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Original article

The effect of loop size on loop security and elongation of a knot

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ABSTRACT

Introduction: While repairing a teared rotator cuff tendon with suture anchors and horizontal mattress suture configurations, knots should be secure at time zero while approximating the tendon to the bone, otherwise any failure in loop security may cause undesired clinical results. Optimum distance between suture limbs passed through the tendon, in other words the bite size, is still not clear in the literature. The aim of this study was to test the effect of loop size, which is directly related to the bite size, on loop security and elongation of a knot.
Hypothesis: We hypothesized that a knot with a smaller loop size would be more secure. We asked if a knot with shorter circumference (1) would offer a better knot security; (2) would produce less elongation following repeated traction cycles.
Material and methods: Two parallel metal rods in 3.0 mm diameter were fixed to load cells of dynamic testing machine. Four groups, from A to D, had the initial rod to rod distances of 2-4-6-8 mm respectively ($n = 10$). Surgeon's knots were prepared with 2/0 Ultrabraid® sutures around the rods. A tension meter was used for tying each half hitch under equal tension. Crosshead distances were recorded after 7 N pre-load and subsequent 1000 repetitive cyclic loads between 7-30 N.
Results: Elongations after a 7 N preload for groups A to D were 0.107 mm (± 0.006), 0.143 mm (± 0.018), 0,16 mm (± 0.025), 0.185 mm (± 0.018) respectively. This increase was significant ($p < 0.05$, power > 0.95) between each group except between groups B and C. Maximum elongations after 1000th cycle for groups A to D were 0.32 mm (± 0.124), 1.12 mm (± 0.333), 1.162 mm (± 0.211), 1.292 mm (± 0.241) respectively. Only samples in group A (0.732 mm ± 0.124) elongated significantly less than others ($p < 0.05$, power > 0.95). No knots unravelled or ruptured.
Discussion: This study basically reports that a knot with a shorter loop circumference has superior properties regarding loop security and resistance to elongation. From the perspective of clinical importance, shorter distance between suture limbs of mattress configuration may provide a more secure fixation of the rotator cuff tendon to the bone.
Level of evidence: II.

1. Introduction

Various knots and tying techniques were described to achieve a successful soft tissue repair, particularly for arthroscopic shoulder surgery; rotator cuff tendon repair. Despite technical advances, the weakest link in this chain seems to be the suture and soft tissue interface. Although the quality of the soft tissue has an important effect on a repair construct, this variable is quite dependent on the host. On the other hand surgeons have a chance to control other factors such as suture type, stitch configuration and knot types [1].

Concerns still exist about the security of an arthroscopic knot. As previously described by Burkhart et al., "loop security" is the ability of a knot to maintain its initial loop tightness [2]. Basically surgeons use half hitches or sliding knots to approximate the tissue edges; initial construct should be secure at time zero, otherwise any failure in loop security before knot tightening can cause undesired clinical results. Therefore maintaining a perfect loop security at time zero is a primary goal in arthroscopic knot tying. However, optimum distance between suture limbs passed through the tendon, in other words the bite size (Fig. 1), is still not clear in the literature.

The aim of this study was to test the effect of loop size on loop security and elongation of a knot. Different loop sizes (loop circumference lengths) were representative for different distances between the suture limbs of mattress configuration (bite size) passing through the tendon tissue while performing a rotator cuff

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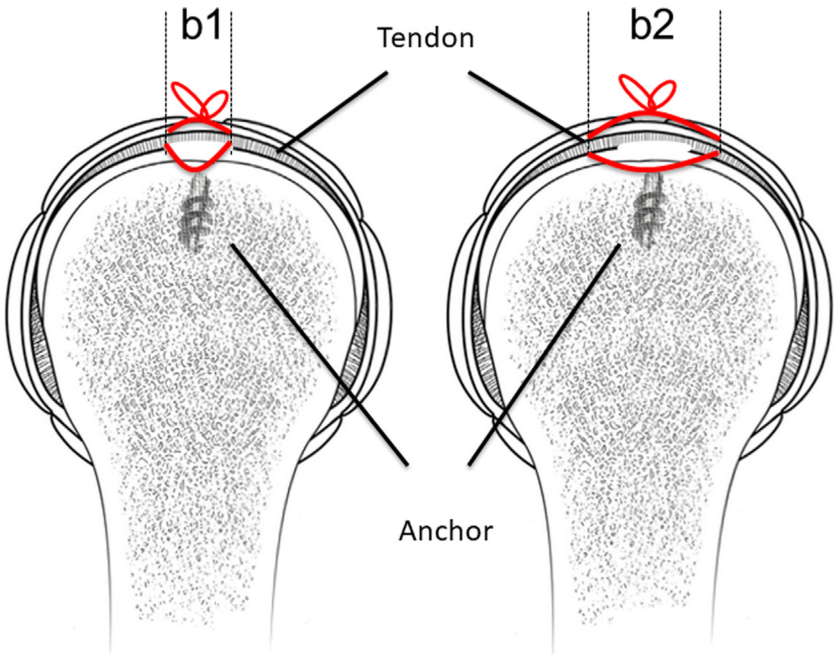

Fig. 1. Sagittal view of the shoulder; sutures (red coloured) from the anchor pass through the tendon by mattress configuration with different distances between suture limbs, in other words different bite sizes (b1: small bite size with a shorter loop circumference, and b2 large bite size with a longer loop circumference).

Fig. 2. Surgeon's knot configuration.

repair. We hypothesized that a knot with a shorter loop circumference would be more secure compared to knots with longer loop. We asked if a knot with shorter circumference:

- would offer a better knot security;
- would produce less elongation following repeated traction cycles.

2. Material and method

Two parallel metal rods in 3.0 mm diameter were fixed to load cells of dynamic testing machine (Zwick/Roell® Z010). Surgeon's knot was chosen for the experiment (Fig. 2). A tension meter (Lutron® FG-5005) was used for tying each half hitch under equal tension (30 N) (Fig. 3). Knots were prepared with 2/0 Ultrabraid® (Smith and Nephew®) ultra-high molecular weight polyethylene (UHMWPE) sutures around the rods.

In literature, supraspinatus tendon thickness was reported in between 4.4–7.4 mm [3,4]. Reported distances between suture limbs for a horizontal mattress suture configuration (Fig. 1) are in between 4–10 mm [5–7]. According to these findings, loop circumference length of a horizontal mattress suture configuration in a rotator cuff tendon repair may vary from 20 to 35 mm. Therefore, four groups were formed each having 2 mm (group A), 4 mm (group B), 6 mm (group C) and 8 mm (group D) initial rod-to-rod distances (Fig. 4), and calculated loop circumference lengths of the groups according to the formula described by Lo et al (2 × rod interval + 4 × rod radius + rod circumference) [8] were 19.4 mm, 23.4 mm, 27.4 mm and 31.4 mm respectively. Elongations were measured by rod-to-rod separation and recorded.

Each group with different loop circumferences was tested with 10 separate samples ($n = 10$). Primarily, a 7 N preload was applied and the elongation was recorded which reflected the "loop security" [2,9,10].

Our secondary criteria was elongation under cyclic loading between 7 and 30 N at a strain rate of 12 mm/min for 1000 cycles [10]. The difference in elongation between the first and 1000th cycles was recorded and defined as maximum elongation. In literature, elongation of 3 mm or above represents the threshold for clinical failure [2–4]. Elongation reflects the knot security defined as the ability of a knot to resist slippage when submitted to cyclic loading and until load to failure [11–13].

Power analysis conducted using G Power (Erdfelder, Faul, &Buchner, 1996) revealed that in order for an effect of this size to be detected (80% chance) as significant level at the 5% level, a sample size of 9 would be required. According to that power analysis, we determined our sample size as 10. Statistical analysis was done using SPSS (v 11.0.1; LEAD Tech, Chicago, IL) to calculate statistical significance. Means and standard deviations were calculated for all groups. One Way ANOVA test was performed. Each group was then compared individually with the remaining groups using a Tukey post hoc test. The results were expressed within 95% confidence interval and the level of statistical significance was set at $p < 0.05$.

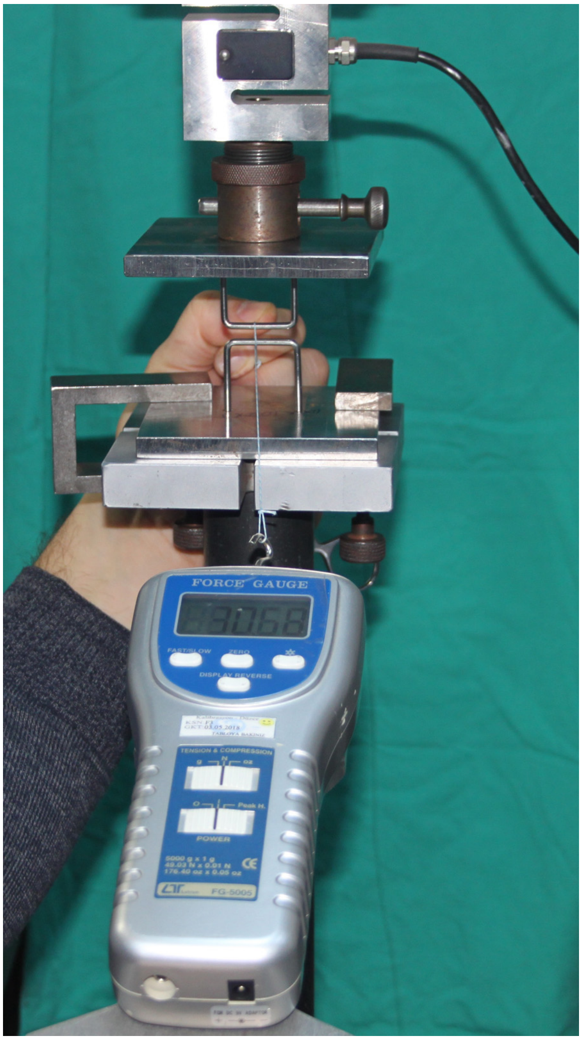

Fig. 3. Each knot was tied under equal tension (30 N) with the help of a force gauge device.

Table 1
Mean rod to rod elongation distances under a 7-N preload, and after cyclic loading between 7-30 N. (CI: Condifence Interval, SD: Standard Deviation).

	7 N preload (mm) (Mean ± SD) Confidence Interval	Cyclic elongation (mm) (Mean ± SD) Confidence Interval
Group 1 (2 mm)	0.107 ± 0.006 95% CI [0.103–0.11]	0.732 ± 0.12 95% CI [0.646–0.818]
Group 2 (4 mm)	0.143 ± 0.018 95% CI [0.13–0.156]	1.12 ± 0.33 95% CI [0.884–1.356]
Group 3 (6 mm)	0.16 ± 0.025 95% CI [0.142–0.178]	1.162 ± 0.21 95% CI [1.012–1.312]
Group 4 (8 mm)	0.185 ± 0.018 95% CI [0.172–0.198]	1.292 ± 0.24 95% CI [1.12–1.464]

3. Results

3.1. Preload test results

As the initial loop circumference increased, crosshead elongation with a 7-N preloading gradually increased too, (Table 1). This increase was statistically significant ($p < 0.05$, power > 0.95) between each group except between groups B and C.

3.2. Cyclic loading (Maximum elongation) test results

As the initial loop circumference increased, maximum elongation with cyclic loading gradually increased too, (Table 1). However, only samples in group A elongated significantly less than all other groups ($p < 0.01$, power > 0.95). No knots unravelled or ruptured with cyclic load testing.

4. Discussion

The results revealed that knot with the shortest loop circumference had superior properties than the knots with larger circumferences regarding two important pre-failure values: loop security and resistance to elongation.

Different authors studied the in vitro effect of the initial suture construct on the tendon repair biomechanics. Horizontal mattress stitch is the most preferred suture configuration for the rotator

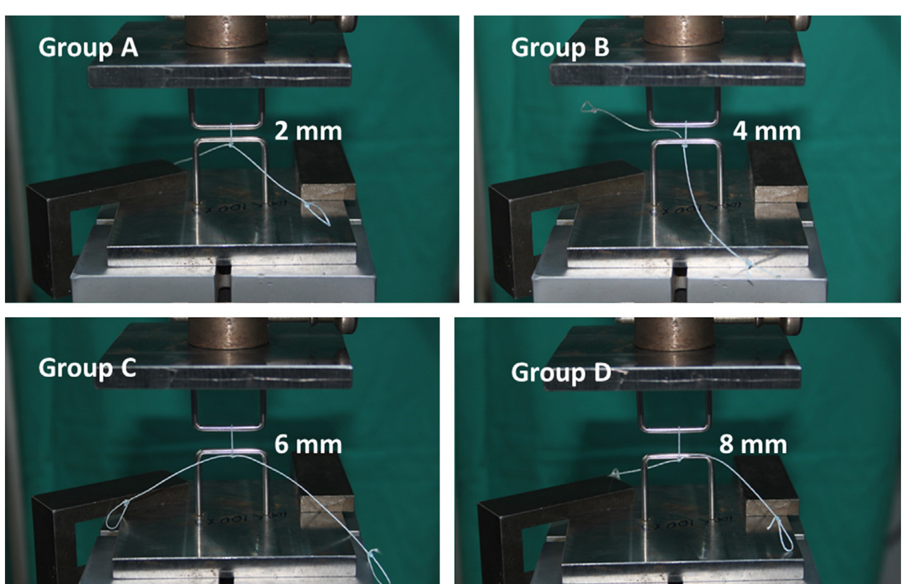

Fig. 4. Groups with different rod-to-rod distances, resulting in different loop circumferences.

cuff repair. As Tamboli et al. mentioned, there are conflicting studies in the literature about horizontal mattress stitches, which expose tendon to re-tear, while increasing ultimate load to failure of double-row rotator cuff repair [10]. However those studies were mainly focused on the tendon–suture interface. In the horizontal mattress configuration, the effect of loop size (Fig. 4) on loop security and knot elongation were not known yet. Knot and loop security are both important measurements for evaluating knot configurations [2,3,14]. It is important because a loose suture will not hold tissue apposed. Although none of the groups in the present study reached the 3 mm clinical failure threshold, elongations after preloading and cyclic loading were correlated with the initial loop sizes. Group with the smallest loop size (19.4 mm circumference) significantly provided less elongation than all other groups. Based on these findings, the hypothesis of the study was confirmed, and these biomechanical findings would be helpful for surgeons regarding the bite size in rotator cuff repair.

In the literature, similar studies are seeking the answer for the same question. Tamboli et al investigated the effect of bite size used to create horizontal mattress stitches on repaired bovine Achilles tendons [10]. First, they found significantly less gapping and less longitudinal tendon strain in horizontal mattress stitches with smaller bite sizes. Then, they demonstrated that increasing the bite size of the mattress stitch increased the ultimate strength of the configuration and prevented the suture-tendon interface failure. The first result is similar to our findings, however tying each half hitch under equal tension by a tension meter is obviously more standardised method, and is the superiority of the present study.

Bite size in mattress configuration was also a parameter in the study of Hapa et al. [5]. They investigated whether the bite size or bite distance from tear edge is of primary importance in rotator cuff repair. It has been reported that sutures placed laterally close to the free tendon edge are weaker than sutures placed close to the myotendinous junction [15]. Fibril diameter and fraction area differences were claimed to be the reason. To eliminate the bias effect of tissue quality disparities in the present study, knots were tied on same sized metal rods, because it was aimed to evaluate only the effect of loop size on loop and knot security.

Although authors aimed to eliminate all the possible variables to focus on the biomechanics of the loop–knot interface, this experimental setup caused some limitations. The biomechanical analysis was performed on a mechanical model. Knots were tied in a dry environment which may not represent wet situations. Only 2/0 Ultrabraid® suture material was used, however different suture materials might have different tensile properties. Surgeon's knot was the only knot configuration as well. Last limitation was about tying each half hitch under equal tension for standardisation. 30 N was chosen by the authors of the study, because a similar standardisation method has not been reported before.

In conclusion, our results showed that an increase in loop circumference length of a knot configuration decreases loop security and increases maximum elongation. Smaller bite size may provide more secure fixation of the rotator cuff tendon to the bone. These findings will be a guide for surgeons and for the future researches about the bite size in rotator cuff repair.

Disclosure of interest

The authors declare that they have no competing interest.

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Author Contributions

Umut Akgün: Conceptualization, Methodology.
Selim Ergün:Investigation, statistics,Writing.
Mustafa Karahan: Writing and reviewing, supervision.

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