Biomechanical evaluation of finger trap suture variants for securing catheters

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Objective—To biomechanically evaluate various finger trap patterns and suture materials for securing 5F polyvinylchloride and polypropylene catheters.

Design—In vitro prospective study.

Sample—132 finger trap constructs.

Procedures—Each group of constructs comprised 6 to 10 replicates each of 3 finger trap patterns tied with 2-0 glycolide-lactide copolymer (GLC), braided nylon, and monofilament polypropylene suture on 5F polypropylene and polyvinylchloride catheters. The 3 finger trap variants were of similar lengths but differed in the number of surgeon’s throws included in the pattern. Constructs were tested with a universal materials testing machine to the point of failure or a maximum of 100 mm of distraction. Force and distraction data were evaluated for significance with a competing risks model.

Results—There was no difference in performance (as measured by the proportion of test failures, median distraction distance, or median force at failure or end of testing) attributable to the finger trap pattern variants. Sixteen of 66 constructs with polyvinylchloride catheter material failed at ≤100 mm distraction, whereas all polypropylene constructs failed during testing. For polypropylene catheters, braided nylon or GLC suture withstood greater distraction distance and force, respectively. For polyvinylchloride catheters, differences among suture types were nonsignificant.

Conclusions and Clinical Relevance—Data suggested that, for the material combinations evaluated, a finger trap suture pattern with fewer knots may provide catheter security similar to that for patterns tied with a more traditional pattern. These results should not be extrapolated to catheters of different diameters or materials, patterns tied with different suture sizes, or clinical performance in vivo without further testing. (J Am Vet Med Assoc 2015;246:515–521)
preference for braided versus monofilament suture was not reported. Smeak13 described a technique of placing a 0.5- to 1.0-cm section of suture through the skin approximately 1 to 2 cm away from the tube exit site and tying a square knot with equal suture end lengths. The ends were tied to the tube by use of a surgeon’s knot, then crisscrossed down the tube, with 4 to 6 surgeon’s knots spaced 0.25 to 0.50 cm apart that slightly compressed the tube without compromising the lumen.15

The tension placed on the tube by the knots reportedly resulted in constriction of the suture pattern, resulting in increased catheter hold.13 More recently, Radlinsky10 described the finger trap as a suture pattern initiated with a purse-string suture through the skin around the base of the tube, tied with 2 square knots, leaving 2 equal lengths of suture. The pattern proceeds away from the patient along the tube where suture ends are crossed on the side of the tube adjacent to the patient and tied on the contralateral side with a surgeon’s throw that slightly compresses the tube.11 The suture crossing on the patient side and contralateral surgeon’s throws are spaced at least as wide as the tube diameter, and ≥ 6 crossings and surgeon’s throws are placed.10 The pattern is finalized with 2 square knots.10 Anecdotally, we have encountered numerous other variations on the theme.

Other investigators have biomechanically evaluated and compared finger trap sutures with 4 knots to the 4 friction suture technique with nonabsorbable suture and a variety of tube materials and diameters in a cadaver model.16 However, to our knowledge, an objective, biomechanical study evaluating the biomechanical properties of alternate knot placement, fewer knots, and suture and catheter material influence on security of catheters affixed with finger trap sutures has not been performed. The aims of the study reported here were to examine the influence of catheter material, suture material, and finger trap knot patterns on catheter security as well as to describe an alternate model for testing. The null hypothesis was that there would be no significant difference among finger trap styles, suture types, or catheter materials in resistance to axial load.

Materials and Methods

Leather swatches (40 × 20 × 3 mm; n = 132) were fabricated with 2-mm-diameter holes positioned 10 and 14 mm from 1 end on midline of the long axis. For each suture type, catheter type, and finger trap variant, a single square knot tied between the 2 holes secured the suture to the leather swatch, leaving 2 suture ends of approximately equal length. All finger trap variants were tied by 1 surgeon experienced with the techniques; 2-0 GLC,a monofilament polypropylene,b and braided nylonc suture materials were used to create finger traps on 5F polypropylenea and polyvinylchloridec catheters placed so that 1 end extended 110 mm through the swatch (Figure 1). A permanent marking pen was used to create reference lines on the proximal and distal sides of the final knot to facilitate evaluation for slippage.

Finger trap variant techniques—Three finger trap variants were created (Figure 2). The first (finger trap variant 1; n = 52) was a traditional type of finger trap pattern currently used in the authors’ practices similar to the technique described by Radlinsky.10 The 2 suture ends affixed to the leather swatch were crossed under and around the catheter, and a surgeon’s throw was placed on the surface of the catheter facing the swatch hole located 14 mm from the end on midline (ie, proximal surface), with sufficient tension to slightly indent the tube. The strands were crossed under and around the tube, and another surgeon’s throw was placed on the proximal surface with sufficient tension to slightly indent the tube. This was repeated 4 more times and finalized with a square knot on the sixth repetition. The distance between locations where the sutures crossed was equal to or greater than the tube diameter.

The second finger trap variant (finger trap variant 2; n = 44) was created by affixing suture to the leather swatch and crossing the suture ends under and around the catheter as described in variant 1, but without surgeon’s throws on the proximal surface for the first 5 repetitions (these were replaced by simple crossing of the suture ends). A surgeon’s throw that slightly indented the tube was used to complete the sixth repetition, and the pattern was finished with a square knot (Figure 2).

A hybrid between finger trap variants 1 and 2 was also created (finger trap variant 3; n = 36). The 2 ends of suture affixed to the leather swatch were crossed around the catheter as described in finger trap variant 1, with a surgeon’s throw that slightly indented the tube used to complete the first repetition and the sixth repetition; suture was crossed on the proximal side for the
out at 5 mm/s. Displacement began as force was applied
time. Sampling frequency was 50 Hz with rate of pull-
recorded force and distraction distance as a function of
data acquisition via the serial port, and the softwareg
43 mm for all constructs. A transducer was connected
tances of the catheter through the eyed adaptor and then
catheter was affixed to an eyed adaptor on the materi-
to the catheter and stopped at failure or after reaching
100 mm of distraction. Failure was defined as suture
breakage, suture slippage, or catheter breakage. Suture
breakage included any detectable unraveling or break-
age of any portion of the finger trap suture. Suture slip-
page was defined as suture visibly sliding over the tube
beyond the reference marks. Catheter breakage was de-
defined as plastic deformation of the catheter. Plastic de-
formation of the polypropylene catheters was associated
with a visible color change of the material. If multiple
modes of failures occurred, the first was considered the
failure mode. All testing was digitally video recordedb
to enable repeated evaluation. Constructs with incom-
plete data collection or technical malfunction during
construct testing were excluded from analysis.

**Results**

Incomplete data collection due to errors during
testing resulted in the removal of 3 constructs from the
data analysis. A single construct of finger trap variant 1,
tied with GLC suture on a polypropylene catheter (from
a total of 10), and 2 constructs of finger trap variant 2,
tied with GLC suture on polypropylene catheters (from
a total of 10), were removed from analysis. Evaluation
of proportions of right-censored data for each level of
finger trap variant, suture, and catheter type revealed
that 35 of 51 (68.6%) constructs that involved finger
trap variant 1 failed during testing (ie, at or below the
maximum of 100 mm distraction), resulting in censor-
ing of the remaining 16 (31.4%) constructs. Twenty-
six of 42 (61.9%) constructs that involved finger trap
variant 2 failed during testing, with the remaining 16
(38.1%) censored. Eighteen of 36 (50%) that involved
finger trap variant 3 failed during testing, and 18 (50%)
censored. These were not significantly \( P = 0.213 \)
different. Denominators for the proportions of tests var-
ied because of the differing number of construct vari-
ants tested in the analysis.

Every polypropylene catheter construct failed during
testing, with 0 of 63 results censored. Sixteen of 66 (24.2%)
polyvinylchloride catheter constructs also failed, resulting
in censoring of the remaining 30 (75.8%) constructs; the difference between catheter
types was significant \( P < 0.001 \). For suture type com-
parisons, 31 of 49 (63.3%) GLC-tied constructs failed
during testing (18 [36.7%] censored), 29 of 44 (65.9%)
braided nylon–tied constructs failed during testing (15
[34.1%] censored), and 19 of 36 (52.8%) monofilament
polypropylene–tied constructs failed during testing (17 [47.2%] censored). These were not significantly (\(P = 0.455\)) different. When test results for constructs created with polyvinylchloride catheters only were considered, 8 of 26 (30.8%) GLC-tied constructs failed, leaving 18 (69.2%) censored; 7 of 22 (31.8%) braided nylon–tied constructs failed, with 15 (68.2%) censored; and 1 of 18 (5.6%) monofilament polypropylene–tied constructs failed, with 17 (94.4%) censored. These values did not differ significantly (\(P = 0.095\)). The competing risks model for finger trap data for all replicates and all combinations of variables revealed no significant differences among the 3 variants (Table 1). However, the competing risks model revealed some significant interactions of suture type and catheter material (Tables 2 and 3). For polypropylene catheters, braided nylon and GLC suture withstood greater distraction distance and force, respectively. Every polypropylene catheter tested failed through plastic deformation of the catheter material at the sites where the finger trap engaged the catheter, resulting in shorter distraction distances, compared with polyvinylchloride catheters. However,

### Table 1—Results of analysis with a competing risk model evaluating in vitro security variables for 3 finger trap constructs created with 2-0 GLC, braided nylon, and monofilament polypropylene suture on 5F polypropylene and polyvinylchloride catheters.

<table>
<thead>
<tr>
<th>Catheter Suture</th>
<th>Distance (mm)</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polypropylene</td>
<td>GLC</td>
<td>23.569 (14.0826–30.186)</td>
</tr>
<tr>
<td>Braided nylon</td>
<td>27.676 (19.3241–35.685)</td>
<td></td>
</tr>
<tr>
<td>Polyvinylchloride</td>
<td>GLC</td>
<td>99.998 (54.6550–100.060)</td>
</tr>
<tr>
<td>Braided nylon</td>
<td>99.996 (51.7092–100.058)</td>
<td></td>
</tr>
<tr>
<td>Monofilament polypropylene</td>
<td>100.027 (77.3750–100.049)</td>
<td></td>
</tr>
</tbody>
</table>

Table 2—Catheter-by-suture type interactions for distraction distances in a competing risk model comparing in vitro security variables for 3 finger trap variants tied on polypropylene or polyvinylchloride catheters with various types of 2-0 suture material.

<table>
<thead>
<tr>
<th>Catheter Suture</th>
<th>Distance (mm)</th>
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<td></td>
</tr>
</tbody>
</table>

Table 3—Catheter-by-suture type interactions for force in a competing risk model comparing in vitro security variables for 3 finger trap variants tied on polypropylene or polyvinylchloride catheters with various types of 2-0 suture material.

<table>
<thead>
<tr>
<th>Catheter Suture</th>
<th>Force (N)</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polypropylene</td>
<td>GLC</td>
<td>31.4443 (27.5745–33.2092)</td>
</tr>
<tr>
<td>Braided nylon</td>
<td>30.4525 (27.0658–34.0972)</td>
<td></td>
</tr>
<tr>
<td>Monofilament polypropylene</td>
<td>29.9298 (28.1173–31.7939)</td>
<td></td>
</tr>
<tr>
<td>Polyvinylchloride</td>
<td>GLC</td>
<td>28.2445 (21.9335–32.3499)</td>
</tr>
<tr>
<td>Braided nylon</td>
<td>28.7081 (19.3615–33.9616)</td>
<td></td>
</tr>
<tr>
<td>Monofilament polypropylene</td>
<td>27.7035 (23.8559–31.7129)</td>
<td></td>
</tr>
</tbody>
</table>
all polyvinylchloride catheter failures were attributable to slippage of the catheter through the finger trap beyond the reference marks.

**Discussion**

To our knowledge, this is the first study to biomechanically evaluate the influence of alternate finger trap patterns with respect to different suture and catheter materials. Our clinical experience is that the suture material chosen for the finger trap is often selected in a number of ways, including surgeon preference and availability (eg, suture remaining from that used for incisional closure or what is available in a limited hospital inventory). We selected 2-0 suture materials for the present study because we believed they would more likely withstand the amount of force required to slightly indent the stiff polypropylene catheter material than a smaller-diameter suture would; 2-0 suture is also the smallest diameter reported in the study by Smeak.15

The purpose of a finger trap is to secure the catheter by the suture binding against the catheter as the suture arms that cross each other are placed under traction and drawn down against the catheter. A general characteristic of braided materials is a higher coefficient of friction (so-called drag), when compared with monofilament materials.17 Our results suggested that this increased coefficient of friction does not always benefit a finger trap’s ability to provide overall catheter security, given the lack of significant difference in force and distraction distances for polyvinylchloride catheters tied with braided suture (GLC and braided nylon) when compared with monofilament (monofilament polypropylene) in vitro. The specific method for creating a finger trap can vary tremendously, and our impression is that the chosen method relies little on objective data and much more on personal opinion. Although it may seem to be a minor issue, finger trap patterns that use throws at multiple intersections of the crossing suture take longer to create and use more suture material. Furthermore, the very nature of a throw at each suture intersection would seem to prevent, or at least inhibit, the arms of the suture from sliding past each other and tightening against the underlying catheter. Finger trap variants 2 and 3 were modifications of finger trap variant 1 observed over time by the authors in their clinical practice. These variants had fewer knots than finger trap variant 1 and provided the authors with clinically based alternatives to finger trap variant 1 to evaluate the influence of knots on the finger trap–catheter interaction. Because there were no significant differences among the finger trap variants in this study, it seems most appropriate to use the simplest and most rapid method that results in a secure coupling of the catheter to the animal.

Given the degree of variability and limited objectivity in the literature describing finger trap patterns and their relative security, we sought to determine whether variations in material composition of suture and catheters, as well as variations in the finger trap pattern, had an effect on finger trap security. Although not a substitute for in vivo testing, an in vitro model for testing is a reasonable first step because it avoids patient morbidity while allowing evaluation of the interaction of the suture, suture pattern, and catheter material, all of which are physical variables that do not require animal use for assessment. We used leather swatches instead of cadaveric skin or other material to affix the materials for testing to provide uniformity in the material used to anchor the suture and to avoid some of the inherent variability of the tissues and in the amount of tissue included in the pattern when suturing the constructs to cadaveric skin. Cadaveric skin tends to be more elastic in comparison with leather and exposes the constructs to bodily fluids, which may affect construct behavior during testing and alter results. Our model did not account for the effects of fluids on the constructs; therefore, it is possible that different types and amounts of bodily fluids may alter performance of some or all of the tested constructs in a clinical setting. We chose to create a hole in the leather swatch that was larger than the catheter diameter so that only the interaction of the suture with the catheter was evaluated (vs any potential interaction between the leather swatch and catheter).

Our testing was limited to a maximum displacement of 100 mm by the equipment available for use; therefore, we did not reach a failure point (defined as catheter or suture breakage or suture slippage relative to reference marks) for all constructs tested. Although this was a limitation, we are not aware of any data that describe what a clinically relevant maximum distance of distraction of a catheter is or what amount of force resistance is required to adequately secure catheters with finger traps. We believed that distraction of 100 mm (or 2.33 times the catheter segment) was a subjectively appropriate maximum from a clinical standpoint; however, a standard has not been established. Song et al16 reported distracting larger catheter materials 27 cm in testing similar constructs to failure. The magnitude and direction of force that finger trap–secured catheters are subjected to in veterinary patients have not been quantified; therefore, there is presently no recommendation for the force these constructs
should be able to resist in the clinical setting. To our knowledge, a model for simulating the forces placed on such catheter materials by veterinary patients in a clinical setting has not been described in the literature, and previous evaluation has relied on unidirectional axial loading of materials for test purposes. Forces applied to catheters in vivo occur from a variety of directions; therefore, unidirectional axial testing may not simulate the exact forces acting on these materials in a clinical setting, and correspondingly, the interactions between catheter and suture material may vary in those circumstances. Multiplanar fatigue testing of constructs versus load-to-failure axial testing may result in differing recommendations concerning catheter security in a clinical setting. Similarly, cyclic loading to failure may result in outcomes different from our results. Findings of the present study may have clinical relevance, but the authors caution readers to view these findings as a starting place for examining the clinical utility of these constructs in live patients.

Additionally, the interactions between finger trap pattern, suture material, and catheter material are complex and dependent on factors such as suture size and composition, tube diameter and composition, and the friction generated between catheter and suture during distraction as well as suture tension. Many combinations of suture material, suture pattern, catheter size, and catheter material could have been tested, but we chose to test a limited array of combinations that, in our experience, reasonably mimicked common clinical variations. Variability in the specific dimensions of each finger trap was minimized by having 1 investigator tie all sutures. However, we did not precisely control the length of the finger trap along each catheter or degree of tension applied at each knot to simulate a more realistic clinical scenario. Most descriptions of finger trap sutures call for throws that slightly indent the catheter material; however, the optimum force required to achieve this has not been standardized and likely varies with suture composition, suture diameter, catheter composition, and catheter diameter. Furthermore, the ideal degree of catheter indentation created with the suture has not been quantified, and surgeons have therefore relied on subjective assessment for the degree of appropriate indentation in creating these patterns. These limitations may create bias in the results and are also present in a similar report. Repeating the study with > 1 individual creating the finger traps may further define the extent of finger trap construct variability and the impact of such variability on the ability of the finger trap to secure the catheter without unacceptable distortion or damage to the catheter. However, this was beyond the scope and resources available for the present study.

The use of absorbable materials for securing catheters is common in clinical practice, on the basis of the authors’ collective experience in a variety of referral and academic practices. The reasons for this are unknown but speculated to be because of the suture’s availability or common use in surgery and the variety of suture inventory, which is often limited. The present study did not account for the complex interaction and degradation of these materials as would occur in products used in vivo. The GLC suture material loses 20% of its tensile strength within 2 weeks and 70% within 3 weeks after placement in living tissue; therefore, this material should only be selected for securing short-term catheters. Other absorbable monofilament suture materials have longer resorption times but were not evaluated in this study because we were primarily interested in the physical interactions of smooth and braided sutures with the polyvinylchloride and polypropylene catheters. Another reasonable criticism of the present study would be of the comparison of monofilament polypropylene with braided nylon. Because suture materials have different physical properties, a more direct comparison would have been facilitated by the use of braided and monofilament nylon sutures. All polypropylene catheters failed during testing by plastic deformation of the catheter material by permanent elongation and luminal narrowing where the finger trap engaged the catheter, whereas failures in polyvinylchloride catheters were uniformly by slipping of the catheter through the finger trap. In the present study, we considered failure as the point at which the first sign of slippage was observed; therefore, it is possible that the finger trap patterns could have constricted as testing continued to prevent further slippage of the catheter. This phenomenon may enable continued use of a catheter in a clinical setting. We speculate that the amount of clinically acceptable slippage would vary greatly according to catheter purpose, patient size, and possibly other variables.

Load recorded at failure or end of testing may vary in part because of subtle variations in the spacing of the crossings of the finger trap along the segment of catheter undergoing distraction. Although the proportion of censored tests for polyvinylchloride catheters weakly suggested that monofilament polypropylene–tied constructs were less likely to fail at ≤ 100 mm distraction, compared with other suture materials, there was no significant difference in median distraction distance or force at failure among suture types for constructs created with polyvinylchloride catheters. The competing risks analysis revealed that, in constructs created with polypropylene catheters, braided nylon enabled the greatest distraction distance, and GLC resisted the greatest force. Our evaluation of the data suggests that for 5F polypropylene and polyvinylchloride catheters, there was no difference in security (as measured by median force and distraction distances during load testing) among the 3 finger trap variants tested. On polypropylene catheters, braided nylon or GLC outperformed monofilament polypropylene suture.

Although, to our knowledge, previous studies have not reported displacement data, we quantified the amount of distraction the various constructs tolerated. Although we do not currently know the amount of distraction that veterinary patients subject catheters to, future study may reveal this information. This has the potential to affect the clinical relevancy of the data, may help direct materials chosen for future study, and may contribute to future data sets.

Owing to the complex nature of finger trap catheter security, the authors caution that the data obtained in this report should not be extrapolated to catheters.
of different diameters or materials, patterns tied with fewer knots may provide catheter security similar to that of a finger trap tied with a more traditional pattern. From a practical standpoint, not placing throws at every crossing of the suture speeds creation of the finger trap.

References

Appendix

Summary of constructs created in an in vitro study to biomechanically evaluate various finger trap patterns and suture materials for securing SF polyvinylchloride and polypropylene catheters.

<table>
<thead>
<tr>
<th>Finger trap variant and suture type</th>
<th>Catheter type</th>
<th>Polypropylene</th>
<th>Polysorb</th>
<th>All</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Variant 1</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GLC</td>
<td>Polypropylene</td>
<td>10</td>
<td>10</td>
<td>20</td>
</tr>
<tr>
<td>Braided nylon</td>
<td>Polypropylene</td>
<td>10</td>
<td>10</td>
<td>20</td>
</tr>
<tr>
<td>Monofilament polypropylene</td>
<td></td>
<td>6</td>
<td>6</td>
<td>12</td>
</tr>
<tr>
<td><strong>Variant 2</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GLC</td>
<td>Polypropylene</td>
<td>10</td>
<td>10</td>
<td>20</td>
</tr>
<tr>
<td>Braided nylon</td>
<td></td>
<td>6</td>
<td>6</td>
<td>12</td>
</tr>
<tr>
<td>Monofilament polypropylene</td>
<td></td>
<td>6</td>
<td>6</td>
<td>12</td>
</tr>
<tr>
<td><strong>Variant 3</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GLC</td>
<td>Polypropylene</td>
<td>6</td>
<td>6</td>
<td>12</td>
</tr>
<tr>
<td>Braided nylon</td>
<td></td>
<td>6</td>
<td>6</td>
<td>12</td>
</tr>
<tr>
<td>Monofilament polypropylene</td>
<td></td>
<td>6</td>
<td>6</td>
<td>12</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>132</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Finger trap variant 1 was a traditional finger trap pattern in which the 2 suture ends were crossed under and around the catheter, and a surgeon’s throw was placed on the proximal surface with sufficient tension to slightly indent the tube. The strands were crossed under and around the tube, and another surgeon’s throw was placed on the proximal surface with sufficient tension to slightly indent the tube. This was repeated 4 more times and finalized with a square knot after the sixth repetition. Finger trap variant 2 was initiated as described for variant 1 with suture ends crossed under and around the catheter, but surgeon’s throws were replaced by crossing the suture ends on the proximal surface for the first 5 repetitions. The sixth repetition was completed with a surgeon’s throw that slightly indented the tube, and the pattern was finished with a square knot. Finger trap variant 3 was a hybrid between finger trap variants 1 and 2. Suture ends were crossed under and around the catheter as described for variant 1, with a surgeon’s throw that slightly indented the tube, placed for the first and sixth repetitions, and the pattern was finished with a square knot. All constructs were created on leather swatches with 2 2-mm-diameter holes; a single square knot tied between the 2 holes secured the suture to the leather swatch.

References