Optimum Double Rhombic Flap Design for Z-Plasty

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Optimum Double Rhombic flap design for z-plasty

Group 13

Abdullah Abdul Hameed Khan

Guo Wei Choy

Faculty mentor: Dr. Jinseok Kim
Abstract

In the surgical field, Rhombic flap and z-plasty are common methods in surgical proceedings to treat close different types of injuries. Each method has its pros and cons. When both methods are applied together, it would complement each other weakness. This senior design project purpose is to investigate the magnitude difference of stress a double rhombic flap design for z-plasty compared to its predecessor which only has the rhombic flap design and a single z-plasty incision.

Disclaimer:

This project report was written by students at Western Michigan University to fulfill an engineering curriculum requirement. Western Michigan University makes no representation that the material contained in this report is error-free or complete in all respects. Persons or organizations who choose to use this material do so at their own risk.

Acknowledgments:

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Dr. Bade Shrestha
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Introduction

In medicine especially in plastic surgery, rhombic transposition flaps technique is widely used for complex wound closure, where transposing a skin flap leads to a stress field throughout the tissue around affected area. These stress field causes the tensile stresses on the blood flow causes an adverse effect that have been led towards the subject of extensive studies about these stresses that are deemed to be a major cause of flap failure. In fact, the reduction in magnitude of these tensile stresses can result in a short healing time and it also helps to prevent harmful consequences such as the formation of necrosis, granulation, and ischemia (Bucalo and Iriondo, 1995; Cacou and Muir, 1995; Lister and Gibson, 1972). In the field of Rhombic flap designs there have been many studies which pays special attention to the stress consideration. One of the earliest efforts is by Limberg who used a paper model to examine transposition flaps that leads towards his classical rhombic flap. Since then, there has been numerous variations to these surgical techniques and among these techniques are the flaps of Defourmental and Webster. These variations in the flap designs give rise to two important concerns: which design result in the best stress field and is there any design that is better in terms of stress field. To look for the answer to these questions, the objective of this senior design is to obtain an optimum double rhombic flap design for Z plasty which is a combination of rhombic flap and z plasty design that can be a replacement for the conventional flaps. This design will help to reduce the stress distribution caused by the stress field on the wound or closure area by the transposition of the rhombic and z flaps. Since this experiment requires data from numerous trails and experiments that involve living being as a subject, to overcome this concern and to fulfill the clinical aspect of this design computer simulation, Finite Element Analysis, program ANSYS was utilized to carry out a parametric study to determine an optimum rhombic angle that can minimize these stresses on the skin. By reducing these magnitudes of tensile stresses can result in a reduction in healing time and prevent harmful consequences...
Methods:

Finite element models (FEM):

The FEM is implemented in the Finite Element Analysis program ANSYS. Models are created in DesignModeler of ANSYS. Each model is created with the same material properties and boundary conditions. 2nd order Ogden Hyperelastic material properties are used with coefficients $\mu$ and $\alpha$ to represent the skin. For the representation of the suture, strings were used to close the gap between the rhombic and flaps and their model type is assigned as cable so that they will represent the function of the suture as close as possible. Strings were assigned with materials properties that were tailored according to the needs of the contraction of string to represent the closure. To simulate the closure of wound each string is assigned with a thermal condition and the start temperature of the simulation is set to 22 degrees Celsius. This approach is used so that when temperature of string is lowered, it will shrink and represent wound closure. Each iteration for analysis is done with lower temperature till the gap in the design is closed.
A preliminary design was created in FEA software ANSYS with two rectangular surfaces representing the skin and cables representing the sutures. The surface materials were 2nd order Ogden hyperelastic material. The sutures materials used was structural steel with certain properties altered such as coefficient of thermal expansion to 0.006 C\(^{-1}\) and Young’s modulus of 2E08 Pa. The goal of this design is to close the gap between the two rectangular surface which will simulate a wound closure.
Boundary Conditions

Figure 2: Boundary conditions of Preliminary Design model

Figure 3: Thermal conditions of Preliminary Design model

In Figure 2, the boundary condition that has been set on the left and right side of the model as fixed ends which are being represented as blue colored lines. In figure 3, thermal conditions of -22 degrees Celsius was set at each suture which are red in color. This thermal condition purpose is to close the 2 mm gap between the two rectangular surfaces as to recreate a wound closure.

The distance between the two rectangular surfaces was 2 mm and the gap was close due to the low temperature being applied at the cables that was between the two rectangular surfaces. The left side of the left rectangular surface has been set to be a fixed end to allow the skin surfaces to stretch and therefore able to see the deformation of the skin surface. The same is applied to the
right side of the right rectangular surface. Table 1 contains the constant values require for hyperelastic model Ogden to be used.

<table>
<thead>
<tr>
<th>Constant Parameters</th>
<th>MU1 (MPa)</th>
<th>A1</th>
<th>MU2 (MPa)</th>
<th>A2</th>
</tr>
</thead>
<tbody>
<tr>
<td>-</td>
<td>0.0289</td>
<td>22.2</td>
<td>-1.49</td>
<td>-1</td>
</tr>
</tbody>
</table>

Table 1. Material constants of Elastomer sample (Ogden)

**Reference Design**

**Rhombic flap design for z-plasty:**

![Rhombic flap design for z-plasty](image)

*Figure 4: Reference model geometry view*
Note: This reference model from Figure 3: from the rhombic transposition flap toward Z-plasty: An optimized design using the finite element method (Journal of Biomechanics., 3672-3678) by A. Rajabi, A. Dolvvich, J. Johnston,(2015).

The reference model will be used to compare with the design model to prove that the double rhombic flap design for z-plasty will reduce stress intensity on the skin. This will be achieved by performing the stress analysis on the reference model. Table 2 shows the characteristics of the reference model.

<table>
<thead>
<tr>
<th>Design Parameter</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diameter of outer circle</td>
<td>150mm</td>
</tr>
<tr>
<td>Thickness of outer circle</td>
<td>1.5mm</td>
</tr>
<tr>
<td>Radius of Sutures</td>
<td>0.0075mm</td>
</tr>
</tbody>
</table>

Table 2: Characteristics Geometry of Reference model
Figure 5 shows an overview of the reference model. Reference model is a representation of a rhombic flap. To avoid intersection points formed between sutures, frozen model for each individual suture is required.
Figure 6: Fixed end boundary condition on Reference model

Figure 6 shows the boundary condition fixed set to the circumference of the circle shown in the blue circle. This would show the boundaries of the study.
Figure 7: Thermal conditions on reference model

Figure 7 shows the thermal condition applied on the sutures on the reference model. Low temperature is applied at those thermal condition to cause the gaps to shrink and represent a closing wound. Due to the different length of the sutures, multiple different thermal condition is required for a proper simulation of wound closure as shown as the equation below.

\[ \Delta L = \alpha \cdot L \cdot \Delta T \]

\( \Delta L \) : Displacement

\( \alpha \) : Thermal expansion coefficient
\( L \) : Original length

\( \Delta T \) : Change in temperature

However, if the \( L = \Delta L \) to close the gap, then the equation could be rewritten as:

\[
\frac{\Delta L}{L} = \alpha \cdot \Delta T
\]

In this simulation, \( \alpha \) was set as 0.006 C\(^{-1}\) which would mean that \( \Delta T = 166.67 \) °C. Hence, any temperature change below that would cause the solution to invert and not converged. The initial temperature applied is 22 degrees Celsius and the final temperature was set -140 degrees Celsius.

**Design Model**

**Double Rhombic flap design for z-plasty**

Rhombic design with double z-plasty is created in the FEA software ANSYS. This model is achieved with the design parameter that is provide in Table 3.

<table>
<thead>
<tr>
<th>Design Parameter</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diameter of outer circle</td>
<td>300mm</td>
</tr>
<tr>
<td>Thickness of outer circle</td>
<td>1.5mm</td>
</tr>
<tr>
<td>Radius of Sutures</td>
<td>0.0075mm</td>
</tr>
</tbody>
</table>

Table 3: Characteristics Geometry of Design model

The design is start with creating an outer circle of diameter 300mm with thickness of 1.5mm. then a Rhombus is cut in the outer circle with equal length of sides of 30mm (ABCDEFGH). There is small gap of 0.6mm which represent the incision on the skin (DEFGH). \( \theta_1 = 30 \) and \( \theta_2 = 60 \) which are the angles that will be vary for determining the optimized model that will have a least stress distribution on the skin as we can see in the Figure 8. After all the required parameters use and the model is created which can be seen in Figure 9. The outer surface has materials properties of 2\(^{nd}\) order Ogden. The sutures materials properties altered such as coefficient of thermal expansion and Young’s modulus. Once the base of the design is done, strings with cross-section of circle with radius of 0.0075mm. Sutures which are represented by
strings can be seen in Figure 10 down below. Once sutures are added to the model, this completes the design for simulation.

Figure 8: Actual Model with respective variables.
Figure 9: Double rhombic flap Design for z-plasty

Figure 10: Design with strings that represents sutures.
For the boundary condition, fixed end is applied to the outer side of the circle which can be seen in figure in the color purple. Thermal condition is applied to each string so that they will shrink when the simulation is run at different Temperature which can be seen in Figure 11.

![Figure 11: Actual Design with Boundary conditions](image)

Each string is connected to a specific side of the Model which can be seen in Figure 12 from top left to bottom right in the highlighted color red. This helps in closing the gap which is representing the closure of wound.
Figure 12: Assignment of strings to specific sides.
Simulation:

Once design is completed with all the required parameters, analysis of deformation and Equivalent stress was obtained. Each iteration of analysis is performed till the gap is closed to represent the closure of wound. During each iteration temperature for the thermal condition in the strings are changed to make the string shrink. By doing this process of changing the temperature the gap of the wound start closing in each iteration. While performing each analysis and repeating the structure of changing temperature in each iteration to close the gap between the surfaces, different types of errors start appearing in the result that keeps on delaying and causing the analysis to fail.

Results:

Figure 13: Deformation of basic model after adding thermal condition.
The distance between the two rectangular surfaces was 2 mm and the gap was close due to the low temperature being applied at the cables that was between the two rectangular surfaces. The left side of the left rectangular surface has been set to be a fixed end in order to allow the skin surfaces to stretch and therefore able to see the deformation of the skin surface.
Figure 15: Deformation Analysis of Reference model
Figure 16: Stress Analysis of Reference model
Figure 17: Deformation Analysis for Actual Model

Figure 18: Stress Analysis for Actual Model
Table 4: Stress result Comparison.

Table 4 shows the data that is obtained during this analysis. The data obtained is not the anticipated data that were anticipating in the end. This is not the data that were anticipating because the goal of closing the gap fully to represent the wound closure is refrained by two of the challenges that faced whenever the analysis is done in each iteration with different Temperature for the sutures.
Challenges:

Limited elements would cause the simulation to come to position that elements size and number of elements needs to be adjusted. If element number is increases, it come to the point that the software license limits to go any further. Still analysis is run at the maximum number of elements and element size to increase the accuracy of data and allow the simulation to proceed.

After the elements size adjustments, the time taken for each iteration causes time constraints. The time needed to perform the analysis in each iteration took more than the anticipated time. Due to these challenges, the project did not meet all its objective and multiple angle analysis was not performed which can be seen in Figure 19-22.
Additional Models:

Figure 19: Actual model with $\theta_1 = 0$ and $\theta_2 = 30$
Figure 20: Actual model with different angle.
Figure 21: Actual Model with $\theta_1 = 45$ and $\theta_2 = 45$
Figure 22: Actual Model with different angles
Future Steps to resolve the current issues.

Smaller dimensions would help with one of the challenges faced which was due to the element limit given the software version being used. Having smaller dimensions would decrease the total number of elements while having a finer mesh.

Having optimal mesh would increase the accuracy of the generated stress and decrease the load time for each iterations time for each simulation.
Reference:

