INSTRON TENSILE TESTING:

THE USAGE OF COATED VICRYL SUTURES AND STERI-STRIPS™ IN WOUND CLOSURE

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A. BACKGROUND

In clinical settings, physicians must prioritize several options when determining which method of wound closure is ideal for the circumstances of each individual injury. These options include the mechanical properties of the wound closure, the cosmetic results after complete healing, the efficiency of implementation, and the patient's comfort level. Two common methods for wound closure are the use of sutures, specifically coated vicryl sutures, and Steri-Strips™. Coated vicryl sutures are shown to be excellent promoters of wound healing[1], especially at wound sites that undergo tensile and flexural loads, such as the knee or chest. Steri-Strips™ are commonly used on shallow wounds under lesser loads, such as facial lacerations, and are shown to have cosmetic[2] as well as time-saving advantages over sutures. Steri-Strips™ can be applied either parallel or perpendicular to the laceration[3] (see Appendix, Figure 2).

In Experiment #2, the effectiveness of the pulley stitch and vertical mattress suture techniques was investigated. Findings suggest that skin surrogates held together by the pulley stitch suture technique exhibited significantly less strain (0.197) under 1000 g uniaxial loading than the skin surrogates held together by the vertical mattress suture technique (0.132; $p = 9.11 \times 10^{-3}$). Furthermore, in Experiment #3, the tensile and failure properties of chicken skin and skin surrogates were investigated using the Instron 4444. Results suggest that at different loading rates (5 mm/min and 100 mm/min), the stiffness (1.363 ± 0.441 vs. 1.585 ± 0.301, $p = 0.2069$) and failure force (14.613 ± 3.759 N vs. 21.599 ± 11.501 N, $p = 0.0964$) of the chicken skin were not significantly different. Thus, this experiment combines Instron tensile testing and wound closure methods in order to examine the tensile properties, specifically stiffness and failure force, of Confor™ foam skin surrogates held together by pulley stitch sutures and Steri-Strips™ and investigate findings on a basis of clinical relevance.

B. OBJECTIVES AND HYPOTHESIS

I) Experimental Objectives:
- a) To quantify values of stiffness and failure force of Confor™ foam skin surrogates under tensile loading in the Instron 4444.
- b) To compare values of stiffness and failure force between samples held together by coated vicryl sutures and Steri-Strips™.
- c) To examine the fracture and failure tendencies (i.e. type of failure, location of failure) of the surrogates for clinical relevance.

II) Primary Hypothesis
- a) The values of stiffness and failure force of skin surrogates held together by coated vicryl sutures will be significantly greater than the respective values of skin surrogates held together by Steri-Strips™.

III) Secondary Hypotheses
- a) The skin surrogates held together by coated vicryl sutures will exhibit failure through the sutures punching through the surrogates
- b) The skin surrogates held together by Steri-Strips™ will exhibit failure through separation of the Steri-Strips™ from the surrogate surface

C. EQUIPMENT

I) Major Equipment
- Instron Model 4444 benchtop materials testing machine

The Instron Model 4444 allows for the measurement of force and displacement of a sample being loaded by a constant-rate tensile loading force.

II) Laboratory Equipment
- LabView software
- scissors
- ruler
- weight set
- forceps (2)

The LabView software is used along with the Instron. Data (force and displacement) are collected at a maximum rate of 20 points/second, and the loading rate can reach a maximum of 100 mm/min. Data are saved in an Excel spreadsheet for ease of analysis. The scissors are used to cut the skin surrogates. The ruler is used to measure the geometries of the skin surrogates and the placement of the sutures and Steri-Strips™. The weight set is used to calibrate the Instron. Forceps are used in suture placement and also to load each sample into the clamps of the Instron.

III) Supplies
- permanent marker (fine point)
- notebook paper

A fine point permanent marker is used to place markings on the location of suture placement on the skin surrogates (see Appendix, Figure 4). Notebook paper is used to record failure patterns for each trial.

IV) Newly Purchased Equipment
- Confor™ polyurethane foam (1/4", green)
- coated vicryl sutures (needles attached)
- Steri-Strips™

A different Confor™ polyurethane foam (green) with a higher tensile strength than used previously in Experiment #3 is necessary because the pink Confor™ foam was found to be a poor surrogate for chicken skin (stiffness = 0.19 ± 0.01 vs. 1.58 ± 0.30; $p = 1.51 \times 10^{-7}$). Furthermore, the Confor™ foam will be easier to work with than skin samples, which tend to have geometric properties beyond normalization (i.e. density, uniformity, thickness). A uniform skin surrogate will allow for the accurate comparison of the two wound closure methods since all other experimental conditions will be held constant.

The use of coated vicryl sutures and Steri-Strips™ will allow for the comparison of two clinically used methods of wound closure.

D. PROPOSED METHODS AND ANALYSIS

I) Skin Surrogate Preparation

1. Cut 40 1" x 1" inch segments of Confor™ foam.
2. On 20 segments, draw a line 1/4" from the boundary and place three dots 1/4" away from the line (Figure 4). These markings will be used as guides for suture placement.
3. Suture these 20 segments together into 10 surrogates by using three pulley stitches (see Appendix, Figures 3 and 4). Use one continuous suture for all three stitches.
4. Cut Steri-Strips™ (original length 4") to lengths of 1" (20 1" segments needed).
5. Join 20 remaining segments into 10 surrogates using 2 1" Steri-Strips™ perpendicular to the line of the wound (see Appendix, Figure 5, for placement).

Upon entering the laboratory, each group should familiarize themselves with the Instron machine and its functionality under the guidance of the lab staff. This is essential to ensure the safety and proper operation of the machine. If deemed necessary, a trial run should be performed using an intact segment of Confor™ foam. Total time spent becoming familiar with the Instron should not exceed *1 hour*. The skin surrogate preparation should take *no more than 1 1/2 hours* to complete. Groups should come familiar with the pulley stitch suture method or else this could be a potential drawback to lab efficiency. One group member should be responsible for cutting the Confor™ foam, another for suturing, and another for placement of the Steri-Strips™. Care should be taken to use the same closure technique for each surrogate.

II) Surrogate Loading Using Instron

1. Calibrate Instron using weight set (refer to lab manual).
2. Clamp a surrogate into the Instron. Clamps should be 1.5" apart.
3. Load surrogate at a rate of 20 mm/min and a sample rate of 20 points/second.
4. Record force and displacement using LabView software and save to Excel file.
5. Observe and record failure patterns, including location and method of failure.
6. Repeat for all 10 suture-held surrogates and all 10 Steri-Strips™-held surrogates.
7. Construct plots of force vs. displacement using MATLAB.
8. Determine the failure force (the maximum force during the trial) and the stiffness (the ratio of force to displacement of the region of proportionality).

Surrogate loading using the Instron is the longest portion of the experiment. However, time can be minimized if a group member begins to load surrogates as soon as the sutures or Steri-Strips™ are placed. Each run, 20 in total, will take approximately *3-4 minutes*, with several minutes in between to place the next sample and save the file using the LabView software. Total time spent loading surrogates on the Instron should be approximately *2 1/2 hours*. Groups should work efficiently, while maintaining consistent loading conditions for each run.

III) Statistical Analysis

1. Tabulate values of failure displacement, failure force, and stiffness for the 10 suture-held surrogates and the 10 Steri-Strips™-held surrogates. Report averages and standard deviations for all values.
2. Perform one-tailed, unpaired t-tests assuming unequal variances on the failure force and stiffness of the 10 suture-held surrogates versus the 10 Steri-Strips™-held

surrogates in order to compare the two methods of wound closure and the tensile properties of the respective surrogates.

Data analysis and statistical analysis requires an individualized examination of each trial run. Force vs. displacement graphs for each trial run will need to be constructed in MATLAB. From these graphs, a linear best-fit line can be constructed on the region of proportionality using a MATLAB m file previously used in Experiment #3. Furthermore, the failure force must be determined from the point of maximum force applied to the surrogate. This can be done quickly and accurately using the "max" command in MATLAB.

Figure 1 below is a representative graph of force vs. displacement of Confor™ foam surrogates obtained from Experiment #3. Graphs obtained from the experiment should be comparable. Since the surrogates in the experiment have a greater tensile strength than those used in Experiment #3, the failure force and stiffness (noted in Figure 1 as the maximum point of each plot and the linear region of proportionality) should theoretically be higher.

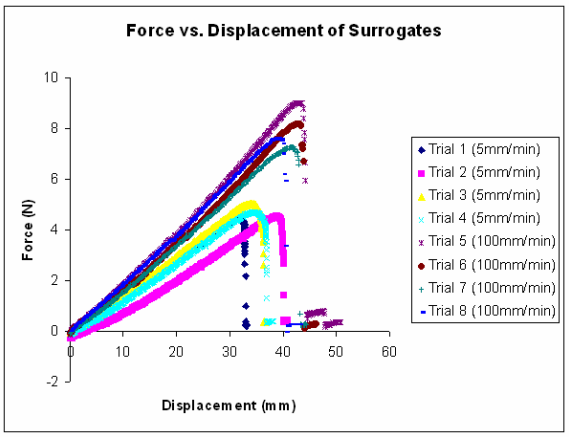

Figure 1: Force vs. displacement graph of Confor™ foam surrogates loaded at 5 and 100 mm/min obtained from Experiment 3.

E. POTENTIAL PITFALLS AND ALTERNATIVE METHODS/ANALYSIS

In Experiment #3, Microsoft Excel was used for data analysis. However, inconsistencies in the selected linear region as well as in determining the maximum force were noticeable between trials and also between lab members. As a result, it is recommended that MATLAB be used for data analysis. MATLAB's "max" command is an accurate method to determine the maximum (failure) force. From this value, the appropriate region can be selected for construction of a linear fit. This will eliminate inconsistencies and errors in data analysis. Otherwise, one would expect a higher standard deviation between values of failure force and stiffness.

Furthermore, in Experiment #3, it was observed that the failure patterns of the Confor™ foam surrogates were not always consistent at the line of closure. Lateral strain caused by the clamps during tensile loading often caused failure near the bottom clamp instead. Thus, Poisson's ratio, the ratio of the lateral strain to the longitudinal strain, must be minimized to allow for failure at the sutures or Steri-Strips™ instead of elsewhere in the material. If failure is observed near the clamps, the geometries of the surrogates would need to be changed to limit such Poisson effects (deformations). This can be done by expanding the widths of the ends of the surrogates so that

the ends are wider than the middle, where wound closure occurs. Thus, samples would be shaped more like an hourglass, and the effects of deformation would be reduced.

There is also a possibility for errors in the two methods of wound closure applied to the Confor™ foam surrogates. The knots at the ends of the sutures could potentially be pulled through the foam while under tension, causing the sutures to lose their structural integrity prior to failure. This error can be avoided by tying larger-sized knots at the suture ends, thus not allowing for the knots to pass through the foam. Also, the Steri-Strips™ might not adhere properly to the foam. This would allow for failure at the area of connection prior to when failure might be expected if skin samples had been used. Such an error is not easily avoided, however, and depends on the surface properties of the Confor™ foam as well as the adhesive properties of the Steri-Strips™. If such errors occur, a second method of wound closure would need to be chosen (Dermabond™ liquid skin adhesive[4] and staples[5] are also proven successful in wound closure).

Lastly, there is a possibility that the sutures and Steri-Strips™ will perform better than expected under tension, causing failure in the middle of the surrogate but not along the sutures or Steri-Strips™. To prevent this from happening and in order to accurately compare the wound closure methods, the number of stitches can be reduced from three to two and the number of Steri-Strips™ can be reduced from two to one, thus minimizing the area of force on the wound closure and in effect maximizing the stress on each individual suture or strip (stress = force/area).

F. BUDGET

Item	Supplier	Specifications	Quantity	Cost Per Item	Total Cost of Item
Steri-Strips™	3M	10 strips/pack; 1/4" by 4"	15	$2.16	$32.40
Confor™ Polyurethane Foam	McMaster-Carr	1/4" thick; green; 36" by 20"; tensile strength = 20 psi; stretch limit = 90%	2	$20.21	$40.42
Coated Vicryl Sutures	Novartis-Ethicon	36 sutures/pack; 5-0 size; C-3 needles; 18" long each	6	$170.20	$1021.20
Shipping & Handling			3	$10	$30

TOTAL COST: $1124.02

Each group will use 2 Steri-Strips™ on each of 10 surrogates for a total of 20 Steri-Strips of length 1". Each group thus requires 5 Steri-Strips™ of length 4" that can be cut into 20 Steri-Strips™ of length 1". Thus, 15 packs of 10 yields a total of 150 1/4" by 4" Steri-Strips™ would be adequate for 20 groups. This allows for 50 extra Steri-Strips™ for feasibility testing and in case several extras are needed for a group's individual experiment.

Each group also requires 40 Confor™ foam segments of 1" by 1" geometry for a total of 40 in^2 per group. 20 total groups x 40 in^2 = 800 in^2 of foam required. Each sheet is 720 in^2, so two must be purchase, allowing for almost twice the necessary amount per group extra.

Each group also requires 10 sutures x 20 groups = 200 sutures. 6 packs of 36 = 216 sutures will be purchased.

An average $10 shipping & handling was added to each of the 3 orders for a total of $30.
Total costs for new equipment purchases equal $1124.02 (56.20% of the allotted budget).

G. REFERENCES:

1. Ford HR, Jones P, Reblock K, Simpkins DL. Intraoperative handling and wound healing characteristics of coated polyglactin 910 antibacterial suture and coated polyglactin 910 suture. Surg Infect. 2005; 6:313-321.
2. Pederson, J M., J R. Struckmann, H K. Kjaergard, J P. Geerdsen, and P E. Hansen. "Late Cosmetic Results of Wound Closure, Strips Versus Suture." Neth J Surg 39 (1987): 149-150.
3. Pushpakumar, S B., R P. Hanson, and S Carroll. "The Application of Steri-Strips." J Plast Surg 113 (2004): 1106-1107.
4. Knott, P D., J E. Zins, J Banbury, R Djohan, R J. Yetman, and F Papay. "A Comparison of Dermabond Tissue Adhesive and Sutures in the Primary Repair of the Congenital Cleft Lip." Ann Plastic Surg 58 (2007): 121-125.
5. Zeplin, P H., K Schmidt, M Laske, and U E. Ziegler. "Comparison of Various Methods and Materials for Treatment of Skin Laceration by a 3-Dimensional Measuring Technique in a Pig Experiment." Ann Plastic Surg 58 (2007): 566-572.

H. APPENDIX

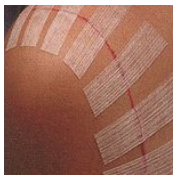

Figure 2: Steri-Strips™ applied to a wound perpendicularly to the line of the laceration.
(courtesy of 3M©; http://www.3M.com)

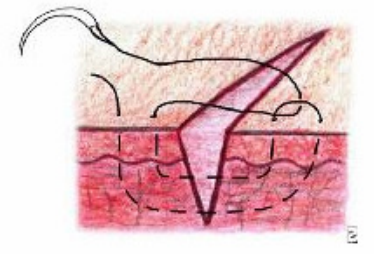

Figure 3: Pulley stitch method of suture placement. Each point of entry and exit should be on either a line or dot, as indicated in Figure Y.
(courtesy of eMedicine, WebMD; http://www.emedicine.com)

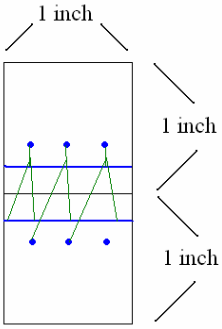

Figure 4: Diagram of a skin surrogate held by coated vicryl sutures. The lines of entry are 1/4" from the edge, and the points of entry are 1/4" from the line. Points of entry are 1/4" apart.

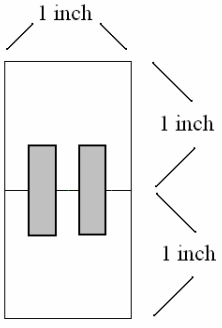

Figure 5: Diagram of a skin surrogate held by Steri-Strips™. The Steri-Strips™ (1/4" wide) are each placed 1/6" from the boundaries with 1/6" separating them in the middle.