Biomechanical Comparison of Four Sliding Knots and Three High-Strength Sutures: Loop Security Is Much Different Between Each Combination

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ABSTRACT: There are many types of sliding knots and suture materials used in arthroscopic surgery. The purposes of this study are (i) to evaluate the loop security of standard sliding knots when using different types of high-strength suture materials and (ii) to compare the loop security of a new sliding knot (Chula knot) to other standard sliding knots. Four configurations of sliding locking knots (Weston, SMC, Tennessee and Chula knots) were tied using three commonly used suture materials: MagnumWire, Hi-Fi, and FiberWire. The suture loops were mounted on two metallic hooks of the universal testing machine. Then, the suture loop was pulled apart until failure. The Weston knot demonstrated the greatest load to failure in all suture materials. By using MagnumWire, the load to failure was as follow: Weston 53.2 N, Chula 48.8 N, SMC 39.2 N, and Tennessee 29.3 N. By using Hi-Fi, the load to failure was as follow: Weston 58.8 N, Chula 51.5 N, SMC 38.1 N, and Tennessee 28.7 N. By using FiberWire, the load to failure was as follow: Weston 38.8 N, Chula 29.7 N, SMC 23.2 N, and Tennessee 21.9 N. Weston knot has the highest loop security in all suture materials. Weston—HiFi combination demonstrate the strongest loop security. Conversely, the weakest combination is Tennessee—FiberWire. Chula knot has similar properties to other commonly used arthroscopic sliding knots. Our findings indicate that surgeons should be careful in selecting proper knot—suture combinations. © 2016 Orthopaedic Research Society. Published by Wiley Periodicals, Inc. J Orthop Res 34:1804–1807, 2016.

Keywords: chula knot; loop security; suture material; sliding knot

In arthroscopic surgery, strong repair construction relies on several factors. Arthroscopic knot is one of the most important factors to determine the outcome.[1,2] The ideal arthroscopic knot should have optimal loop and knot security, low knot profile, easy to tie, and low incidence of premature or unintended locking.

Loop security of a sliding knot originates from its ability to resist backsliding when tension is released on the post strand after locking is confirmed by pulling the non—post limb. Knot security refers to the strength of the completed knot after it is locked with successive three reversing half-hitch throws.[2,3]

Previous studies recommend that sliding knots should be locked with three reversing half-hitch knots on alternate posts (RHAPs).[4] After adding three RHAPs, the knot security will depend mostly from the half-hitch throws. Most of them are not significantly different in load to failure and clinical use.[1,2] However, loop security of initial sliding locking knot without RHAPs is different significantly between each knot types.[1–3] Success of a sliding locking knot depends on the initial sliding knot that can inherently maintain under tension without slack until it is seated by subsequent locking half-hitches.[5] Many chronic retracted rotator cuff tears can not be fully mobilized. Surgeons have to repair the tendon under tension.[6,7] Thus, the first throw of sliding knot is extremely important to hold the retracted tendon attaching to the anatomical footprint before the next three RHAPs were subsequently employed. Ability to hold a large tissue gap on the first throw depends totally on locking mechanism of the first sliding knot without RHAPs. Therefore, to compare the mechanical characteristics of sliding knots, it is more relevant to evaluate the initial loop security rather than the knot security with additional three RHAPs.

There are many types of high-strength suture materials for arthroscopic surgery. The main advantages of newer suture materials are that they have superior tensile strength and are difficult to break. High-strength suture materials are constructed of braided ultra-high molecular weight polyethylene (UHMWPE) with or without a core filament. However, literature demonstrated that particular type of high-strength suture material may have a higher chance of knot slippage because of its surface characteristic and frictional property.[8] Thus, performance of these suture materials especially in terms of loop security should be carefully evaluated before clinical application of them with particular sliding knot configuration.

In this biomechanical study, we also evaluate the loop security of our innovative sliding locking knot, which we call the Chula knot. The Chula knot has a special property in that it can be unfastened and retightened in case of premature locking and unintended loop loosening. We recently published the knot tying and retensioning techniques in a video illustration.[9]

The purposes of this study are (i) to evaluate the loop security of standard sliding knots when using

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different types of nonabsorbable, braided, high-strength suture materials, and (ii) to compare the loop security of a new sliding locking knot (Chula knot) to other standard traditional sliding knots. The hypothesis of our study are (i) there are no differences between sliding knot configuration in terms of loop security when using different suture materials and (ii) the Chula knot has loop security comparable to other arthroscopic sliding knots.

METHODS

Study Design

The loop security of four different arthroscopic sliding knots: Weston,[10] Tennessee slider,[11] SMC,[12] and Chula knot[9] were evaluated (Fig. 1). Three different types of No. 2 suture materials were used: MagnumWire (Arthrocare, Austin, TX), Hi-Fi (Conmed Linvatec, Largo, FL), and FiberWire (Arthrex, Naples, FL). All of suture materials are constructed of braided UHMWPE. FiberWire has a UHMWPE core filament while the others are absent of a core. Each knot was tied using each of the sutures. Therefore, 12 combinations of knot configurations and suture types were tied. Eight knots were tied for each combination, for a total of 96 knots.

Knot Tying

All knots were tied by a sports medicine fellowship-trained orthopaedic surgeon who was familiar with tying each knot as described by its developers. After soaking in normal saline solution for 5 min, all knots were tied on 30 mm circumferential plastic post using surgical glove and arthroscopic single-hole knot pusher (Linvatec). During knot tying, care was taken to ensure optimal knot and loop security by removing twists, eliminating slack between throws, and tensioning the two suture limbs. After each knot was tied, the non-post limb was pulled to lock the knot in place and prevent the knot from slipping backward. The knotted suture loop was carefully transferred from the post to the testing machine as similarly described in the literature.[1,13,14] The knot was soaked in normal saline solution before mechanical testing.

Biomechanical Testing

All knots were tested by the universal testing machine (EZ-S model, Shimadzu, Kyoto, Japan). The suture loop were mounted on two metallic hooks with 3.6-mm-diameter circular cross section and placed the knot centered between two hooks, and did not contact either metallic hook (Fig. 2). Each suture loop was preloaded to 5 N before being tested to remove excessive slack. Then, the suture loop was pulled apart at a strain rate of 0.1 mm/s until failure. The primary outcome is the load to failure of each knot configuration and suture material. The load to failure was the highest load to displace the length of suture loop within 3 mm. Early knot slippage at very low tension and suture breakage were also defined as failure modes.

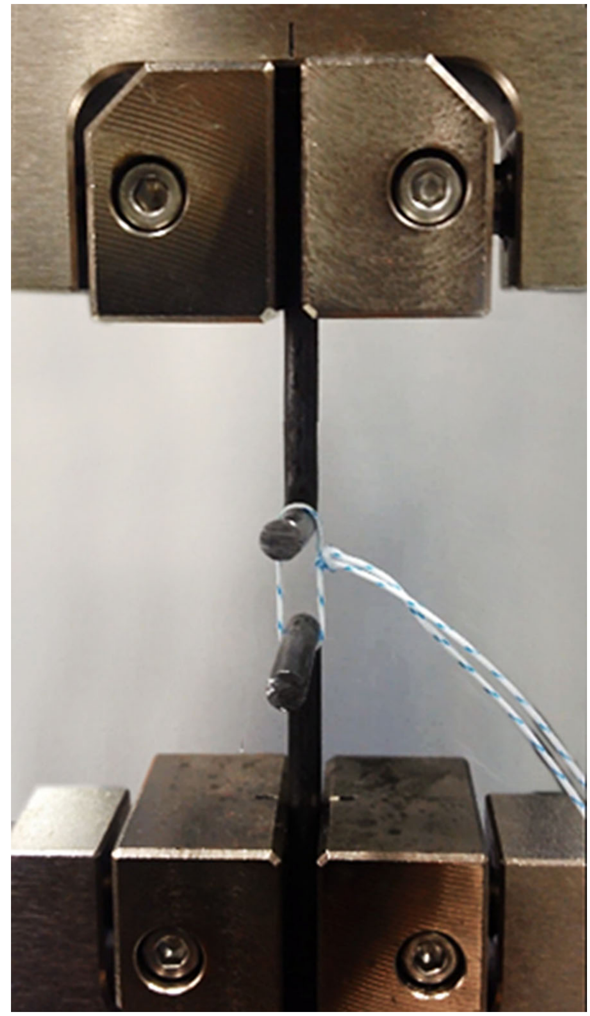

Figure 2. The machine testing of loop security.

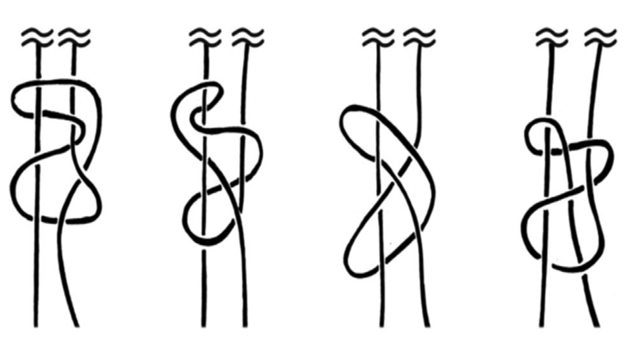

Figure 1. The configurations of four sliding knots.

Statistical Analyses

All statistical analyses were performed with the SPSS software package (version 16.0; SPSS, Chicago, IL). The statistic to compare the load to failure between suture loop combinations was evaluated using one—way analysis of variance (ANOVA) with Tukey HSD post hoc test; $p < 0.05$ was considered to be statistically significant.

RESULTS

General Results

Summary of the load to failure of each sliding knot was shown in Table 1. All knots failed by knot slippage. There was no knot failure by suture breakage. The overall load to failure of Weston knot was higher than Chula knot followed by SMC knot and Tennessee knot, respectively.

Table 1. Result of Load-to-Failure of Each Knot Configuration and Suture Material

	MagnumWire	HI-FI	FiberWire
Weston	52.2 ± 10.2 N	58.8 ± 13.5 N	38.8 ± 3.2 N
SMC	39.3 ± 9.6 N	38.2 ± 10.2 N	23.3 ± 10.6 N
Tennessee	29.3 ± 5.8 N	28.8 ± 6.2 N	21.9 ± 2.5 N
Chula	48.8 ± 4.8 N	51.5 ± 6.6 N	29.8 ± 6.5 N

Comparison Between Different Sliding Knots

MagnumWire

Weston knot had higher load to failure than SMC knot and Tennessee knot ($p < 0.05$). Chula knot had higher load to failure than Tennessee knot ($p < 0.05$). When comparing between Weston knot and Chula knot, they were not statistically different ($p = 0.098$).

Hi-Fi

Both Weston knot and Chula knot had higher load to failure than SMC knot and Tennessee knot ($p < 0.05$). There were no significant differences between Weston and Chula knot ($p = 0.436$).

FiberWire

Weston knot had higher load to failure than SMC, Tennessee and Chula knot ($p < 0.05$). Furthermore, FiberWire had lower load to failure than MagnumWire or Hi-Fi in all knot configurations (Fig. 3).

DISCUSSION

A definition of loop security is that of "the ability to resist backsliding when tension is released on the post strand after locking is confirmed by pulling the non-post limb."[2,3] The loop security is more important than knot security since knot security essentially resulted from the half-hitch throw that was added after initial sliding knot.[1] Previous studies demonstrated that most of sliding knots with additional half-hitched throws had optimal knot security.[15–18] Most of knot configurations with additional half-hitched throws would not create any statistical difference in load to failure. The real difference between each sliding knot configuration was a loop security that holds the first stroke in a large tissue gap when tension from the post strand was released.

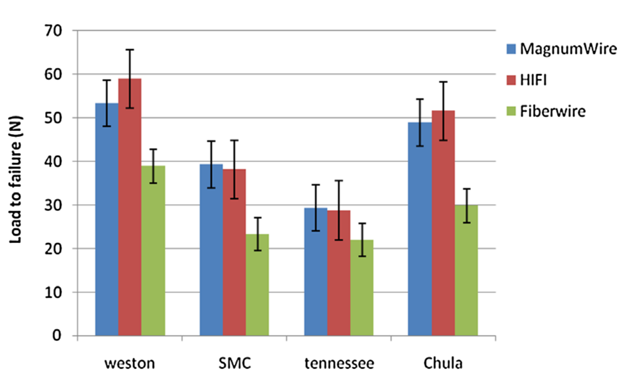

Figure 3. The load to failure of four different knot configurations using three different suture materials.

The first throw of sliding locking knot is important. The knot must hold the retracted rotator cuff tendon in order to attach the tendon to the bony footprint or to hold a large tissue gap in side-to-side cuff repair. The sliding knot must resist the tension of retracted tendon otherwise loop loosening will occur even the next three RHAPs are employed.

In general, we found that Weston knot had the highest loop security in all three suture materials, followed by Chula, SMC, and Tennessee knots, respectively. Tennessee knot demonstrated the lowest loop security in all suture materials.

When load to failure of each knot—suture combination was analyzed, Weston—HiFi demonstrated the strongest loop security (58.8 N), followed by Weston—MagnumWire (52.2 N), and Chula—HiFi (51.5 N). Conversely, the three weakest combinations were Tennessee—Fiberwire (21.9 N), SMC—FiberWire (23.3 N) and Tennessee—HiFi (28.8 N).

Internal interference of each sliding locking knot depends on its configuration. In our assumption, Weston knot has the highest loop security because of its structural complexity resulting in high internal interference and friction. High-strength suture materials without a core filament (Hi-Fi & MagnumWire) tend to have more loop security than FiberWire. The difference in knot strength may possibly be from the surface properties or the presence of a core filament.

Surgeons should be careful in selecting proper knot—suture combinations. Significant decrease in loop security of some knot—suture combinations may lead to loop loosening during the knot tying process, especially when we try to close a large tissue gap.

Abbi et al.[8] demonstrated that FiberWire was more than twice as strong as No. 2 Ethibond (Ethicon, Somerville, NJ) in terms of absolute load to failure. However, they found that the tendency for knot slippage was much greater with FiberWire than with Ethibond. This was probably the result of differences in the surface properties. Our results seem to correspond with this study. We also found that FiberWire had a lower loop security when compare to another two high-strength sutures in every knot configurations.

In addition, we also evaluated a new sliding locking knot (Chula knot). In the past practice, we had encountered premature locking problems from some well-known sliding locking knots. We have developed the chula knot to solve this serious problem and used it in our clinical practice for many years with promising results. In this study, Chula knot demonstrated an optimal loop security with all suture material types. The overall load to failure of Chula knot was greater than SMC and Tennessee knot significantly ($p < 0.05$) in MagnumWire and Hi-Fi groups.

The Chula knot has a unique property that is not observed in other knot configurations. We have named this property "retensioning ability." Unintended premature locking of an arthroscopic knot causes loop loosening and leads to poor fixation. To solve this problem, the Chula knot can be unfastened and the loop can again be tightened even though the knot is already locked.

If unintended premature locking occurs after throwing the knot intraoperatively, an arthroscopic probe can be inserted and then used to hook the post limb and rotate in a clockwise direction. Minimal force is applied while pulling on it. The Chula knot can then be unfastened. After that, it can be retightened by pulling the post limb and locking the knot again.[9]

There are some limitations in this study. First, this is a biomechanical study. One should carefully use this result in clinical practice because there are some differences between in vivo and in vitro studies. For instance, when sliding, the knot could be abraded or weakened by eyelet of anchor.[19] Second, knot tensioning with the tensionometer was not performed similar to previous study.[1] Knot tensioning with tensionometer may be not clinically important because the arthroscopists do not use the tensionometer to tension the knot in real arthroscopic surgery. However, in our study, we attempted to tie every knot as strong as possible. Third, all knots were tied by one surgeon whose familiarity with certain knots was greater than others, although this was minimized by practice knot tying. Practice sessions were conducted before tying any knot unfamiliar to the surgeon. Another limitation of this investigation was that we did not use a canula during the tying process as we usually performed in real arthroscopic surgery.

CONCLUSION

In summary, Weston knot has the highest loop security in all suture materials. Weston—HiFi combination demonstrates the strongest loop security. Conversely, the weakest combination is Tennessee—FiberWire. Chula knot has similar properties to other commonly used arthroscopic sliding knots.

AUTHORS' CONTRIBUTIONS

SK. has made contribution to the conception and design the study, interpretation of data, drafting the article and revising the content. PW. has made contribution to acquisition of data, lab works, analysis and interpretation of data, as well as, drafting the article. KK. has contributed in the drafting of the article and in critically revising for important and intellectual content. TP. has made contribution to the conception and design the study, interpretation of data, drafting and revising the article. All authors have read and approved the final submitted manuscript.

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