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Effect of Core Suture Technique and Type on the Gliding Resistance during Cyclic Motion following Flexor Tendon Repair: A Cadaveric Study

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Abstract

We investigated the effects of two suture techniques using three suture types in a human model in vitro. We obtained 60 flexor digitorum profundus (FDP) tendons from cadavers and measured the gliding resistance during 1,000 cycles of simulated flexion–extension motion and load to failure of six groups: the modified Kessler (MK) repair using 3-0 coated, braided polyester (Ethibond, Ethicon, Somerville, NJ), 3-0 coated, braided polyester/monofilament polyethylene composite (FiberWire®; Arthrex, Naples, FL), or 4-0 FiberWire; and the Massachusetts General Hospital (MGH) repair using 3-0 Ethibond, 3-0 FiberWire, or 4-0 FiberWire. The 3-0 Ethibond MGH suture had significantly higher ultimate load to failure than the 3-0 or 4-0 FiberWire MK suture. The 3-0 and 4-0 FiberWire MGH sutures had significantly higher load to failure than the three MK groups. The gliding resistances of the three MGH groups were significantly higher than that of the three corresponding MK groups. The MGH repair had more gliding resistance than an MK repair, even when comparing large diameter suture in the MK repair with smaller diameter suture in the MGH repair. In this study, suture technique was more important in predicting repair load to failure and gliding resistance than the nature or caliber of the suture material that was used.

Keywords

core suture; gliding resistance; suture; tendon repair; human cadaver

The main challenge in flexor tendon repair is allowing the sutured tendon to heal while avoiding adhesion formation. A protocol of early rehabilitation changes the process of adhesion formation and is associated with better clinical outcomes.^{1,2} Tendon loading during rehabilitation is affected by several components: muscle tension; joint stiffness; resistance of edematous soft tissue; external load; and the gliding resistance inside the synovial sheath and pulley system.^{3,4} As aggressive therapy may result in rupture of the tendon repair before healing has occurred, it is critical to understand how to produce a strong tendon repair that does not rupture or gap. Such repairs should combine suture material and technique to provide the greatest load to failure while minimizing gliding resistance within the synovial sheath.^{5–7}

FiberWire® (Arthrex, Naples, FL), a suture made from long-chain polyester in a braided polyester jacket, has superior strength in materials testing and other studies.^{8,9} Previous research demonstrated that 3-0 FiberWire has a lower frictional coefficient (0.054) than 3-0 coated, braided polyester (Ethibond, Ethicon, Somerville, NJ; 0.076).⁵ For the repaired tendon evaluation using a grasping modified Pennington core suture technique and a monofilament polypropylene (Prolene, Ethicon) 6-0 running peripheral suture, the gliding resistance of the repaired tendons with FiberWire and Ethibond were similar.⁵ Similarly, the load to failure of the two repairs and the force to produce a 2 mm gap were also not significantly different.⁵ However, other research demonstrated that FiberWire outperforms both Ethibond and Prolene in gap formation, tensile strength, and mode of failure when using locked flexor tendon repair suture [Massachusetts General Hospital (MGH) repair], but not when using a grasping-type, non-locking repair (Strickland repair).⁹ The friction of the MGH repair was significantly higher than that of modified Kessler (MK) repair because the MGH repair had more suture material exposed outside the tendon surface.¹⁰

The size of the suture material is also important. One study reported that a 3-0 Ethibond suture was 41% stronger than a 4-0 Ethibond suture when human flexor digitorum profundus (FDP) tendons were repaired using a MK technique.¹¹ However, thicker material adds bulk to the repair and may increase the tendon gliding resistance. A high-friction repair can more than offset the gain in strength by increasing gliding resistance and causing abrasion of the tendon sheath.¹²

While many studies compared gliding resistance, ultimate load, and stiffness of different core suture immediately after repair,^{5-7,13} gliding characteristics of different core sutures after repetitive motion have not been reported. Since the gliding resistance of tendon grafts is affected by repetitive motion,^{14,15} tendon repairs might behave similarly to their core sutures. The load to failure of the core sutures after repetitive motion would also be useful new information. Our purpose was to investigate the effects of two core suture techniques using three suture types on tendon gliding resistance and tendon repair load to failure, using a human cadaver model of zone 2 repair and 1,000 cycles of simulated tendon motion.

MATERIALS AND METHODS

Specimen Preparation

After Institutional Review Board approval, 5 right hands and 10 left hands from 15 fresh cadavers were obtained, including 7 males and 8 females, with an average age of 80.6 years (range 61–97). One hand of each cadaver was used to obtain 60 FDP tendons. Each finger was disarticulated at the MCP joint level, preserving the flexor tendons at the wrist. The FDP tendons were accessed through a transverse incision in the flexor sheath, just distal to the A2 pulley. The tendons were marked at the distal end of the pulley at full passive extension and flexion with a 4.9 N weight attached to the proximal FDP tendon to maintain tension. The distance between these two markers represented the FDP tendon excursion during full finger range of motion. A transverse laceration was made 12 mm distal to the proximal mark to ensure movement of the repair site through the pulley system during testing.

The tendons were randomly allocated into six groups, with 10 tendons per group. Each group was repaired with a different suture material and method (Fig. 1): 3-0 Ethibond MK suture; 3-0 FiberWire MK suture; 4-0 FiberWire MK suture; 3-0 Ethibond MGH suture; 3-0 FiberWire MGH suture; or 4-0 FiberWire MGH suture. All repairs included a simple continuous epitendinous suture technique using 6-0 Prolene.¹⁶ The running epitendinous throws was ~2 mm from the lacerated tendon ends, with 1 mm between each throw. The number of epitendinous throws ranged from 12 to 16, depending upon tendon size. All core

and epitendinous suture knots were tied with four square knots. All repairs were performed by the same investigator (T.M.) to ensure consistency of technique.

Measurement of Frictional Force

The friction between tendon and pulley was measured using the method of Uchiyama et al.^{17,18} Briefly, the proximal and middle phalanges, proximal pulley, flexor digitorum superficialis (FDS), parietal membrane of the proximal pulley, and visceral membrane of the FDP were preserved, while removing the remaining tendon sheath and bone. A Kirschner wire was used to fix the proximal interphalangeal joint in the extended position. Each specimen was mounted on a custom testing device with the palmar side upward (Fig. 2). To maintain tension in the FDS tendon, a 2 N weight was attached to its proximal end. This load was determined based on previous *in vivo* tendon research on the load experienced by normal tendons *in situ*.^{19,20}

The measurement system consisted of a mechanical actuator with a linear potentiometer, two tensile load transducers, and a mechanical pulley. The transducers were attached to the proximal and distal ends of the FDP tendon. The distal transducer was connected to a 4.9 N weight to simulate passive finger mobilization, again based on previous *in vivo* research.^{19,20} The proximal transducer was connected to the actuator. Based on the experience of previous studies, a set arc of contact, 30° and 20° between the horizontal plane and the proximal and distal transducer cables, respectively, was sufficient to provide adequate measurement of the gliding resistance.^{4,17} The tendon was pulled proximally by the actuator against the weight at a rate of 2 mm/s. Excursion was limited to the distance between the two FDP tendon markers. The forces at the proximal and distal tendon ends and the tendon excursion were recorded. The specimens were kept moist throughout testing by immersion in a saline bath. The force differential between the proximal and distal tendon ends represented the gliding resistance. The mean gliding resistances over the excursion range were calculated and reported.

The data for the intact FDP tendon were initially recorded for pre-repair. After repair of the tendon, the data were recorded after every 50 cycles up to 500 cycles and then after every 100 cycles up to 1,000 cycles.

Tendon Repair Load to Failure

The repaired tendon load to failure was then measured using a servo-hydraulic testing machine (MTS, Minneapolis, MN). The repaired tendon was secured in the testing machine and distracted to failure at a rate of 20 mm/min. A differential variable reluctance transducer (DVRT; Microstrain, Williston, VT) was attached to the tendon spanning the repair site to measure gap formation during testing. Tensile force, grip-to-grip displacement, and gap displacement measured by the DVRT transducer were collected at a rate of 20 Hz. Throughout testing the tendons were kept moist by spraying with physiologic saline. Maximal breaking force and the force to produce a 2 mm gap were recorded. In addition, a regression line was fit to the linear region of the force versus gap formation to measure the resistance to gap formation.

Gap Measurement

If a gap was visually observed over the 1,000 cycles of testing, it was measured by a caliper, and the related motion cycle number was recorded.

Statistical Analysis

A previous study showed that the average gliding resistance of a human FDP tendon before and after repair using 3-0 Ethibond was 0.29 N (SD = 0.13 N) and 1.12 N (SD = 0.46 N),

respectively.⁵ Using these data, we estimated an 80% power at a significance level of $p < 0.05$ with a sample size of 10 to detect a difference in gliding resistance of 0.22 N (20% decrease).

The two factors (suture technique and suture material/caliber) were analyzed using two-factor ANOVA. Because four digits from one hand of 15 unique cadavers were used, it was necessary to account for the within-cadaver correlation among the digits. This was accomplished utilizing generalized estimating equations (GEE) in a generalized linear models framework. Separate analyses were conducted at each of 1, 100, and 1,000 cycles, and also after normalizing the results of 1, 100, and 1,000 cycles to the results of the intact state. Load to failure and stiffness were analyzed in the same manner. In addition, the effect of testing cycle was evaluated separately for each experimental condition using one-factor ANOVA. For each model, contrast statements were generated to perform pairwise testing of each level of the independent variables. All statistical tests were two-sided; the threshold of statistical significance was set at $\alpha = 0.05$.

RESULTS

During 1,000 cycles of tendon motion, no gap formation was noted in any tendon. No significant difference was found in the gliding resistance of the intact FDP tendons among the six groups (Table 1).

Comparison between Suture Techniques

The MGH suture had significantly higher gliding resistance than the MK suture at all cycles ($p < 0.05$). Both the MK and the MGH repairs at 1 cycle had significantly higher gliding resistance than those at 100 cycles ($p < 0.05$). The MGH suture had significantly higher force for 2 mm gap, maximal failure ultimate load, and stiffness than the MK suture (all $p < 0.05$; Table 2; Fig. 3).

Comparison between Suture Types among the MK and MGH Groups

No significant difference in the gliding resistance, the normalized gliding resistance, load to failure, or stiffness occurred among the three MK groups. In contrast, the 4-0 FiberWire MGH suture had significantly lower gliding resistance than the 3-0 Ethibond MGH suture at 1,000 cycles ($p < 0.05$), the 3-0 FiberWire MGH suture at 1 ($p < 0.05$), and 100 cycles ($p < 0.05$). The 3-0 Fiber-Wire MGH suture also had significantly lower gliding resistance than the 3-0 Ethibond MGH suture at 1,000 cycles ($p < 0.05$; Tables 1 and 3).

The differences in force for 2 mm gap, maximal failure ultimate force, and stiffness were not significant among the three MGH groups. For the normalized data, the friction of the 4-0 FiberWire MGH suture was significantly lower than that of the 3-0 Ethibond MGH suture at 1 ($p < 0.05$), 100 ($p < 0.05$), and 1,000 cycles ($p < 0.05$), and that of the 3-0 FiberWire MGH suture at one ($p < 0.05$) and 100 cycles ($p < 0.05$). The normalized friction of the 3-0 FiberWire MGH suture was also significantly lower than that of 3-0 Ethibond MGH suture at one ($p < 0.05$), 100 ($p < 0.05$) and 1,000 cycles ($p < 0.05$).

Comparison of Gliding Resistance and Load to Failure among Techniques

The gliding resistance of each of the three MGH groups was significantly higher than that of each of the three MK groups at any cycle ($p < 0.0001$). All of the MK repair groups had less gap resistance and ultimate load than the MGH repair groups, but only some of these differences were significant. The 4-0 FiberWire MK suture absorbed significantly lower force for 2 mm gap than the 3-0 FiberWire MGH suture ($p = 0.0005$) and the 4-0 FiberWire MGH suture ($p = 0.001$). The 3-0 FiberWire MGH suture absorbed significantly higher

force for 2 mm gap than the 3-0 FiberWire MK suture ($p = 0.0044$). The 3-0 Ethibond MGH suture had significantly higher load to failure ultimate load than the 3-0 FiberWire MK suture ($p = 0.046$) and the 4-0 FiberWire MK suture ($p = 0.0001$). The 3-0 and the 4-0 FiberWire MGH suture had significantly higher maximal failure load to failure than any of the three MK groups. The stiffness of the three MGH groups was also significantly higher than that of the corresponding MK groups (Fig. 4; Tables 1 and 3).

Comparison of Normalized Gliding Resistance

The normalized gliding resistance of the 3-0 Ethibond MGH suture was significantly higher than any of the others at all cycles (Table 2; Fig. 4).

Comparison of Gliding Resistance in Cyclic Motion within Repair Technique

The gliding resistance of the 3-0 Ethibond MK suture at one cycle was significantly higher than at 100 ($p = 0.004$) or 1,000 cycles ($p = 0.044$). The gliding resistance of the 3-0 Ethibond MGH suture at 1,000 cycles was significantly higher than at 100 cycles ($p = 0.019$). The gliding resistance of the 3-0 FiberWire MGH suture at 1 cycle was significantly higher than at 100 ($p = 0.019$) and 1,000 cycles ($p = 0.032$). The gliding resistance of 4-0 FiberWire MGH suture at 100 cycles was significantly higher than at 1 ($p = 0.048$) and 1,000 cycles ($p = 0.005$; Table 1; Fig. 5).

DISCUSSION

In our study, the gliding resistance of the 3-0 Ethibond MK suture, the 3-0 FiberWire MGH suture, and the 4-0 FiberWire MGH suture at one cycle were significantly higher than for their respective repairs at 100 cycles. The gliding resistances of the 3-0 Ethibond suture and the 3-0 FiberWire MGH suture at one cycle were also significantly higher than for their respective repairs at 1,000 cycles. We believe that this effect may be due to a smoothing out of the repair over the first few cycles of motion, perhaps by equalizing tension on the suture limbs. Although, this effect did not disproportionately affect the repair techniques that we studied, the gliding resistance after 100 or 100 cycles in vitro may be a more appropriate measure of a repair's gliding resistance than the results after one cycle.

We found no significant differences in gliding resistance among the three MK repairs, but differences existed between the 3-0 and 4-0 FiberWire MGH repairs at one and 100 cycles, between the 3-0 Ethibond and 3-0 FiberWire MGH repairs at 1,000 cycles, and between the 3-0 Ethibond and 4-0 FiberWire MGH repairs at 1,000 cycles. These data suggest that the MK repair may be more "forgiving", perhaps because this repair leaves less suture material exposed on the tendon surface than the MGH repair. We also observed that the MGH repair had significantly higher gliding resistance, almost double that of the MK repair at all cycles, a difference similar to that noted by Momose et al.⁷ This emphasizes that the differences in friction between these two methods is a reflection of the suture design and not the suture caliber or material. We believe that these differences relate to the amount of suture material exposed on the anterior tendon surface and the presence of knots on the surface, consistent with the findings of Momose et al.⁷ Unfortunately, we do not have sufficient information to comment on the effect of the geometry of the suture material on the tendon surface as opposed to its absolute amount. Suture oriented parallel to the direction of motion might have affect friction differently than suture oriented perpendicular to the direction of motion.

We also observed that the load to failure of the MGH repair was ~30% more than the MK repair, similar to the work of Wassermann et al.²¹, but somewhat less than that reported by Greenwald et al.²² However, our load to failure measurements were made after 1,000 cycles of motion and so are not strictly comparable to previous studies. Nevertheless, this finding

again suggests that the differences between the MGH and MK repairs in load to failure reflect their differences in design, for example, in the use of locking versus grasping loops, and not a reflection of the suture material used. The normalized gliding of the 3-0 Ethibond MGH repairs was significantly higher than that of the other repairs at all cycles (Table 2), suggesting that 3-0 Ethibond may be too large to use effectively with an MGH repair. Our data also showed though that with the MGH repairs, different suture material did produce differences in gliding resistance, specifically showing that the 4-0 FiberWire and 3-0 Ethibond repairs had similar load to failure but significantly different gliding resistance at 1,000 cycles. The 4-0 and 3-0 FiberWire repairs also had similar loads to failure but significantly different gliding resistances at 1 and 100 cycles. Our data suggest that no advantage in load to failure exists in using a larger caliber suture in an MGH repair, while there are disadvantages in terms of increased friction.

The main strength of our study is that we systematically assessed the effect of suture caliber, design, and composition on a standard tendon repair in a consistent in vitro model. Under similar experimental conditions, we showed that, using common repair methods, the effect of suture design superseded that of suture material, especially for the MK repair. We have also showed that, within suture designs, larger caliber sutures do not necessarily increase load to failure after 1,000 cycles, though it may increase gliding resistance. This is an argument against the idea that “bigger is better” when choosing suture caliber for tendon repair.

This study does, though, have important limitations. First, the DVRT device used to measure gap formation might affect load to failure. However, the device was inserted into an intact part of the tendon above and below the suture site. Thus, while the device might damage some tendon fascicles, it would not have weakened the repair construct. The DVRT also might have displaced during testing, affecting the gap recordings. However, we directly observed each tendon during testing and saw no such displacement. Second, this was an in vitro study. The set-up was non-physiological, in that the tendon glided against a segment of an annular pulley, not the intact digital sheath, and the angles of loading the tendon were fixed. These are different from in vivo conditions. We measured the gliding resistance during 1,000 motion cycles to simulate rehabilitation therapy, but no component of healing or post-operative edema could be simulated. Third, tendon diameter varied from specimen to specimen, as did, consequently, the number of epitendinous suture throws. This was based on published descriptions but could have affected the results.

In summary, we showed that the MGH repair has almost double the gliding resistance and ~30% more load to failure than the MK repair and that these differences are only slightly affected by differences in suture material or caliber. Our findings suggest a possible preference for 4-0 over 3-0 suture caliber when using the MGH repair, as the friction is less, while the load to failure is similar. Whether a change in the geometry of the MGH repair might alter its frictional characteristics while maintaining its excellent strength remains unknown. This would be an interesting topic for a future study.

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References

1. Grewal R, Saw SS, Bastidas JA, et al. Passive and active rehabilitation for partial lacerations of the canine flexor digitorum profundus tendon in zone II. *J Hand Surg [Am]*. 1999; 24:743–750.

2. Zhao C, Amadio PC, Paillard P, et al. Digital resistance and tendon strength during the first week after flexor digitorum profundus tendon repair in a canine model in vivo. *J Bone Joint Surg [Am]*. 2004; 86A:320–327.
3. Bhatia D, Tanner KE, Bonfield W, et al. Factors affecting the strength of flexor tendon repair. *J Hand Surg [Br]*. 1992; 17:550–552.
4. Zhao C, Amadio PC, Zobitz ME, et al. Gliding characteristics of tendon repair in canine flexor digitorum profundus tendons. *J Orthop Res*. 2001; 19:580–586. [PubMed: 11518265]
5. Silva JM, Zhao C, An KN, et al. Gliding resistance and strength of composite sutures in human flexor digitorum profundus tendon repair: An in vitro biomechanical study. *J Hand Surg [Am]*. 2009; 34:87–92.
6. Tanaka T, Amadio PC, Zhao C, et al. Gliding characteristics and gap formation for locking and grasping tendon repairs: A biomechanical study in a human cadaver model. *J Hand Surg [Am]*. 2004; 29:6–14.
7. Momose T, Amadio PC, Zhao C, et al. Suture techniques with high breaking strength and low gliding resistance: Experiments in the dog flexor digitorum profundus tendon. *Acta Orthop Scand*. 2001; 72:635–641. [PubMed: 11817881]
8. Komatsu F, Mori R, Uchio Y. Optimum surgical suture material and methods to obtain high tensile strength at knots: Problems of conventional knots and the reinforcement effect of adhesive agent. *J Orthop Sci*. 2006; 11:70–74. [PubMed: 16437352]
9. Miller B, Dodds SD, deMars A, et al. Flexor tendon repairs: The impact of fiberwire on grasping and locking core sutures. *J Hand Surg [Am]*. 2007; 32:591–596.
10. Zhao C, Amadio PC, Momose T, et al. Remodeling of the gliding surface after flexor tendon repair in a canine model in vivo. *J Orthop Res*. 2002; 20:857–862. [PubMed: 12168678]
11. Taras JS, Raphael JS, Marczyk SC, et al. Evaluation of suture caliber in flexor tendon repair. *J Hand Surg [Am]*. 2001; 26:1100–1104.
12. Zhao C, Amadio PC, Zobitz ME, et al. The effect of suture technique on adhesion formation after flexor tendon repair for partial lacerations in a canine model. *J Trauma*. 2001; 51:917–921. [PubMed: 11706340]
13. Kubota H, Aoki M, Pruitt DL, et al. Mechanical properties of various circumferential tendon suture techniques. *J Hand Surg [Br]*. 1996; 21:474–480.
14. Sun Y, Yang C, Amadio PC, et al. Reducing friction by chemically modifying the surface of extrasynovial tendon grafts. *J Orthop Res*. 2004; 22:984–989. [PubMed: 15304269]
15. Taguchi M, Sun Y, Zhao C, et al. Lubricin surface modification improves extrasynovial tendon gliding in a canine model in vitro. *J Bone Joint Surg [Am]*. 2008; 90:129–135.
16. Kleinert HE, Kutz JE, Atasoy E, et al. Primary repair of flexor tendons. *Orthop Clin North Am*. 1973; 4:865–876. [PubMed: 4598164]
17. Uchiyama S, Amadio PC, Coert JH, et al. Gliding resistance of extrasynovial and intrasynovial tendons through the A2 pulley. *J Bone Joint Surg [Am]*. 1997; 79:219–224.
18. Coert JH, Uchiyama S, Amadio PC, et al. Flexor tendon-pulley interaction after tendon repair. A biomechanical study. *J Hand Surg [Br]*. 1995; 20:573–577.
19. Lieber RL, Amiel D, Kaufman KR, et al. Relationship between joint motion and flexor tendon force in the canine forelimb. *J Hand Surg [Am]*. 1996; 21:957–962.
20. Schuind F, Garcia-Elias M, Cooney WP III, et al. Flexor tendon forces: In vivo measurements. *J Hand Surg [Am]*. 1992; 17:291–298.
21. Wassermann RJ, Howard R, Markee B, et al. Optimization of the MGH repair using an algorithm for tenorrhaphy evaluation. *Plast Reconstr Surg*. 1997; 99:1688–1694. [PubMed: 9145140]
22. Greenwald DP, Randolph MA, Hong HZ, May JW. Augmented Becker versus Modified Kessler tenorrhaphy in monkeys: Dynamic mechanical analysis. *J Hand Surg*. 1995; 20A:267–272.

Figure 1. Schematic drawings of the two core suture methods (A) the modified Kessler suture; (B) the MGH suture.

Figure 2.

Experimental set-up and testing apparatus for the gliding resistance of repaired tendon/pulley system. The specimen with repaired FDP tendon was mounted on the testing apparatus (Permission has been requested to reuse this figure from the publisher).

Figure 3.

Top: Mean gliding resistance of the FDP tendons in the MK and MGH sutures for intact tendons and repaired tendons at 1, 100, and 1,000 cycles. Bottom: Mean force for 2 mm gap, maximal failure ultimate load, and stiffness in the two groups. Error bars represent SD; * $p < 0.05$.

Figure 4. Mean gliding resistance of the FDP tendons in the six groups at different cycles of tendon motion.

Figure 5.

Mean normalized to intact state gliding resistance of the FDP tendons in the six groups at different cycles of tendon motion. We divided after-repair gliding resistance by pre-repair gliding resistance for the normalization.

Table 1
Gliding Resistance, Force for 2 mm Gap, Maximal Failure Ultimate Load and Stiffness (Mean $\pm$ SD)

Suture Method	Gliding Resistance (N)				Force for 2 mm Gap (N)	Maximal Failure Ultimate Load (N)	Stiffness (N/mm)
	Pre-Repair	At 1 Cycle	At 100 Cycles	At 1,000 Cycles			
3-0 Ethibond MK	0.24 $\pm$ 0.13	0.87 $\pm$ 0.31	0.78 $\pm$ 0.23	0.78 $\pm$ 0.20	32.8 $\pm$ 15.26	40.3 $\pm$ 12.14	29.7 $\pm$ 9.88
3-0 FiberWire MK	0.23 $\pm$ 0.12	0.88 $\pm$ 0.28	0.81 $\pm$ 0.27	0.81 $\pm$ 0.23	31.7 $\pm$ 10.92	41.5 $\pm$ 7.07	30.7 $\pm$ 15.13
4-0 FiberWire MK	0.25 $\pm$ 0.14	0.84 $\pm$ 0.34	0.81 $\pm$ 0.24	0.86 $\pm$ 0.29	29.5 $\pm$ 4.54	39.6 $\pm$ 7.66	29.4 $\pm$ 9.77
3-0 Ethibond MGH	0.19 $\pm$ 0.11	1.71 $\pm$ 0.58	1.60 $\pm$ 0.48	1.83 $\pm$ 0.32	34.4 $\pm$ 10.29	48.5 $\pm$ 9.46	54.2 $\pm$ 17.47
3-0 FiberWire MGH	0.24 $\pm$ 0.07	1.70 $\pm$ 0.26	1.57 $\pm$ 0.24	1.53 $\pm$ 0.29	43.2 $\pm$ 12.43	56.3 $\pm$ 10.56	52.6 $\pm$ 10.81
4-0 FiberWire MGH	0.26 $\pm$ 0.08	1.43 $\pm$ 0.13	1.31 $\pm$ 0.24	1.36 $\pm$ 0.26	38.5 $\pm$ 8.44	52.0 $\pm$ 8.88	50.9 $\pm$ 20.67

$p < 0.05$: 3-0 Ethibond MK at 1 cycle versus at 100 cycles, at 1 cycle versus at 1,000 cycles.

3-0 Ethibond MGH at 100 cycles versus at 1,000 cycles.

3-0 FiberWire MGH at 1 cycle versus at 100 cycles, at 1 cycle versus at 1,000 cycles.

4-0 FiberWire MGH at 1 cycle versus at 100 cycles, at 100 cycles versus at 1,000 cycles.

Table 2

Gliding Resistance, Force for 2 mm Gap, Maximal Failure Ultimate Load and Stiffness (Mean $\pm$ SD)

Suture Technique	Gliding Resistance (N)			Force for 2 mm Gap (N)	Maximal Failure Ultimate Load (N)	Stiffness (N/mm)
	At 1 Cycle	At 100 Cycles	At 1,000 Cycles			
MK	0.87 $\pm$ 0.30	0.80 $\pm$ 0.24	0.82 $\pm$ 0.24	31.4 $\pm$ 10.84	40.5 $\pm$ 8.95	29.9 $\pm$ 11.45
MGH	1.61 $\pm$ 0.39	1.50 $\pm$ 0.36	1.57 $\pm$ 0.34	38.7 $\pm$ 10.79	52.3 $\pm$ 9.86	52.5 $\pm$ 16.29

Table 3

p-Values

	Gliding Resistance			Normalized Gliding Resistance			Force for 2 mm Gap	Maximal Failure Load	Stiffness
	At 1 Cycle	At 100 Cycles	At 1,000 Cycles	At 1 Cycle	At 100 Cycles	At 1,000 Cycles			
MGH(3-E) vs. MGH(3-F)	0.9715	0.8582	0.0388	0.0466	0.0415	0.0004	0.0841	0.0965	0.7872
MGH(3-E) vs. MGH(4-F)	0.1242	0.0772	< 0.0001	0.003	0.0019	< 0.0001	0.2914	0.2921	0.6685
MGH(3-F) vs. MGH(4-F)	0.0021	0.0249	0.1728	0.0139	0.0113	0.4193	0.296	0.3372	0.781
MK(3-E) vs. MGH(3-E)	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	0.8122	0.0566	0.0001
MK(3-E) vs. MGH(3-F)	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	0.1113	0.0532	0.0005	< 0.0001
MK(3-E) vs. MGH(4-F)	< 0.0001	< 0.0001	< 0.0001	0.0241	0.032	0.4325	0.2659	0.0221	0.0002
MK(3-E) vs. MK(3-F)	0.9411	0.6988	0.7396	0.7281	0.6608	0.8983	0.816	0.7979	0.8569
MK(3-E) vs. MK(4-F)	0.8495	0.7815	0.4824	0.9026	0.7208	0.6942	0.4945	0.8803	0.9442
MK(3-F) vs. MGH(3-E)	< 0.0001	< 0.0001	< 0.0001	0.0004	0.0001	< 0.0001	0.5213	0.0461	0.0002
MK(3-F) vs. MGH(3-F)	< 0.0001	< 0.0001	< 0.0001	0.0137	0.0164	0.143	0.0044	0.0004	0.0005
MK(3-F) vs. MGH(4-F)	< 0.0001	< 0.0001	< 0.0001	0.2934	0.3803	0.5111	0.1208	0.0045	0.0206
MK(3-F) vs. MK(4-F)	0.7474	0.9679	0.6217	0.6631	0.9074	0.7907	0.5506	0.5132	0.787
MK(4-F) vs. MGH(3-E)	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	0.1548	0.0001	< 0.0001
MK(4-F) vs. MGH(3-F)	< 0.0001	< 0.0001	< 0.0001	< 0.0001	0.0036	0.2304	0.0005	0.0002	< 0.0001
MK(4-F) vs. MGH(4-F)	< 0.0001	< 0.0001	< 0.0001	0.0397	0.191	0.6953	0.0011	0.0002	0.0029

3-E, 3-0 Ethibond; 3-F, 3-0 FiberWire; 4-F, 4-0 FiberWire.

Bold values represent $p < 0.05$.