Gliding resistance after FDP and FDS tendon repair in zone II

An in vitro study

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ABSTRACT – Many suture techniques have been described for flexor tendon repair. While many of these sutures have been tested and used clinically, the interaction between repairs of the flexor digitorum profundus (FDP) and flexor digitorum superficialis (FDS) in the same digit has not been rigorously examined. Moreover, while much data are available on the mechanical properties of various suture techniques for FDP repair, much less is known about the mechanical performance of FDS repairs during motion of tendons.

To make up for this lack of information, we measured the gliding resistance of the repaired FDP tendon, as compared to different FDS tendon repairs in a human cadaver model. The FDP tendon was repaired with a modified Kessler technique, while the FDS was repaired with a modified Kessler (n = 10), Becker (n = 10), or a new double running zig-zag suture (n = 10). The modified Kessler repair had a threefold increase from normal gliding resistance, the Becker repair increased twofold, and the zig-zag repair increased twofold. The peak gliding resistance increased twofold with a modified Kessler repair, 2.5-fold with a Becker repair, and 2.5-fold with a zig-zag repair.

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For many hand surgeons, repair of flexor tendon injuries in zone 2 presents a clinical problem (Strickland and Glogovac 1980, Strickland 1985, Kwai Ben and Elliot 1998, Strickland 2000). The surgeon faces a dilemma since the finger is kept immobile during healing, dense adhesions may bind the tendons in the sheath and limit motion. On the other hand, uncontrolled early flexion may disrupt the tendon repair. It is now well known that controlled motion increases tensile strength, reduces the formation of adhesions and improves clinical results, but normal function remains an elusive goal (Adolfsson et al. 1996, Baktir et al. 1996, Strickland and Glogovac 1980, Sirotakova and Elliot 1999).

Many techniques for tendon repair have been described. Traditional suture techniques, such as the Bunnell, Kessler (Kessler and Nissim 1969), Kleinert (Kleinert et al. 1973), and Tsuge (Tsuge et al. 1977) repairs, are widely used. The modified Kessler technique (Papandrea et al. 1995) is often the reference suture for mechanical studies. In previous studies, the modified Kessler technique with a running peripheral finishing suture seemed to be neither too bulky (Norris et al. 1999), nor too weak, with an average breaking strength around 30 N, and a gliding resistance around 0.8 N in the flexor digitorum profundus (FDP).

There is also some debate regarding treatment of the flexor digitorum superficialis (FDS) in cases where both tendons are lacerated in zone IIc. Zone II, also called “no man’s land”, is the area between the proximal reflection of the synovial sheath and the terminal portion of the FDS. The subdivision IIc, defined by Tang and Shi (1992), is the portion covered by the A2 pulley. The FDS bifurcates at about the midportion of this area. This sub-zone contains the narrowest fibro-osseous gliding canal, making it easier to compress or entrap the gliding contents here. An option is the excision of one slip of the FDS tendon. However, excision of this tendon jeopardizes tendon nutri-

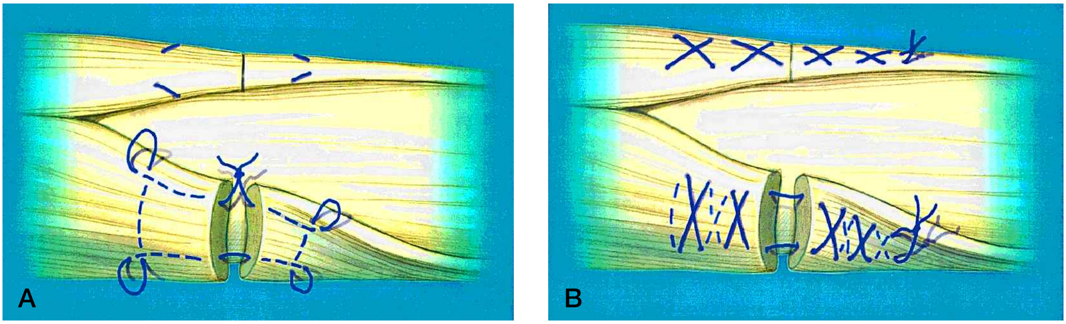

Figure 1. (A) Modified Kessler suture; (B) Becker suture.

tion, as the resulting resection of the vinculum longum, which passes through the FDS, reduces the vascular supply of the FDP tendon (Amadio et al. 1985). Therefore, the resection must be limited, and not extended to the IIb sub-zone (Tang and Shi 1992). Resection of the FDS may also affect finger motion, and cause a swan-neck deformity (Tubiana 1973). The other treatment option is to repair both of the damaged tendons (Lister et al. 1977, Nielsen and Jensen 1984, Strickland 2000). There is evidence that suturing both tendons in this constricted canal may impair tendon gliding (Tang and Shi 1992, Tang 1994). However, mechanical examinations of FDS repairs to date have considered only the suture breaking strength (Boulas and Strickland 1993).

To make up for the lack of information on the mechanical performance of FDS repairs and the mechanical interaction of the repaired FDS, FDP and pulley, we compared the gliding resistance of the repaired FDP tendon in the fibrous tendon sheath (A2 pulley) to three types of FDS tendon repairs in a human cadaver model.

Material and methods

We used 10 cadaveric frozen fresh human hands for this in vitro study. The specimens came from 7 males and 3 females with a mean age of 79 (39–95) years. Both right and left hands were used.

The second, third, and fourth digits of each hand were dissected through Bruner incisions. The entire digit tendon system was exposed, leaving the sheath intact. An incision was made in the sheath between the A2 and A3 pulleys. With the finger in full extension, a mark was made on both the FDP and FDS tendons at the level of the distal edge of the A2 pulley. The finger was then moved to full flexion by traction on the flexor tendons, and a second mark was made on both tendons, again at the distal edge of the A2 pulley. Tendon excursion from full extension to full flexion was considered to be the distance between these two marks.

With the digit in a position of 45 degrees PIP flexion and full DIP extension, we created a complete laceration of both tendons at the level of the ?? just proximal to the distal edge of the A2 pulley. This common site of tendon injury can occur after grasping a sharp object. With a laceration at this level, the FDP repair site passes through the pulley canal during flexion, while the FDS repair effectively narrows the canal. Following identification of the tendon excursion and creation of the laceration, the proximal phalanx, the proximal part of the middle phalanx, the FDP and FDS tendons and the A2 pulley were dissected free and prepared for testing.

We repaired the FDP tendon in each case with a modified Kessler repair using a 3-0 Surgilon suture, and a running circumferential suture of 6-0 Prolene. This repair is commonly performed clinically (Williams and Amis 1995, Diao et al. 1996). We studied three types of suture techniques of the FDS tendon: 1) Modified Kessler repair using 4-0 Ticron (n = 10); 2) Becker repair using 4-0 Ticron (n = 10) (Figure 1); and 3) a new zig-zag running suture technique using 6-0 Nylon (n = 10) (Figure 2).

The zig-zag running suture was made on the anterior face of the FDS slip with a 30-degree inclination between the tendon axis and the outside stitch. The knot was inside the laceration and

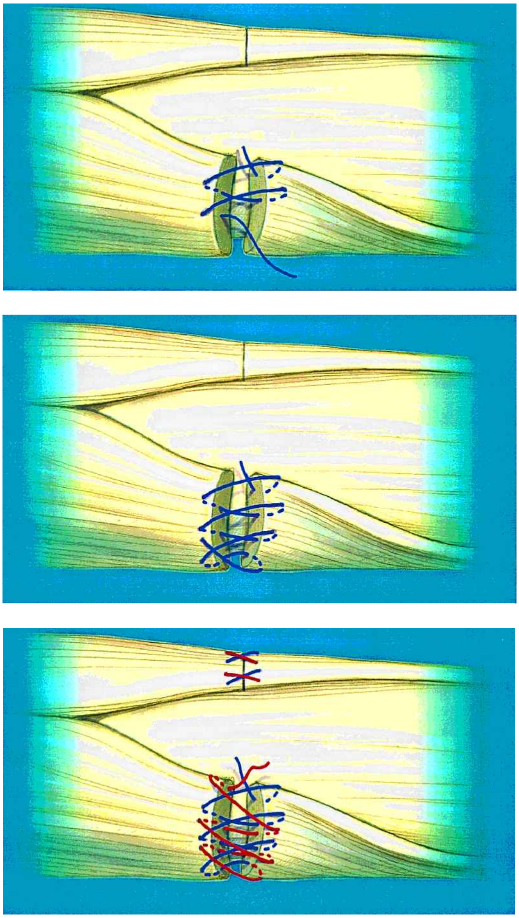

Figure 2. The new Zig-Zag suture.

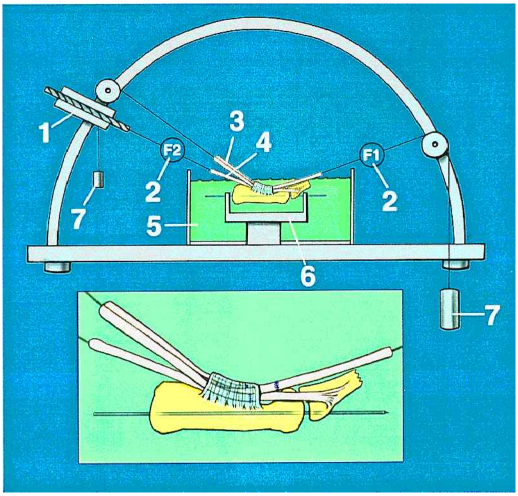

Figure 3. Testing device: (1) motor; (2) tensile load transducer; (3) FDS; (4) FDP; (5) saline bath; (6) custom jig; (7) weight.

3 loops were placed on each end of the two slips of the FDS.

The gliding resistance of every specimen was tested, using a previously described experimental device (An et al. 1993) (Figure 3). The tendons were tested three times: 1) intact FDP with intact FDS; 2) sutured FDP with intact FDS; and 3) sutured FDP with sutured FDS. In the testing set-up, the FDS remained stationary while the FDP glided through the sheath. A 2 N weight was attached to the proximal end of the FDS while the distal end remained attached to the middle phalanx. The proximal end of the FDP was attached to a custom-made force transducer (F_p) and then to a mechanical actuator with a linear potentiometer. The distal FDP was also connected to a force transducer (Fd) and then to a 4.9 N weight. Experience has shown that fixed angles between the horizontal plane and the proximal (30 degrees) and distal (20 degrees) cables were sufficient to measure gliding resistance (Uchiyama et al. 1995). The FDP tendon was moved at a rate of 2 mm/sec. The excursion was limited to the distance between the two FDP markers. The specimen was immersed in a saline bath throughout testing.

We calculated the gliding resistance between the FDP and proximal pulley, FDS, and bone using a previously described method (Uchiyama et al. 1995). In brief, since Fd remains constant (4.9 N), the composite gliding resistance for flexion and extension motion was calculated as $(1/2)*(F_p \text{ flexion} - F_p \text{ extension})$. Over the excursion range, the mean composite gliding resistance was calculated as well as the peak gliding resistance during flexion.

We compared gliding resistance among the three tendon repair groups using repeated measures analysis of variance (since each cadaveric hand contributed one digit to each of the three tendon repair groups). Significant results were further analyzed with the Tukey-Kramer multiple comparisons test. P-values less than 0.05 were considered significant.

Results

Following the FDP repair, the increase in gliding

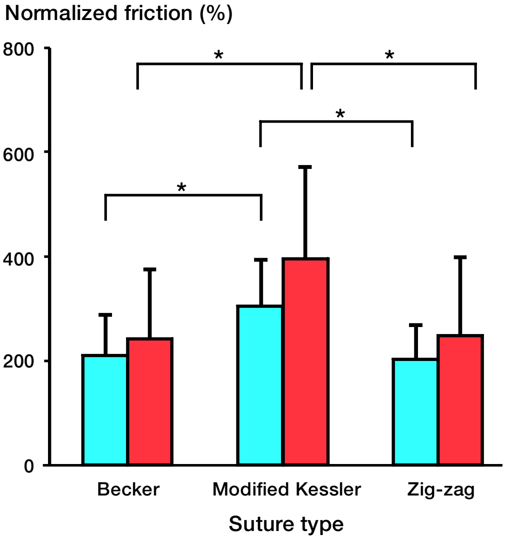

Figure 4. Mean friction (blue) and peak friction (red) normalized to intact tendons for three types of FDS repair. Significant differences ($p < 0.05$) are indicated by an asterisk.

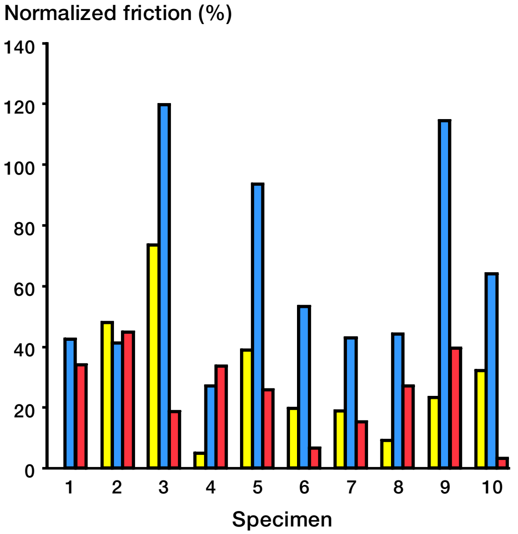

Figure 5. Chronological normalized mean friction for the 10 specimens. Becker – yellow, modified Kessler – blue, and zig-zag – red.

resistance from normal was identical among the 3 groups, as expected ($p = 0.9$ for average gliding resistance and $p = 0.6$ for maximum), increasing by an average of 145 (SD 55)%, while the maximum gliding resistance increased 185 (SD 101)%.

Following FDS repair, we found a difference in the average gliding resistance among the three repair methods ($p = 0.01$) (Figure 4). The modified Kessler repair showed an increase of 302 (SD 90)% from normal, the Becker increased 209 (SD 78)%, and the zig-zag increased 202 (SD 65)%. The increase in mean gliding resistance of the modified Kessler repair was significantly greater than both the Becker and zig-zag repairs.

The maximum gliding resistance after FDS repairs showed similar trends. The peak gliding resistance increased 395 (SD 174)% with a modified Kessler repair, 242 (SD 134)% with a Becker repair, and 244 (SD 152)% with a zig-zag repair. The maximum gliding resistance of the modified Kessler repair was greater than both the Becker and zig-zag repairs ($p = 0.02$).

Unlike the modified Kessler and zig-zag suture, there appeared to be a relationship between gliding resistance and experience with the Becker repair. The first tendon repaired with a Becker suture ruptured during testing and its results were not included in the analysis. The following two tendons with a Becker repair had an average gliding resistance greater than twice the overall mean shown in Figure 5. The impression of the surgeon who repaired the tendons (author PP) was that there was a learning curve in using the Becker repair, since the results were more consistent for tendons 4 through 10.

Discussion

It is generally accepted that postoperative motion can reduce the formation of adhesions after tendon repair. Therefore, gliding resistance after flexor tendon repair is an important factor, which could influence the outcome of surgery, especially in zone 2, where there are two flexor tendons inside the tendon sheath. The tendon will have more difficulty in moving if the gliding resistance is greater than the force applied to the tendon during postoperative therapy. Although gliding resistance between the FDP tendon and A2 pulley has been studied (Nishida et al. 1999, Zhao et al. 2000), the gliding characteristics after injury and repair to both tendons is unknown.

Our findings show that FDS repair increases the gliding resistance during FDP motion. This increase in friction may explain the worse clinical results when both tendons are injured and repaired in zone II, with an increased risk of gap and adhesion formation and poorer motion, as compared to injury of the FDP alone. The differences appear to be related to the choice of FDS repair. The modified Kessler repair showed higher friction than the Becker or zig-zag repairs. A previous study evaluating the breaking strength showed that the modified Kessler repair of the FDS was weaker than with a Becker repair (Miller and Mass 2000). As the modified Kessler repair has both higher friction and lower strength, it would seem inadequately adapted for an FDS slip repair, unlike its effectiveness as a suture method for the FDP. The literature contains no data on the breaking strength of the new zig-zag suture.

One limitation in our methodology is that the FDS remained stationary in the testing model. During normal flexion, the FDS and FDP move relative to each other. Ideally, for a gliding resistance test of both tendons, mechanical actuators should pull each tendon at different rates. Although our method is a simplification of this ideal, the scenario we tested would produce the highest gliding resistance, as the repair sites are at the same location beneath the A2 pulley. Therefore, we believe that comparisons among the three repair techniques reflect the relative differences that would occur in vivo. Another limitation is that for this in vitro study, we could not evaluate any positive or negative effects of healing, such as adhesions or restoration of the gliding surface.

It is clear that the gliding resistance is greater when both the FDP and FDS are repaired, which may be one reason why a poorer outcome is commoner after a multiple tendon injury. Our findings suggest that the Becker or zig-zag suture seems to be a better method for FDS repair.

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