Loop and knot security of a novel arthroscopic sliding-locking knot using high-strength sutures

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ABSTRACT

Objective: We evaluated the loop and knot security of a novel arthroscopic knot, the Wiese knot, using different types of sutures.

Methods: The Wiese knot was tied using four different brands of braided sutures (Ethibond, Orthocord, FiberWire, and UltraBraid) with and without a series of three reversing half-hitches (RHAPs) and tested for loop and knot security.

Results: Orthocord provided the greatest amount of loop security. FiberWire delivered the highest knot security. UltraBraid had the greatest ultimate force. Three half-hitches increased the maximal load to clinical failure.

Conclusion: The biomechanical characteristics of the Wiese knot are affected by suture material qualities.

1. Introduction

The goal of arthroscopic rotator cuff and labral repair is to appose and secure soft-tissue to bone until healing occurs, which often requires the use of arthroscopic knots. Effective knots possess optimal knot and loop security. Loop security describes the knot's propensity to juxtapose soft tissue to bone while the surgeon is tying the knot.¹ Knot security is the ability of the knot to resist slippage, which depends on friction, internal interference, and the slack between throws. Knot security describes the knot's capacity to maintain the apposition of soft-tissue to bone.¹

Multiple studies have shown that knot and loop security are dependent on knot configuration, suture material, and instrumentation used to tie arthroscopic knots.^{1–14} Although numerous arthroscopic knot types and suture material exist, consensus on the best combination has yet to be determined. As new suture material, arthroscopic instrumentation, and knot configurations are developed, biomechanical studies assessing knot and loop security should be performed.

The Wiese knot is an arthroscopic knot that is both sliding and locking.¹⁵ Similar to other knots, it is looped through itself to allow adequate friction. The locking feature sets this knot apart from others in that pulling the contralateral limb allows the knot to change configuration and lock into place.¹⁵ The purpose of this study was to assess the loop and knot security of the Wiese knot, with and without half-hitch configurations, using various commercially available suture

materials in order to compare the biomechanical characteristics of this novel knot to other knots already described in literature.

1.1. Methods

The protocol for this study was approved by the institutional review board (IRB).

The knot and loop security were tested using No. 2 size sutures with four brands of braided sutures: FiberWire (Arthrex, Naples, FL), Orthocord (DePuy Synthes Mitek, Raynham, MA), UltraBraid (Smith and Nephew, Andover, MA), and Ethibond (Ethicon US, Somerville, NJ).

Forty total loops were tied; five loops tied with each of the four suture brands using the Wiese knot, and five loops tied in each of the four suture brands using the Wiese knot backed up by 3 reversing half-hitches on alternating posts (RHAPs) (Fig. 1). Although the Wiese knot is a sliding knot with locking capability, loops were tested with three RHAPs because this more closely mirrors clinical practice. All loops were tied by a single, fellowship-trained attending shoulder surgeon who uses the Wiese knot in clinical practice.

Each knot was tied around a 31.4 mm-circumference metal dowel, which is included in the Fundamentals of Arthroscopic Surgery Training (FAST [Sawbones, Vashon Island, WA]) module to ensure a consistent loop circumference of 31.4 mm before locking the knot or throwing the three RHAPs. The 31.4 mm-circumference dowel was chosen because a

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Fig. 1. Depiction of tying the Wiese knot. Image reproduced with approval. Parada SA, Shaw KA, Eichinger JK, Boykin NT, Gloystein DM, Ledford CL, Arrington ED, Wiese PT. The Wiese knot: a sliding-locking arthroscopic knot. *Arthroscopy Techniques*. 2016:e1-4.

30 mm loop length has been shown to be a representative length of suture loop used to attach soft tissue to bone in shoulder surgery in previous studies of loop and knot security⁹ and the 31.4 mm dowel is easily provided by the FAST module. Each loop was tested on an Instron ElectoPuls E10000 Linear Test Instrument (Instron, Norwood, MA) (Fig. 2).

A 5 N (N) preload was applied to each loop prior to testing to remove slack from the system at a load well below those seen clinically in the shoulder, and has been used in prior studies of loop and knot security.^{9,10} The loop circumference was measured at that time using the equation loop circumference = 2 × cross-head displacement + 4 × hook radius + hook circumference as previously described by Lo et al.⁹ Each loop was tested to mechanical failure. Maximum tensile load (N) at failure, tensile load at 3 mm elongation (N), and method of mechanical failure (either knot slippage or material

Table 1
Average loop security, knot security, and ultimate force to failure of multiple suture brands with and without three reversing half-hitch on alternating posts (RHAPs). *Italics** = without RHAPs.

Suture Brand	Loop		Knot		Ultimate	
	Security		Security		Force	
	(mm)		(N)		(N)	
	Mean	St.Dev	Mean	St.Dev	Mean	St.Dev
<i>dEthibond*</i>	31.7	0.5	80.2	16.9	103.6	30.2
<i>FiberWire*</i>	31.5	0.2	33.2	13.5	38.1	15.7
<i>Orthocord*</i>	30.7	0.7	28.1	18.9	35.6	19.9
<i>UltraBraid*</i>	31.5	0.4	29.7	11.4	41.0	8.9
Ethibond	30.5	0.8	119.5	10.4	142.4	8.4
FiberWire	31.3	0.2	230.7	20.3	260.3	22.1
Orthocord	30.4	0.4	180.5	4.1	228.9	27.9
UltraBraid	31.9	0.6	207.7	11.1	274.9	18.2

breakage) was recorded. Tensile load at 3 mm of elongation was chosen because loop elongation of greater than 3 mm is accepted in the literature as indicative of knot failure.⁹ Crosshead speed was set for an elongation rate of 60 mm/min, or two times the length of loop being tested because this is the U.S. Pharmacoeia (USP) standard for suture tensile strength testing.

Data variables collected included loop security, knot security, maximum tensile force, and failure mechanism. Statistical comparison was made with a 1-way analysis of variance (ANOVA) method with $p \leq 0.05$.

2. Results

Loop security was statistically greater (indicated by smaller size) for

Fig. 2. Set-up for knot testing. A. Instron machine used for testing the biomechanical strength of suture loops. B. The loops were placed so that the knot was half-way between the Instron hooks.

Table 2
P-values comparing different suture brands with or without three RHAPs. *Italics** = without RHAPs. Underline = comparing with to without three RHAPs. **Bold** = statistically significant ($p < 0.05$).

Loop Security	Ethibond	FiberWire	Orthocord	UltraBraid
Ethibond	<u>0.0271</u>	0.4775*	0.0473*	0.5579*
FiberWire	0.0704	<u>0.2145</u>	<i>0.0646*</i>	<i>0.8973*</i>
Orthocord	0.8501	0.0031	<u>0.3460</u>	0.0625*
UltraBraid	0.0621	0.6623	0.0180	<u>0.9008</u>
Knot Security				
Ethibond	<u>0.0106</u>	0.0045*	0.0035*	0.0036*
FiberWire	0.00001	<u>0.0000</u>	<i>0.6388*</i>	<i>0.6720*</i>
Orthocord	0.0001	0.0021	<u>0.0000</u>	<i>0.8748*</i>
UltraBraid	0.000001	0.0252	0.0036	<u>0.0000</u>
Ultimate Force				
Ethibond	<u>0.0786</u>	0.0149*	0.0117*	0.0218*
FiberWire	0.00003	<u>0.0000</u>	<i>0.8304*</i>	<i>0.7302*</i>
Orthocord	0.0014	0.0441	<u>0.0000</u>	<i>0.6002*</i>
UltraBraid	0.00001	0.4722	0.0178	<u>0.0000</u>

Orthocord (30.4 ± 0.4 mm) than both FiberWire (31.3 ± 0.2 mm, $p = 0.003$) and Ultrabraid (31.9 ± 0.6 mm, $p = 0.018$), but not Ethibond (30.5 ± 0.8 mm, $p = 0.8501$) (Tables 1 and 2). Reverse half-hitches did not significantly change the loop security, with the exception of Ethibond ($p = 0.027$).

Reverse half-hitches did significantly improve the knot security for all suture materials. FiberWire suture with 3 RHAPs resisted an average force of 230.7 ± 20.3 N before clinical failure at 3 mm of knot displacement, which was statistically greater than all other types of suture. UltraBraid required the greatest amount of ultimate force at 274.9 ± 18.2 N, and was significantly stronger than all other suture brands.

Knot slippage was the cause of knot failure in 32 of the 40 knots (80%). Ethibond suture had the greatest amount of sutures break (4/5 with 3 RHAPs and 1/5 with no RHAPs). Each instance of suture breakage occurred at the knot (Fig. 3).

3. Discussion

Arthroscopic knots must be biomechanically strong enough to withstand the tensile force of the tissues they are repairing. While biologic failure of muscles and tendons occurs with cyclic loading, material (suture) failure usually occurs with a single rapid pull.¹ Loop and knot security are biomechanical characteristics of arthroscopic knots that determine the quality of the arthroscopic knot and suture material combination to appose and maintain soft tissue apposition in

tissue repairs.⁹ The Wiese knot is a novel sliding-locking knot configuration used in arthroscopic tissue repairs.¹⁵ This study illustrates that Wiese knot is a biomechanically effective knot.

As illustrated in other studies, the loop and knot security are dependent on the suture material in addition to the knot configuration.^{2,3,9,10,12} Using the Wiese knot with three RHAPs, FiberWire provided the optimal tensile strength with the Wiese knot configuration. Lo et al. reported that the yield load of FiberWire without knots to be 240 N, only slightly higher than the material breakage load of 236 N found in the current study when testing a suture loop tied with the Wiese knot.¹⁰

One of the secondary goals of this study was to compare the biomechanical characteristics of the Wiese knot to those of knots described in previous studies (Table 3). The method of this study was modeled after the Burkhart et al. study in 2000,¹ which was later modified by Lo et al., in 2004⁹ and 2010.¹⁰ Methods of certain other studies vary in detail from those of the current study, for instance by tying the knots through cannulas or soaking the sutures in saline to replicate the in vivo environment,^{12,13} thus limiting quantitative comparisons with the data of the current study. However, if the effect of these variations is considered small, the current results suggest that the security of the Wiese knot is comparable, and with some materials, superior to that of established knots in the field of arthroscopy.^{2,4–14}

The loop security of the Wiese knot described in this study is also comparable to that reported in previous studies. Orthocord has been shown to have great loop security due to its “bungee-cord like” effect whereby the circumference at 5 N preload can be less than that of the dowel around which the suture is tied.¹⁰ We also found this effect with Ethibond sutures. Although the loop security of FiberWire and UltraBraid was not as great as Orthocord or Ethibond, the circumference with 5 N preload was the same size as the dowel for FiberWire and 0.5 mm larger for UltraBraid, illustrating that using the Wiese knot provides functional loop security regardless of the type of suture used.

Our study revealed that reverse half-hitches on an alternating post improves knot security by 40–200 N when using the Wiese knot. Kim et al. describe that three half-hitches can increase the strength of knots by 75–92% for the SMC, Giant, and Field knots.⁶ Therefore, it is recommended to perform 3 RHAPs when tying arthroscopic knots.

One limitation of this study is that the Wiese knot was tested singularly without a different knot configuration for direct comparison with clinical standards. However, since the methods of the current study closely follow those of Lo, et al, the findings are postulated to incur only nominal compromise in comparison to those historical controls.^{9,10} Also, the study was performed in a laboratory setting and may not replicate operating room settings. It should be emphasized that all knots were performed by a single fellowship-trained shoulder surgeon who regularly uses the Wiese knot in his practice, thus others

Fig. 3. Ethibond loop A. Loops are completely intact prior to testing. B. All loop breakage was at the knot after force was applied by the Instron machine.

Table 3
Comparison of biomechanical characteristics of previous studies.

Source	Knot Configuration	Suture Brand	Knot Security (N)	Loop Security (mm)	Source	Knot Configuration	Suture Brand	Knot Security (N)	Loop Security (mm)
Lo, 2010	Surgeon's	Fiberwire	185 ± 32	30.3 ± 0.5	Shah, 2007	Roeder's	Fiberwire	127 ± 22	34 ± 0.4
		Ethibond	102 ± 7	30.4 ± 0.4			UltraBraid	98 ± 10	34 ± 0.3
		Orthocord	113 ± 18	29.5 ± 0.2			Orthocord	92.2 ± 13.2	32.5 ± 0.3
		Herculine	90 ± 43	31 ± 1.6			Fiberwire	121.5 ± 16	33.6 ± 0.5
		Max Braid	70 ± 29	30.4 ± 0.4			UltraBraid	141 ± 37	34 ± 1
		UltraBraid	63 ± 25	31.1 ± 1.4			Orthocord	102 ± 13	31.2 ± 0.5
	Roeder's	Fiberwire	198 ± 29	31 ± 0.4		SMC	Fiberwire	127 ± 12	34.3 ± 0.5
		Ethibond	89 ± 8	31.8 ± 0.4			UltraBraid	124 ± 25	34 ± 0.9
		Orthocord	90 ± 22	31 ± 1.0			Orthocord	91 ± 13	33.4 ± 1.1
		Herculine	118 ± 25	32.1 ± 0.9			Fiberwire	137 ± 25	34 ± 0.7
		Max Braid	98 ± 25	31.9 ± 0.6			UltraBraid	133 ± 31	33.8 ± 0.7
		UltraBraid	68 ± 9	32.1 ± 0.6			Orthocord	84 ± 8	33.2 ± 0.9
	Weston	Fiberwire	134 ± 35	31.5 ± 1.1		Surgeon's	Fiberwire	90 ± 24	34.5 ± 1
		Ethibond	91 ± 21	33.2 ± 1.0			UltraBraid	85 ± 8	34.1 ± .9
		Orthocord	103 ± 12	32.1 ± 0.6			Orthocord	70 ± 10	34.3 ± 0.9
		Herculine	73 ± 27	32.7 ± 1.4	Swan, 2009	Surgeon's	ForceFiber	230 ± 46	
		Max Braid	112 ± 33	33.9 ± 1.8			Max Braid	246 ± 34	
		UltraBraid	96 ± 13	34.3 ± 2.9			Ethibond	111 ± 21	
Lo, 2004	Duncan	Fiberwire	124 ± 23	31.2 ± 0.7			Ticron	134 ± 24	
		Ethibond	68 ± 5	31.2 ± 0.8			Fiberwire	146 ± 28	
	Nicky's	Fiberwire	131 ± 16	31.3 ± 0.4		Duncan	ForceFiber	156 ± 56	
		Ethibond	71 ± 5	31.6 ± 0.2			Max Braid	193 ± 61	
	Tennessee	Fiberwire	104 ± 11	32.3 ± 0.1			Ethibond	85 ± 30	
		Ethibond	84 ± 10	32.2 ± 0.4			Ticron	126 ± 23	
	Roeder's	Fiberwire	157 ± 25	30.7 ± 0.5			Fiberwire	124 ± 37	
		Ethibond	100 ± 10	30.7 ± 0.4		SMC	ForceFiber	207 ± 46	
	SMC	Fiberwire	103 ± 19	34.8 ± 0.3			Max Braid	239 ± 61	
		Ethibond	96 ± 15	35.6 ± 2.2			Ethibond	118 ± 14	
	Weston	Fiberwire	192 ± 32	32 ± 0.6			Ticron	150 ± 9	
		Ethibond	101 ± 4	32 ± 0.6			Fiberwire	189 ± 41	
	Surgeon's	Fiberwire	103 ± 12	30.5 ± 0.3		Roeder's	ForceFiber	200 ± 43	
		Ethibond	198 ± 37	30.5 ± 0.2			Max Braid	196 ± 57	
							Ethibond	100 ± 19	
							Ticron	112 ± 25	
							Fiberwire	130 ± 44	

without this experience may not have the same results.

In conclusion, loop and knot security of the new Wiese knot compare functionally to those of established knots. As with others, these biomechanical characteristics vary according to suture material.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at <https://doi.org/10.1016/j.jor.2018.08.031>.

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