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ORIGINAL ARTICLE

A Biomechanical and Ease of Learning Comparison Study of Arthroscopic Sliding Knots

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Abstract

Introduction This study aims to compare the biomechanical properties and ease of learning and tying of our novel knot (UM Knot) with other commonly used arthroscopic sliding knots.

Materials and methods The Duncan, HU, SMC, Pretzel, Nicky's and square knots were selected for comparisons with UM knot. All knots were prepared with size 2 HiFi® suture by a single experienced surgeon and tested with cyclic loading and load to failure tests. The ease of learning was assessed objectively by recording the time to learn the first correct knot and the total number of knots completed in 5 min by surgeons and trainees.

Results The UM knot average failure load is significantly superior to the HU knot ($p<0.05$) and comparable to Duncan, SMC, Pretzel and Nicky's knots. According to the ease of learning assessment, UM, Duncan, SMC, Pretzel and Nicky's knots took statistically less time to learn than the HU knot. Although not significant, the failure count due to slippage is fewer in UM knot compared with other knots.

Conclusions This study showed that UM knot is among the easiest knot to learn and tie, along with Duncan, SMC, Pretzel and Nicky's knots. Their biomechanical properties are comparable and their loads to failure were superior to the HU knot.

Keywords Arthroscopic sliding knot · Failure load · Knot security · Shoulder surgery · Sports surgery · Tensile strength

Introduction

A successful arthroscopic repair depends on several factors, including the surgeon's technique, tissue quality and security of the arthroscopically tied knot. Multiple studies have been conducted to evaluate both suture characteristics and knot performance. Several biomechanical studies have been performed to determine the important characteristics of arthroscopic knots to maintain the tissue apposition [1, 2]. These characteristics include loop security, knot security and the intrinsic properties of the suture [1, 3, 4]. The challenges of arthroscopic knot tying have been addressed with the development of new knot types that are intended to make knot tying easier without compromising its security.

Many studies have been performed to compare the biomechanical properties of the existing arthroscopic knots [5–7], examine the biomechanical properties of arthroscopic knots and suture materials [1, 2, 6, 8–10] and evaluate the ease of learning [11]. However, no study has compared the biomechanical properties and evaluated the ease of learning and tying between different arthroscopic knots. The surgeon's ability to learn and tie an arthroscopic knot is an important factor to consider. Therefore, it is desirable for the technique of knot tying to be easily reproducible and provide consistent results regardless of the surgeon's experience.

Throughout our practice, we have developed the UM knot (Fig. 1), a non-locking sliding knot capable of producing performance results similar to the other widely used non-locking sliding knots. Due to its simple preparation, we believe that this knot can be included into the list of

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Fig. 1 The UM knot

alternative knots to be introduced to the novice arthroscopic surgeons.

Thus, this study aims to compare the biomechanical properties and ease of learning and tying of UM knot with other commonly used arthroscopic sliding knots. Our hypothesis is that the UM knot would be comparable to the established knots in terms of biomechanical properties and ease of learning, making it suitable to be one of the knots for an arthroscopic surgeon to learn.

Method

The Duncan, HU [12], SMC [13], Pretzel [14], Nicky's [15] and square knots (Fig. 2) were selected for comparison with UM knot. Only one suture material, HiFi® (ConMed Linvatec, NY), was used in the test as it is among the commonly used suture in arthroscopic procedures. The HiFi® suture is an Ultra High Molecular Weight braided polyethylene suture, sized two according to standard United States Pharmacopeia with a length of 94 cm. According to the manufacturer, it has a minimum tensile strength of 280 Newton (N), a maximum tensile strength of 339 N and an average tensile strength of 314 N.

Ten of each arthroscopic knot were analysed for biomechanical properties [8, 16]. Knot-tying process was conducted to simulate the arthroscopic conditions while ensuring the knots consistency. The suture material was first soaked in normal saline at room temperature for 3 min before tying the knot. The knots were tied through a cannula

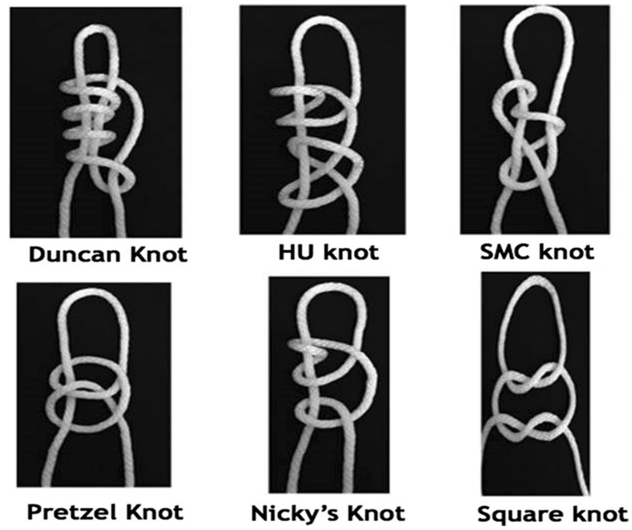

Fig. 2 The arthroscopic knots selected for comparison with UM knot

by a single sport orthopaedic surgeon, experienced in all types of knots in sitting position. Each knot was created around a 7 mm in diameter metal hook. The knot was tied outside of the 8.4 mm cannula and pushed down using a single-hole knot pusher (Fig. 3). After the initial sliding knot, four half hitches were applied to complete the process.

For UM knot, the knot was tied by making an underhand throw under post and loop strand, followed by another underhand throw under post strand. The loop strand was brought over below the first underhand thrown and then followed by another underhand throw over post strand and under loop strand. The knot was completed by applying four half hitches.

Fig. 3 Knot tying process using an 8.4 mm cannula assisted with a single-hole knot pusher

The knots were immediately tested for mechanical loading with the Instron® Tensile and Compression Tester Model 3365 (Instron®, UK). Cyclic loading and load to failure test were performed in two consecutive stages on the same knot. A 7 N preload was initially applied to avoid potential displacement errors that result from initial slack in the suture loop and to establish the zero starting point as a point reference [4, 5, 7, 8]. After the preload was reached, cyclic loadings from 7 to 30 N were applied for 50 cycles at a rate of 1 N/s [4, 5]. A triangle wave shape of tensile extension cyclic mode was set and the maximum displacement during the cyclic loading was recorded.

Each knot was then subjected to the load to failure test. The suture loop was pulled to failure at a set rate of 1.25 mm/s [5], with the clinical failure defined as the maximal load at 3 mm displacement of the suture [4]. The ultimate load at failure and the mode of failure by either slippage or breakage were recorded.

For evaluation of ease of learning, 31 candidates comprised of non-orthopaedic surgeons and orthopaedic trainees without arthroscopic knot tying experience were recruited to evaluate the ease of learning and tying of the new arthroscopic knot. The candidates were divided into groups of four or five and each group was elaborated about the learning session. Knots prepared by the candidates were validated by an experienced sport orthopaedic surgeon.

For the learning session for each knot, the groups were presented once with a knot's instruction video, followed by their attempts to tie the knot with the instruction video played repeatedly. The resulting knots were validated and the time taken to complete the first correct knot was recorded.

In the second part of the evaluation, candidates were given 5 min and they were instructed to tie one type of knot as many as they could. All completed knots were validated and the correct number of knots was recorded. These cycles were repeated for the other remaining five knots to be assessed. The order of knot types to tie was randomised for each group to prevent any potential bias that knots learned later in the study were easier to tie than knots learned earlier. The names of knots were also not disclosed to any of the candidates throughout the whole exercise.

The data were tested for normality using Kolmogorov–Smirnov and Shapiro–Wilk test on the values for the load at clinical failure. All the data collected correspond to the normal distribution with all values were within 95% confidence interval with $p > 0.05$.

Statistical significance in maximum elongation, time taken to learn and tie the first correct knot and average numbers of knots completed in 5 min were determined with one-way analysis of variance (ANOVA) with Tukey's post-test. The rate of knot failure was analysed using Chi square test.

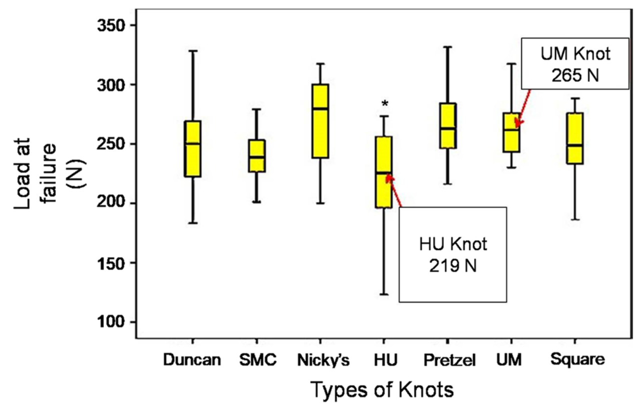

Fig. 4 The load at clinical failure of different arthroscopic knots (*$p < 0.05$)

Table 1 Mean of maximum knot elongation at cyclic loading

Knots	Maximum knot elongation[a] (mm)	Mode of failure	
		Knot slippage	Suture breakage
UM	0.41 ± 0.20	4	6
Duncan	0.55 ± 0.36	9	1
HU	0.59 ± 0.13	9	1
SMC	0.67 ± 0.35	9	1
Pretzel	0.64 ± 0.29	6	4
Nicky's	0.48 ± 0.24	6	4
Square	0.51 ± 0.20	5	5

[a]Mean ± SD

The statistical significance level was set at $p < 0.05$ for all comparison. All results were presented as mean ± standard deviation unless stated otherwise.

Results

For biomechanical test, the mean failure load ranged from 215 to 275 N, with HU knot had the lowest load to clinical failure at 218.9 ± 46.6 N (Fig. 4). The load to clinical failure of HU knot was found significantly lower than Nicky's (271.3 ± 38.1 N, $p = 0.03$) and Pretzel (268.5 ± 34.6 N, $p = 0.04$) knots. Load to clinical failure for UM knot (265.3 ± 26.5 N) did not differ significantly with others.

All knots had a maximum elongation ranging from 0.41 to 0.67 mm (Table 1). However, there was no significant difference between the seven knot configurations ($p = 0.09$). Among the other knots, UM knot was the least failed by slippage (four out of ten knots). The Duncan, HU and SMC knots slipped more often (all knots slipped nine out of ten) than Pretzel and Nicky's (all six out of

Table 2 Mean time (s) taken to complete the 1st knot

Knots	N	Time (s)		
		Minimum	Maximum	Mean ± SD
UM	28	18	265	69.1 ± 60.4
Duncan	31	18	185	69.6 ± 43.7
HU	24	30	297	164.3 ± 82.2[†]
SMC	27	20	267	82.8 ± 61.7
Pretzel	30	16	223	56.1 ± 38.0
Nicky's	28	17	263	68.0 ± 55.3

Comparison made with one-way ANOVA

[†] $p < 0.001$ when compared with the other knots

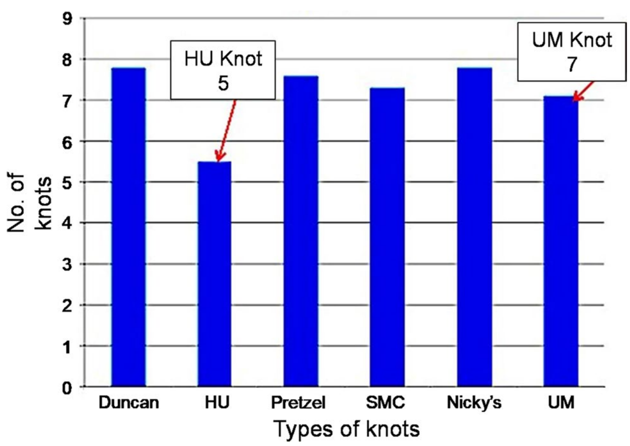

Fig. 5 The average number of knots completed in 5 min

ten) knots in this current study. However, the difference was not significant after Bonferroni Correction where the difference was only considered statistically significant if $p < 0.0035$ after the adjustment.

For evaluation of ease of learning, the time taken to learn and complete an arthroscopic knot ranged from 185 to 297 s (Table 2). The HU knot took the longest average time to learn at 164.3 ± 82.2 s, which was highly significantly longer to complete ($p < 0.001$) when compared with all knots. In contrast, the mean time taken to learn and tie UM knot was comparable to Duncan, SMC, Pretzel and Nicky's knots. Majority of the candidates were able to learn and complete the first correct knot within 5 min. However, 18 candidates were not able to finish on time with seven of them being the HU knots. The least number of knots completed in 5 min is HU knot with an average of 5.5 knots. However, the difference is not significant (Fig. 5). On the other hand, the number of completed UM knots was comparable to the other knots.

Discussion

This current study sought to evaluate UM knot, a new arthroscopic knot tying method that potentially provides a biomechanical reliability and somewhat less dependent on the surgeon's experience or ability. Evidence of the reliability of this new arthroscopic knot was compared biomechanically with other commonly used arthroscopic knots. Its reproducibility, on the other hand, was compared with other arthroscopic knots by evaluating the learning time, the total number of knots completed within stipulated time together with a subjective questionnaire. The new UM knot performs better compared with the HU knot and was proven to be comparable to the other knots. The UM knot could withstand high tension and is readily learned by the surgeon and reproducible.

As in traditional open procedures, the knots tied with arthroscopic assistance must achieve a secure fixation with consistency. An important consideration in a surgical repair of musculoskeletal injuries is to maintain the structural integrity of the repair site while healing occurs. Separation of the tissue, even by a few millimetres, can be deleterious during healing even if the knotted suture never fails [1].

Multiple studies have emphasised the importance of loop and knot security for optimisation of arthroscopic rotator cuff repair [2, 8, 9, 17, 18–20]. Regardless of knot or suture development, the stability of a repair construct is dependent on a surgeon's experience and ability. Therefore, it is important to consider these factors to minimise such technical variations when developing an arthroscopic knot.

The average load at failure for all our tested knots are within the range of those reported in the literature [21]. The mode of failure was also a determinate of the 'weak link' of each suture and knot combination. The breaking of the suture implies that the knot held well instead of slipping apart.

Prior studies have found that knot security is inversely proportional to the pliability of the suture and directly proportional to the coefficient of friction [22, 23]. These studies have also indicated that the type of knot tied in the suture was also a factor in knot security. In addition, Burkhart et al. have reported that internal interference is one of the most important factors in tying a tight, secure knot [24].

As mentioned earlier, two important factors in arthroscopic knot tying are (1) the ability of the surgeon to learn and tie an arthroscopic knot and (2) the ability of the knot to resist displacement and failure [25]. This study revealed that the HU knot is the most difficult to learn and tie in comparison with the new UM knot and other established arthroscopic knots. The high number of candidates unable to complete the HU knot in 5 min in the current study supports that it was more difficult to learn and tie. This observation also shows that the new UM knot is easy to learn and tie and its difficulty is comparable to Duncan, SMC, Pretzel's and Nicky's knot.

Through a post-experiment questionnaire, a few subjective opinions were also gathered from the current study. The Duncan knot was ranked as the most easily learned knot, whereas the HU knot was ranked as the most difficult knot (data not shown). These subjective findings were consistent with the objective evaluation in terms of time to learn the first complete knot and the total number of knots being completed in 5 min. Through this questionnaire, the new UM knot is also comparable to the other tested knots in terms of the knot's organisation, security and sliding property. In addition, most participants considered that the results of the HU knot were less ordered compared with the other knots.

This study found that the UM, Duncan, SMC, Pretzel and Nicky's knots were among the easiest knot to learn and tie. The biomechanical study also showed that they are comparable and their loads to failure were superior to the HU knot. Other than mentor and arthroscopic courses, American Orthopaedic Society has reported that published literature is the third most common source of knot selection for arthroscopic surgeon [11]. Thus, this report may provide as a source for novice arthroscopic surgeons and introduce UM knot into their sliding knot repertoire for its favourable biomechanical properties and its ease of learning.

The current study used a sample of convenience and only employed one experienced orthopaedic surgeon from our institution to compare the biomechanical properties between the knots. Thus, generalisation could not be made from the current study. A multi-centred study may overcome the limitation, provide new variables and add valuable information on the knots' strength.

In addition, the tied knots resulted from the ease of learning study were not tested for its biomechanical properties and quality. A biomechanical assessment of the different knots produced from the participants would be able to justify the quality of the newly learnt arthroscopic knots.

The suture samples for this study were supplied by the manufacturers. The sample selection relied on the availability of suture materials supplied and thus, not randomly selected from the total population available.

In conclusion, this study showed that UM knot is among the easiest knot to learn and tie, along with Duncan, SMC, Pretzel and Nicky's knots. Their biomechanical properties are comparable and their loads to failure were superior to the HU knot.

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Compliance with Ethical Standards

Conflict of Interest All authors declare that they have no conflict of interest.

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