Facial Burn Injury Treatment: A Review of Facial Mask Fabrication Using Rapid Prototyping Technology

A.F Aiman[*1, a], M.N. Salleh[2, b], K.A Ismail[1, c]

[1]School of Manufacturing Engineering, University Malaysia Perlis, Arau, Perlis, Malaysia.

[2]School of Technology Management and Logistics , University Utara Malaysia, Sintok , Kedah.

[a*]aiman@unimap.edu.my, [b]najib@uum.edu.my, [c]k.azwan@unimap.edu.my

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Abstract This article gives an overview of the fabrication process of the facial mask that used in pressure therapy treatment for facial burn injury. The use of the different processes either conventional or 3D scanning method is discussed within this paper. The objective of this paper is to propose a new method of fabricating the facial mask using reverse engineering method and vacuum casting for producing a mask from elastic material, especially medical grade silicone. Vacuum casting was known for the capability of replicate the details on the master part and the ease of fabrication process. Analytical study of the face mask will be conducted using CAE software to simulate the pressure exerted by the designated mask.

1. Introduction

Pressure therapy is commonly used to treat burn injury, especially hypertrophic scars. The possible mechanism regarding the pressure therapy is by increasing collagen lysis and slowing protein synthesis [1], [2] even though the exact mechanism of how pressure positively influenced the maturation of hypertrophic scars are not fully understood[3]. Pressure therapy was used since early 1970s and proven the healing process[2], [3]. Mostly, for the human body part pressure garment is used throughout the treatment. However, the problems arise with the concave and convex area of the human body[4]. Even though there are still debates among researchers about the ideal pressure exerted by the pressure garment, most researchers agreed to state that the best pressure exerted from pressure garment is in the range of 15-24mmHg or 1999.85 -3199.74Pa [3], [5], [6]. Nevertheless in practices, pressure and garment fit were mostly assessed using ‘‘sight, touch and experience”[2], [7].

Facial area is one of the complex and contoured surface to develop a pressure garment. There were many practices in applying the pressure garment for the facial area, but it compromises the appearance due to the complexity of face and head contours. Regarding the facial burn injury, there are two methods of pressure therapy used in the treatment[8]. The treatments are the pressure garment using medical grade elastic fabric and the use of a mask known as Transparent Facial Ostrosis (TFO)[9]. By using a facial pressure garment, the elastic fabric is form to cover the scar area and stitch together in order to give the compression. This process is time consuming and requires skilled technician. However, the usage of pressure garment is mostly made for full face or head coverage area. As for partial face mask, most of the TFO are used in the treatment.

(a) Facial pressure garment (b) Facial mask

Figure 1: Types of facial pressure therapy treatment[8].

2. Theory of Laplace law in pressure garment construction

The pressure garment applied the theory of Laplace Law in order to calculate the pressure distribution[6]. The theory of using Laplace`s Law was originally developed in 1806 to explain the surface tension phenomenon of liquids and droplets or soap bubbles formation. Then, the original theory was developed to relate the wall tension and radius of cylinders to the pressure difference that existed between the pressure to push the two halves of the cylinder apart and the wall tension pulling the two halves together.

$$Pressure\ (P, Pa) = \frac{tension\ \ in\ the\ cylinder\ \ wall\ \ (T, Nm^{-1})}{radius\ \ of\ \ the\ cylinder\ \ (r, m)}$$

Or $$P = \frac{T}{r} \qquad (1)$$

Using the Laplace law to predict pressures exerted by pressure garments

Circumference of the limb or body part is measured (not the radius), therefore it would be more useful if the Laplace Law was amended to predict pressure from the fabric tension and circumferences of the body part. The pressure (in Pa) exerted by the pressure garment sleeves made from fabric with tension “T” could be predicted for a cylinder of circumference ‘c’ (in cm), since r (m) = (c (m)/2∏) = (c (cm)/100)/2 as follows:

$$Pressure\ (Pa) = \frac{T}{\frac{c}{100}/2\pi} \qquad\qquad C = 2\pi r$$

$$= \frac{T\ X\ 200\pi}{c}$$

$$= (628.319T)\ c^{-1}$$

Pressure in mmHg, since 1mmHg equal to 133.322Pa, the Laplace Law predicted in pressure mmHg would be:

$$Pressure\ (mmHg) = \left(\frac{628.319T}{133.32}\right)c^{-1}$$

$$= (4.713T)c^{-1}$$

Regarding the theory of the pressure garment reduction factor, it has been discussed and elaborated [10] . As for this paper, the scope is mainly focus on the facial area which is the most contoured part in human body. Section 3 discussed about the simulation from finite element analysis process and section 4 will discussed more about the previous method of fabricating the face mask including process, material and the effectiveness of the facial mask regarding pressure therapy.

3. Simulation and analysis of pressure therapy treatment using CAD/CAE

Referring to CAE analysis for the pressure garments, contact mechanics is the fundamental theory used for modeling the pressure garment, since the pressure arises from the contact between the body and a garment[11]. The theory of stresses in shells was used for the finite- element analysis[11], [12].

The model is based on the following series of assumptions as:

I. The human body is assumed to be a linear material whose behavior is governed by Hook’s law.
II. The garment is approximated as an isotropic and homogenous material.
III. The stress through the fabric thickness is assumed to be zero.
IV. The friction between the body and the garment is neglected.
V. The body is assumed to be a combination of a cylinder and cones.
VI. The contact between the body and garment is the same in all places.

This research will conduct the simulation of the face mask built from selected elastic polymer, and to achieve the targeted pressure which is in the range of 15-24mmHg. The maximum value of 24mmHg will be use as an indicator for the simulation because the pressure exceeding 25mmHg will be consider as too high and will cause discomfort to the patient body. A pressure calculation and 2D pressure prediction distribution model was developed and discussed by previous research [13].

4. Method of fabricating facial mask: Conventional and 3D scanner

TFO is widely used for facial burns treatment regarding the effectiveness of the TFO to minimize the hypertrophic scarring and maintaining the face contours against the deforming scars. Compression pressure is achieved through the force provided by the harness systems (straps and anchors) that are used to secure TFO on the face[9]. Based on some case study, the TFO is applied mostly after four months after injury.

Generally, there are two methods of fabricating the facial mask that practiced by the occupational therapist in rehabilitation unit. First is the traditional method that involves a lot of processes and direct contact with the burned patient. The traditional method will take several hours of labor-intensive and often painful to the patient. The process described used alginate impression material, plaster bandages for reinforcement and high-temperature thermoplastics. Furthermore, anesthesia was described to be used during this process[1]. They also described the process involved the application of alginate over a face lubricated with petroleum jelly in order to obtain a facial impression. Then it will be followed by the construction of a positive mould using plaster of paris and finally, the construction of the plastic mask.

The latest technology for the burn treatment is by using a 3D scanner that scans the burn area[1], [14]–[16]. Several types of 3D scanner was used to provide the cloud data[17]. The point of cloud data from the scanning process will be used to generate the mask using CAD software, and the part will be exported to a stereolitography or stl file for rapid prototyping process. This process improves the accuracy and fabrication on the concave or convex body area.

(a) facial casting using contact method

(b) Non-contact method using scanning device.

Figure 2: Face mask fabrication methods [9].

The process of using a 3D scanning method involve several steps, which are the scanning process, 3D part modeling, rapid prototyping process, mould making, and lastly mask fabrication. Referring to figure 2, the facial mask had been made from a silicone lined silicone lined Silon-STS with a thickness of 1.4 mm. As for the silicone material, the medical grade silicone has been proven as a safe material to be use for human[18], [19].

Several cases reported that the face mask was built using rapid prototyping technology, and it is proven that by using the method, the accuracy and fitting of the mask are better than using the conventional method. The report stated that the mask for the patient was built from the 3D surface scanning, and then the model generated and convert to stl file. The part was built using the powder based rapid prototyping system using ZCorp machine as shown in figure 3. The post-processing, curing are done to harden the powder based part and the part will be used to construct a positive mould using plaster of paris. After that, the plastic mask will be fabricated using vacuum forming process using conventional plastic sheet of Polyethylene Tetrephthalate Glycol (PETG). Next, the mask was trimmed to fit the scar area. As for the eyes and nose area, the section will be cut out and trimmed. Then the mask will be equipped with the harness system that will give force and pressure to the scar area covered by the mask.

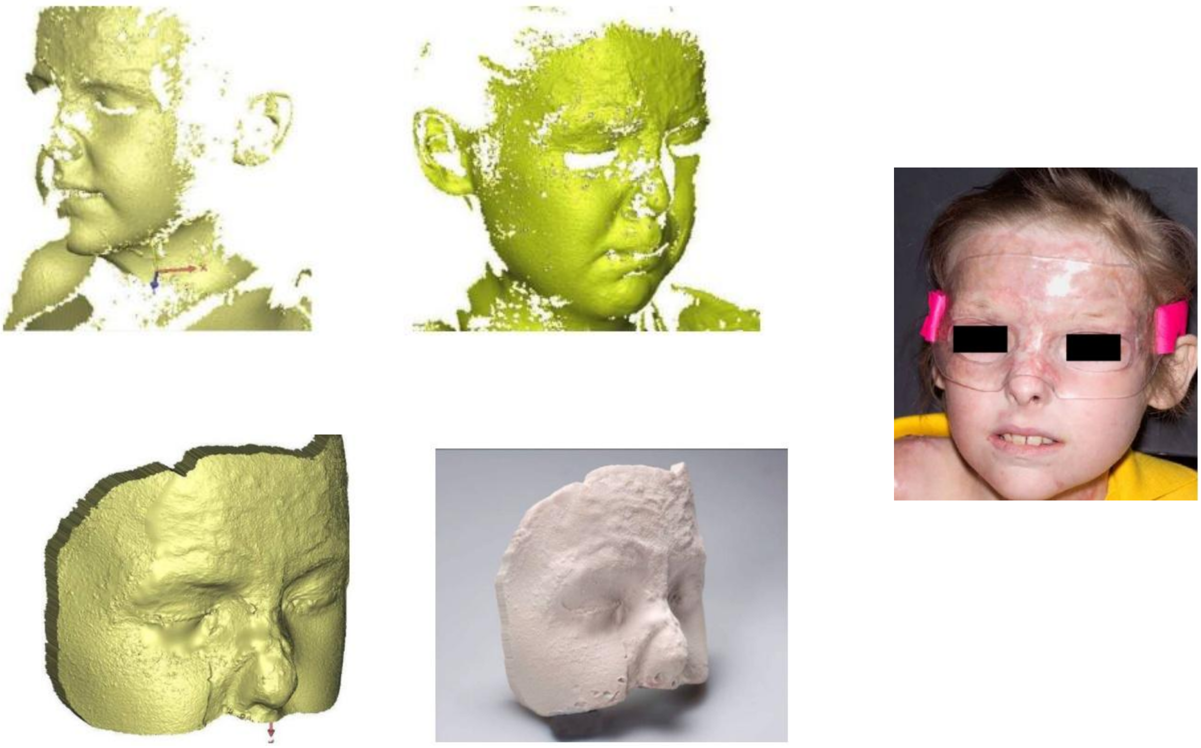

Figure 3: The process of using 3D powder based printer Z Corp. [14].

5. Opportunities and limitations of computer aided design in facial burn treatment.

3D scanning and reverse engineering revolutionized the hypertrophic scar treatment in a better way. It has been proven by the previous cases reported from other authors [1], [9], [14], [15], [20]–[22][13]. The usage of the technology involves the emergence between different background of expertise such as engineering, medical, therapist, physiology and others to ease the treatment and produce better results. By using the scanning process, there is no direct contact with the patient involve in the process which is different from the previous method that mostly painful to the patient. The accuracy of the garment or mask fitting increase and produce better results in healing process. Other benefits of the computer-aided design in burn injury treatment is the computer-aided surgical planning which the solution can be planned ahead and visualized before the actual surgical or treatments were done.

However, the data from the surface scanning process cannot give the exact properties such as tissue`s tension, elasticity, or weight density. The insufficient information from the data scan will increase the time to develop and visualize the scar area, especially where the burn area is larger and most of the part was badly damaged. As for the solution, the symmetrical image is used to visualize the other side of the missing area and built using CAD software. If the data still insufficient, the image of the family members will be used in order to get the most identical pattern to the patient`s face[16].

Several researches were done to improve the process such as the approaches are emerging from the finite-element method, which simulates physiological processes via mathematical approximation.

6. Proposed method using vacuum casting and medical grade silicone for face mask construction.

Based on the previous research, reports shows that the medical grade silicone was safe to use and the material can be used for vacuum casting process as the material comes in the liquid form. The mechanical properties will be used to predict the pressure distribution based on the mathematical equation that will be developed later through the experiment and results.

Vacuum casting will be used for mask fabrication due to the preliminary experiment. Master mould will be made of the FDM part by using a silicone rubber mould. By using this method, the mask can be cast for several units and can be used for test with different variables. As for the human head, the ballistic gel will be used for head casting in order to simulate the human tissue. The pressure sensor will be placed on different points of the facial area to record the pressure distribution.

By using the vacuum casting process, the process of heating the plastic sheet and trimming the mask can be eliminated rather than using a vacuum forming process that needs trimming process after the vacuum forming process. Based on the author`s knowledge, there is no process of mask fabricating using the vacuum casting process were done before. This process will be conducted in order to compare with the previous process and to make the fabrication process easier and with minimal cost.

7. Discussion & Conclusion

Regarding the review on the face mask and the involvement of CAD in mask fabrication, most researchers did not give a quantified data on the pressure distribution and experiment by using pressure sensor. The techniques used mostly using the same process flow that used a 3D scanner to gain a cloud data. Then, the data will go through cleanup process and CAD modeling. Several reports indicated that the masks are fabricated using a rigid thermoplastic that used a vacuum forming process. However, most researches on the automatic generated model from the scan data are still ongoing in order to improve the automatic algorithm for automatic modeling generation and reducing the time of CAD modeling, especially on the padding design.

This research will focus on the pressure distribution using an experimental face mask fabricated using vacuum casting method. The controllable variables will be the thickness of the mask and the force exerted by the harness point. However, the result will not be the same if applied to a human body due to the uncontrollable human tissue behavior. Data from the mannequin will be as a prediction of the pressure distribution with the relation of force from the harness point and thickness of the face mask.

Regarding the face mask material, it is perhaps that this research will continue to get a new material that is porous and suitable for the mask fabrication. Even more, the material must be capable to undergo the process of vacuum casting. By having a porous material, the face mask can be formed as a breathable product and eliminate the problem cause by the sweat and uncomfortable problems to human face.

Figure 4 shows the methodology and approach that will be used to conduct this research.

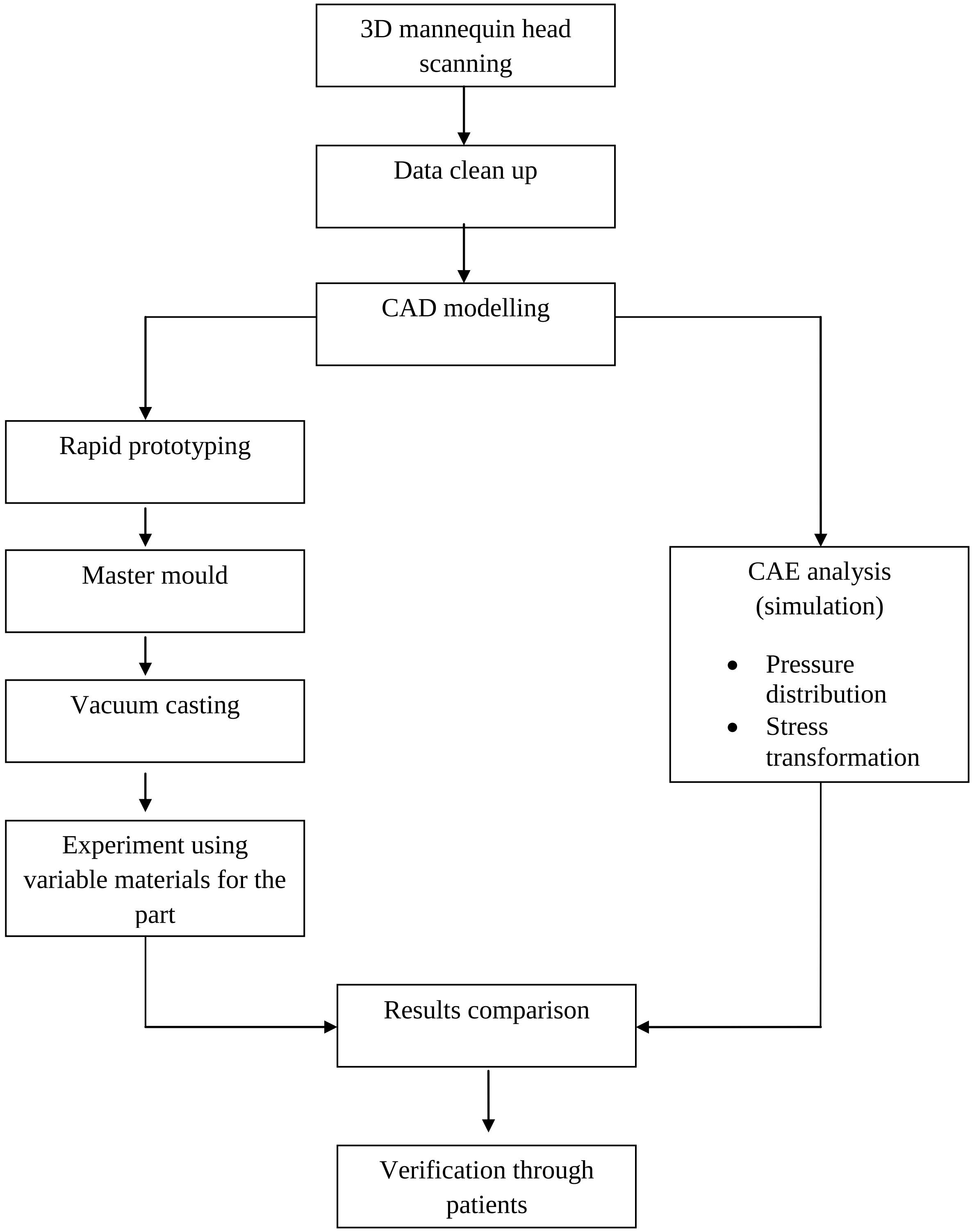

Figure 4: Methodology of the research.

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