Comparison of tensile strength among simple interrupted, cruciate, intradermal, and subdermal suture patterns for incision closure in ex vivo canine skin specimens

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OBJECTIVE
To compare suture placement time, tension at skin separation and suture line failure, and mode of failure among 4 suture patterns.

DESIGN
Randomized trial.

SAMPLE
60 skin specimens from the pelvic limbs of 30 purpose-bred Beagles.

PROCEDURES
Skin specimens were harvested within 2 hours after euthanasia and tested within 6 hours after harvest. An 8-cm incision was made in each specimen and sutured with 1 of 4 randomly assigned suture patterns (simple interrupted, cruciate, intradermal, or subdermal). Suture placement time and percentage of skin apposition were evaluated. Specimens were mounted in a calibrated material testing machine and distracted until suture line failure. Tensile strength at skin-edge separation and suture-line failure and mode of failure were compared among the 4 patterns.

RESULTS
Mean suture placement time for the cruciate pattern was significantly less than that for other patterns. Percentage of skin apposition did not differ among the 4 patterns. Mean tensile strength at skin-edge separation and suture-line failure for the simple interrupted and cruciate patterns were significantly higher than those for the intradermal and subdermal patterns. Mean tensile strength at skin-edge separation and suture-line failure did not differ significantly between the intradermal and subdermal patterns or the simple interrupted and cruciate patterns. The primary mode of failure for the simple interrupted pattern was suture breakage, whereas that for the cruciate, intradermal, and subdermal patterns was tissue failure.

CONCLUSIONS AND CLINICAL RELEVANCE
Results suggested external skin sutures may be preferred for closure of incisions under tension to reduce risk of dehiscence. (J Am Vet Med Assoc 2016;248:1377-1382)

Many suture patterns and materials have been described for routine incision closure. Considerations for selection of an appropriate suture pattern and material include inflammatory response, risk of surgical site infection, knot security, tensile strength, suture handling, cost, risk of dehiscence, and speed of application. Each suture pattern has its unique advantages and disadvantages. Common interrupted external suture patterns in the skin include the simple interrupted and cruciate patterns. These patterns allow more precise approximation of the skin edges along with more security than continuous buried suture patterns. However, those external suture patterns may wick bacteria into the incised tissues that can cause inflammation and increase the risk for surgical site infection, particularly when performed with a multifilament suture material.

In the late 1800s, an intradermal suture pattern was described that avoided penetration of the epidermis, which helped to decrease wicking of bacteria from the epidermis into the subcutaneous tissues. More recently, intradermal, or subcuticular, suture patterns have been used to reduce scarring or eliminate the need for suture removal in both human and veterinary medicine. Intradermal and subcuticular suture patterns are often placed as continuous patterns with the primary holding strength from parallel bites within the dermis. The terms intradermal and subcuticular are often used interchangeably; however, intradermal will be used exclusively to describe that pattern.
tern throughout this report. A subdermal suture pattern is another type of internal suture pattern that is placed in the hypodermal layer, or white line, and has similar advantages as the intradermal pattern. Buried suture patterns may not be as secure as external interrupted suture patterns because of variations in tissue holding strength or the number of knots along a suture line.

Selection of suture patterns for routine skin closure is based primarily on surgeon preference rather than scientific evidence or surgical principles to minimize risks of infection and foreign material and reduce tension. This is partly because few studies have been performed to evaluate the various suture patterns used for skin closure in veterinary medicine. One such study only evaluated suture patterns in a clinical setting. Unfortunately, a comparison of the holding tensile strengths of common suture patterns to determine optimal skin closure has not been conducted. The primary aim of the study reported here was to compare the initial SST and MT strength at failure for 4 skin closure methods (simple interrupted, cruciate, intradermal, and subdermal) in ex vivo specimens of canine skin. Secondary aims were to assess and compare suture placement time and wound apposition among the closure methods. We hypothesized that neither the tensile strength nor wound apposition would differ significantly among the 4 methods and that the intradermal and subdermal patterns would be faster to place than the simple interrupted and cruciate patterns.

**Materials and Methods**

**Ex vivo skin specimens**

All study procedures were approved by the Iowa State University Institutional Animal Care and Use Committee. Sixty skin specimens were harvested from 30 purpose-bred Beagles following euthanasia for reasons unrelated to the study reported here. The dogs were euthanized by IV administration of an overdose of pentobarbital-phenytoin sodium solution. All skin specimens were harvested within 2 hours after euthanasia and tested within 6 hours after harvest.

A template (10 X 10 cm) was placed on the lateral aspect of the proximal portion of each pelvic limb to demarcate the skin specimens for harvesting. Each skin specimen was marked for an 8-cm skin incision with premeasured markings for suture placement by use of a customized stamp. Then, a skin incision was made in a proximal-to-distal orientation in the center of the template parallel to normal skin tension lines that extended through the biceps femoris muscle fascial plane for its entire length between the greater trochanter of the femur and the stifle joint. Following the incision, the skin specimen was harvested with minimal subcutaneous adipose tissue along the template borders. The specimens were kept moistened with laparotomy sponges that were soaked with saline (0.9% NaCl) solution until tested.

**Experimental procedure**

An electronic random number generator was used to assign 1 of 4 suture patterns (simple interrupted, cruciate, intradermal, or subdermal) to each skin specimen. Each skin specimen was affixed to a piece of cardboard with six 22-gauge needles that were located at each corner of the specimen and at both ends of the incision during suturing. The incision in the middle of each specimen was closed with the assigned pattern by use of 3-0 poliglecaprone 25 on a reverse-cutting (FS-2) needle. One investigator (EMZ) placed all suture patterns with the guidance of premeasured markings to standardize the distance between sutures. The simple interrupted skin suture pattern was initiated with the needle placed 8 mm from the incised edge (bite width, 8 mm) at the most cranial aspect of the incision. The needle and suture material were passed perpendicularly through the epidermis and dermis, crossed the incision, and passed perpendicularly through the dermis and epidermis to exit 8 mm from the opposite incised edge. A knot was tied, the suture material was cut, and the process was repeated at each premeasured marking (there was 8 mm between markings) until 11 simple interrupted sutures had been placed (Figure 1). The cruciate skin suture pattern was performed in a similar manner as the simple interrupted skin suture pattern demonstrated.

**Figure 1**—Photograph of representative canine skin specimens, each with an 8-cm incision that was closed with a cruciate (A), simple interrupted (B), intradermal (C), or subdermal (D) suture pattern. Skin specimens were harvested from the lateral aspect of the proximal portion of the pelvic limbs of 30 purpose-bred Beagles within 2 hours after euthanasia. Each skin specimen was marked for an 8-cm skin incision with premeasured markings for suture placement by use of a customized stamp; those markings are still visible on the specimens. The skin specimens were then randomly assigned to be sutured with 1 of the 4 suture patterns. The specimens were sutured and underwent biomechanical testing within 6 hours after harvest. Specimens with inadequate subdermal tissue for suture pattern placement were excluded from the study.
interrupted suture pattern, except instead of tying the suture material after the first suture was placed, another suture was placed and the ends of the suture material were tied across the incision to form an X. That process was repeated until at least 5 cruciate sutures had been placed. The intradermal pattern was a continuous suture pattern placed in the dermis parallel to the edge of the incision; the bite length was 8 mm, and the initiation site for each successive bite slightly overlapped with the exit site of the previous bite on the opposite side of the incision. The subdermal pattern was performed in the same manner as the intradermal pattern, except it was placed in the remnant of the panniculus carnosus. The intradermal and subdermal suture patterns were secured at each end with a buried knot. To minimize variability, all knots for all patterns consisted of a square knot with 3 additional throws (ie, 5 total throws). An assistant was present to cut the suture, and the ends for all sutures were ≥ 3 mm long to ensure that the knots did not come undone.

Suture pattern placement time was defined as the time from initiation of the first bite to completion of the last knot and was recorded for each skin specimen. Each specimen was photographed with a digital camera. The extent of skin apposition was assessed and measured. Skin apposition was defined as the absence of visible subcutaneous tissues and perfect alignment of skin margins in all planes. The percentage of skin apposition was calculated as (the length of the incision for which the assigned suture pattern resulted in appropriate skin apposition divided by the entire length of the incision) x 100.

After a specimen had been sutured and photographed, it was individually mounted in a custom-made stainless steel tissue-gripping fixture for biomechanical testing. The fixture consisted of 2 steel plates with a corrugated inner surface that would squeeze the specimen together with 2 turn screws on each side (Figure 2). The upper and lower fixtures were allowed to move side to side and forward and backward to allow even distribution of force over the length of the specimen as the plates were separated by the testing frame’s actuator. The fixture was secured in a material testing frame with a 1,000-N load cell calibrated and verified to be accurate to within 1% of the total load cell capacity. A surgical light was mounted in front of the specimen with a dark background mounted behind the specimen. A perpendicular strain was placed on the sutured incision by actuator displacement at a rate of 1 mm/s. Load, time, and actuator displacement data were recorded at 100 points/s. All biomechanical testing was recorded with a video camcorder to evaluate failure mode and ensure documentation of the maximum destructive force reached for each specimen. Suture pattern failure (ie, the end point for testing) was defined as light passing through the incision as seen on the dark background. The camcorder was placed at an oblique angle to the light such that the specimen mounted in the testing machine, the backdrop, and a computer monitor were in the recording field of view (Figure 3). This allowed recording of the load and displacement at the exact moment
when there was a separation of the skin and tissue edges sufficient to allow light to pass. Each specimen was evaluated with a single displacement-to-failure ramp. All recordings were reviewed to determine failure mode (suture breakage, knot failure, or tissue failure) and maximum load at failure for each specimen.

Statistical analysis
Specimens were excluded from statistical analysis if they were inadequate for suturing subsequent to harvesting or slipped within the fixture grips or if there was a machine malfunction during biomechanical testing. For example, specimens with inadequate subdermal tissue for suture pattern placement and those in which the skin separated before application of tension or for which recording of the biomechanical testing was incomplete were excluded from the analysis.

Objective outcomes of interest included suture pattern placement time, percentage of skin apposition, load at initial skin separation (measured as SST), and MT at suture pattern failure by either suture breakage or tissue failure. The data distribution for each outcome was assessed for normality by means of a Shapiro-Wilk test with a \( P < 0.01 \). Each outcome was analyzed by the use of a 1-way ANOVA in which suture pattern was the independent variable. For outcomes with significant \( F \) ratios, pairwise comparisons among the 4 suture patterns were performed by use of the Tukey honest significant difference test. A Fisher exact test was used to compare the mode of failure among the 4 suture patterns. All analyses were performed within a statistical computation website, and values of \( P < 0.05 \) were considered significant for all analyses unless otherwise specified.

Results
Of the 60 skin specimens that were collected, 6 were excluded from analysis because of inadequate subdermal tissue for suture placement, skin separation prior to tension application, or incomplete recording of biomechanical testing. Consequently, there were 13 specimens in both the simple interrupted and cruciate pattern groups and 14 specimens in both the intradermal and subdermal pattern groups.

The mean ± SE suture placement time for the cruciate pattern (261 ± 13 seconds) was significantly shorter than that for the simple interrupted (345 ± 11 seconds), intradermal (378 ± 10 seconds), and subdermal (365 ± 20 seconds) patterns. The mean suture placement time did not differ significantly among the simple interrupted, intradermal, and subdermal patterns. The mean percentage of skin apposition did not differ significantly among the 4 patterns. See Figure 1 for remainder of key.

<table>
<thead>
<tr>
<th>Suture pattern</th>
<th>Simple interrupted</th>
<th>Cruciate</th>
<th>Intradermal</th>
<th>Subdermal</th>
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<td>Suture breakage</td>
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<td>0</td>
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<tr>
<td>Tissue failure</td>
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<td>9</td>
<td>14</td>
<td>14</td>
</tr>
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<td>None</td>
<td>1</td>
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Sixty skin specimens were harvested from the lateral aspect of the proximal portion of the pelvic limbs of 30 purpose-bred Beagles within 2 hours after euthanasia. An 8-cm incision was made in the middle of each specimen, and each specimen was randomly assigned to be sutured with 1 of 4 suture patterns. The specimens were sutured and underwent biomechanical testing within 6 hours after harvest. Of the 60 skin specimens that were collected, 6 were excluded from analysis because of inadequate subdermal tissue for suture placement, skin separation prior to tension application, or incomplete recording of biomechanical testing. Consequently, there were 13 specimens in both the simple interrupted and cruciate pattern groups and 14 specimens in both the intradermal and subdermal pattern groups.
The mean ± SE SST and MT for the simple interrupted (SST, 264.764 ± 44 N; MT, 312.391 ± 36 N) and cruciate (SST, 187.21 ± 42 N; MT, 226.958 ± 41 N) patterns were significantly greater than those for both the intradermal (SST, 56.724 ± 7 N; MT, 86.164 ± 11 N) and subdermal (SST, 30.354 ± 7 N; MT, 112.015 ± 16 N) patterns. The mean SST and MT did not differ significantly between the simple interrupted and cruciate patterns or between the intradermal and subdermal patterns.

The frequency distributions for the modes of failure for the 4 suture patterns evaluated were summarized (Table 1). The mode of failure differed significantly among the suture patterns. The only mode of failure for the intradermal and subdermal suture patterns was tissue failure. Of the 13 specimens assigned to the cruciate pattern group, the sutured incision for 9 failed subsequent to tissue failure, whereas that for the remaining 4 failed because of suture breakage. Conversely, of the 13 specimens assigned to the simple interrupted pattern group, the sutured incision for 4 failed subsequent to tissue failure, 8 failed because of suture breakage, and 1 did not fail despite the application of an MT of 528 N.

Discussion

Many suture patterns are available for routine skin closure in veterinary patients; however, few studies have been performed to compare the tensile strength among those patterns.3 In the present study, we compared the tensile strength among 4 suture patterns commonly used for skin closure in veterinary patients. The simple interrupted and cruciate suture patterns withstood more tension and maintained skin apposition better during biomechanical distraction than did the continuous intradermal and subdermal patterns. Thus, our hypothesis that there would be no difference in tensile strength or wound apposition among the 4 suture patterns was disproved. Our findings suggested that use of simple interrupted or cruciate suture patterns in addition to, or in place of, intradermal or subdermal suture patterns may be preferred for the closure of wounds likely to be subjected to a lot of tension.

Results of the present study indicated that external suture patterns were stronger than buried suture patterns. Factors that varied among the 4 suture patterns evaluated included pattern type (interrupted or continuous), tissue layers engaged, and suture orientation. For incisions closed with an intradermal suture pattern, the parallel orientation of the suture material relative to the edge of the incision limited the amount of dermis between the suture line and the incision, whereas for the external (simple interrupted and cruciate) skin suture patterns, there was a standard 8 mm of dermis between the suture line and the edge of the incision. We believe this was the primary structural difference between the external and buried (intradermal and subdermal) suture patterns. In the present study, external sutures were placed 8 mm from the edge of the incision and 8 mm apart, which is consistent with current guidelines for suture application.1 Additionally, the external suture patterns penetrated all layers of the skin, whereas the buried suture patterns penetrated only 1 layer (dermis [intradermal pattern] or panniculus carnosus [subdermal pattern]). The inclusion of all tissue layers in the external suture patterns may have contributed to the increased tensile strength of those patterns, compared with the tensile strength of the buried suture patterns. The number of knots along the suture line was greater for the external suture patterns, compared with that for the continuous patterns. However, it is unlikely that the number of knots incorporated into the suture pattern affected the tensile strength of the closure because tissue failure, not suture failure, was the mode of failure for all incisions closed with the continuous suture patterns. The proportion of sutured incisions that failed subsequent to tissue failure was greater for the specimens in the cruciate pattern group than for specimens in the simple interrupted pattern group. A potential explanation for that finding might be that the simple interrupted pattern with its even distribution of knot placement did a better job of transferring tension to the suture material and away from the tissue than did the cruciate pattern. Cruciate sutures tend to pull tissue toward the center of the suture where the knot is placed, which results in stretching of the skin between 2 adjacent sutures. For the incisions sutured with the cruciate pattern that failed subsequent to tissue failure, it was the tissue between adjacent sutures that failed. Another interesting finding of the present study was that the mean MT for the subdermal pattern was numerically higher than the mean MT for the intradermal pattern, whereas the mean SST for the subdermal pattern was numerically lower than the mean SST for the intradermal pattern. We attributed that finding to differences in the depth and strength of the tissues incorporated into those suture patterns. The intradermal suture pattern was placed in the dermis, whereas the subdermal suture pattern was placed in the panniculus carnosus, which is deeper than the dermis and likely contributed to the lower mean SST for that pattern. However, the panniculus carnosus is more pliable than the dermis, which probably accounted for the higher MT for the subdermal pattern, compared with that for the intradermal pattern.

In human medicine, wound closure methods are compared primarily on the basis of infection rate or cosmesis.10,11 In the present study, apposition of the epidermal margins along the sutured incision was assessed as a predictor of scar formation. We suspect that skin apposition is positively correlated with cosmesis, but that can be only confirmed with an in vivo study. Regardless, the percentage of skin apposition did not differ significantly among the 4 suture patterns evaluated in this study.

Results of the present study indicated that the mean suture placement time was lowest for the cruciate suture pattern, which disproved our hypothesis that the continuous suture patterns could be placed faster than...
the external suture patterns. Although the intradermal and subdermal patterns were continuous, they were also buried, and ensuring that those sutures were placed in the appropriate tissue layer may have taken longer than simply passing the needle through all tissue layers as was done for the external suture patterns. A similar finding was reported by investigators of another study. In the present study, the number of throws (n = 5) applied to each knot was standardized in accordance with recommendations for continuous suture patterns given the type of suture material used provided in other studies. Generally, the knots for most interrupted skin sutures are nonabsorbable and consist of only 3 to 4 throws. The fact that all knots in the present study consisted of 5 throws might have inflated the time required to place the interrupted and cruciate patterns, compared with that typically required in clinical practice.

The primary limitation of the present study was its ex vivo nature. To our knowledge, the amount of tension typically applied to an incision following routine skin closure or that leads to dehiscence is unknown. The tensile strength of the 4 suture patterns evaluated in the present study should be objectively compared in an in vivo model to aid clinicians in deciding which pattern is best for routine closure of wounds. Although we were able to compare the tensile strength among 4 suture patterns in an ex vivo model, those results cannot be extrapolated to determine the amount of tension that can be safely applied to a routine skin closure in a live patient at rest or during exercise. Because tension is commonly encountered during the closure of wounds or defects on extremities, the skin specimens for the present study were harvested from the lateral aspect of the proximal portion of the pelvic limbs, and all incisions were made along skin-tension lines as recommended in practice. The holding strength of the subdermal pattern is dependent on the robustness of the panniculus carnosus and will vary among body locations. At the proximal aspect of the limbs, the panniculus carnosus exists as only a thin layer of fascia. Hence, variability in incision location and orientation may affect biomechanical testing results for skin suture patterns. Additional studies to evaluate other suture patterns and materials and that include determination of the in vivo tensile strength for sutured incisions at various body locations are warranted.

Results of the present study indicated that, compared with intradermal and subdermal suture patterns, external (simple interrupted and cruciate) skin suture patterns were able to withstand greater tensile strength before skin separation or complete failure. For closure of wounds or incisions in areas likely to be exposed to moderate tension, a simple interrupted or cruciate skin suture pattern should be considered as the sole method or in addition to other methods for skin apposition.

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Footnotes
b. i490 custom-made self-inking stamp, Brother International, Bridgewater, NJ.
d. Monocryl, Novartis Animal Health, Somerville, NJ.
e. DMC-TZ5, Panasonic Corp, Kadoma, Osaka, Japan.
f. Electrodynamic Material Testing System 800LE3, TestResources Inc, Shakopee, Minn.
g. Handycam DCR SR47, Sony Corp, Tokyo, Japan.

References