Initial Loop and Knot Security of Arthroscopic Knots Using High-Strength Sutures

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Purpose: There are many options for arthroscopic knots including the type of knot and suture material used. The current investigation evaluated knot properties using 3 high-strength suture materials tied in 5 common arthroscopic knot configurations. **Methods:** Four arthroscopic sliding knots including the Roeder, Weston, SMC, and Tennessee Slider and an arthroscopic nonsliding Surgeon's knot were evaluated. Each knot was tied with each of 3 No. 2 polyblended suture types (Fiberwire [Arthrex, Naples, FL], Ultrabraid [Smith & Nephew, Andover, MA], and Orthocord [Mitek, Raynham, MA]). Each configuration was tied 8 times, for a total of 120 samples. Loop security and knot security were then evaluated by using a previously described protocol comparing the different knot types and suture material. **Results:** With respect to loop security, Orthocord performed better than the other tested suture materials, producing on average smaller knot loops. For the nonsliding Surgeon's knot, there was no difference in loop security observed between suture types. For the Roeder knot, Fiberwire had superior knot security compared with Ultrabraid and Orthocord ($P < .001$). For the Weston knot, Ultrabraid showed superior knot security compared with Orthocord ($P < .02$). Knot security for the Tenessee slider knot was better for both Fiberwire and Ultrabraid compared with Orthocord ($P < .001$, respectively). Similar results were seen with the SMC knot, with Fiberwire and Ultrabraid outperforming Orthocord ($P < .001$, respectively). The nonsliding Surgeon's knot had significantly lower mean loads to failure compared with arthroscopic sliding knots for each tested suture material ($P < .02$ for all comparisons). **Conclusions:** Loop security and knot security varied depending on the type of knot tied and suture material used. Arthroscopic sliding knots performed better than the nonsliding Surgeon's knot. **Clinical Relevance:** Surgeons should try to use sliding knots instead of Surgeon's knots when using polyblend suture material. Differences between the brands in this suture category will change the characteristics of the knots thrown and may ultimately affect tissue fixation. **Key Words:** Sliding knots—Loop security—Knot security—Biomechanics.

With the advent of newer sutures, the surgeon is now presented with an overwhelming choice of various arthroscopic knots combined with different suture materials. Surgeon use of arthroscopic knots and suture material is commonly based on personal preference rather than scientific data. When discussing the physical properties of a knot, 2 attributes should be described: loop security and knot security. Loop security has been defined as the ability to maintain a tight suture loop as the knot is tied.[1] Factors that may affect loop security include the expansion of the loop and the deformation of the knot that may occur during knot locking. Knot security is the ability of a knot to resist slippage when a load is applied.[2] Various properties may affect knot security including its internal friction, slack between throws, and suture pliability.

Interest in suture material has been raised by the recent development of high-strength synthetic braided sutures.

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Fiberwire (Arthrex, Naples, FL), Ultrabraid (Smith & Nephew, Andover, MA), and Orthocord (Mitek, Raynham, MA) are 3 of the more commonly used brands of this new category of suture. These sutures are all polyblend sutures with slight differences to each other.[3] Fiberwire contains an additional polyethylene core that is covered by a polyester braided "jacket." Ultrabraid is made of a polyethylene braided suture configured in a unique braid design. Orthocord's polyblend suture also contains a polydioxanone (PDS) component that allows for partial absorption of the suture. All these sutures come in size No. 2 and have reported strengths superior to No. 2 Ethibond (Ethicon, Somerville, NJ); however, their loop and knot securities have yet to be compared in the literature.

The purpose of this study is to determine whether any significant differences exist between these 3 high-strength suture materials—specifically, how do they compare in both loop security and knot security when used with a variety of commonly used arthroscopic knots? We hypothesized that a difference in loop security and knot security would be seen between the tested knot configurations and suture materials used.

METHODS

Four arthroscopic sliding knots preferred by the authors were selected: the Roeder (sliding), Weston (locking-sliding), SMC (locking-sliding), and Tennessee Slider (sliding) (Fig 1). Because previous studies have shown the need for following each knot with 3 reversing half hitches on alternating posts, all sliding knots were followed with 3 reversing half hitches on alternating posts.[4,5] All locking-sliding knots were locked before throwing the reversing half hitches.

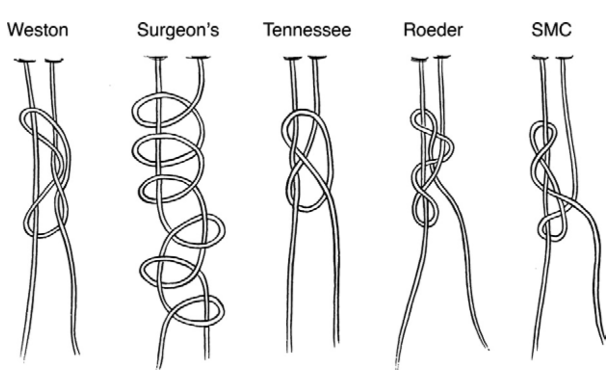

Figure 1. The 4 arthroscopic sliding knots (Roeder, Weston, SMC, and Tennessee Slider) and the arthroscopic nonsliding Surgeon's knot used for testing. All sliding knots were followed with 3 reversing half hitches on alternating posts.

Figure 2. Testing of an arthroscopic sliding knot in a water bath containing normal saline at 37°C to simulate an in vivo environment.

Additionally, an arthroscopic nonsliding Surgeon's knot was tested. This knot consists of 3 half hitches on the same post, followed by 3 reversing half hitches on alternating posts.[5] Each knot was tied with each of the 3 No. 2 polyblended suture types, making 15 different knot-suture combinations. Each configuration was tied 8 times, for a total of 120 samples.

The following model was designed to be similar to those previously described in the literature.[5-7] For each knot configuration, the suture material used was chosen at random to ensure technical consistency. All knots were tied over a 30-mm circumference dowel, creating a closed-suture loop. The 30-mm circumference loop model has been used in the literature to represent the typical suture loop created during an arthroscopic rotator cuff repair.[5,8] A single-hole arthroscopic knot pusher was used for knot tying to simulate techniques used in surgery. All knots were tied by the same surgeon to minimize variability in the samples.

Before testing, knots were soaked in normal saline at 37°C for 5 minutes to simulate an arthroscopic environment. All knots were tested on an Instron 2000 Universal Material Testing Machine (Instron, Canton, MA). The suture loops were placed around 2 parallel hooks of known diameter (3.95 mm). Care was taken to position the knot midway between the hooks to maintain a consistent testing environment. The knots were tested in a water bath containing normal saline at 37°C (Fig 2), a model that has been used in the

TABLE 1. *Initial Loop Circumference (Mean in Millimeters ± Standard Deviation)*

	Roeder	Weston	Tennessee	SMC	Surgeon's
Fiberwire	33.98 ± 0.42	33.55 ± 0.51	34.00 ± 0.74	34.33 ± 0.54	34.48 ± 1.01
Ultrabraid	33.96 ± 0.28	34.01 ± 1.03	33.75 ± 0.65	34.13 ± 0.93	34.05 ± 0.88
Orthocord	32.54 ± 0.33*	31.21 ± 0.51*	33.23 ± 0.92	33.39 ± 1.12	34.34 ± 0.89

*Denotes statistically significant difference between the Roeder and Weston knots tied with Orthocord compared with all other combinations ($P < .001$ for all comparisons).

literature to simulate an in vivo environment.[3,6,9] To determine initial loop circumference, a 5-N preload was placed to remove slack from the loop. The initial crosshead displacement required to reach this preload was measured, and the initial loop circumference was calculated from the equation: loop circumference = (2 × crosshead displacement) + (4 × rod radius) + (rod circumference).[5] This calculation, and its deviation from an ideal 30 mm, was a measurement of loop security. The higher the loop security, the closer the loop circumference was to 30 mm.

Knots were then tested with a single load to failure at a crosshead speed of 0.5 mm/s.[7] Failure was defined as an additional crosshead displacement of 3 mm. Three millimeters of displacement is generally accepted in the literature as a clinical failure because this would indicate a soft-tissue gap that would obstruct healing.[4,5,9-12] Maximum force was recorded at 3 mm of crosshead displacement.

Analysis of variance combined with multiple comparison Student *t* tests were used to compare the 15 different suture-knot combinations; $P < .05$ was used to define significance.

RESULTS

Initial loop security was statistically better for the Roeder and Weston knots using Orthocord compared with all other combinations ($P < .001$ for all comparisons) (Table 1). For the nonsliding Surgeon's knot, this trend did not continue, and no statistical difference was seen between the 3 different suture types and initial loop circumference.

Knot security as measured by maximum load at 3 mm of additional crosshead displacement was compared for each knot type. No suture loops failed by suture breakage. In the Roeder knot, Fiberwire outperformed both Ultrabraid and Orthocord with respect to load to failure ($P < .004$ and $P < .001$, respectively). For the Weston knot, Ultrabraid had superior knot security compared with Orthocord but not Fiberwire ($P < .015$ and $P = .402$, respectively). Fiberwire and Ultrabraid performed similarly in the SMC and Tennessee Slider knots ($P = 1.0$ for each), but both had significantly better knot security than Orthocord ($P < .0001$ and $P < .001$, respectively) (Table 2).

Although the trend of Orthocord having the lowest load to failure continued in the Static Surgeon's knot, there was no statistical difference in maximal load to failure between any of the other knot configuration-suture material combinations. The Surgeon's knot had a statistically significant lower maximal load to failure overall as compared with all other knots used in the study ($P < .013$).

TABLE 2. *Maximum Load to Failure (Mean in Newtons ± Standard Deviation)*

	Roeder	Weston	Tennessee	SMC	Surgeon's
Fiberwire	127.1 ± 22.2*	121.5 ± 16.1	136.7 ± 24.7‡	127.2 ± 11.6‡	89.7 ± 24.3§
Ultrabraid	97.9 ± 9.6	140.5 ± 36.6†	133.3 ± 30.5‡	124.4 ± 24.7‡	85.4 ± 7.6§
Orthocord	92.22 ± 13.2	102.4 ± 13.2	83.6 ± 8.0	91.2 ± 12.6	69.7 ± 9.8§

*Denotes significant difference in knot security for the Roeder knot tied with Fiberwire compared with Ultrabraid and Orthocord ($P < .004$ and $P < .001$, respectively).

†Denotes significant difference between Ultrabraid and Orthocord for the Weston knot ($P < .015$).

‡Denotes significant difference between both Fiberwire and Ultrabraid compared with Orthocord for the SMC and Tennessee Slider knots ($P < .0001$, and $P < .001$, respectively).

§Denotes significantly lower knot security of the Surgeon's knot compared with all other knot-suture combinations ($P < .013$).

DISCUSSION

Although high-strength braided sutures have gained widespread use in the United States, there has been little published in the orthopaedic literature comparing their loop and knot securities. This study shows statistically significant differences in these parameters with different combinations of arthroscopic knot configuration and suture material used.

Loop security should be interpreted as the performance of the knot at time zero before any load is applied. To the surgeon, this correlates to how closely the suture loop can be made to ideal and how closely the tissue can be approximated intraoperatively. A knot will never be tighter than immediately after it is tied. Knot-suture combinations with poor loop security may have a soft-tissue gap approaching a clinical failure before a load is applied. Our data showed that the loop security achieved with a nonsliding Surgeon's knot left a very small margin of error for clinical failure. Therefore, to avoid initial loop circumferences that leave significant gaps in the repair, surgeons use sliding knots over Surgeon's knots when using polyblend suture material.

As a measure of knot security, we measured the maximum force at 3 mm of crosshead displacement, indicating a clinical failure. Orthocord had a significantly lower load to failure in all of the sliding knots studied. Fiberwire and Ultrabraid generally performed similarly, with only significant differences seen in the Roeder knot in which Fiberwire was superior. Surgeon's knots tied with all 3 suture materials showed an average load to failure of 81.5 N (range, 59.2 to 130.3 N; standard deviation = 17.4), which was significantly lower than all other knots studied ($P \leq .013$). No significant difference was seen between the suture material and knot security in the Surgeon's knot, possibly indicating it fails by a mechanism unrelated to suture type.

Applying these data to a clinical setting, the reader must question whether this difference in data will lead to a difference in clinical outcome. First, we must ask what demands are placed on the suture loops in vivo. Previous studies by Burkhart et al.[13] have shown that for a 4-cm tear of the rotator cuff, depending on the number of anchors and sutures used, each loop should be responsible to hold approximately 37 to 61 N. All sliding knots studied showed failure strength well above this level. However, Surgeon's knots had an average load to failure of 81.5 N with a range from 59.2 to 130.3 N. This shows that the Surgeon's knot's maximal load to failure may approach the range in which a clinical failure is expected in vivo. This, however, is in contrast to a previous study in which Fiberwire was compared with Ethibond.[5] In that study, the Surgeon's knot showed superior knot security to all other knots studied in both suture types. However, the authors of that study tied all knots by hand, without using a knot pusher. Previous studies have shown that the use of a knot pusher is associated with lower loads to failure when compared with hand-tied knots.[2] The use of a knot pusher in our experimental model may explain the differences between our findings and those reported by Lo et al.[5]

Although the values for knot security in our model were similar to those described in other biomechanical evaluations of arthroscopic sliding knots, we found that the mean loads to failure in our study were slightly lower than the failure loads in these reports. In a comparison of 5 knot configurations using No. 2 Ethibond versus No. 2 Fiberwire, Abbi et al.[7] reported a mean failure load of 276 N across all of the tested knot types tied with Fiberwire sutures. Similarly, in an evaluation of 3 different knot configurations tied with No. 2 Ethibond or No. 2 Force Fiber, a new high-strength braided suture material, Mahar et al.[14] reported mean loads to failure for the Force Fiber ranging from 224 to 279 N. We believe that these differences can be attributed to the fact that in these other studies, the knots were tested dry, whereas in our model, the knot-suture material combinations were tested in an aqueous solution to simulate an in vivo environment. It is possible that when wet, alterations of the biomechanical properties of the knots occur, contributing to a slight decrease in their load to failure. In a recent study by Wust et al.,[3] the mechnical and handling properties of braided polyblend sutures were evaluated in a similar aqueous environment. Although direct comparisons between our results and those reported by Wust et al. cannot be made because of the different knot types used experimentally, their reported loads to failure were in the 150- to 260-N range.

Limitations of the current investigation include the fact that our laboratory investigation evaluated the initial loop security and knot security of isolated arthroscopic knots. Although we attempted to re-create an in vivo environment by testing our knot-suture material combinations in an aqueous solution, in the true in vivo situation, loads are applied to a combination of suture anchors, suture material, knots, and soft tissue. Therefore, although we believe that our findings of differences in loop security and knot security between different knot configurations and suture-type combinations are relevant, they may not translate to the clinical situation. Additionally, it is possible that there was variability with respect to the throwing of the arthroscopic knots. We attempted to limit this by having all knots thrown by a single surgeon with experience tying each of the selected knots and randomizing the tying order of the knot-suture combinations.

CONCLUSIONS

Orthocord had a significantly lower load to failure in all of the sliding knots tested. Fiberwire and Ultrabraid had similar knot security characteristics, with only significant differences seen in the Roeder knot. Suture loops tied with Orthocord tended to have a lower initial circumference; however, this was statistically significant in only the Roeder and Weston knots. The nonsliding Surgeon's knot had a significantly lower load to failure when compared with all other knots tested. This would suggest that the surgeon should try to use sliding knots instead of Surgeon's knots when using polyblend suture material. This study shows significant differences between the newly introduced high-strength polyblend sutures. The orthopaedic surgeon must recognize that differences between the brands in this suture category will change the characteristics of the knots thrown and may ultimately affect tissue fixation.

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