methods, like peripheral running, side-locking loop or cross stitch, were not used in this study, the values of the forces for 2 mm gap formation and ultimate strength are less than the measures in the other biomechanical studies.

When considering ultimate strength in the very early post-operative period, active finger flexion can be performed without rupture especially in the groups repaired with thick sutures (E3, P3) (Figure 1). However, these forces can lead to plastic deformation, signifying persistent displacement at the repaired site leading to clinical failure. So, active flexion should not be allowed in the early post-operative period. Yet, the question “when can active flexion be performed” cannot be directly answered with the results of this study.

Considering passive finger and wrist movement, there are numerous differences between the groups. Evaluating the ruptured sutures, the main determining factor is the suture material (Figure 2). Passive finger and wrist motion can be permitted with the sutures when specifically repaired with thickness and suture methods did not generate any differences in persistent displacement. When considering the loosening knots, the main influences also include the suture material (Figure 3). Method and thickness did not seem to generate any variations. However, in the pullout group, the main determining factor was method (Figure 4). Just like the results of Zatiti’s study [22], in our study, as well, the more the transverse and oblique suture passings there are, the more resistance to failure is and the less suture pullout was.

As a result, the following can be reasonable to infer from this study: 1.) stronger suture material is preferable but its thickness can be 3-0 or 4-0; 2.) oblique passing is favored over longitudinal passing; 3.) obviously, suture strengthening methods, like epitendineous running sutures and core sutures, should be employed [22]; 4.) in the early post-operative period, only passive mobilization should be utilized. The results of this study ultimately showed that tensile properties of the repairation vary considerably based on different suture materials and design. However, the yield point differences between the materials and techniques are also quite relevant.

**Conflict of interest statement**
The authors have no conflicts of interest to declare.

**References**
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