A Biomechanical Comparison of High-Strength Tape Suture Versus High-Strength Round Suture

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Disclosure Information

**Research Support**
- Arthrex – donated suture
- Zimmer Biomet – donated suture

**Consultant**
- J. Paul Schroeppepl, M.D.
  - Consultant for Vericel
- Bryan Vopat, M.D.
  - Consultant for Johnson & Johnson
- Scott Mullen, M.D.
  - Consultant for Stryker Sports Medicine
Purpose

- High-strength tape sutures are being increasingly utilized in arthroscopic and open orthopedic procedures.
- Many publications have demonstrated benefits to using tape suture over round suture with regards tendon-footprint contact pressures and suture-tendon interface failure.
- The purpose of this study is to compare the biomechanical properties, including knot security, loop security, and knot size, of high-strength tape suture and high-strength No. 2 suture tied with commonly used knots.
  - Knot security refers to the knots ability to resist slippage.
  - Loop security is the ability to maintain a fixed suture loop while tying the knot.
Materials & Methods

- Suture loops were prepared by tying suture around a 30 mm rod (Figure 1)
  - Laboratory conditions were structured to mimic intraoperative conditions

- One hand-tied knot and two arthroscopic knots were used
  - Hand-tied surgeon’s knot
  - Samsung Medical Center (SMC) knot & Tennessee Slider

- Four suture designs were compared
  - 2 tape sutures
    - BroadBand™ (Zimmer Biomet), SutureTape™ (Arthrex)
  - 2 round (No. 2) sutures
    - MaxBraid™ (Zimmer Biomet), FiberWire® (Arthrex)

Figure 1: Arthroscopic knots tied through cannula. Surgical gloves were worn while tying all knots.
Materials & Methods

- Ten loops were tested for each suture-knot configuration in each of two testing modes (Figure 2)
  - Single load to failure or cyclic loading

- Knotted-suture loops were pretensioned to 10 N, then loaded to failure at a rate of 1.0 mm/s or cyclically loaded from 10 to 60 N at 1.0 Hz for 1000 cycles
  - Knots surviving cyclic testing were loaded to failure following the single load to failure (LTF) protocol
  - Failure load recorded was the maximum tensile force applied between 0 and 3 mm of displacement, consistent with other publications

Figure 2: Material testing apparatus. All knots were tested using an MTS servo-hydraulic machine (MTS Systems). Knots were kept and tested in a 37°C normal saline bath. Suture was also presoaked prior to tying.
Materials & Methods

- Loop security was evaluated by measuring the displacement, or loop elongation, after preloading to 10 N
- The amount of suture loop elongation after cyclic loading was recorded as cyclic elongation
- Knot volume was measured using Adobe Photoshop (Adobe Systems) software (Figure 3)
- Statistical Analysis
  - Data were compared using, independent t-Tests, analysis of variance and the Tukey post-hoc test and considered significant at $P < 0.05$.

Figure 3: Measuring knot volume. Photoshop software was used to measure knot height ($h$) and diameter ($d$) using the ruler as a reference. Presuming each knot to be relatively cylindrical in shape, the following formula was used to measure volume: $V = \frac{\pi}{4} d^2 h$
Knot security evaluated in single load-to-failure testing (Figure 4)

- Hand-Tied Surgeon’s Knot
  - BroadBand ($322.09 \pm 41.36$ N) had a statistically significant higher failure load than both MaxBraid ($263.27 \pm 37.99$ N) and FiberWire ($200.30 \pm 33.34$ N)
  - SutureTape ($294.67 \pm 39.09$ N) failed at a significantly higher load than FiberWire, but not MaxBraid

- SMC Knot
  - There was no statistically significant difference between the tape sutures and round sutures tied with the SMC knot

- Tennessee Slider
  - There was not a statistically significant difference shown between the tape sutures and round sutures tied with the Tennessee Slider
Results
Single Load-to-Failure

Figure 4: Single load-to-failure (3 mm)\(^a\); \(n = 10\) for all groups

\(^a\)Mean maximum force (N) measured from 0 to 3 mm of displacement

*abbreviations: N, Newtons; SMC, Samsung Medical Center*
Knot security evaluated with load-to-failure testing after cyclic loading (Figure 5)

- Hand-Tied Surgeon’s Knot
  - BroadBand (301.64 ± 57.38 N) and SutureTape (305.80 ± 28.25 N) failed at significantly higher loads than FiberWire (202.73 ± 24.27 N), but not MaxBraid (293.11 ± 19.07 N)

- SMC Knot
  - There was no statistically significant difference between the tape sutures and round sutures tied with the SMC knot

- Tennessee Slider
  - Similar to the hand-tied group, BroadBand (239.71 ± 59.63 N) and SutureTape (218.92 ± 49.26 N) demonstrated significantly higher failure loads than FiberWire (135.37 ± 39.27 N), but not MaxBraid (208.14 ± 75.08 N)
Results
Cyclic Loading – Load-to-Failure after Cyclic Testing

Figure 5: Load-to-failure following cyclic testing (3 mm); n = 10 for all groups

Mean maximum force (N) measured from 0 to 3 mm of displacement after completion of cyclic load testing

abbreviations: N, Newtons; SMC, Samsung Medical Center
Cyclic elongation (Table I) measures the ability of the knotted suture loop to maintain its circumference during cyclic loading

- It is quantified as the amount of suture loop elongation at the end of cyclic loading

- **Hand-Tied Surgeon’s Knot**
  - BroadBand (0.64 ± 0.07 mm) and SutureTape (0.69 ± 0.13 mm) showed less elongation than MaxBraid (0.95 ± 0.10 mm), but no significant difference compared to FiberWire (0.76 ± 0.13 mm)

- **SMC Knot**
  - There was not a statistically significant difference shown between the tape sutures and round sutures tied with the SMC knot

- **Tennessee Slider**
  - No significant difference was shown between the tape sutures and the round sutures tied with the Tennessee Slider
## Results

### Cyclic Loading – Cyclic Elongation

<table>
<thead>
<tr>
<th>Suture/Knot</th>
<th>BroadBand</th>
<th>SutureTape</th>
<th>MaxBraid</th>
<th>FiberWire</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hand-Tie</td>
<td>0.64 ± 0.07</td>
<td>0.69 ± 0.13</td>
<td>0.95 ± 0.10</td>
<td>0.76 ± 0.13</td>
</tr>
<tr>
<td>SMC</td>
<td>1.22 ± 0.41</td>
<td>1.55 ± 0.73</td>
<td>1.45 ± 0.57</td>
<td>1.05 ± 0.71</td>
</tr>
<tr>
<td>Tenn. Slider</td>
<td>1.63 ± 0.52</td>
<td>0.87 ± 0.39</td>
<td>1.29 ± 0.55</td>
<td>1.23 ± 0.55</td>
</tr>
</tbody>
</table>

*Each cell demonstrates the mean cyclic elongation ± standard deviation.

*Measured as the amount of elongation that occurred from the moment the suture loop is pre-tensioned at 10 N to the end of cyclic loading.

*Abbreviations: mm, millimeters; N, Newtons; SMC, Samsung Medical Center; Tenn. Slider, Tennessee Slider.
Loop security can be quantified as the amount of loop elongation (Table II) that occurs when the suture loop is pretensioned to 10 N, or the resulting loop circumference (Figure 6)

- **Hand-Tied Surgeon’s Knot**
  - BroadBand (1.09 ± 0.22 mm) demonstrated significantly less loop elongation than MaxBraid (1.43 ± 0.20 mm) and FiberWire (1.25 ± 0.21 mm)
  - SutureTape (1.32 ± 0.19 mm) showed no statistical difference compared to the round No. 2 sutures

- **SMC Knot**
  - There was no statistically significant difference between the tape sutures and round sutures tied with the SMC knot

- **Tennessee Slider**
  - No significant difference was shown between the tape sutures and the round sutures tied with the Tennessee Slider
## Results

### Loop Security – Loop Elongation

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</tr>
<tr>
<td>SMC</td>
<td>1.09 ± 0.37</td>
<td>1.25 ± 0.61</td>
<td>1.12 ± 0.31</td>
<td>1.26 ± 0.59</td>
</tr>
<tr>
<td>Tenn. Slider</td>
<td>1.04 ± 0.44</td>
<td>0.92 ± 0.60</td>
<td>0.94 ± 0.25</td>
<td>0.95 ± 0.43</td>
</tr>
</tbody>
</table>

*Each cell demonstrates the mean loop elongation ± standard deviation.

*Measured as the amount of elongation that occurs with pre-tensioning the knotted suture loop to 10 N, based on the ideal loop circumference of 30 mm.

Abbreviations: mm, millimeters; N, Newtons; SMC, Samsung Medical Center; Tenn. Slider, Tennessee Slider
Results
Loop Security – Loop Circumference

Figure 6: Loop circumference (10 N)c,d; n = 20 for all groups

cMean loop circumference after all knotted suture loops pre-tensioned to 10 N
dAll measurements based on ideal loop circumference of 30 mm

abbreviations: mm, millimeters; N, Newtons; SMC, Samsung Medical Center
Knot size measured as knot volume (Figure 7)

- **Hand-Tied Surgeon’s Knot**
  - SutureTape (8.35 ± 0.93 mm³) demonstrated a statistically significant smaller knot compared to MaxBraid (10.19 ± 1.62 mm³) and FiberWire (11.21 ± 1.64 mm³)
  - BroadBand (9.24 ± 0.92 mm³) was found to have significantly less knot volume than FiberWire, but not MaxBraid

- **SMC Knot**
  - BroadBand (17.79 ± 3.33 mm³) exhibited a significantly larger knot than MaxBraid (14.49 ± 2.18 mm³), but not FiberWire (16.50 ± 2.95 mm³)
  - SutureTape (15.54 ± 2.14 mm³) did not demonstrate any significant difference when compared to the No.2 sutures

- **Tennessee Slider**
  - SutureTape (8.86 ± 1.30 mm³) was found to have significantly less knot bulk than FiberWire (10.88 ± 1.98 mm³), but not MaxBraid (10.00 ± 1.63 mm³)
  - BroadBand (9.56 ± 1.28 mm³) did not demonstrate any significant difference when compared to the No.2 sutures
Results
Knot Size

Figure 7: Knot Size\(^e\); n = 20 for all groups
\(^e\)Mean knot volume for each suture-knot configuration
Abbreviations: mm\(^3\), cubic millimeters; SMC, Samsung Medical Center
Conclusion

- Benefits of high-strength tape suture, including increased resistance to pullout at the suture-tendon interface and increased tendon-footprint contact pressures, have led to their increased use in orthopedic procedures.

- This study demonstrates the efficacy and safety of using tape sutures in knotted suture loop constructs:
  - Overall, the tape sutures performed as well or better with regards to knot and loop security.
  - With the exception of the SMC knot, the tape sutures trended toward having smaller knot volume than No. 2 suture.

- When using tape suture in knotted constructs, one can be assured that the knot will behave at least as well as its round No. 2 suture counterpart, with the potential benefit of being more secure, and less bulky.