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Tensile strength of a weave tendon suture using tendons of different sizes

Background

This study compared the maximum load, stress, elongation at failure and the mode of failure of three kinds of tendons most frequently used for tendon grafting and tendon transfers, using the Pulvertaft weave suture.

Methods

Sixty tendons were used from fresh human cadaver upper and lower extremities. The performed repairs included: 9 specimens of flexor digitorum superficialis or profundus tendon with flexor digitorum superficialis or profundus tendon (thick-thick suture), 10 specimens of flexor digitorum superficialis or profundus tendon with palmaris longus tendon (thick-medium thin suture), and 10 specimens of flexor digitorum superficialis or profundus tendon with plantaris tendon (thick-thin suture).

Material testing machine (Zwick/Roell Z020) was used to test repairs to failure.

Findings

The mean maximum load at failure increased with the thickness of donor tendon. For the thick – thick specimen, the maximum load at failure was 125 newtons (N), for the thick - medium thin specimen it was 86,8 N, and for the thick – thin it was 65,2 N. These differences were all statistically significant.

Interpretation

The active rehabilitation protocol is possible only with thick – thick connections used , the strength of the thick – medium thin connection is on the border of indications for the active rehabilitation protocol, and the thick – thin connection strength is sufficient only for the passive rehabilitation protocol.

Key words: weave suture, tendon graft, tensile strength

Introduction

Tendon grafting and tendon transfers are basic reconstructive techniques in hand surgery. The proximal as well as distal attachment of the tendon and the fate of grafts have been extensively studied previously. The connections between tendons should withstand loads sufficient for implementing rehabilitation, particularly in tendon reconstruction where early motion is mandatory to prevent adhesion formation (Khan et al., 1997, Silfverskiold and May, 1995). Proximal weave tendon sutures in grafting using the Pulvertaft technique (Pulvertgaft, 1956) are the strongest of all, according to Urbaniak et al. (1975). Since failures of these connections have been reported (Boyes and Stark, 1971, Hunter and Salisbury 1971, Wehbe et al., 1986), various studies have been conducted to evaluate improvements in their performance. New kinds of sutures have been introduced, such as spiral linking technique (Kulikov et al., 2007), loop tendon technique (Kim et al., 2007) or lasso technique (Bidic et al., 2009). For the weave suture itself, new kinds of stiches are also studied that are considered stronger than original mattress stich, for example the cross stich (Gabuzda et al., 1994), or better preserving vascularity of tendons, such as the corner stich suture (Tanaka et al., 2006). To the best of our knowledge, however, no studies have been conducted to evaluate the tensile strength of weave sutures commonly applied in tendon grafting using donor tendons of different thickness, such as connections of flexor tendons with each other or with palmaris longus tendon and plantaris tendon. This study was performed to investigate the maximum load to rupture, peak stress, elongation at failure and the mode of failure so as to select the safest suture for the active rehabilitation protocol.

Methods

Sixty tendons from 12 fresh human cadaver upper extremities and 10 fresh human cadaver lower extremities were harvested, transected and repaired with the end - weave technique. Flexor digitorum profundus (FDP) tendons of the index and middle fingers (20 tendons), flexor digitorum superficialis (FDS) tendons of the index and middle fingers (19 tendons), palmaris longus (Pl) tendons (11 tendons) and plantaris (Pt) tendons (10 tendons) were used.

The FDS, FDP, Pl, Pt tendons in our experiment were harvested only from fresh cadavers, within 48 hours after death. We think it is more close to real-life situation than frozen tendons. The Pl, and the FDS and FDP tendons of the index, middle and ring fingers were harvested from forearm using standard approach. After harvesting, the tendons were cleaned from additional tissue and wrapped in humid swabs. Similarly, the Pt tendons were harvested through standard approach from tip of the medial malleolus to two-thirds of the tibia, and prepared as the other tendons. The tendons were analyzed within 2 hours after harvesting.

The repairs were performed in three different groups. A FDS or FDP tendon was connected either to FDS or FDP tendon (thick-thick suture, 9 specimens). The FDS or FDP tendon was sutured to Pl tendon (thick – medium thin suture, 10 specimens), and FDS or FDP tendon was sutured to plantaris tendon (thick – thin suture, 10 specimens). Tendons were sutured with 3 weaves in each repair with cross – stiches of 4 - 0 nylon suture. Matress sutures were placed through the free tendon end with 4 – 0 nylon suture. Differences in diameter between FDS and FDP were insignificant, while the diameter differences between digital flexors, Pl and Pt were all statistically significant.

Biomechanical test

The Zwick/Roell Z020 material testing machine was used to assess maximum load to repair failure. The maximum load, stress and elongation at failure were recorded using data software. All specimens were tested at room temperature at a constant elongation rate of 20 mm/min with a preload elongation speed of 5 mm/min and applied tension of 1 N.

The specimens were clamped in the testing machine. The ends of tendons were prepared by wrapping their ends with a 2-0 braided suture and fixed to sand paper with glue (Fig. 1, 2). This method allowed a strong contact between clamp and tendon without a risk of pulling it out. The grips were fixed approximately 15 mm from the end of the repair sutures. The specimens were kept moist with a saline mist. There were 5 which failed due to slipping from the clamps and these trials were excluded from further analysis.

The recording of mode of failure was illustrated by photograph at time interval 3-5 second for analysis.

Statistical analysis was performed using the Student t-test for comparison of the mean values. The differences were considered statistically significant for P values below 0,05.

Results

The strongest connection proved to be the thick-thick suture with the mean maximum load at failure of 125 N (tab. 1). The mean maximum load decreased when thinner donor tendons were used with the maximum load at failure of thick-medium thin connections of 86,81 N and thick – thin connections of 65,24 N (tab. 1). These differences were statistically significant (thick-thick v/s thick-medium thin: p = 0,0043; thick-thick v/s thick-thin: p <0,001; thick-medium thin v/s thick-thin: p = 0,001). Interestingly, the maximum load stress was significantly higher in thinner tendons. In the thick – thick connection, it was 10,2 N/mm2, in the thick - medium thin it was 14,79 N/mm2, and in the thick – thin connection it was 20,78 N/mm2 (tab. 2). The mean elongation of tendons at the point of rupture was only slightly different and did not reach statistical significance. For the thick – thick model it was 18,92 mm, for the thick - medium thin it was 20,14 mm, and for the thick – thin model it was 15,63 mm (tab. 3). The failure occurred either in the pull – out or intrasubstance rupture mode. Suture failures didn't occur in our material. The pulling – out of the tendon was dominant in thick – thick connections (6 of 9 cases) and intrasubstance rupture was dominant in thin – thin connections (9 of 10 cases). In thick – medium thin connections, intrasubstance failure prevailed (4 of 11 cases). No lesions have been seen at the sites of tendon attachment to clamps. All trials that failed due to slipping of tendons from the clamps were excluded from the study.

Discussion

The main goal of our investigation was to find a technique that would allow active rehabilitation protocol and early movement that would prevent adhesions. Although there have been numerous papers on the fate of tendon graft and distal attachment, few studies have been conducted on the proximal suture (Gabuzda et al., 1994, Urbaniak et al., 1975, Wehbe et al., 1986). The weave method (Pulvertaft, 1956) has been used for decades now to attach tendon ends in grafting and tendon transfer, particularly in proximal juncture. The great advantage of the Pulvertaft weave is a strong connection of the tendons, confirmed both in vitro and in vivo by Urbaniak et al. (1975). The disadvantage of this method is formation of a bulky suture site, which makes it impossible to use this method in the flexor tendon sheath (Pulvertaft, 1956).

In clinical practice, the Pulvertaft weave is used for tendon transfer in the hand and forearm region for suturing flexor or extensor tendons (thick – thick connections in this study). In clinical practice, different types of digital flexor connections are used, with either FDP - FDP, FDP - FDS and FDS - FDS sutures possible, based on usability and viability of tendons found intraoperatively. In tendon grafting, the FDS – FDP suture is used in two - stage flexor tendon reconstruction (Paneva – Holevich, 1969).Connections between FDP and Pl tendons (thick – medium thin in this study) are used for tendon grafting in zone I - III flexor tendon reconstruction. FDP to Pt connections (the thick – thin sutures in this study) are used for tendon grafting in zone I - V flexor tendon reconstruction. The Pt tendon is used also for bridging a defect when FDP is sutured to the intact FDS tendon.

Rehabilitation after tendon reconstruction is of utmost importance. Generally, motion and stress of the tendon connections after secondary tendon reconstruction is considered the primary factor that prevents adhesion at the repair site (Aoki et al., 1995, Silfverskiold and May, 1995).

The theory of superiority of passive rehabiliation protocol over active concerns only primary laesions and repair of flexor tendons in zone II (no-man;s land) (Boyer et al., 2001, Duran et al., 1976, Peck etal., 1998), furthermore, this theory is sometimes questioned(Kuwata et al., 2007).

Our experimental model simulates the procedure of weave suture used in the reconstruction of flexor and extensor tendons and tendon transfers in secondary repair. Generally, in secondary tendon repair, the postoperative mobilization requires a balance between protection of the repair site and prevention of adhesion formation. In secondary repair where the connection between motor tendon and tendon graft is common on forearm or metacarpus, the advantages of early active motion and stress are amply documented experimentaly and clinically in the latest papers (Bidic et al., 2009, Gabuzda et al., 1994, Khan et al., 1997, Kim et al., 2007, Kulikov et al., 2007, Silfverskiold and May, 1995, Smith et al. 2004, Tanaka et al., 2006).

It is difficult establish what tensile strength is required for in vivo active rehabilitation. In literature there is no unequivocal data about the strength of tendon sutures for active rehabilitation protocol. According to Urbaniak et al., (1975), it is 19N, Schuind et al. (1992), claimed it to be 45 N, and Savage (1985) (by deduction he included friction and swelling), it was about 75 N. To take into consideration the in vivo conditions, including the resistance of suture site, swelling and friction we accepted the border of 75 N for active rehabilitation protocol.

In literature, tendons were evaluated experimentally using different models, such as cadaver flexor tendons (Gabuzda et al., 1994, Tanaka et al., 2006), pig trotter extensor tendons (Kulikov et al., 2007), pig trotter flexor tendons (Bidic et al., 2009), and chicken flexor tendons (Kim et al., 2007). In most of these studies tendons of similar shape and size were compared, such as human flexor tendons or pig trotter tendons (Kulikov et al., 2007).

In our study, the thick - thick connection with the mean maximum load of 125 N was demonstrated to be similar to the results obtained by Tanaka et al. (2006) and Gabuzda et al. (1994). Although the tensile strength increased with the number of weaves, the strength of 3 weave technique proved sufficient for the active rehabilitation protocol (Gabuzda et al., 1994). Measuring the maximum load to failure is a method of assessing the tendon suture applicability to the rehabilitation protocol. The repair strength that exceeds 95 N is necessary for the early active mobilization protocol (Kulikov et al., 2007, Choueka et al., 2000). The thick - thick connection fulfills this criterion. The thick – medium thin connection, with Pl tendon used as a graft, had a mean peak load to failure of 86 N, which is slightly below the durability necessary for implementing the active rehabilitation protocol. This finding is very important when Pl tendon is considered for grafting in I - III flexor tendon injuries. The thin – thin connection, with the maximum load to failure of 65 N does not allow the use of the active rehabilitation protocol. This fact limits the range of rehabilitation methods considerably after zone I – V flexor tendon repair when Pt is used. However, the use of Pt tendon is sometimes necessary when, for example, the tendon bed is narrow or a very long graft is needed.

The peak stress values show that the maximum stress is greater in the smallest tendons. The mean peak stress for thick - thin connections was 20 N/mm^2, for the thick-medium thin one it was 14 N/mm^2, and for the thick-thick connection it was 10 N/mm^2. This data shows that the tendon suture strength cannot be directly estimated simply by comparing thickness of different tendons.

The elongation of tendon repairs at failure in our material was slightly different, but still statistically insignificant. The elongation of the repair was about 20 mm at failure. This number is considered critical for the good tension and excursion of a tendon in clinical practice. The mode of rupture was described by Tanaka et al. (2006) as suture failure, pull-out of the tendon and intrasubstance rupture of the tendon. In our material this distinction was not clear as we observed a mixed mode of failure during the elongation process of specimens. In our opinion, the most important mode of failure is the one that occurs during the first stage of lengthening until rupture. Accordingly, we decided to include in our study the mode of failure which was dominant in the initial stage of elongation. We did not observe any suture failure. Intrasubstance failure mode was characteristic for connections of flexor digitorum tendon to thinner tendons like palmaris longus tendon and plantaris tendon. (Fig. 2). The pull – out mode was characteristic for superficial- deep flexor tendon sutures, and that is the finding that is similar to those of Tanaka et al. (2006) who reported that the pull - out mode of failure was dominant in 3 weave connections of human flexor tendon in vitro (Fig. 3).

Conclusions

As the results from our study indicate, the strongest tendon connection for tendon graft and tendon transfer is obtained when suturing tendons of similar sizes (e.g. the human flexor tendons of the hand). This method allows implementation of the active rehabilitation protocol. The durability of Pl tendon connected to thicker flexor tendons is on the borderline, but sufficiently strong to withstand the forces generated during the active rehabilitation protocol. The strength of Pt to flexor tendon suture makes it impossible to implement the active rehabilitation protocol. However, the use of Pt tendon is sometimes indicated for grafting in narrow spaces or bridging long defects as its durability is possible for passive rehabilitation protocols.

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Figure 1

The specimen ready to experiment. The weave suture is performed and tendon ends are prepared by wrapping their ends with a 2-0 braided suture.

Figure 2

The intrasubstance failure mode in a thick – thin specimen. The tendon end is visible in the clamp wrapped with a 2-0 braided suture and fixed to sand paper with glue.

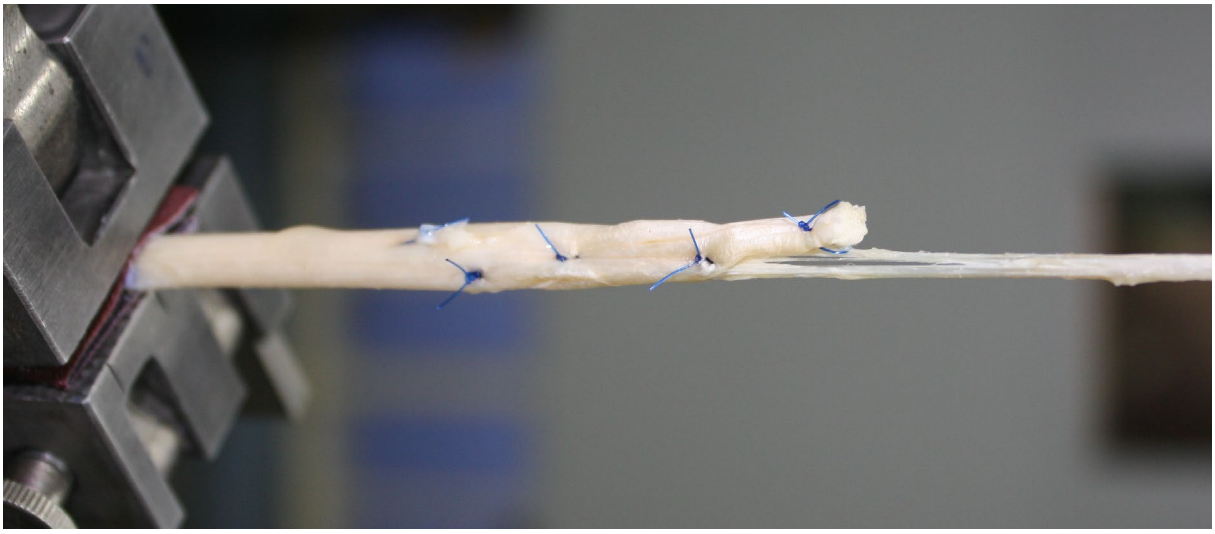

Figure 3

The pull – out mode of failure in a thick-thick specimen.

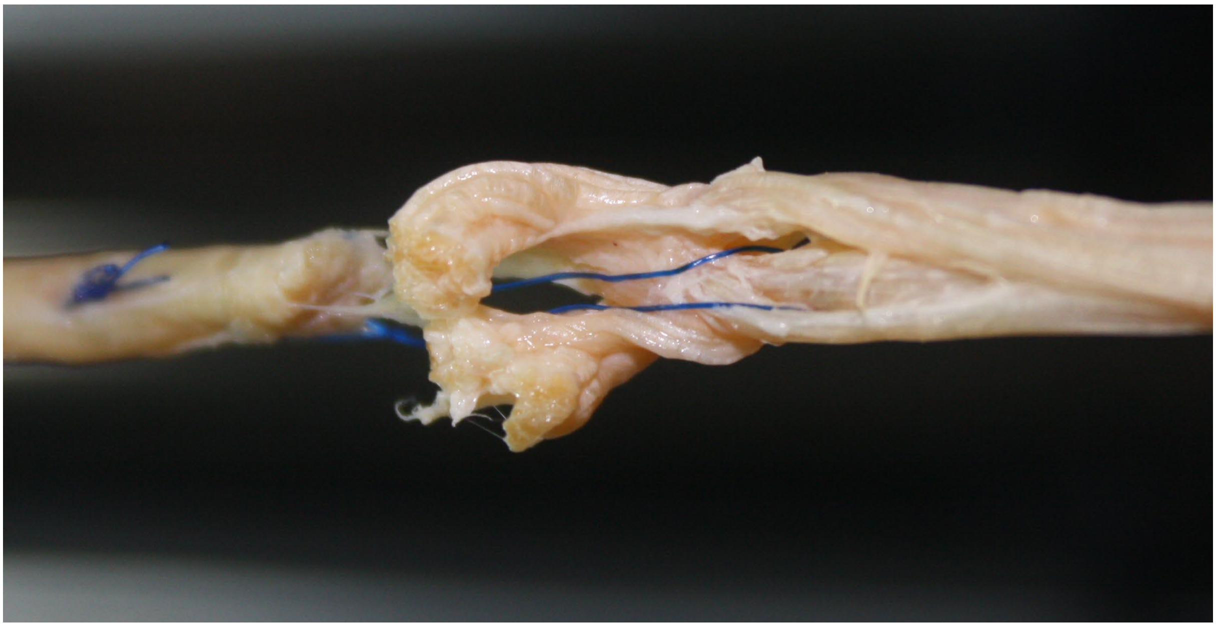

Table 1.

Mean maximum load at failure (N).

Type of connection	Mean	SD	Min	Max
Thick – thick	125	35,54	59,4	171,1
Thick – medium thin	86,81	14,52	57	112,5
Thick - thin	65,24	12,86	42	87,5

Table 2.

Mean maximum load stress (N/mm^2).

Type of connection	Mean	SD	Min	Max
Thick – thick	10,2	5,7	4,7	24,2
Thick – medium thin	14,79	3,84	5,9	20,4
Thick - thin	20,78	4,1	13,4	27,9

Table 3.

Mean elongation at failure (mm).

Type of connection	Mean	SD	Min	Max
Thick – thick	18,92	8,41	9,8	33,1
Thick – medium thin	20,14	6,87	13,8	38,5
Thick - thin	15,63	3,41	11,6	22,1

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