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RESEARCH ARTICLE

Relationship between applied load and clearance in suture knots

Amena S. Shermadou[1] **Steven R. Lindheim**[2] **Jerome L. Yaklic**[2] **Tarun Goswami**[1*]

[1] Department of Biomedical, Industrial and Human Factors Engineering, Wright State University, Dayton, OH 45435, USA
[2] Department of Obstetrics and Gynecology, Boomshoft School of Medicine, Wright State University, Dayton, OH 45435, USA

Correspondence to: Tarun Goswami, Department of Biomedical, Industrial and Human Factors Engineering, Wright State University, Dayton, OH 45435, USA; Email: tarun.goswami@wright.edu

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Abstract: Ethicon Coated Vicryl absorbable sutures of different diameters were studied in order to determine if a relationship exists between the load and measured clearance. A prototype was designed to simulate knot location. Tensile tests were conducted on the suture knots followed by clearance measurements after each load level was applied. From the results it was concluded that the measured clearance was directly proportional to the amount of load applied to the suture knot. Also, based on the diameter of the suture, the smaller the diameter, the lower was the total displacement of the knot or the clearance.

Keywords: suture knot, knot clearance, biodegradable, biocompatibility

1 Introduction

Sutures are sterile surgical thread used to hold skin, tissue and organs together after an injury or surgical incision. Sutures represent a biomaterial market share of $1.3 billion a year [1–8]. Suturing is a technique that has been used for at least 4000 years [1]. There are two different types of sutures: absorbable sutures and non-absorbable sutures [3]. Absorbable sutures are typically used internally because they break down in the tissue as the wound/incision heals. Absorbable materials of sutures do not have to be removed once the wound is healed because they dissolve throughout the healing process. Example materials of absorbable sutures are Polyglactin, Polyglycolic Acid, and Catgut [2]. Non-absorbable sutures are normally used superficially on skin. They are made to resist the body's attempt to dissolve. Once the wound or incision heals, medical personnel must remove the non-absorbable sutures. Some of the materials used to make non-absorbable sutures are silk, steel and polyester [1–3]. (see Figure 1)

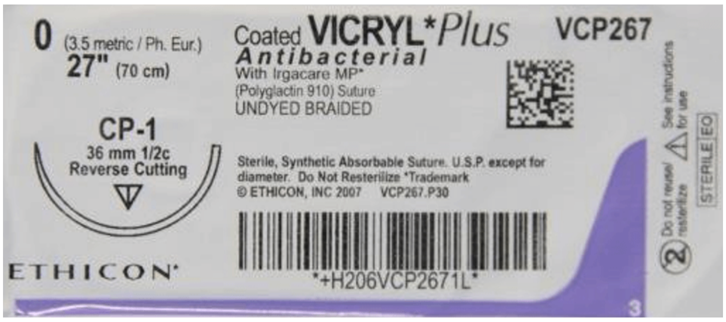

Figure 1 Ethicon Coated Vicryl Sutures used in this study to test the tensile strength on the suture knot. Pictured is the packaging for the size 0 suture.

Important characteristics of suture materials are that they must be strong to avoid breaking under loads. If the patient accidentally overexerts themselves in the area of the stitches this can cause the suture to break. The material also needs to be compatible with the human body to prevent toxicity and allergic effects to the patient. Because the body tries to reject the suture as it is considered a foreign object, the material needs to be able to resist the body's ability to fight it. The suture material must also be able to withstand sliding because this will cause easy loosening of the knots, which will lead to fluid passing through causing infections [1].

Major problems with sutures include the excessive tightening or loosening of knots. These problems can cause infection due to fluid passing through different layers and can cause lacerations due to skin or tissue breaking [5]. The problems with loosening or tightening of the skin can be due to lack of consistency among doctors with knot tying. The fact that surgeons do not have haptic feedback capabilities, in robotic surgery performed from a distance, they aren't able to determine how tight or loose a knot might be on the patient. Patients can also cause the loosening of knots because of overexertion and excessive movements in or around the wound/incision site. Therefore, there is a need to understand the art of suturing, number of throws to apply in a "knot" and then knowing how the knot will pull under the action of load after a wound is closed. These questions motivated this research undertaken by an undergraduate student in biomedical engineering.

2 Materials and methods

The type of suture that will be used is an absorbable suture made by *Ethicon*. The material is polyglactin. The tests were conducted using a *Test Resources* Tensile Strength Machine. These machines have clamps [6–8] that held the sample being tested. Because sutures are made of fine surgical thread, coarse sandpaper was used to ensure the suture is secured between the clamps (Figure 2a). The base used to tie suture knots on was a standard kitchen sponge wrapped and secured with Liquid Nails glue around a small wooden, cylinder. A cut was made along the length of the sponge as the location of where the surgical knots were tied. A total of three knots were made using the 'surgeon's knot'. Each knot was spaced 18mm apart (Figure 2b). The initial clearance was found by measuring the distance from the deepest point of the cut to the knot before being stretched. Each suture knot was tested at 5, 10 or 15 Newton's (N), (1 load value per knot).

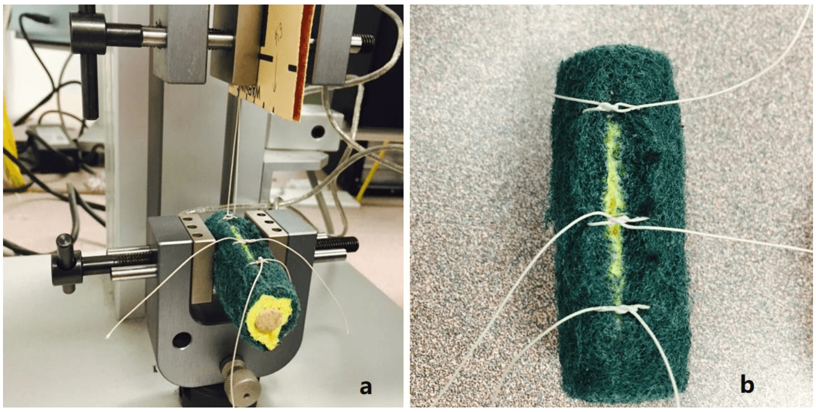

Figure 2 **a**: Prototype loaded in tensile machine with one knot secure in between the clamp with sandpaper; **b**: Three suture knots tied onto prototype made of sponge, 18 millimeters apart.

The testing procedure was standardized prior to beginning the actual test. In order to make sure that the knot tested was being pulled in a perpendicular direction, three marks were made on the sandpaper that corresponded to the three knot points on the sponge. That way, when the next knot was tested the position on the sandpaper would change accordingly to keep the perpendicularity between the knot and the suture thread being pulled. The final setup can be seen in Figure 3 and 4.

Once the prototype was secured within the upper and lower clamp of the tensile test machine, it was necessary to set boundaries on the machine to specify the information that was needed for collection (the load and the stretch amount). The position rate specifies how many millimeters (mm) per minute the prototype will be stretched. This was set as 0.3 millimeters/minute. Next, the maximum load had to be identified in order for the machine to stop applying load once the set max load has been reached. Since the sutures were tested at 5N, 10N and 15N, the maximum load was entered in increments of 5N as the value of load the suture was being tested. After each load increment was reached, a digital caliper was used to measure the clearance based on the stretch after load application. Once this value was measured, the initial clearance was determined by subtracting the initial clearance from the final clearance.

3 Results

Table 1 shows the results of tensile testing using the Vicryl Polyglactin Suture, Sizes 0, 2 and 4. In addition to collected data, the correlation coefficient was calculated using Matlab software in order to mathematically support the relationship between increased tensile load and clearance. All three plots are the Load(N) *vs.* Position (mm) for Knot 1 of the three different size sutures

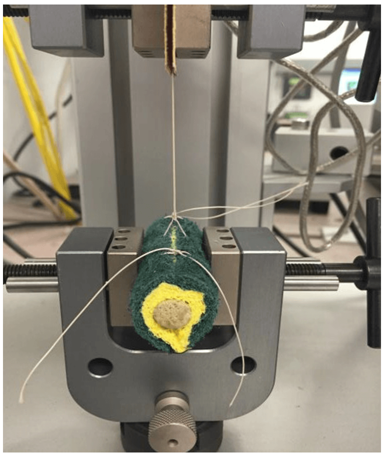

Figure 3 Front profile of knot displacement as the tensile machine applies 10 N.

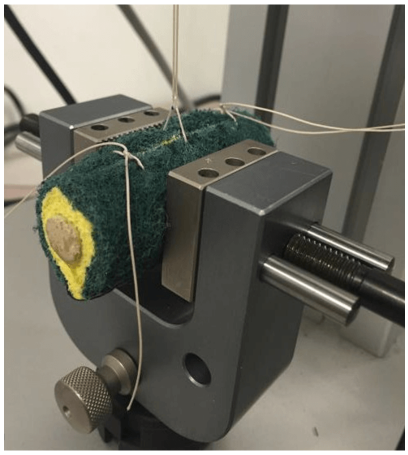

Figure 4 Side profile of knot displacement as the tensile machine applies 10 N.

(Size, 0, 2 and 4, respectively) used in this study. In Figure 5, Plots describe the Load(N) *vs.* Position (mm) for Size 0 (knots, 1, 2 and 3, respectively) used in this study. In Figure 6, Plots describe the Load(N) *vs.* Position (mm) for Size 2 suture (Knots 1, 2 and 3, respectively) used in this study. In Figure 7, Plots show Load(N) *vs.* Position (mm) for Size 4 suture with (Knot 1, 2 and 3, respectively) used in this study (as the diameter decreased, linearity in the trend seen for size 4, whereas at higher diameter the relaxation may have taken place during hold).

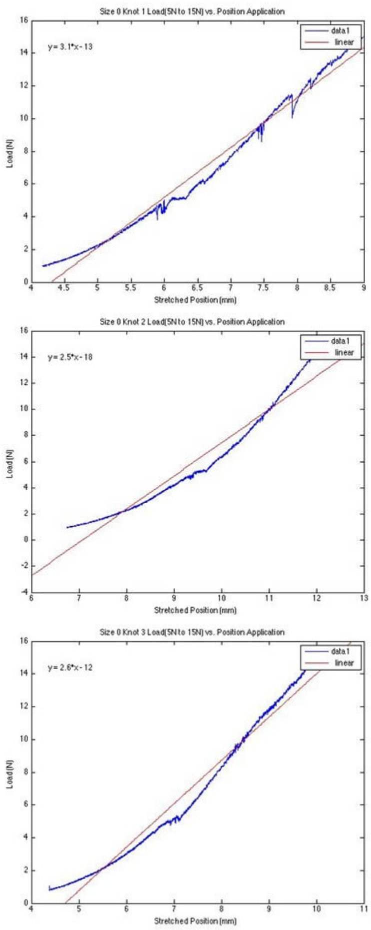

Figure 5 Load(N) *vs.* Position (mm) for Size 0 (knots, 1, 2 and 3, respectively)

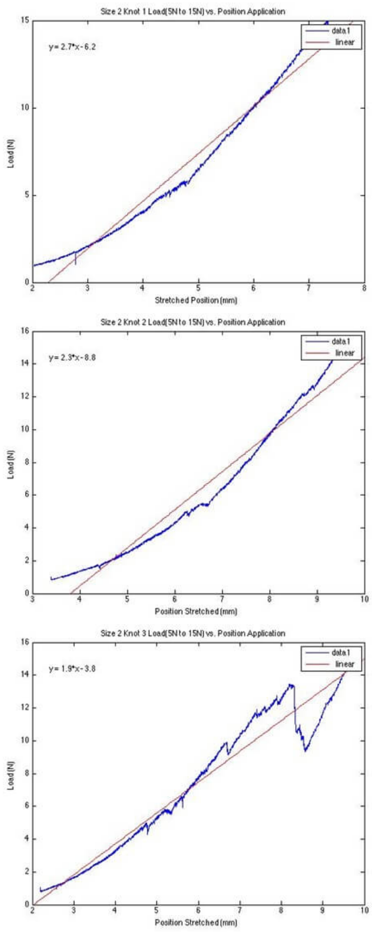

Figure 6 Load(N) *vs.* Position (mm) for Size 2 suture (Knots 1, 2 and 3, respectively)

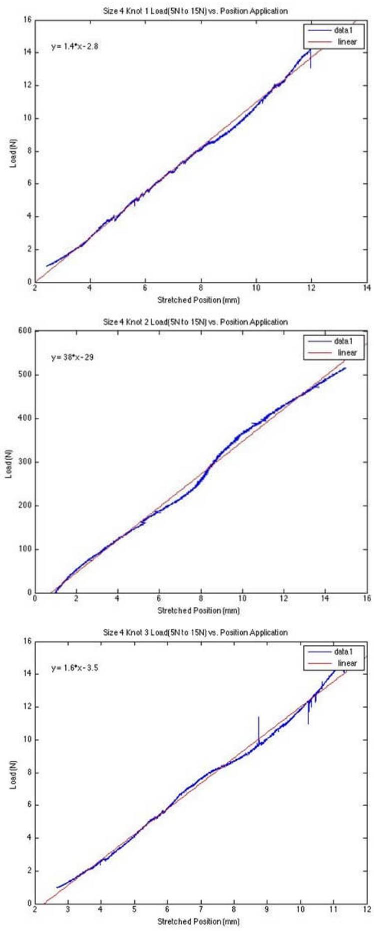

Figure 7 Load(N) *vs.* Position (mm) for Size 4 suture (Knots 1, 2 and 3, respectively)

Table 1 Results of tensile testing using the Vicryl Polyglactin Suture

Size	Load (N)	Knot 1	Knot 2	Knot 3
		Final Clearance (mm)	Final Clearance (mm)	Final Clearance (mm)
Ethicon Coated Vicryl, Size 0	5	3.30	2.52	3.38
	10	7.33	7.03	6.57
	15	9.52	10.20	10.39
	Correlation	0.99	0.99	0.98
Ethicon Coated Vicryl, Size 2	5	5.41	5.58	5.44
	10	6.55	6.61	6.75
	15	8.62	8.36	8.58
	Correlation	0.96	0.94	0.98
Ethicon Coated Vicryl, Size 4	5	5.67	5.20	5.34
	10	6.92	6.86	6.72
	15	7.77	7.92	7.83
	Correlation	0.99	0.99	0.99

4 Discussion

The amount of load applied to a suture knot is crucial in the health of the patient. If a suture knot is either too loose or tight, complications can arise for the patient. When a suture knot is too tight, lacerations and broken tissue surrounding the stitch may become infected. If the suture is too lose, fluid passage can occur and some areas of the body can be exposed to other areas causing bacteria and infections.

Based on the results, it can be seen that within a single suture type, the clearance measurements remain consistent across all three knots on the prototype. In addition to that based on the the data, load *vs.* the stretched position resulted in a clear linear relationship between the variables. These results can be seen with each suture size. It can be seen that even when the same test was conducted with different suture diameters, the proportional relationship between the load and displacement remained consistent and agrees with the other suture size results.

From a mathematical standpoint, the results from the calculated correlation coefficient confirm that a relationship between the tensile load and displacement of the knot does exist. The results from calculating the correlation coefficient can be a value around +1, 0 or -1. If the value is close to +1, this means a direct relationship exists. If the value was a small number close to 0, the variables are statistically not significant. Lastly, if the result of calculating the correlation coefficient is a value close to -1, the variables are related but completely different. As shown in Table 1 above, the correlation coefficients calculated for all different sizes of sutures ranged from 0.94-0.99 thus concluding a direct proportional relationship between the displacement and the tensile load.

A line of best fit was included in the plots of Figure 5, 6 and 7 with a corresponding slope value. The slopes stayed consistent ranging from 2.5-3.1 with some outliers. Possible sources of error that could have caused a few varied results were due to measuring techniques. Since the clearance was measured while the suture was still held in the clamps during the collection process, any nudge or slight movement involving the suture resulted in a bump in the plots. These can be seen around the area were the line intersects with 5N, 10N or 15N on the y- axis. Improvements to the measuring techniques would allow for more accurate data and thus less skewed results.

From the comparison of the different suture sizes, it can be seen that as the diameter of the suture decreased from size 0 to size 4, the displacement range between the 5N clearance measurement and the 15N clearance measurement, decreased from one suture size to the next. This can be due to the stiffness of the sutures. The smaller the suture, the less flexible the suture was and because of this, it did not stretch as much while the load was being applied. Finer sutures like the size 4 sutures are typically used for areas that have higher tension and that is clear from the results that it would take more tension to allow for more displacement.

5 Conclusion

(1) As the load applied increased, the knot displacement increased. (2) The tests for all three knots showed similar results that verified the relationship between the load and the knot clearance was directly proportional at 3 load levels. (3) The direct proportionality did not change due to suture size. (4) Both the correlation coefficient and the slopes of the line of best fit for the plots, confirm the proportionality relationship. (5) The smaller the suture size, the smaller the displacements range between the knot location at 5N and the knot location at 15N.

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