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Comparison of step-cut and Pulvertaft attachment for flexor tendon graft: a biomechanics evaluation in an in vitro canine model

T Hashimoto, A. R. Thoreson, K.-N. An, P. C. Amadio, and C. Zhao

Orthopedic Biomechanics Laboratory, Division of Orthopedic Research Mayo Clinic, Rochester, MN, USA

Abstract

The purpose of this study was to compare two different methods of joining tendons of similar and dissimilar sizes between recipient and donor tendons for flexor tendon grafts. Flexor digitorum profundus (FDP) and peroneus longus (PL) canine tendons were harvested and divided into four groups. The repair technique we compared was a step-cut (SC) suture and a Pulvertaft weave (PW). FDP tendons were significantly larger in diameter than PL tendons ($p < 0.05$). The volume of the SC repairs using either FDP or PL tendon as a graft was significantly smaller than PW repairs ($p < 0.05$). The ultimate load to failure and repair stiffness in FDP graft tendons significantly increased compared with the PL graft tendons ($p < 0.05$). The SC suture can be used as an alternative to the PW, with similar strength and less bulk for repairs using graft tendons of similar diameter. Surgeons should be aware of the effect of graft tendon size and repair method on strength and bulk when performing flexor tendon grafts.

Keywords

Flexor tendon; graft; repair; biomechanics

Introduction

The Pulvertaft weave (PW) has been the most common technique for proximal suture of flexor tendon grafts since it was first reported in 1956. This technique was originally designed to join tendons of different diameters together whereby smaller tendons are passed through two to three slits created in larger tendons, and are then sutured (Pulvertaft, 1956). However, when tendons of similar size are joined, bulk at the weave site may be a concern.

Recently, some alternatives to PW have been reported. The spiral linking technique (Kulikov et al., 2007) has been developed and matches the PW in ultimate load to failure. Other methods, such as the double-loop technique, lasso tendon repairs, loop-tendon methods, and side-to-side repairs have also been reported (Bidic et al., 2009; Brown et al., 2010; De Smet et al., 2008; Jeon et al., 2009; Kim et al., 2007). However, although each of these methods is a reasonable alternative to the PW judging by the ultimate load to failure, concerns over bulkiness remain.

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Corresponding author: Chunfeng Zhao MD, Mayo Clinic, Orthopedic Biomechanics, Laboratory, 200 First Street SW, Rochester, MN 55905 USA, zhaoc@mayo.edu.

Conflict of Interests

None declared.

Becker et al. reported a bevelled cut technique to eliminate gap formation following primary tendon repair in 1977. Using this technique, both of the tendon ends are cut into bevelled surfaces and sutured by overlapping; consequently, the diameter at the repair site does not increase compared with that of the original tendons. In cases of tendon repair, this method requires some tendon shortening, but this problem is avoided in cases of tendon graft, where the length of the graft can be adjusted so that the correct overall length is maintained. The ultimate load to failure of the Becker technique is higher than that of the Kessler and Bunnell repairs, as well as that of other techniques commonly used for tendon repair (Becker and Davidoff, 1977). Gordon et al. (1992) compared the strength of the Kessler-Tajima technique and a different SC technique, and also showed that the SC was stronger than the Kessler-Tajima technique. These studies show that SC techniques can reduce repair bulkiness while approximating the strength of the PW (De Smet et al., 2008; Gabuzda et al., 1994; Gordon et al., 1992). However, no study has examined the influence of tendon diameters on the strength of tendon repairs. Such data would be particularly useful when the surgeon has a choice of graft tendons — for example, an autologous palmaris longus (a thin tendon) versus an allograft flexor tendon — to reconstruct a defect in a finger flexor.

The purpose of this study was to compare the strength and geometry resulting from a step-cut (SC) technique to the PW and to determine the influence of graft tendon diameter on those parameters in an in vitro canine model.

Methods

Tendon harvest and repair

Forty-eight forepaw flexor digitorum profundus (FDP) tendons from the second to fifth digits and 16 hind-paw peroneus longus (PL) tendons were used. These specimens were obtained from eight euthanized, mixed-breed dogs that had been used for other studies approved by our Institutional Animal Care and Use Committee. Bilateral forepaws below the wrists and hind paws below the knees were immediately harvested after euthanization. The paws were kept frozen at -80°C and thawed at 4°C 1 day before repair. All tendons were repaired using either a PW or SC technique. Tendon repairs were equally divided into four groups as follows: (a) PL to FDP repair using SC; (b) PL to FDP repair using PW; (c) FDP to FDP repair using SC; (d) FDP to FDP repair using PW. All PL tendons served as graft tendons. For FDP to FDP repairs, the graft tendons were matched using the tendon from the same digit of the contralateral paw. PW repairs were performed with two weaves and two 4-0 Ethibond (Ethicon Inc., Somerville, New Jersey, USA) cross-stitches at each weave and four 4-0 Ethibond mattress sutures at the corners of the tendon ends. SC repairs were 20 mm in length, preserving two-thirds of the tendon width. These were repaired with three 4-0 Ethibond cross-stitches at the repair site and a 6-0 Prolene (Ethicon Inc.) circumferential epitendinous locking stitch (Figure 1).

Specimens were equally assigned to each group based on individual dog and digit (second to fifth) in order to diminish the influence of the interaction of these factors.

Maximum medial lateral and anteroposterior diameter of repair site

The maximum medial lateral (ML) and anteroposterior (AP) diameters of each tendon were measured before and after repair (Figure 2). Photos of each tendon with a scale were captured and analyzed using the computer software Image J (National Institutes of Health, Bethesda, Maryland, USA). Maximum ML and AP diameters were measured before repair at the midpoint of the extrasynovial portion of the FDP tendon, 1.0 cm proximal to lateral malleolus in PL tendons, and at the thickest point in the repair site after repair.

Mechanical testing

After repair and diameter measurement, each repaired tendon was mounted on an 858 Mini Bionix II servohydraulic testing machine (MTS Systems, Eden Prairie, Minnesota, USA). Specimens were gripped approximately 3 mm away from the ends of the repair sites using custom-made clamps. The distance between the two grips was 25 mm. Tendons were distracted at a rate of 20 mm/min until complete rupture of the repair occurred. Force was measured using a load cell (Lebow, Troy, Michigan, USA) mounted on the MTS machine. Throughout testing, tendons were kept moist using saline mist. Ultimate load to failure and stiffness, which was defined by calculating the slope of the linear region of the tendon displacement and force curve, were assessed using MATLAB (MathWorks Inc., Natick, Massachusetts, USA). The failure modes of each tendon repair were recorded along with force and cross-head displacement data throughout the test.

Statistical analysis

The diameters of tendons before and after repair were analyzed between all groups using one-way analysis of variance (ANOVA) and post-hoc pair-wise comparisons using Tukey's technique. Ultimate load to failure and stiffness were analyzed using the same method. Fisher's exact test was performed to assess the failure modes. $p < 0.05$ for any statistical analysis was considered significant.

Results

The FDP tendons were significantly larger than the PL tendons in ML diameter ($p < 0.0001$; one-way ANOVA) (Figure 3) and SC repairs using either PL or FDP tendons were significantly smaller than PW repairs in AP diameter ($p < 0.0001$) (Figure 4). SC repairs using PL were smaller than all the other groups in ML diameter ($p < 0.0001$).

As shown in Figure 5, the ultimate load to failure and stiffness of SC repairs tended to be higher than those of PW repairs, but no significant difference was found between the two techniques. However, using FDP tendons as the graft significantly increased both the ultimate load to failure ($p < 0.0001$) and stiffness ($p < 0.0001$) compared with PL tendons for both techniques. In addition, when mechanically testing the repair sites, failures of core sutures occurred by pull-out from tendon stumps in all tendons except in group D (FDP to FDP repair using PW), in which one knot became untied in two tendons, while the core sutures pulled out from the tendon stumps in the rest. Similarly, the epitendinous sutures of seven tendons pulled out from repair sites in group A (PL to FDP repair using SC), whereas six epitendinous sutures in group C (FDP to FDP repair using SC) broke at their midsubstance ($p < 0.0406$, Fisher's exact test) (Table 1).

Discussion

This study had two major findings. First, SC repair significantly reduced repair site bulkiness compared with PW repair, without decreasing mechanical strength. Second, we found that the mechanical properties of repairs were influenced by the diameter of the tendons involved. The larger FDP tendons were stronger than smaller PL tendons.

Bulky repair sites in tendon transfers and grafting may prevent smooth tendon gliding and increase friction (De Smet et al., 2008; Jeon et al., 2009; Kulikov et al., 2007). In addition to the PW, there are lasso and loop-tendon repairs, each of which requires folding back a tendon stump onto itself, which also increase bulkiness and affect smooth gliding. In contrast, some techniques for primary repair or tendon grafting are clearly less bulky. Becker and Davidoff reported that their bevelled-cut technique for primary repair made the repair sites no greater than that of intact tendons (Becker and Davidoff, 1977). Brown et al.

(2010) investigated their side-to-side repair in a human cadaver model and showed that the repair sites had a cross-sectional area comparable with that of the PW. These methods do not fold the tendon back onto itself, and the former technique also requires cutting off some tendon fibres beforehand. In the SC repair, each tendon stump is cut to two-thirds of its original width. This decreases the repair site bulkiness and could be a better method for proximal repair of tendon reconstructions to allow smoother gliding, especially when the tendons being joined are of similar width.

In this study, the mechanical properties of the SC repair were similar to those of the PW repairs, a technique that has been a standard method for tendon grafting (Pulvertaft, 1956). Bidic et al. reported that the side-by-side repair was significantly weaker than the three-weave PW. This repair was different from that considered in this study; in the former, they used three core sutures without an SC and did not use epitendinous sutures. Gordon et al. investigated other SC repairs for primary tenorrhaphy and noted that the strength of their SC repair was greater than the Kessler-Tajima repairs, a result attributed to the higher number of epitendinous sutures in their SC (Gordon et al., 1992). We agree with Gordon et al. that the epitendinous sutures play an important role in preserving the mechanical strength of the SC repair in this study and that longer repairs may result in greater strength. Moreover, although we set the length of the SC repair at 20 mm in order to keep the length consistent with that of the PW repair in this study, in clinical cases, the SC length can be changed to fit the local anatomy and, if needed, set longer, which may result in higher tensile strength.

The donor source may also have an influence on the mechanical properties of the tendon graft junction. Boyes and Stark reported the clinical results of 607 cases of flexor tendon grafting and noted that 50% of the little finger superficialis donor grafts ruptured after repair. They recommended not using such small tendons as donors (Boyes and Stark, 1971). Similarly, Wehbe noted that the difference between a 2 mm and 3 mm tendon could translate into a significant difference in strength, but no tensile test was performed (Wehbe, 1992). To our knowledge, this is the first report that has investigated the effect of graft tendon size on the mechanical properties after repair as would be done in tendon grafting. We agree with Boyes and Stark, and Wehbe, that smaller diameter grafts result in weaker junctures, which may predispose to failure.

Donor sources for flexor tendon grafting include autografts such as palmaris longus, plantaris, toe extensors and flexors, and others (Moore et al., 2010; Wehbe, 1992), as well as various allograft tendons (Asencio et al., 1996; Liu, 1983). Palmaris longus tendons, one of the most popular donor choices, can be easily harvested and used as either a long (distal forearm to fingertip) or short (palm to fingertip) graft. The disadvantages for this donor tendon include its occasional absence (Mbaka and Ejiwunmi, 2009; Ndou et al. 2010) and extrasynovial origin, with a greater propensity for adhesion than an intrasynovial tendon (Leversedge et al., 2000). In contrast, allogeneic FDP tendons can be cut to suit any length and can be quickly prepared. An intrasynovial allograft such as FDP may cause fewer adhesions than an extrasynovial autograft (Hasslund et al., 2008) and could also be stronger. However, because the recipient and donor tendons are similar in size, the repair becomes bulky if the PW suture technique is used, which may impair tendon gliding. Our data suggest that using the SC repair can overcome this drawback without adversely affecting repair strength and stiffness.

There are several weaknesses to this study. First, we chose an in vitro animal model. There is little homogeneity in the reported studies of tendon graft repair strength, which vary according to species as well as specific technical aspects, such as weave number, weaving method, suture material, suture size, and suture technique; this makes direct comparison across the studies difficult (Brown et al., 2010; Jeon et al., 2009). We used canine tendons

because the in vitro findings can be studied experimentally in vivo. We chose the cross-stitch because it is stronger than the mattress suture (Gabuzda et al., 1994). Another study limitation is that we only evaluated strength at a single time point, immediately after repair. Results might differ after cyclic testing, testing in specific applications such as a finger tendon graft, or in vivo (Hasslund et al., 2008; Webster and Werner, 1983). Moreover, allogeneic tendons may heal more slowly than autografts (Dustmann et al., 2008; Scheffler et al., 2008), neutralizing the benefit of any difference in initial strength (Maeda et al., 1997). Further in vivo studies are needed to track the mechanical properties of the repairs and graft sources during the course of healing.

In conclusion, the SC technique seems to be a valid alternative to the PW technique, especially in repairs using tendons of similar diameter. Surgeons should be aware of the effect of graft tendon size on repair-site strength and bulk when performing tendon graft surgery.

Acknowledgments

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Figure 1.

Left column: A series of macroscopic pictures showing the step-cut (SC) repair. Tendon segments 20 mm in length and a third of the tendon in width were excised to make the SC (*middle panel*). Tendons were joined by three cross-stitch sutures of 4-0 Ethibond and an epitendinous suture of 6-0 Prolene (*bottom panel*). *Right column:* Pictures showing the Pulvertaft weave (PW) repair. The first 5 mm weave was created 5 mm from the recipient tendon end (*middle panel*). Tendons were joined by two 4-0 Ethibond cross-stitch sutures per weave and four 4-0 Ethibond mattress sutures at the tendon ends (*bottom panel*).

Figure 2. Macroscopic pictures showing diameter measurements. *Upper panel:* Medial lateral diameters were measured at the standardized points indicated by large arrows. Small arrows indicate the portion of peroneus longus (PL) tendon corresponding to the lateral malleolus. *Lower panel:* Anteroposterior diameters were measured using the same method. FDP = flexor digitorum profundus tendon.

Figure 3.

Dot plot graphs showing donor and recipient tendon diameters before repair. Graft medial lateral (ML) diameters of groups C and D were significantly larger than those of groups A and B. Each bar represents the mean of each group. * $p < 0.05$. (A) peroneus longus (PL) to flexor digitorum profundus (FDP) repair using step-cut (SC); (B) PL to FDP repair using Pulvertaft weave (PW); (C) FDP to FDP repair using SC; (D) FDP to FDP repair using PW. AP = anteroposterior.

Figure 4.

Dot plot graphs showing diameters of repair sites. The anteroposterior (AP) diameters of groups A and C were significantly smaller than those of groups B and D. The medial lateral (ML) diameter of group A was significantly smaller than those of groups B, C, and D. Each bar represents the mean of each group. *,† denotes a significant difference ($p < 0.05$) compared with groups A and C, respectively. (A) Peroneus longus (PL) to flexor digitorum profundus (FDP) repair using step-cut (SC); (B) PL to FDP repair using Pulvertaft weave (PW); (C) FDP to FDP repair using SC; (D) FDP to FDP repair using PW.

Figure 5.

Dot plot graphs showing the ultimate load to failure and stiffness. Groups C and D had significantly higher tensile strength and stiffness than groups A and B. Each bar represents the mean of each group. $*p < 0.05$. (A) Peroneus longus (PL) to flexor digitorum profundus (FDP) repair using step-cut (SC); (B) PL to FDP repair using Pulvertaft weave (PW); (C) FDP to FDP repair using SC; (D) FDP to FDP repair using PW.

Table 1

Failure mode of each repair group. Values indicate number of tendons included in each category. Groups C and D had less “pull-out” than groups A and B. (A) peroneus longus (PL) to flexor digitorum profundus (FDP) repair using step-cut (SC); (B) PL to FDP repair using Pulvertaft weave (PW); (C) FDP to FDP repair using SC; (D) FDP to FDP repair using PW

Group	Core sutures		Epitendinous suture	
	Pull-out	Untied	Pull-out	Break
A	8	0	7	1
B	8	0	–	–
C	8	0	2	6
D	6	2	–	–