Breaking Strength of Suture Techniques
Table of Contents

Abstract ................................................................. 3

Introduction .......................................................... 4

Research ............................................................... 5

Materials and Methods ............................................ 11

Data ................................................................. 13

Discussion .......................................................... 17

Conclusion ........................................................... 20

Reference ............................................................ 21

Acknowledgements .................................................. 23
Abstract

This experiment was performed to determine the best suture technique by testing the breaking strength of each technique. Breaking strength is defined as the tearing of the suture or the skin, and once reached classifies the suture as failed. The suture technique with the highest breaking strength would be considered the best technique. The techniques compared were continuous, simple interrupted, locking and horizontal mattress. The hypothesis was the simple interrupted technique would have the highest breaking strength of the four techniques.

These techniques were tested on pig skin. The material used to suture remained constant. Twenty pieces of pig skin were cut to the measurements of 5 cm by 10 cm. A 2 cm incision was made in the middle of each sample. Each of the four techniques was demonstrated by closing the incisions, and each was repeated five times. Each sample was attached to a dual force meter connected with Logger Pro Software in order to record the force being applied in Newtons. A 20 g weight was added systematically every 12 seconds until suture failure occurred.

ANOVA and t tests demonstrated a statistical difference between the four techniques. The locking suture showed a statistically lower breaking strength when compared to the other techniques. The horizontal mattress stitch demonstrated a statistically higher breaking strength than the other three, classifying it as the best technique. Therefore, the initial hypothesis of simple interrupted technique having the highest breaking strength was not supported.
Introduction

The purpose of this experiment was to compare common suture techniques in order to determine which technique has the highest breaking strength, which would make it the most effective in terms of withstanding stress. Breaking strength of a suture is defined as, “the limit of tensile strength at which suture failure occurs.” (Lai, S. Y., Ciné-Med 2010). The breaking strength of a suture is determined when tearing or ripping of the skin or suture occurs, classifying the suture as failed. Multiple variables affect tensile strength, such as material of the suture, mobility of suture area, and suture technique. Each technique has a different tensile strength because each technique has specific components. Four techniques were used in this experiment; continuous running (“continuous”), simple interrupted, locking and horizontal mattress (“mattress”). The continuous technique is performed by threading a single piece of suture material through the incision in an unbroken fashion. Conversely, when the simple interrupted technique is used, a knot is tied after each stitch is placed, resulting in a row of individual sutures. The locking suture technique results in a self-locking chain of connected sutures. Lastly, mattress sutures double back across the incision twice before knotting. These style variances affect tensile and breaking strengths, therefore the hypothesis generated was the simple interrupted technique would have the highest breaking strength out of all four techniques.

Research

Sutures are an integral part of many surgical procedures and treatments; they provide a time cushion allowing the skin or injured area to heal. Without surface sutures, incisions would heal slower or not at all, while running a greater risk of infection due to the openness of the wound. Without internal sutures, organs would not have time to repair or heal after procedures,
and would be unable to maintain homeostasis. Sutures, although commonplace, vary widely in technique and material. The techniques range from simple stitches to complex individually tied sutures. The materials range from cotton to surgical steel, some thinner than a single strand of hair. Each technique and material is utilized for individual procedures or injuries, specific to certain areas and depths. The suture technique and material is also determined by the amount of pressure applied to the injury. Surgeons choose the smallest possible suture that will adequately hold the healing wound together, and one that’s loss of tensile strength is slower than the gain of tissue strength.

There are many suture techniques; the most common are continuous running ("continuous"), simple interrupted, horizontal mattress ("mattress"), purse, far-and-near and locking. Each of these has its own advantages and disadvantages. A continuous stitch is one singular piece of material threaded uninterruptedly, which allows quick implantation of the stitch. However, this speed creates a risk for mis-attachment of wound edges. Unlike the continuous stitch, the simple interrupted stitch is more complex requiring the utilization of knot tying. It provides more exact connection of wound edges because each stitch is tied separately. The mattress stitch is used for deep wounds or incisions, because each stitch penetrates deep into both sides of the wound and is tied individually. Mattress stitches are defined as horizontal and vertical, horizontal stitches implying a stitch made parallel to the wound edge, where vertical implies a stitch made perpendicular to the wound edge. A purse string suture is used to close circular wounds or appendiceal stumps, (Ciné-Med, n.d.) as the stitch parallels the edge of the wound. A far-and-near stitch uses a double loop technique, switching between the further and closer edges of the wound providing a secure attachment. Lastly, locking stitches are a type of
running stitch where each stitch creates a chain with the one before it, classifying it as self locking, and used for approximating wound or incision edges.

These techniques all have their best application, similar to the individual materials used in suturing. The materials in sutures are classified by either monofilament or multifilament, absorbable or non-absorbable, and natural or synthetic. Monofilaments are made of a single strand of material, and are more resistant to microorganisms. These pass through tissue cleaner and smoother than multifilament sutures, but because they are so thin, the risk for a damaged suture is higher, which could result in suture failure. In contrast, multifilament sutures are made by twisting or braiding several filaments together, allowing for a greater tensile strength and better pliability than monofilament stands (Suture Material and Structure, Lai, 2010). However the thickness also creates a higher level of friction, which leads to tissue irritation. While these sutures handle well, the increased mass and surface area introduces a higher risk of pathogens which could lead to incision infection. Absorbable sutures are used for temporary support, because the mass and volume of the suture progressively decreases. If the absorbable material is naturally based, it will dissolve via enzymes, but if synthetically produced, it will degrade by hydrolysis. Surgeons must take into account if the patient has a fever or infection, which would increase the absorption rate of absorbable sutures. The area where the suture is located and the amount of fluid there must also be considered, for if high, would also speed the absorption rate. Absorbable sutures do not elicit as much of a tissue reaction as nonabsorbable sutures, but nonabsorbable sutures are unaffected by the biological metabolism of the body, making them permanent.

Each broad group of materials has many specific threads included in it. Natural absorbable sutures include, collagen, surgical gut plain, and surgical gut chromic, which means
the thread is treated with chromium salt. Polyglactin 910, poliglecaprone 25, polysorb, polydioxanone, barbed suture, and caprosyn are materials that are included in synthetic absorbable sutures. Surgical silk, surgical cotton and surgical steel are natural nonabsorbable sutures. Nylon, polyester, polybutester, coated polybuster, polypropylene and surgipro II make up the synthetic nonabsorbable group (Suture Characteristics, Lai, 2010). Sutures are further classified in three major classes. In Suture Material and Structure, Lai states the classes, “Class I - silk or synthetic fibers or monofilament, twisted or braided construction. Class II - cotton or linen fibers, or coated natural or synthetic fibers in which the coating contributes to suture thickness without adding strength. Class III - metal wire or monofilament or multifilament construction” (2010, p. 1).

These materials prove advantageous in repairing certain injuries. Surgical gut plain is helpful in repairing rapidly healing tissue, tying blood vessels and other epidermal uses. Polyglactin 910 and poliglecaprone 25 sutures are often seen in soft tissue insertion and vessel ligation. Polydioxanone sutures are used for the approximation of soft tissues, mainly in pediatric, cardiovascular, gynecologic, ophthalmic, plastic and digestive surgeries. Barbed sutures are for self-anchoring surgeries, usually gastrointestinal wound closures, where surgical steel is used for abdominal wall closure, sternum closure, and retention. Nylon is also used in retention and skin closure, and is the most typical type of superficial suture. Polyester fiber is used for vessel connection and placement of prosthetics. Coated polybutesters are used for musculoaponeurotic, colonic and vascular tissue, where polypropelene is used for sutures that require removal. Lastly, surgipro II sutures are used in plastic, cardiovascular, general and orthopedic surgery (Suture Characteristics, Lai, 2010). These injuries are all located in different skin types: epithelial, muscle, connective and adipose. The skin is divided into many layers, the
epithelial tissue, muscle tissue, adipose tissue, or subcutaneous fat, and connective tissue are the main four. Each of these categories have sub layers and types which give them unique and individual functions and properties. Together they and cover and line the entire the body.

Epithelial tissue is the first line of protection against foreign objects. This, in addition to prevention of water loss and nutrients are called a barrier function. Having a cut or open wound ruins the sealed barrier that is skin, and opens it up to pathogens, bacteria and other microorganisms. This type of tissue is also responsible for the synthesis of Vitamin D. Without Vitamin D, bones would become brittle and fracture quite easily (“Vitamin D”, 2011) and the skin would become unhealthy. The epithelial tissue also houses accessory organs, such as sweat and oil glands, and hair follicles. Epithelial tissue is composed of collagen and elastic fibers, in addition to nerves and muscle. As one ages, the collagen and elastic fibers decrease, producing wrinkles. The secretion and production of the sebaceous glands also decreases with age. The skin has the ability to regenerate, because the dermis is actively going through mitosis, which also gives the epithelial tissue natural healing properties. This is what sutures aid, the natural healing process of the skin and other tissue.

Connective tissue primarily lines body cavities and holds other tissues together. This type of tissue also plays a role in movement by providing a framework in partnership with the skeleton (“Connective Tissue”, n.d.). Other tissues are embedded in the connective tissue, such as nerve endings or muscle tissue. The connective tissue provides a communication system within the body; blood vessels and nerves travel thought it and it acts as transport between tissues. Because some cells are not close enough to a capillary or blood vessel to transport whatever that cell is holding, connective tissue is required. Connective tissue constructs a pathway for diffusion of nutrients and oxygen to other parts of the body. This can also be
utilized by invading pathogens, and in order to prevent this, the body distributes defense cells in the connective tissue. Connective tissue is generally areolar tissue, the main unspecialized form of tissue. Other types include fibrous, elastic, lymphoid and adipose tissue (“Connective Tissue Study Guide”, King, D., 2010).

Adipose tissue is a special form of connective tissue, as mentioned above. There are two types of adipose: white and brown. 60-65% of white adipose is made of lipids (“Adipose Tissue”, Albright, A.L. & Stern, J. S., 1998), which are extra sugar molecules, and in humans, adipose is primarily white. Adipose has three functions: insulation, cushioning or protecting, and acting as an energy source. The level of insulation is dependent upon the amount of adipose; people with more adipose will have more insulation and warmth than those with less adipose. This tissue type surrounds most vital organs and absorbs shock that would otherwise harm the organ. It also functions as storage for excess sugar or food, which can be later transformed into energy or fuel for the body. Fat is necessary for these reasons, but there is a fine line between a healthy amount of fat and a surplus amount. Excess adipose is distributed according to sex; in men it gathers in the stomach, and in women it gathers in the lower body. Excess adipose can lead to obesity, which can place one at risk for diabetes, heart disease or any number of ailments.

Muscle tissue can be divided by structure into smooth muscle, skeletal muscle and cardiac muscle. Smooth muscle forms layers of muscle that are made up of fibers, thin elongated cells. It is involuntary tissue, independent of brain signals. It unconsciously does the function it is designed for, such as regulating blood pressure. Skeletal muscles function together to coordinate movements, and is similarly made of fibers. This includes contraction and relaxation of muscles. Cardiac muscle is found only in the walls of the heart. It is an involuntary muscle, and controls the contractions of the heart (“Muscle Tissues”, n.d.). The fibers of each muscle
type are unique in striations and thickness. Thickness and amount of muscle are also unique to each individual.

A consistent tensile strength is important in sutures, for healing and protection purposes. If strength is weakened by repetitive pressure or stress through movement, or decreases faster than tissue strength increases, healing will not be achieved and the suture will most likely fail. The goals of a successful wound closure include “obliteration of dead space, even distribution of tension along deep suture lines, maintenance of tensile strength across the wound until tissue tensile strength is adequate, and approximation and eversion of the epithelial portion of the closure” (Overview, Lai, 2010). Many of these characteristics are related to tensile strength. Lai defines tensile strength as “a measure of a material or tissues ability to resist deformation and breakage” (Suture Qualities, 2010, p. 2). This has a direct correlation with wound breaking strength, “the limit of tensile strength of a healing wound at which separation of the wound edges occurs” (Suture Qualities, Lai, 2010, p. 2). Breaking strength classifies a suture as failed and occurs at the tearing or ripping of the suture itself or the skin the suture held together. Breaking strength is the limit of tensile strength the suture can maintain. The higher the mobility of the area where the sutures are located demands an increase in tensile strength which would then result in an higher breaking strength, both of which are vital for a successful suture.

New advancements have been made utilizing sutures. The newest advancement is robotic technology. Robotic surgery is minimally invasive, and with smaller incisions, decreased hospital stays and quicker recovery, many patients are choosing it over the traditional surgery when available. Even with all of these advancements, choosing and applying the correct tensile strength is still very sensitive, and requires skilled surgeons paired with state-of-the-art technology. Surgeons still have to compensate for lack of sensory feedback when using robotics
in surgery. A study by Martell, J., Elmer, T., Gopalsami, N., & Park, Y. S. proposed a way to measure suture displacement in robotic surgery. Entitled “Visual Measurement of Suture Strain for Robotic Surgery”, Martell, J. et. al. suggested a way to compute and provide feedback without bulky and unreliable sensors (2011). By placing a mark on the suture and video processing the suture being inserted, they mathematically calculated the strain measurement with equations of strain computation, quadratic regression and a strain measurement test. Different suture material was used and tested repeatedly. A simpler version of this math is used by other researchers. A dual force meter was utilized; a piece of technology that measures pushing and pulling forces on a piece of material.

Sutures have been in surgery for a very long time. Yet after all the advancements that have occurred, they are still utilized. The techniques and materials might have changed and become more sophisticated, but it does not matter if they are inserted by a candy striper or robots, they are an essential part of surgery.

**Materials and Methods**

In order to test this hypothesis, weights were added to samples of suture techniques and measured on a dual force meter using Vernier Logger Pro Software until breaking strength was reached. Pig skin was measured and cut to a 5 cm x 10 cm rectangle using a ruler and scalpel. A 2 cm incision was made in the middle of the sample cutting through the entire depth of the sample. The incision was then sutured closed using one of the four techniques. This was repeated five times for all four techniques, totaling 20 samples. The number of stitches in the incisions was dependent upon the suture technique. Each sample was individually and systematically tested on a dual force meter, and data was recorded using Vernier Logger Pro.
Software. Dual range force sensors, also known as dual force meters, are used for measuring pushing or pulling force. The dual force meter was mounted and used to measure the vertical force and pull applied to the pig skin in Newtons. This force was applied using 20 g weights. These weights were added methodically every 12 seconds at an increment of 20 g until breaking strength was reached causing suture failure to occur. For each sample, the software and dual force meter was zeroed before the testing was performed.

Each graph was compiled from data samples collected at a rate of .02 minutes/sample, totaling 50 samples per minute. The x-axis showed time in minutes and the y-axis illustrated the force being applied in Newtons. A graph from a sample can be seen below. All data was recorded using the software and organized in a journal.
Data

Figure 1 Force Recorded (N) to Reach Breaking Strength

<table>
<thead>
<tr>
<th>Sample Number</th>
<th>Continuous</th>
<th>Simple Interrupted</th>
<th>Locking</th>
<th>Mattress</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4.951 N</td>
<td>4.840 N</td>
<td>4.367 N</td>
<td>5.358 N</td>
</tr>
<tr>
<td>2</td>
<td>5.345 N</td>
<td>5.372 N</td>
<td>4.162 N</td>
<td>5.254 N</td>
</tr>
<tr>
<td>3</td>
<td>5.131 N</td>
<td>5.332 N</td>
<td>4.168 N</td>
<td>5.596 N</td>
</tr>
<tr>
<td>4</td>
<td>4.566 N</td>
<td>5.360 N</td>
<td>4.174 N</td>
<td>5.205 N</td>
</tr>
<tr>
<td>5</td>
<td>4.553 N</td>
<td>5.023 N</td>
<td>4.593 N</td>
<td>5.421 N</td>
</tr>
<tr>
<td>Average</td>
<td>4.909 N</td>
<td>5.185 N</td>
<td>4.293 N</td>
<td>5.367 N</td>
</tr>
</tbody>
</table>
This graph measures the averages of breaking strengths of all four techniques in Newtons. Notice that the mattress technique’s standard deviation shown by the error bar does not overlap with the other three. Seeing that mattress has the highest average, it suggests a significant difference therefore making mattress the best technique. Also note that the locking technique’s standard deviation does not overlap any other the other three. This suggests a significant difference from the other three, and because it has a lower average, classifies locking as the worst technique.
Figure 3 ANOVA Test

<table>
<thead>
<tr>
<th>Groups</th>
<th>Count</th>
<th>Sum</th>
<th>Average</th>
<th>Variance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Column 1</td>
<td>5</td>
<td>24.546</td>
<td>4.9092</td>
<td>0.1213822</td>
</tr>
<tr>
<td>Column 2</td>
<td>5</td>
<td>25.927</td>
<td>5.1854</td>
<td>0.0581178</td>
</tr>
<tr>
<td>Column 3</td>
<td>5</td>
<td>21.464</td>
<td>4.2928</td>
<td>0.0356057</td>
</tr>
<tr>
<td>Column 4</td>
<td>5</td>
<td>26.834</td>
<td>5.3668</td>
<td>0.0236127</td>
</tr>
</tbody>
</table>

ANOVA

\[
P-value = 1.88315 \times 10^{-5}
\]

Figure 4 T test

<table>
<thead>
<tr>
<th>Techniques Compared</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Continuous v. Simple Interrupted</td>
<td>0.183023</td>
</tr>
<tr>
<td>Continuous v. Locking</td>
<td>0.00833577</td>
</tr>
<tr>
<td>Continuous v. Mattress</td>
<td>0.0276176</td>
</tr>
<tr>
<td>Simple Interrupted v. Locking</td>
<td>0.000184272</td>
</tr>
<tr>
<td>Simple Interrupted v. Mattress</td>
<td>0.000184272</td>
</tr>
<tr>
<td>Locking v. Mattress</td>
<td>0.00000936752</td>
</tr>
</tbody>
</table>
Figure 5 Locking Technique Chart
Discussion

Figure 1 is a data table which shows the individual samples’ breaking strengths in addition to the averages of each technique in Newtons. Newtons are the SI unit of force. A Newton is equal to the force required to accelerate one kilogram at the rate of one meter per second squared. The formula for a Newton is \( N = \text{kg(m/s}^2\text{)} \).

Figure 2 shows the breaking strength averages in Newtons of all four techniques. Standard deviation was used to create error bars on this chart.

The formula for standard deviation is

\[
\sigma = \sqrt{\frac{1}{N} \sum_{i=1}^{N} (x_i - \bar{x})^2}
\]

where

\( \sigma = \text{standard deviation} \)

\( x_i = \text{each value of dataset} \)

\( x \) (with a bar over it) = the arithmetic mean of the data (This symbol will be indicated as mean from now)

\( N = \text{the total number of data points} \)

\( \sum (x_i - \text{mean})^2 = \text{The sum of } (x_i - \text{mean})^2 \text{ for all data points.} \)

Standard deviation is used for measuring the precision of samples or trials. It measures how far the data varies from the average. Error bars can be constructed from standard deviation values and show the range of the average if one were to add and subtract the standard deviation to the average. If the error bars overlap in a chart, as they do for the continuous and simple interrupted techniques, it shows no significant difference between the two; one is not better than the other. As seen in Figure 2 the mattress error bar does not overlap with the other three. This coupled with it having the highest average determines that it has the highest breaking strength,
and therefore is the best suture technique. One can see in Figure 2 that the locking error bar similarly does not overlap or touch any of the other three. Because it has the lowest average and does not overlap the other techniques, the conclusion can be made that it has a significantly lower breaking strength making it the worst suture technique.

ANOVA stands for Analysis of Variance, and is a statistical test which compares the differences within three or more groups. This is the equation for an ANOVA test.

\[
\bar{x} = \frac{\sum x}{n}
\]

where \( n \) is the number of measurements
\( x \) are the measurements to be averaged
and \( S \) means sum of.

There are three common types of ANOVA tests, one-way or single factor, two-way, and N-way or multivariate. One-way ANOVA tests are used to determine if the samples of one general group are alike or not, and only involve one variant factor. The single factor ANOVA was utilized in this analysis. ANOVA tests produce a P-value, and if the P-value is below 0.05, there is a significant difference within the group of data. P-value is the probability that the sets of data are truly different. The lower the P-value, the higher the percent that the two sets of data are different. Having a 0.05 P-value gives a 95% chance that the two sets of data are different. This is called a confidence interval. As seen in Figure 3, the P-value for the ANOVA test applied to the data was \( 1.88315 \times 10^{-5} \), showing a 99% chance there was a significant difference within the group.

T tests were run between all the averages of the techniques to determine specifically where the data differed. Each technique’s average was compared with the other three averages.
A t test is a statistical test which compares between two means of data with a normal distribution. Below is the equation for a matched t test.

\[
 t = \frac{\bar{x} \cdot \sqrt{n}}{\sqrt{s}} \quad \text{and} \quad s^2 = \frac{\sum x^2 - (\sum x)^2}{n - 1}
\]

where \( n \) is the number of points
\( \bar{x} \) is the mean of the differences
and \( s \) is the standard deviation of the differences.

T tests, similar to ANOVA tests, produce a P-value. If the P-value is below 0.05, the two sets of data being compared are significantly different. T tests were run between all averages, ensuring complete comparison of data. As seen in Figure 4, the comparison between mattress and the other three techniques produces a P-value below 0.05 each time. This coupled with that technique having the highest average shows it has the highest breaking strength and therefore is the best suture technique. Also of interest in Figure 4 was that when the locking technique was compared with the other three tests, the P-values yielded were also below 0.05 each time. This, in addition to the locking technique having the lowest average, suggests this technique has the lowest breaking strength and therefore is the worst suture technique.

Figure 5 is a graph compiled by the Vernier Logger Pro Software with input from the dual force meter. As you can see there are methodical increases every 0.2 minutes up until the breaking strength was reached. This graph shows the test of the third sample of the locking technique. Notice that the force is measured in Newtons on the y-axis and time is measured in minutes on the x-axis. As seen in Figure 1, breaking strength was reached at 4.168 N, just as depicted on Figure 5.
All of these results do not support the proposed hypothesis of simple interrupted technique having the highest breaking strength, but correlate and form two interesting points of discovery. First, the mattress technique was found to have a significantly higher breaking strength in all tests, and is therefore qualified to be the best suture for this experiment. Also, the locking technique was found to have the lowest breaking strength in all statistical tests, therefore making it the worst technique. These results however are not meant to suggest the best suture technique for every application.

There were some factors that could have affected the results, such as human error. Also, increased time between application of forces could have diminished the amount of force which caused the failure, although the differences should be proportionate. Breaking strength of a suture is usually reached in a singular point, such as reaching too far and ripping the sutures in your side. However, steps were taken to prevent affected results from occurring. Constants were used such as needle type, suture material, and depth and length of incision. The independent variable was the suture technique, and the dependent variable was the breaking strength of the technique. Further experimentation could include exploring the possibilities of the results presented by the data. A wider variance of suture techniques or suture material could also be considered for further deliberation.

Conclusion

The purpose of this experiment was to determine the best suture technique by testing the breaking strengths of four common techniques. The hypothesis was not supported with the data; simple interrupted was not the best suture technique. But the data did prove two interesting points. First, the mattress technique is the best technique to withstand force and stress. Secondly,
the locking technique is the worst technique to withstand strain. All of the data supported these
two points. As said, in depth testing of these results could be an option for future
experimentation.

References

Adipose Tissue aka Body Fat. (2004). Retrieved from Springboard website:
   http://www.springboard4health.com/_adipose.html

   and Internal Medicine, University of California website: http://www.sportsci.org//.html

ANOVA. (2011). Retrieved from Statistics Solutions website:
   http://www.statisticssolutions.com/of-statistical-analyses/

   website: http://biology.clc.uc.edu//muscles.htm

Connective Tissue. (n.d.). Retrieved from Biodiversity and Conservation Biology Department,
   University of Western Cape website: http://www.bcb.uwc.ac.za/sci_ed///.htm

   Software & Technology website: http://www.vernier.com//sensors/bta/

Epithelial Tissue. (n.d.). Retrieved from Biodiversity and Conservation Biology Department,
   University of Western Cape website: http://www.bcb.uwc.ac.za/_ed///epithelial.htm#struc

King, D. (2010, April 13). Epithelium Study Guide. Retrieved from School of Medicine,
   Southern Illinois University website: http://www.siumed.edu/~dking2///.htm


Muscle Tissue. (n.d.). Retrieved from Biodiversity and Conservation Biology Department, University of Western Cape website: http://www.bcb.uwc.ac.za/_ed/ade10//.htm


Acknowledgements

This project would not have occurred without the help of my sponsor, Mrs. Emily Giannantonio. Without your guidance, and replies to many emails, this would not have become a reality.

I would like to thank Nancy Sullivan for shopping with me for pig skin, proofreading and her everlasting support.

I would also like to acknowledge Pat Sullivan-Liebig and Lou Liebig for sharing their knowledge and hands-on experience of sutures.