Operating Room Fatigue: Is Your Twentieth Surgical Knot as Strong as Your First?

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OBJECTIVE: This study aimed to determine the tensile strength in a series of 20 consecutively tied knots. Knot tying is a universally used technique in surgical procedures, and as such, knot integrity and security are essential.

STUDY DESIGN: Twenty was the number of knots chosen as this is the average number of knots required for a vaginal hysterectomy. We used 0-0 gauge, nonexpired, polyglactin 910 to tie 20 knots in succession with less than 20 seconds rest between knots. The knots were tied without a surgeon's knot and 4 additional square knots (1 = 1 = 1 = 1 = 1). The knots were tied by 2 obstetrician/gynecologists investigators over the period of 2 weeks to minimize fatigue. The sutures were then soaked in 0.9% sodium chloride for 60 seconds and subsequently transferred to a Chatillon LTCM-100 tensiometer (Ametek, Largo, Florida) where the tails were cut to 3 mm length. The force required to break the knots was recorded. To detect a difference over time while maintaining power of 80% with a type I error rate of 5%, a minimum of 17 series of knots were needed (thus, 340 total knots after tying 20 knots per series). To buffer against unanticipated variability in the tensile strengths over time, we rounded the number of knot series up to 20, so a total of 400 knots were tied.

RESULTS: A total of 800 knots were tied. All the sutures broke at the knot and 36% untied. For analyses, the data for each series of knots were collapsed into quarters (ie, knots 1–5, 6–10, 11–15, and 16–20). A repeated-measures analysis of variance found that there were no statistically significant differences between the four quartiles ($p = 0.87$). A paired samples t-test comparing the first knots in each series with the last knots in each series showed no difference ($p = 0.99$). Similarly, a paired samples t-test comparing the first 10 knots to the last 10 knots showed no difference over time ($p = 0.8$). To determine whether there was a change in likelihood of knots coming untied, as more knots were tied, Cochran's Q was used to look across the entire series of 20 knots. This analysis of proportions coming untied revealed no differences over time ($p = 0.61$). To compare across quarters, a Friedman test was used and similarly showed no change over time ($p = 0.92$). The different investigators were controlled for in the analysis as a covariate, which turned out to be statistically significant, $p = 0.003$.

CONCLUSIONS: Under laboratory conditions, the order of knots tied does not change the tensile strength of the material. This would infer that fatigue does not influence the tensile strength for a series of 20 knots; however, additional studies with a larger number of knots series may be warranted. (J Surg 69:215-217. © 2012 Association of Program Directors in Surgery. Published by Elsevier Inc. All rights reserved.)

KEY WORDS: fatigue, materials testing, sutures, suture techniques

CORE COMPETENCIES: Patient Care, Medical Knowledge, Practice Based Learning

INTRODUCTION

Indisputably, knot integrity is an essential part of any surgical procedure. We completed a search of the literature (MEDLINE; January 1966—April 2011; English language; search terms; "suture," "knot security," "knot integrity") and noted several gaps in the literature. Previous studies have examined variables affecting knot strength, such as suture type, suture end length, number of throws, and tying modality.[1,2,3] Interestingly, intraoperator variability has not been examined critically as a variable in knot tying. It is not currently established whether knot strength is affected by the order in which a knot is tied, over a short period, similar to a hysterectomy.

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TABLE 1. Descriptive Statistics for Knot Failure for Each Quarter in the Time Series of 20 Consecutive Knots Tied by 2 Surgeons

Quarter	N (Knots)	N (Series)	Mean Newtons	Standard Deviation	% Untied
Q1: Total	200	20	80.4	18.9	36.5
Q1: Surgeon A	100	20	86.8	15.7	30.0
Q1: Surgeon B	100	20	74.0	20.1	43.0
Q2: Total	200	20	79.2	14.3	37.0
Q2: Surgeon A	100	20	84.0	13.6	28.0
Q2: Surgeon B	100	20	74.3	13.6	46.0
Q3: Total	200	20	81.0	18.4	36.5
Q3: Surgeon A	100	20	85.6	14.9	26.0
Q3: Surgeon B	100	20	76.4	20.7	47.0
Q4: Total	200	20	81.0	21.5	35.0
Q4: Surgeon A	100	20	83.6	19.8	29.0
Q4: Surgeon B	100	20	78.3	23.2	41.0
Q1–Q4 total	800	80	80.4	36.0	36.3
Surgeon A	400	80	85.0	34.4	28.3
Surgeon B	400	80	75.8	37.1	44.3

This project was undertaken in an attempt to determine whether muscle fatigue would affect the operator and how this would be reflected in the tensile strength of the suture/knot. Muscle memory could also play a role if knot strength progressively increases with the number of knots tied. Our objective is to determine the intraoperator variability of tensile strength in a series of 20 consecutively tied knots.

MATERIALS AND METHODS

Polyglactin 910 (Ethicon, Inc, Somerville, New Jersey) is a common suture material used for vaginal hysterectomy.[4] Non-expired 0-gauge United States Pharmacopeia suture was used. A metal hex head screw model with the screws 50 mm on center was used to tie the suture.[5]

The knots were tied without a surgeon's knot and 4 additional square knots (1 = 1 = 1 = 1 = 1).[6] A knot was tied then the surgeon started tying the first throw of the next knot less than 20 seconds later to simulate the time needed to clamp the subsequent pedicle. Each series of 20 knots was separated by at least 20 minutes to ensure that fatigue would not be a factor from 1 series to the next. The knots were tied by a 2 obstetrician/gynecologist investigator over the period of 2 weeks to minimize fatigue. Surgeon A was a chief resident and surgeon B was a junior resident. The surgeons were rested (≥7 hours of sleep in previous 24 hours).[7] All knots were tied wearing surgical gloves. The knots were soaked in 0.9% sodium chloride solution for 60 seconds to mimic in vivo conditions. The tied suture was then immediately transferred to a Chatillon LTCM-100 tensiometer (Ametek, Largo, Florida) where the tails were cut to 3-mm lengths and loaded so the knot was between the pulling hooks.[1] The tensiometer continuously measured load while each suture loop was subjected to tensile forces at a separation rate of 5 mm/min until failure occurred. Failure was defined as breakage of the suture or tail slippage greater than 3 mm, and tensile strength or tension at failure was defined as the tensile force (N) measured at failure. There is no standard, accepted methodology for clinical suture testing, but this is the most common method described in the literature.

Given the repeated measures design of the current study, we were left to estimate the size of difference. To reflect the size of the meaningful differences we observed in our previous research, we powered this study to detect an effect size of $f = 0.30$. To detect this size of difference over time while maintaining power of 80% with a type I error rate of 5%, a minimum of 17 series of knots were needed (thus, 340 total knots after tying 20 knots per series). To buffer against unanticipated variability in the tensile strengths over time, we rounded the number of knot series up to 20, so 400 total knots were tied.

RESULTS

A total of 400 knots was tied in 20 sets of 20 knots each by each surgeon. All the sutures broke at the knot and 36% were untied. For each knot, the Newtons at failure were measured, and the failure type (untied in contrast to broke) was recorded. For analyses, the data for each series of knots were collapsed into quartiles (ie, knots 1-5, 6-10, 11-15, and 16-20). Table 1 displays the descriptive statistics for each series of knots.

Tension at Failure

To establish whether a statistical change over time occurred, a repeated-measures analysis of variance (ANOVA) was used to test whether there were differences in tensile strength between the quarters. The repeated-measures ANOVA found that no statistically significant differences were found between the 4 quartiles ($p = 0.87$). So, no reduction was found in tensile strength over time when tying multiple knots. The different surgeons were controlled for in the analysis as a covariate, which was statistically significant ($p=0.003$). A paired samples t-test comparing the first knots in each series with the last knots in each series showed no difference ($p = 0.6$). A repeated-measures ANOVA was also conducted for the 20 individual time points, and similar results were observed ($p = 0.99$). This was performed to show that the failure to detect a difference between early knots in a series and later knots in a series was not caused by the aggregation of data into ordinal quarters.

Likelihood of Untying

To determine whether there was a change in likelihood of knots coming untied as more knots were tied, Cochran's Q was used to look across the entire series of 20 knots. This analysis of proportions coming untied revealed no differences over time ($p = 0.61$). To compare across quarters, a Friedman test was used and similarly showed no change over time ($p = 0.92$).

DISCUSSION

This laboratory experiment showed that the surgeon's first knot has a similar tensile strength as the 20th when tied with polyglactin 910 sutures. This would infer that fatigue does not influence the tensile strength for a series of 20 knots; however, additional study with more knots series and a wider variety of surgeon experience may be warranted.

Surgery is a physically demanding task. Tachycardia may be considered as an appropriate response induced by the physical or psychological stress of surgery.[8] Studies have shown that heart rate increases above 88 beats per minute from the moment the surgeon stands at the scrub sink until the completion of the case.[9] The pronation and supination movements of the hands can become tiresome during surgery. Future studies may evaluate the effect of fatigue on laparoscopic or robotically tied knots. Our results are not comparable with laparoscopic or robotically tied knots. In future knot studies, the need for randomization of knot type is called into question as there was no statistically significant increase in knot strength despite practice of multiple prior knots.

Strengths of our study include a conservative rate of elongation that underestimates the prevalence of untying by 6%.[10] Two surgical trainees with a specific interest in knot tying completed all knots, minimizing interoperator variability. Tensile strength increased and 44% fewer knots were untied for the sutures tied by the chief resident compared with the junior resident. Limitations of this study include the obvious lack of an in vivo model that recreates the physical and mental stressors of the operating theater. Another limitation is that a surgeon tying a set of 20 knots might behave differently than during lengthier procedures with a greater number of knots tied. Without a way to tie knots mechanically the same way every time, we admit that knot tying is a subjective process. Surgeons tying the same knot configuration may do it with more force over a different span of time or using different instruments. Therefore, knot tying data are inherently limited in generalizability.

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