Assessment of Four Tissue Models on Knot Tensile Strength

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OBJECTIVE: To determine whether the tissue model onto which a knot is tied influences the knot's tensile strength.

STUDY DESIGN: Zero-gauge, nonexpired, silk, polyglactin 910, polydioxanone, and polypropylene sutures were tied on 4 different mock tissue models. The tissue models were standard metal hex head screw, uncooked chicken breast, a tube of packaged "string" cheese, and a cylinder of bubble wrap. The knots were tied without a surgeon's knot and with 4 additional square knots (1 = 1 = 1 = 1 = 1). The knots were tied by a single obstetrician/gynecologist investigator (J.M.D.) over the period of 1 week to minimize fatigue. We compared the knots when subjected to a tensiometer until the suture broke or untied. A minimum of 20 knots per group were needed to detect a moderate effect size with a power of 85% and a type I error rate of 5%.

RESULTS: A total of 407 knots were tied with 4 types of material (silk, polyglactin 910, polydioxanone, and polypropylene), using 4 different models (chicken, bubble wrap, cheese, and metal). Among the knot failures, 113 of 407 untied rather than broke (28%). No differences in the likelihood of knots coming untied between the different models ($p = 0.34$) or tension at failure ($p = 0.81$) were noted. A 4×4 factorial analysis of variance (ANOVA) was conducted to determine the effects of the suture material and model type on tension at failure and whether there was any interaction between the 2 factors. No significant difference was observed in the interaction between suture material and model type ($p = 0.35$), and no effect for model type was found ($p = 0.22$).

CONCLUSIONS: Tissue models that use materials more similar to human tissue do not seem to influence knot strength when compared with standard metal models. We propose that it is possible to have an accurate understanding of how knots withstand force and to simulate an in vivo environment by using low-cost, easily accessible natural and synthetic materials for the mechanism onto which the knot is tied. (J Surg 69: 13-16. © 2012 Association of Program Directors in Surgery. Published by Elsevier Inc. All rights reserved.)

KEY WORDS: suture techniques, tensile strength, suture knot, polyglactin 910

COMPETENCIES: Patient Care, Medical Knowledge, Practice Based Learning

INTRODUCTION

The stability of a surgeon's suture ligature skill is of utmost importance in maintaining wound closure integrity. The assessment of knot tying and other surgical skills has traditionally been a subjective undertaking; however, the importance of objective feedback is recognized.[1] Several curricula for teaching knot tying have been proposed and evaluated. In the same way that we evaluate the surgeon objectively, instruments are needed for measuring suture materials used in simulation laboratories.

In 1995, Dinsmore[2] described the importance of studying knots for an in vivo environment. In addition, recent studies emphasize simulating the in vitro environment with regard to suture material and effects on the knot itself. Studies have been performed by tying knots onto synthetic materials, including aluminum rods, metal rings, and plastic tissue models.[3-5] To have an accurate understanding of how knots withstand force, it is possible that a more complete in vivo environment must be maintained, including the mechanism onto which the knot is tied. Teaching simulation laboratories have used animals (chicken thighs and pig feet) as well as industry-produced human skin-like products. Industry manufactured products can be expensive and difficult to obtain. The cost of training mate-

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rials is one of the largest obstacles to training health care providers in less affluent countries.[6]

The purpose of our study is to determine whether the tissue model onto which the knot is tied varies the results of the knot's tensile strength and rate of untying by comparing 3 models meant to simulate human tissue to a commonly used metal screw model.

MATERIALS AND METHODS

Four suture materials were chosen for the study: silk (Ethicon, Inc, Somerville, New Jersey), polyglactin 910 (Vicryl; Ethicon, Inc), polydioxanone (PDS-II; Ethicon, Inc), and polypropylene (prolene; Ethicon, Inc). Zero-gauge United States Pharmacopeia sutures were used for all experiments. Three tissue models were constructed and compared with a commonly used metal hex head screw model that served as the control.[7] The tissue models were constructed so the suture material could be removed without interrupting the knot. The first model included uncooked chicken breast warmed to room temperature (Boneless Skinless Breast; Tyson Foods, Inc, Springdale, Arkansas) that was used to simulate tying to dense human connective tissue. The chicken breast provided real tissue quality and feel that is absent in other trainer models. Second, a 3-cm cylinder of barrier-sealed bubble material for protective wrapping of mailed items with 0.5-in bubble diameters (3M Scotch Bubble Cushion Wrap; 3M, St Paul, Minnesota) was used. Third, a tube of packaged cheese (Vermont Sharp White Cheddar Cheese Sticks; Sargento Foods, Inc, Plymouth, Wisconsin) was used for its ease of slicing to remove the knotted suture. In addition, because the cheese was packaged, it provided a more realistic suppleness to simulate the tissue compared with the "stiff" feel of the hex head screw model (see Fig. 1).

Knots were tied without a surgeon's knot and with 4 additional square knots (1 = 1 = 1 = 1 = 1).[8] The knots were tied by a single obstetrician/gynecologist investigator (J.M.D.) over

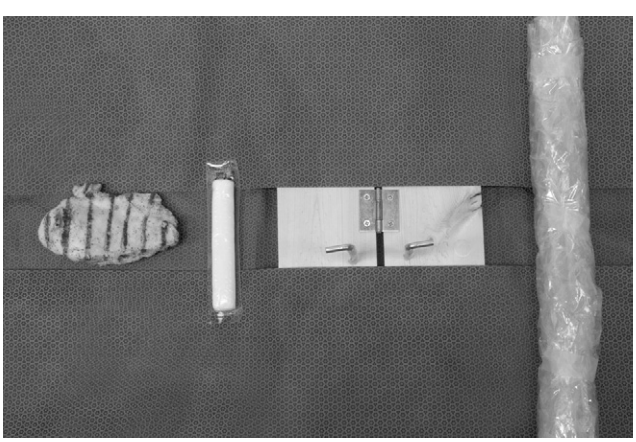

FIGURE 1. Various types of tissue models. Of note, we used uncooked chicken although we photographed a cooked breast for food safety reasons.

the period of 1 week to minimize fatigue. The 4 tissue models were randomized into sets of 16 unique material-tissue model combinations. Each randomized set was tied separately to avoid performance bias. All knots were tied wearing surgical gloves. The knots were soaked in 0.9% sodium chloride solution for 60 s to mimic in vivo conditions. The tied suture was then transferred immediately to a Chatillon LTCM-100 tensiometer (Ametek, Largo, Florida) where the tails were cut to 3-mm lengths.[9] 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 the tensile strength or tension at failure was defined as the tensile force (N) measured at failure.

To determine the effects of knot type and material on knot strength, we conducted an analysis of variance (ANOVA) with tests of main effects for both factors and their interaction. Our prior research demonstrated moderate differences between different material types. This study was powered conservatively to detect a moderate effect size ($f = 0.25$) among the different model types. A minimum of 20 knots per model type were needed to detect the small effect size with power of 85% and a type I error rate of 5%. To buffer against unanticipated variability in the tensile strengths, we boosted the number of knots per tissue model to 25 for a total of 400 knots.

RESULTS

A total of 407 knots were tied with 4 suture materials (silk, polyglactin 910, polydioxanone, and polypropylene), using 4 different tissue models (uncooked chicken, bubble wrap, cheese, and metal). Descriptions of the Newtons at failure and likelihood of coming untied for knots of each material and tissue model combination are presented in Table 1. In all cases, knots that began to unravel continued to untie completely. The loads needed to break suture were always greater than those required for suture untying.

χ^2 analyses revealed no difference in the likelihood of knots coming untied between the different tissue models ($p = 0.34$). An independent samples t test showed a statistically significant difference in tension at failure ($p < 0.001$) between the knots that untied (mean = 34.0, SD = 20.6) and those that broke (mean = 86.8, SD = 20.3). One-way ANOVAS demonstrated that the knots tied on the 4 tissue models did not differ in tension at failure ($p = 0.81$). As would be expected, there were differences between the different suture materials ($p < 0.001$, Fig. 2). A 4×4 factorial ANOVA was conducted to determine the effects of suture material and model type on tension at failure and whether or not there was any interaction between the 2 factors. There was no significant difference in interaction between suture material and model type ($p = 0.35$), nor was there an effect for model type ($p = 0.22$).

TABLE 1. Ultimate Load in Newtons Required for Failure by Suture and Jig Type

Suture Material	Tissue Model	n	Mean	SD	n Untied	% Untied
Polydioxanone	Metal	25	83.4	35.8	6	24.0
	Bubble wrap	25	85.7	32.1	5	20.0
	Cheese	26	79.9	36.2	7	26.9
	Chicken	25	91.1	26.5	2	8.0
	Total	101	85.0	32.7	20	19.8
Polypropylene	Metal	25	79.8	15.2	2	8.0
	Bubble wrap	25	85.9	18.0	1	4.0
	Cheese	28	87.6	14.1	2	7.1
	Chicken	25	69.9	29.9	4	16.0
	Total	103	81.0	21.0	9	8.7
Silk	Metal	25	58.4	6.6	3	12.0
	Bubble wrap	24	47.2	15.2	11	45.8
	Cheese	26	55.9	12.2	5	19.2
	Chicken	25	44.4	15.5	10	40.0
	Total	100	51.6	13.9	29	29.0
Polyglactin 910	Metal	25	64.1	35.6	15	60.0
	Bubble wrap	27	62.1	39.1	18	66.7
	Cheese	26	73.0	36.5	14	53.8
	Chicken	25	83.9	43.9	8	32.0
	Total	103	70.6	39.3	55	53.4
Total	Metal	100	71.4	28.2	26	26.0
	Bubble wrap	101	70.3	32.3	35	34.7
	Cheese	106	74.4	29.3	28	26.4
	Chicken	100	72.3	35.1	24	32.0
	Total	407	72.1	31.2	113	27.8

SD, standard deviation.

DISCUSSION

As surgeons attempt to standardize suture testing methods, various methodologies should be reported to allow for a comparison between studies in the form of a meta-analysis. Critics of prior studies stated that the inability for the suture to "bite" into soft tissue when using a hex head screw tying model may have caused lower tension at the point of knot failure or an increased proportion of knots that untied.[10] This ex vivo experiment showed that multiple types of suture materials did not differ in knot strength or rate of untying between a standard metal model and 3 models meant to simulate human tissue more closely constructed from synthetic and natural products. Therefore, standards for testing have been refined in this article.

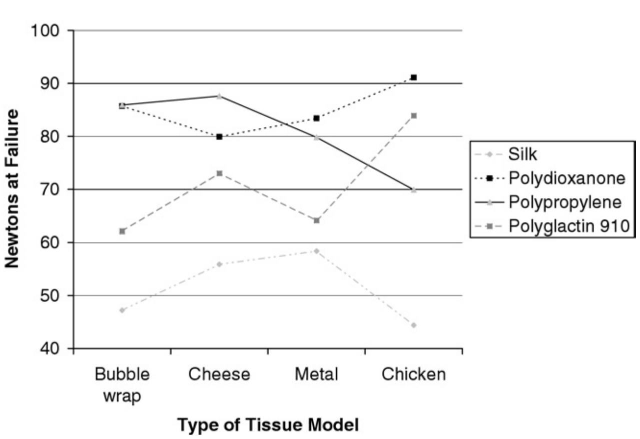

FIGURE 2. Mean tension at failure for knot material and jig type.

Surgical knot tying boards, provided by suture manufacturers, are practice tools that assist in teaching novice learners how to tie knots. However, knot tying kits are not always available at the time of a learning opportunity, are complex to make, and are not designed for removing suture without cutting the knot.[11,12] The total cost of all four tissue models in our study was $22.00, which is one third the cost of 1 commercially available knot-tying tissue model.[13] We suggest using these models, which can be found easily in the hospital cafeteria or the local hardware store. Training on simple and portable models with practice and feedback is an effective and inexpensive way of improving surgical trainee performance.[14] The portability of some synthetic models makes them ideal to take into the operating room for practice before operating on a live patient.

There have been no systematic reviews of the suture and/or knotting properties since the work published by Dinsmore[2] more than 16 years ago.[2] The testing method most studied is the separation rate of looped sutures at variable speeds. These data are of variable quality and their interpretation can give contradictory conclusions.[7,15] We attempted to standardize the tissue model for tying knots after criticism was leveled at our technique of tying on a model with metal hex head screws in a prior study.[10] Previous authors have tied their knots around a stainless steel mandrel of 38-mm diameter,[16] around a plastic mandrel of 33-mm diameter,[17] onto a device that consisted of 2 metal cylinders with a diameter of 10 mm and fixed on a board at a distance of 65 mm,[18] and around 2 polished stainless steel rings.[19] Some authors have not defined what they tied the knots around. Moreover, when using 2 different tissue models to test the tensile strength of robotically tied knots, 2 sets of independent researchers came to the same conclusions noting that the tissue model does not matter.[20,21] Before settling on these 4 tissue models, we considered tissue models of ballistics gel, felt, and other materials.

The advantages of our animal-saving models are several, including the following: (1) low cost, (2) ease of assembly, and (3) reproducibility of results. The 4 ex vivo models provide a substitute to living flesh. The models are sophisticated enough to serve as a platform for nontrivial applications, such as teaching to tie without excessive force. Excessive force can result in the loss of the uteroovarian pedicle high in the pelvis or avulsion of a vessel. These simple models can be used to practice knot tying as well as to practice not applying too much force to the item being ligated.

We demonstrated that it is possible to tie equally strong knots with 4 different tissue models. These inexpensive reproducible models for knot tying enable us to tie numerous sutures, minimizing the risk of calibration bias. In conclusion, we plan to continue using the metal hex head screw model for knot-tying studies. Our research group is currently performing a systematic review to identify deficient areas of study in the knot-tying literature.

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