Comparison of a New Multifilament Stainless Steel Suture with Frequently Used Sutures for Flexor Tendon Repair

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**Purpose** To investigate the mechanical properties of some common suture materials currently in use and compare them with a new multifilament stainless steel suture.

**Methods** We investigated the mechanical properties of 3-0 and 4-0 Fiberwire, 3-0 Supramid, 3-0 Ethibond, and a new 3-0 and 4-0 multifilament stainless steel suture. All suture material was tested in a knotted configuration and all but the Supramid was tested in an unknotted configuration. We measured the load, elongation at failure, and stiffness during both tests.

**Results** The 4-0 multifilament stainless steel showed the least elongation, whereas the 3-0 multifilament stainless steel withstood the highest load of any material in both the knotted and unknotted tests. There was no difference in stiffness between the 3-0 and 4-0 multifilament stainless steel when untied; however, the 3-0 multifilament stainless steel was stiffer when tied. Soaking in a saline solution had no significant effect on the ultimate load, elongation at failure, or stiffness of any of the sutures. The 3-0 Fiberwire and 3-0 Ethibond required at least 5 throws to resist untying.

**Conclusions** Multifilament stainless steel exhibited promising mechanical advantages over the other sutures tested. More research is needed to determine how this material will affect the clinical outcomes of primary flexor tendon repair.

**Clinical relevance** With a secure attachment to the tendon, the multifilament stainless steel’s lower elongation and better knot-holding ability may result in a higher force to produce a 2-mm gap and a higher ultimate tensile strength in a tendon repair. (J Hand Surg 2011;36A:1028–1034. Copyright © 2011 by the American Society for Surgery of the Hand. All rights reserved.)

**Key words** Biomechanics, Ethibond, Fiberwire, flexor tendon, mechanical properties.

Two of the biomechanical properties used to predict the success of a tendon repair are the ultimate tensile strength and the ability to resist gapping. The characteristics of the suture material used for a repair have a noteworthy effect on these parameters, and a number of new suture materials have been developed. Some of the characteristics of an ideal suture material include nonbioreactivity, a high ultimate tensile strength, and the ability to resist elongation, handle and tie easily, and hold knots well.

In 1929, Bunnell advocated the use of silk or chromatic catgut, but by 1940 he had begun to suggest monofilament stainless steel in a crisscross configuration for primary flexor tendon repair. This suture was difficult to handle and was ultimately discarded in favor of monofilament nylon and subsequently Ethibond (EB), a multifilament polyester (Ethicon, Somerville, NJ). More recently Fiberwire (FW) (Arthrex, Naples, FL) has demonstrated some advantageous
properties but has some disadvantages including a poor ability to hold knots.20,27,31,32

Recently, a multifilament stainless steel (MFSS) suture was developed for use in flexor tendon repair. Whereas the use of stainless steel as suture material is not a new idea, the configuration of the stainless steel filaments in this design produces a suture that is easier to handle than the monofilament designs.30,33 The mechanical properties of MFSS may be advantageous in producing strong repairs with secure knots.

The purposes of this study were to investigate the mechanical properties of some common suture materials currently in use and to compare them with a new MFSS suture.

MATERIALS AND METHODS

Suture material physical properties

We investigated the mechanical properties of the following 4 suture materials: FW, a multifilament, ultrahigh-molecular-weight polyethylene core with a braided polyester jacket; Supramid (SM), a multifilament nylon core with a nylon jacket (S. Jackson, Inc., Alexandria, VA); EB, a multifilament polyester suture; and an MFSS suture (Core Essence Orthopedics, Fort Washington, PA). The SM and EB were tested in the 3-0 size, whereas the FW and MFSS were tested in 3-0 and 4-0 configurations.

The MFSS cable is composed of 49 filaments of 316L stainless steel. The filaments in the 3-0 size are 0.034 mm in diameter, with a total suture diameter of 0.31 mm. The 4-0 filaments are 0.024 mm in diameter and the total suture diameter is 0.21 mm. The suture is arranged in 7 bundles of 7 filaments each; although technically a cable, it functions as a suture (Fig. 1).

Untied suture testing

We evaluated the ultimate tensile strength of 5 different suture materials: 3-0 and 4-0 MFSS, 3-0 and 4-0 FW,
and 3-0 EB. The SM suture was only available as a loop of suture with a needle attached. When the suture was removed from the needle, the length of remaining suture was insufficient to be attached to the testing clamps. We therefore tested the SM suture only in the tied configuration.

A total of 25 strands were tested, 5 of each material. To test the ultimate tensile strength and elongation of the sutures, each suture was loaded in uniaxial tension at 1 mm/s using a servohydraulic testing machine (MTS Mini-Bionix 858; Eden Prairie, MN) until failure. A strand of suture was attached to the MTS by a set of clamps (Fig. 2). The suture was wrapped around each spool 3 times and then held securely with a clamp on each side. Wrapping the suture around the spools ensured that the load was applied to the center of the suture, which had a length of 3 cm between spools. A 5-N preload was applied and the suture was subjected to 10 cycles from 5 to 10 N to allow the suture to settle and eliminate any slack from the system. A load cell (INTERFACE SSM-500, Scottsdale, AZ) recorded force data and the MTS displacement transducer recorded displacement. The ultimate load, elongation at failure, and stiffness were measured for each specimen. Stiffness represents the force per unit displacement and was calculated as the slope of a best fit line from 15 to 30 N on the force versus displacement curve.

**Knotted suture testing**

To test the strength of the suture in a knotted configuration, we tied the suture around a 7.6-cm-diameter cylinder to ensure consistent lengths using a surgeon’s knot with 1 additional throw, for a total of 3 throws (2 × 1 × 1) (Fig. 3). In addition, we tested 3-0 FW and 3-0 EB with a surgeon’s knot with 3 additional throws, for a total of 5 throws (2 × 1 × 1 × 1 × 1) (Fig. 3). The 3-0 SM was tied after cutting the suture loop off of the needle. The loop of suture was placed around the 2 spools for testing. The suture loops were cyclically loaded 10 times from 5 to 10 N, then immediately tested to failure at 1 mm/s. As with the untied suture, this cyclic preloading allowed the suture to settle and removed any slack from the system. We tested 6 samples of each material and configuration.

We also tested 6 samples of each suture after soaking them in a physiological saline solution at room temperature for 10 minutes. The ultimate load and elongation at failure were measured for each specimen. Stiffness was calculated for specimens in which the suture failed by breakage, and not calculated for specimens that failed by untying. As with the untied suture, the stiffness was calculated as the slope of a best fit line from 15 to 30 N on the force versus displacement curve.
**Statistical analysis**

To determine which factors significantly affect the mechanical behavior during bench-top testing, stepwise linear regression was conducted with the following initial predictor variables: (1) suture material, (2) suture gauge, (3) number of knots (knotted only), and (4) wet/dry suture material. We ran the stepwise algorithm with $p > .10$ as the exclusion criteria. Pairwise comparisons were then made between suture constructs using Student’s $t$-test with Tukey’s posthoc adjustment for multiple comparisons. We set $p < .05$ as the cutoff for significance; only statistically significant findings are reported in the Results section unless otherwise noted.

**RESULTS**

**Suture only**

The ultimate load of the 3-0 MFSS was the highest of any suture material tested (Table 1). The ultimate load of the 4-0 MFSS was not statistically different from the 3-0 or 4-0 FW. The EB had the lowest ultimate tensile strength.

The elongation at failure was highest for EB, which was statistically greater than any other suture (Table 1). The 3-0 and 4-0 FW had equivalent elongations at failure. The 4-0 MFSS had the least elongation at failure. The 3-0 MFSS had an elongation that was statistically greater than the 4-0 MFSS but less than any other suture material tested.

There was no difference in stiffness between the 3-0 and 4-0 MFSS ($p > .05$); however, both were greater than all other suture materials tested ($p < .05$) (Table 1).

**Knotted suture**

When tied, the 3-0 MFSS withstood 121 N before rupture (Table 2). When tied with 5 throws, the 3-0 FW sustained 53 N before failure, which was not statistically different from the 4-0 MFSS. The double-stranded SM was also not statistically different from the 3-0 FW with 5 knots.

The 4-0 MFSS had the least elongation of any material tested; however, it was not different from the 3-0 MFSS. When tied with 5 throws, the 3-0 FW failed at

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**TABLE 1. Ultimate Load, Elongation at Failure, and Stiffness Results for Unknotted Suture**

<table>
<thead>
<tr>
<th>Suture Material</th>
<th>Size</th>
<th>Ultimate Load (N) (mean ± SD)</th>
<th>Lower 95% Confidence Interval</th>
<th>Upper 95% Confidence Interval</th>
<th>Elongation at Failure (mm) (mean ± SD)</th>
<th>Stiffness (N/mm) (mean ± SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MFSS</td>
<td>3-0</td>
<td>73.8 ± 0.7</td>
<td>72.5</td>
<td>75.0</td>
<td>13.8 ± 1.7</td>
<td>18.5 ± 2.8</td>
</tr>
<tr>
<td>FW</td>
<td>3-0</td>
<td>41.9 ± 3.3</td>
<td>40.1</td>
<td>43.6</td>
<td>11.6 ± 0.3</td>
<td>12.6 ± 0.3</td>
</tr>
<tr>
<td>MFSS</td>
<td>4-0</td>
<td>39.9 ± 1.3</td>
<td>38.2</td>
<td>41.7</td>
<td>5 ± 0.8</td>
<td>4.4</td>
</tr>
<tr>
<td>FW</td>
<td>4-0</td>
<td>36.6 ± 2</td>
<td>34.9</td>
<td>38.4</td>
<td>2.3 ± 0.9</td>
<td>1.4</td>
</tr>
<tr>
<td>EB</td>
<td>3-0</td>
<td>27.3 ± 2.4</td>
<td>25.5</td>
<td>29.1</td>
<td>5 ± 0.8</td>
<td>3.3</td>
</tr>
<tr>
<td>MFSS</td>
<td>3-0</td>
<td>18.5 ± 2.8</td>
<td>17.4</td>
<td>19.7</td>
<td>11.9 ± 1.1</td>
<td>3 ± 1.2</td>
</tr>
<tr>
<td>MFSS</td>
<td>4-0</td>
<td>16.8 ± 1.5</td>
<td>15.2</td>
<td>18.4</td>
<td>11.6 ± 0.3</td>
<td>4.4</td>
</tr>
<tr>
<td>FW</td>
<td>3-0</td>
<td>3.4 ± 0.2</td>
<td>1.8</td>
<td>5.0</td>
<td>2.8 ± 0.1</td>
<td>0.0</td>
</tr>
<tr>
<td>FW</td>
<td>4-0</td>
<td>3.3 ± 0.1</td>
<td>1.1</td>
<td>4.4</td>
<td>1.6 ± 0.1</td>
<td>2 ± 0.1</td>
</tr>
<tr>
<td>EB</td>
<td>3-0</td>
<td>1.6 ± 0.1</td>
<td>0.0</td>
<td>3.2</td>
<td>1.6 ± 0.1</td>
<td>2 ± 0.1</td>
</tr>
</tbody>
</table>

*Rows not connected by the same letter are statistically different ($p < .05$). N = 5 for all groups.
an elongation greater than those with only 3 throws; however, the ultimate load was also greater. The double-stranded SM showed the most elongation.

The 3-0 MFSS was the stiffest material, followed by 4-0 MFSS and 3-0 FW with 5 throws. The 3-0 EB and SM were the least stiff of the materials tested.

Both the 3-0 and 4-0 MFSS failed exclusively by breakage at the knot with only 3 throws. With only 3 throws, the 3-0 and 4-0 FW and 3-0 EB typically untied instead of breaking. When tied with 5 throws, the 3-0 FW and EB broke at the knot instead of untying. The SM broke at the knot.

**DISCUSSION**

The results of this study indicate MFSS has some favorable mechanical properties compared with several suture materials currently in clinical use. The elongation of the MFSS was significantly lower than any of the other suture materials, and the stiffness was significantly higher. When tied, the MFSS only required 3 throws to resist untlying, whereas Fiberwire needed 5 throws. We are not the first investigators to conclude that Fiberwire has the potential for untlying at low loads. A metallic suture material may offer benefits of nonviscoelastic properties. Polymer sutures have been shown to exhibit stress relaxation and creep, unlike stainless steel, which does not have these properties. In addition, stainless steel may offer other benefits, such as being secured by a means other than a knot—for example, crimping.

We are also not the first study to investigate stainless steel for use in primary flexor tendon repair. Trail et al.
in 1989 investigated multiple suture materials and found that whereas MFSS offered many advantages over the polymer-based sutures they tested, the authors ultimately did not recommend it based on its handling characteristics. This has been a consistent problem with MFSS. Although we did not directly address the handling properties in this study, we noted that the MFSS does not have the memory that makes monofilament so difficult to work with and tie. The configuration of the individual filaments creates an overall construct that does not plastically deform or kink when handled. This design creates a suture that has completely different handling characteristics from monofilament designs used in the past.

In 2005, Lawrence and Davis compared a braided stainless steel suture with 4 other materials including FW. They concluded that FW and stainless steel were the most biomechanically suitable when performing flexor tendon repairs. Their study was limited in that the authors only investigated 4-0 suture and only in the tied configuration, but their study supports the hypothesis that an MFSS suture could be a viable option for flexor tendon repair.

Additional research is necessary to determine how this particular MFSS suture will perform in vivo. Future studies should investigate how the ultimate load and gapping of a tendon repair is affected by the MFSS, as well as the ability of this construct to pass unimpeded through the tendon pulley system. Greater stiffness is generally regarded as an advantage to limit gapping. Nevertheless, studies should be conducted to determine whether the increased stiffness of the MFSS would shield the tendon from tensile forces during healing at the risk of causing tenomalacia.

Although we did not perform a formal power analysis, we determined the sample sizes based on numbers used by previous investigators. This is a limitation of the study. Our final data sets were 5 samples per group for the suture only and 12 samples per group for the knotted suture. The straight suture sample sizes are the same as those of Lawrence and Davis, who used 5 samples per group when investigating tied suture, which one would expect to have greater variability. For our tied comparisons, we used 12 samples per group. Again, our outcomes were similar to those of Lawrence and Davis, who tested FW, MFSS, and EB, among other materials. Some of our comparisons did not reach significance but we did observe some trends. One example is the lack of significant differences in elongation at failure between the MFSS and FW when tied. However, in cases like these, one should also consider the mode of failure. The mode of failure for the MFSS was the suture breaking at the knot, whereas the FW failed by untightening.

With a secure attachment to the tendon, the lower elongation and better knot-holding ability of the MFSS may result in higher force to produce a 2-mm gap and higher ultimate tensile strength in tendon repair. More research is needed to determine how this material will affect actual clinical outcomes of primary flexor tendon repair.

REFERENCES