Minimum Number of Throws Needed for Knot Security

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OBJECTIVE: The purpose of the study was to determine the optimal number of throws to ensure knot security.

STUDY DESIGN: Knots were tied with 3, 4, 5, or 6 square throws with 0-gauge coated polyester, polydioxanone, polypropylene, and polyglactin 910. The suture was soaked in 0.9% sodium chloride and subsequently transferred to a tensiometer and broken.

RESULTS: A total of 225 knots were tied. Regardless of the suture type, tension at failure for knots with 4 throws, 5 throws, and 6 throws was higher than tension at failure of knots with only 3 throws (p < 0.05 for each). We found no difference in the tensile strength between knots with 4, 5, or 6 throws (p > 0.05 for each). Knots with 4 throws were significantly more likely to come untied than knots with 5 or 6 throws (p < 0.01).

CONCLUSIONS: Under laboratory conditions, the ideal knot has 5 throws to maximize tensile strength and rate of untying. This finding does not seem to vary by type of suture material. (J Surg 68:130-133. © 2011 Association of Program Directors in Surgery. Published by Elsevier Inc. All rights reserved.)

KEYWORDS: suture techniques, tensile strength, suture end length, polyglactin 910

COMPETENCIES: Patient Care, Medical Knowledge, Practice Based Learning

INTRODUCTION

There are many different considerations in surgical knot construction that can affect the security of a given knot. Several comparative studies have determined that suture type, suture gauge, and knot configuration are key factors in determining knot security. Although knot security is important in wound closure, it should be recognized that suture material elicits a tissue reaction, which can impair wound healing. In 1 study, increasing the knot by 2 throws increased the knot volume by 1.5-fold. More throws did not correlate with better knot security. A secure knot holds at supraphysiologic strengths and does not untie. Tying more throws with the hopes of increased tensile strength is not necessarily a benign action.

A review of the literature (MEDLINE; January 1966 to May 2010; English language; search terms; “suture,” “knot security,” and “knot integrity”) found a limited number of studies addressing knot security. In 1 study, the authors noted that with square knots, the addition of more throws increased holding capacity with polyglactin 910 and increased knot volume. Drake et al. reported differences in suture extrusion rates of a copolymer of glycolide and lactide with 3-throw, 4-throw, and 5-throw knots using a porcine model. The 5-throw surgeon’s knots had a higher cumulative incidence of suture extrusion than the 3-throw or 4-throw surgeon’s knots (30%, 17%, and 10%, respectively). The optimal number of throws for knot security using common sutures for pelvic floor repair remains unknown.

The purpose of the study was to determine the optimal number of throws to ensure knot security while minimizing the amount of suture material. We hypothesized that more throws would create a stronger knot that would not untie.

MATERIALS AND METHODS

Cleveland Clinic Institutional Review Board approval was waived for the study. The 4 suture materials tested were coated polyester, polydioxanone, polypropylene, and polyglactin 910. The suture was tied between 2 hex head screws 50 mm on center. A full length, 0-gauge United States Pharmacopeia standardized suture was used each time a knot was tied. The strands were tied using a surgeon’s knot plus a variable number of square throws. The knots were tied in a random order with 3, 4, 5, or 6 square knots (Fig. 1). The knots were tied by a single...
investigator (N.K.) wearing surgical gloves over a period of 14 days to avoid fatigue. The investigator tying the knots is an obstetrics and gynecology chief resident with an interest in surgical education. Recommendations for the number of throws are not provided by the manufacturer of the suture materials; therefore, all materials were tied with the same number of throws for equal comparison.

The tension phase of the experiment was performed by a single investigator (I.I.) who was not blinded to the number of throws or suture material because of practical considerations. Each knotted loop of suture material was inspected before placing it on the tensiometer. Knots of each loop were studied for imperfections, such as air knots. The suture loops were inspected to rule out flaws in the integrity of the suture material. Suture loops were then submerged completely in 0.9% normal saline for 60 seconds. After soaking, the loops were transferred to the tensiometer. The suture loop was positioned around the upper and lower hooks of the tensiometer so the location of the knot was roughly an equal distance from the two hooks (Fig. 2). At the initial positioning, all suture loops were slack and clearly under zero tension. The tension gauge of the tensiometer was tared to reflect zero tension.

The investigator then began the elongation that slowly advanced the upper hook away from the lower stationary hook at a rate of 5 mm/minute. Ultimately, either the loop would break or the knot would slip. At that time, the peak tensile force on the gauge as well as the outcome of the knot was recorded. This method was repeated for each loop of suture tied. A randomized schedule of knots and suture material was generated before this phase of the experiment and strictly followed to eliminate possible biases.

A power analysis was completed before starting the study. To detect statistically significant main effects for both material and throw count, as well as a statistically significant interaction effect, with 80% power and a 5% chance of type I error, a minimum of 183 knots was needed. This power analysis accounted for the having enough knots in each group to achieve statistical significance. We collected data for 225 knots to account for potential fluctuations in the true effect size. To determine the effect of material and throw count on newtons at failure, we conducted a 4 × 4 factorial analysis of variance. A logistic regression analysis was conducted to determine whether there was any effect of material or throw count on the likelihood of knots coming untied.

RESULTS

A total of 225 knots were tied. The mean tensile force at failure was 88.9 N (N) (standard deviation [SD] = 28.4). In all cases, the knots that began to unravel continued to untie completely. No air knots or material imperfections were noted during the experiment. The loads needed to break suture were always greater than those required for suture untying (Table 1).

Tension at failure

As shown by the analysis of variance, both the material and throw count had statistically significant main effects on the
newtons at failure (p < 0.001 for both). The tension at failure for knots with 4 throws, 5 throws, and 6 throws was higher than tension at failure of knots with only 3 throws (p < 0.05 for each). There was a statistically significant interaction effect in which the effect of the suture material varied depending on the number of throws (p < 0.001). There was no difference in tension at failure between knots with 4, 5, and 6 throws (p > 0.05 for each). Among the knots with 4 throws, polydioxanone knots (mean = 125.3 ± 10.9) failed at significantly greater tension than knots tied with other materials (mean = 83.4 ± 17.9, p < 0.01). The tensile strength of polypropylene did not increase based on the number of throws (mean = 88.2 ± 5.5) (Fig. 3).

**Failure type**

Of the 225 knots tested for tensile strength, 51 untied (22.7%). The logistic regression analysis showed a significant effect of throw count on the likelihood of knots coming untied (p < 0.001). The knots with 3 throws were significantly more likely to come untied than knots with 4 throws (p < 0.001). The knots with 4 throws were significantly more likely to come untied than knots with 5 or 6 throws (p = 0.006). We found no difference in the likelihood of untying between the knots with 5

<table>
<thead>
<tr>
<th>Suture material</th>
<th>n</th>
<th>Mean</th>
<th>SD</th>
<th>Untied</th>
<th>n</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coated polyester</td>
<td>53</td>
<td>77.3</td>
<td>20.7</td>
<td>14</td>
<td>26.4</td>
<td></td>
</tr>
<tr>
<td>Polydioxanone</td>
<td>56</td>
<td>103.5</td>
<td>38.5</td>
<td>16</td>
<td>28.6</td>
<td></td>
</tr>
<tr>
<td>Polypropylene</td>
<td>61</td>
<td>88.2</td>
<td>5.5</td>
<td>0</td>
<td>0.0</td>
<td></td>
</tr>
<tr>
<td>Polyglactin 910</td>
<td>55</td>
<td>85.8</td>
<td>32.2</td>
<td>21</td>
<td>38.2</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Throw count</th>
<th>n</th>
<th>Mean</th>
<th>SD</th>
<th>Untied</th>
<th>n</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 throws</td>
<td>59</td>
<td>62.4</td>
<td>28.4</td>
<td>36</td>
<td>61.0</td>
<td></td>
</tr>
<tr>
<td>4 throws</td>
<td>57</td>
<td>93.7</td>
<td>24.5</td>
<td>10</td>
<td>17.5</td>
<td></td>
</tr>
<tr>
<td>5 throws</td>
<td>57</td>
<td>100.9</td>
<td>21.5</td>
<td>3</td>
<td>5.3</td>
<td></td>
</tr>
<tr>
<td>6 throws</td>
<td>52</td>
<td>100.0</td>
<td>18.4</td>
<td>2</td>
<td>3.8</td>
<td></td>
</tr>
</tbody>
</table>

Total 225 88.9 28.4 51 22.7

throws and the knots with 6 throws (p = 0.778). The analysis showed no effect of material (p = 0.288).

**DISCUSSION**

Pelvic surgeons continue to seek the ideal suture material and knot configuration. What remains constant is the goal to obtain knot security, despite the lack of standardization in knot configurations between surgeons. Using comparable suture sizes and 4 different knot constructions, we have demonstrated that there is a significant effect of the number of throws on the tension at failure. In addition, we noted a significant effect on the failure type, with additional throws decreasing the likelihood of knots coming untied.

In knot tying, as in surgery in general, Occam’s razor holds true: the number of throws needed to build a knot that does not untie. Although 3 throws untied more readily than 4, and 4 throws untied more readily than 5 throws, no statistical difference regarding the likelihood of untying was found between tying 5 throws versus 6. Because the material had no effect on the results, we can conclude that 5 throws generate the maximum amount of strength necessary to protect against untying. More throws do not seem to provide additional knot security. One explanation for this effect is that the friction between

**FIGURE 2.** Drawing of a tensiometer with a suture placed on the hooks.

**FIGURE 3.** Mean tensile strength for suture material and number of throws.
throws of large gauge 0-0 suture is high. Therefore, the added resistance of additional throws does not alter the tension at breakage significantly. Using fewer throws to create a knot of the same strength has benefits of preventing an excessive amount of tissue reaction when absorbable sutures are used. With permanent sutures, using fewer throws minimizes the foreign body reaction. Ultimately, however, the quality of the knots is more important than the number of throws. “Air knots” that do not compress a vascular pedicle can have the ideal number of throws but not stem a hemorrhage. The effect of “air knots” was not evaluated in this study. Surprisingly, the suture material memory did not change the number of throws needed for an appropriately secure knot. For suture with a high memory, such as polypropylene, the surgeon’s knot plus 3 additional square knots secured the suture appropriately. The finding that no knots failed because of slippage also suggests that suture material memory may be an important factor in knot security. For the additional seconds it takes to complete a fifth square throw, the surgeon can decrease the rate of knot untying significantly.

With the increased prevalence of vessel sealing technology and stapling devices for surgical procedures, the basics of knotting suture should not be forgotten. Although tying a secure knot might not be important on every pedicle, it is vitally important for some. Every surgeon should know the difference between half hitches, a granny knot, and a square knot. Quantitative measurements, including the number of newtons at failure, distinguish this study from common instructional resources on knot tying, for example, a video in which knots are broken by hand. The narrator in the video states that 4 throws are required for a secure knot, although neither the suture material nor the rates of untying are described. We sought to examine different knot configurations systematically to provide surgeons with objective data for evaluating knot security.

One strength of this study is that it examines suture material currently used in the field of pelvic reconstructive surgery. Prior studies have used gauges and suture material that is no longer supplied. The study of suture tying is clinically relevant because small changes in tying can affect the entire surgery. By reducing the number of throws, a surgeon might decrease operating time and potentially decrease the rate of morbidity.

The question of knot security is clinically important and has not been answered by prior research using these sutures or gauges. As with all in vitro research, this study has limitations. Soaking the suture material in saline was an attempt to mimic intraperitoneal conditions, but the absorption of liquid is likely different for each material. We applied an elongation rate of 5 mm/minute and monitored tensile forces. Physiologic rates of loading during resting, reflex motions (e.g., coughing), voluntary motions (e.g., valsalva), activities (e.g., exercise), or extreme/explosive activities (e.g., motor vehicle collision) may exert more force over a shorter time period and at different rates. Knots are inherently tensioned differently by various surgeons; therefore, the use of machine-tied knots would isolate variability. Repeating the study would add to the validity of the results, as variance among different surgeons could also be analyzed.

A 5-throw knot meets the definition of knot security. In conclusion, under laboratory conditions, the ideal knot has 5 throws to maximize tensile strength and rate of untying.

REFERENCES


