New Empirical Formula for Reduction Factor of Head Garment

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LIST OF ABBREVATIONS

2D	Two dimensions
3D	Three dimensions
AM	Additive Manufacturing
CAD	Computer Aided Design
CRE	Continuous Rate Extension
FDM	Fused Deposition Modelling
HG	Head Garment
LOM	Laminated Object Manufacturing
LTS	Low Temperature Splinting
MAE	Mean Absolute Error
NCA	Non-Contact Active
NCP	Non-Contact Passive
OT	Occupational Therapist
PG	Pressure Garment
PMS	Pressure Measurement System
POP	Plaster of Paris
PVC	Polyvinyl Chloride
RP	Rapid Prototyping
SLA	Stereolithography
SLS	Selective Laser Sintering
SRF	Single Reduction Factor
TFO	Transparent Face Ortosis

LIST OF SYMBOLS

C	Circumference
C_i	Circumference of the Pressure Garment
C_o	Circumference Original
T	Fabric tension
E	Modulus of elasticity of the fabric
π	Pi
P	Pressure
r	Radius of curvature
Re	Reduction factor

Formula Empirik Baharu Untuk Faktor Pengurangan Bagi Pakaian Tekanan Cerunan Kepala

ABSTRAK

Pakaian Tekanan Cerunan adalah salah satu cara tanpa pembedahan dalam rawatan terapi tekanan, yang menggunakan tekanan sebagai mekanisma penyembuhan untuk parut hipertrofi disebabkan oleh kebakaran. Kajian terdahulu mencadangkan kaedah fabrikasi berdasarkan Hukum *Laplace* yang diubahsuai untuk meramalkan tekanan yang dihasilkan. Dari Hukum *Laplace*, faktor pengurangan dikira menggunakan parameter modulus keanjalan kain, ukuran lilitan tubuh, dan tekanan yang disasarkan. Walau bagaimanapun, sebahagian besar kajian terdahulu dijalankan berdasarkan bahagian tubuh badan terutamanya pada bahagian bawah badan (kaki) dan bahagian atas badan (lengan) yang menyerupai bentuk silinder. Namun, kajian yang dijalankan untuk bahagian kepala adalah amat terhad. Tujuan kajian ini adalah untuk mengkaji keberkesanan kaedah semasa yang digunakan untuk rawatan terapi tekanan di kawasan muka. Berdasarkan kajian dan analisis kaedah rawatan semasa, satu kaedah fabrikasi baharu untuk menghasilkan pakaian tekanan cerunan kepala diperkenalkan. Kaedah baharu ini mampu menghasilkan tekanan optimum yang diperlukan untuk rawatan. Kaedah ini menggunakan pendekatan rekabentuk digital seperti pengimbasan 3D, rekabentuk terbantu komputer dan pembuatan aditif semasa fasa rekabentuk dan pembangunan. Berdasarkan formula terdahulu bagi faktor pengurangan, pakaian tekanan cerunan kepala yang dihasilkan adalah ketat dan tidak sesuai untuk rawatan. Oleh itu, satu pendekatan empirikal digunakan untuk menentukan faktor pengurangan. Faktor pengurangan ini digunakan untuk menghasilkan pakaian tekanan cerunan kepala. Kaedah ini tidak memerlukan ujian tegangan untuk mendapatkan sifat bahan, yang merupakan maklumat penting jika kaedah terdahulu digunakan. Berdasarkan rumusan empirikal yang diperoleh daripada eksperimen, kajian ini berjaya menghasilkan pakaian tekanan cerunan kepala dengan padanan dan tekanan yang lebih baik. Bagaimanapun, terdapat beberapa kawasan mempunyai tekanan sifar terutamanya di kawasan hidung disebabkan oleh kontur muka. Alas rekabentuk langganan dibangunkan untuk memenuhi kontur kawasan tekanan sifar dan berjaya menghasilkan tekanan antara 18 mmHg hingga 32 mmHg. Secara keseluruhannya, pakaian tekanan cerunan kepala yang digabungkan dengan alas rekabentuk langganan menggunakan kaedah baharu ini mampu menjana tekanan yang bersesuaian (15 mmHg hingga 40 mmHg) untuk rawatan terapi tekanan.

New Empirical Formula for Reduction Factor of Head Garment

ABSTRACT

Pressure garment is one of non-surgical method in pressure therapy treatment, which uses pressure as healing mechanism for hypertrophic scars caused from burn injuries. Previous studies proposed a fabrication method based on the modified Laplace`s Law to predict pressure outputs. From the Laplace`s Law, reduction factor is calculated using parameters of modulus elasticity of the fabric, body circumferences, and the targeted pressure. However, most of the previous studies conducted based on lower and upper limbs body parts (arms and legs) which consist more like cylindrical shapes with limited studies conducted for head segment. The aim of this study is to investigate the effectiveness of current methods used for pressure therapy treatment at facial area. Based on investigation and analysis from the current methods in terms of pressure performances, a new fabrication method of head garment is introduced which capable to produce optimum pressure needed for the treatment. This study uses digital design approaches such as 3D scanning, computer aided design and additive manufacturing in design and development phases. Based on the previous reduction factor equation from literature, the produced head garment was tight and not suitable for the treatment. Hence, a new head garment fabrication method is proposed based on empirical approach to determine the reduction factor at particular circumferences of the body parts. In addition, this method does not require tensile test in order to obtain the information on material properties, which is a vital information if the previous methods were to be used. Based on the empirical formula derived from the experiments conducted, this study manages to produce a HG with better fitting and pressure performances. However, there are still some zero pressure areas occurred near nose area due to the complexity of the facial contours. A customized padding is developed to fit the contours of the zero pressure areas and managed to produce pressure ranging from 18 mmHg to 32 mmHg. The overall result of the application of head garment combined with the customized padding developed from this study has produced acceptable pressure outputs (15mmHg to 40 mmHg) for the pressure therapy treatment.

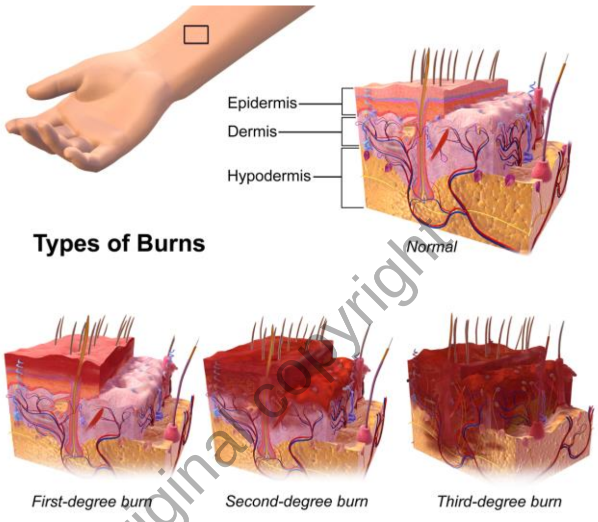
CHAPTER 1

INTRODUCTION

1.1 Pressure Therapy Overview for Burn Injuries

Burn injuries cause both physical and emotional traumatic experiences to the victims. The wounds caused by burn injury mostly develop into scars on the patient's body. Burn scars are referred to as hypertrophic scars which appear red with a lumpy appearance. Some problems caused by hypertrophic scars include itchiness, disfigurement, and contractures. In healthcare, there are two types of scar management, namely surgical and nonsurgical types. Surgical scar management involves a cut into the patient's body for treatment, and conversely for nonsurgical methods. Burn scarring is an unavoidable complication of burn injuries and the amount of scars depends on the severity of the burn injuries as well as the location of the body parts involved. Regarding facial burn injuries, nonsurgical management of facial scars commonly refers to several treatment methods, including pressure therapy, silicone application in combination with pressure garment or stand-alone, splinting, Silon face mask or Transparent Face Orthosis (TFO), massage, and facial exercise/range of motion (Parry, Sen, Palmieri, & Greenhalgh, 2013). Referring to the methods for nonsurgical management, those methods are practised at the rehabilitation phase. As for the burn injury, it can be categorised into four categories, as listed in Table 1.1.

Table 1.1: Classification of burn injuries (McHugh & Winifred, 2006).

Category	**Description**	**Figure**
First-degree burn	Involves only the epidermis. Skin functions remain intact.	
Second-degree burn	Involves the epidermis and possibly parts of the dermis. Blistering occurs.	
Partial thickness burn	First and second-degree burns, collectively.	
Third-degree burn/full thickness burn	Destruction of the epidermis, dermis, and epidermal derivatives, like sweat glands and hair follicles. Also known as full thickness burns.	

Pressure therapy derives from an early surgical principle, referring to the application of bandages and splints, for more than 40 years ago since 1970s (Joanne & Gill, 1995; Macintyre & Baird, 2006; Atiyeh, El Khatib, & Dibo, 2013). Methods of applying pressure have been documented and include, among others, the method of splints, bandaging, and elastic garments. Elastic garment refers to pressure garment (PG), typically used to treat hypertrophic scars because PG is easy to apply, is minimally disruptive to activities, and is available in terms of being commercially available or custom made by skilled technicians, who are known as Occupational Therapists (OTs) attached as hospital personnel working at the rehabilitation unit. Hypertrophic scar refers to a cutaneous condition caused by excessive amounts of collagen deposits which give rise to a raised scar that is mostly thick and red in appearance, causing pain and itchiness, for example as shown in Figure 1.1. In addition, PG can be used to correct the deformity and decrease the need for corrective surgery. Concerning pressure therapy treatment, the PG should be applied to the patient's wounded area for a long period of up to one year until the scar matures and can only be removed for hygiene purposes.

Figure 1.1: Hypertrophic scars caused by burn injuries (*Source:* Kolej Sains Kesihatan Bersekutu, Sg. Buloh).

The amount of pressure exerted from the application of PG has been found to be different for the different types of fabrics used for treatment (Carvalho et al., 2016). Lycra and Tubigrip are the common types of fabric used in PG (Engrav et al., 2010; Pilley, Hitchens, Rose, Alexander, & Wimpenny, 2011). The importance of fabric tension properties that affect pressure outputs has been reported in previous research (Wang, Felder, & Cai, 2011). In order to predict the exerted pressure, fabric tension and radius of curvature of body circumference are the parameters needed in order to calculate the pressure outputs using Laplace's Law (Macintyre, 2007; Yildiz, 2007; Leung, Yuen, Ng, & Shi, 2010; Valentinuzzi & Kohen, 2011). Nevertheless, most PG fabrics supplied to local hospitals are without information of the material properties. In addition, most exerted pressures are measured by OT, using rule of thumb based on visual inspection and verbal response from patient feedback.

The exact mechanism of how pressure positively influences the maturation of hypertrophic scars is not fully understood (Macintyre & Baird, 2006). However, a possible mechanism regarding pressure therapy for healing a scar is by increasing collagen lysis and slowing protein synthesis (Joanne & Gill, 1995; Lin & Nagler, 2003). Normally, PG can be used on any human body part for pressure therapy treatment. However, problems arise with the application of PG when insufficient pressure is exerted at concave and convex areas of the human body parts (Yip, Mehmood, & Shah, 2008). Even though there is still a continuing debate among researchers about the exact ideal pressure to be exerted by the PG for optimal healing, most researchers have agreed that the optimum pressure exerted by the PG should be within the range of 15 mmHg to 24 mmHg or 1999.85 -3199.74 Pa (Macintyre & Baird, 2006; Macintyre, 2007; Candy, Cecilia, & Ping, 2010). It was also reported that pressures greater than 40 mmHg may result in other complications (Engrav et al., 2010). Nevertheless, most pressure garment fittings were assessed using ‘‘sight, touch, and experience” (Joanne & Gill, 1995; Macintyre & Baird, 2005), which perhaps can be subjective. Figure 1.2 shows the examples of hypertrophic scars on burn patients and the result after applying PG for six months.

Figure 1.2: Results after six months of using the PG (*Source:* Kolej Kesihatan Sains Bersekutu, Sg. Buloh).

Regarding pressure measurement devices, sensor application in biomedical engineering has been reported by several authors and proven to be accurate and reliable (Engin, Demirel, Engin, & Fedakar, 2005; Li, Liu, Wang, Shi, & He, 2012). The trend of sensor applications in pressure measurements are improving and developing in terms of reliability and accuracy (Engin et al., 2005; Brophy-Williams, Driller, Halson, Fell, & Shing, 2013; Kumar, Hu, Pan, & Narayana, 2016). Reverse engineering technology also contributes to rehabilitation discipline in providing anthropometry measurements that are useful for pressure therapy treatment (Jones & Riouxb, 1997; Lin & Nagler, 2003; Rogers et al., 2003; Maier & Fadel, 2009; Cho, Park, Boeing, & Hingston, 2010;).

1.2 Research Background

According to previous studies in pressure therapy treatment, it was clearly stated that the range for optimum pressure exerted plays an important role in the healing process. As for the PG, the Laplace's Law equation has proven that the pressure can be predicted using certain parameters. The parameters needed for pressure prediction are modulus of elasticity of the fabric and radius of curvature (Ng & Hui, 2001; Salleh, Lazim, Othman, & Merican, 2012). The modulus of elasticity of the fabric is obtained according to a standard tensile test and radius of curvature is determined from the circumference dimension of the body segment. Regarding reports from previous studies, it was stated that the problem of PG fabrication is due to no information of material properties is provided to the hospitals in order to perform the most appropriate treatment (Macintyre & Baird, 2005; Engrav et al., 2010). With the lack of information about material properties, most PG fabricated in hospitals by the OT do not follow the Laplace Law equation. As a result, the pressure generated from the fabricated PG is not measured and mostly gauged from feedback by the patients (Macintyre & Baird, 2006).

In order to generate pressure from an elastic garment, the size of the garment must be smaller than the original circumference of the body part. The amount of the reduced size of the garment is known as the reduction factor. A study was conducted to calculate the pressure output at a particular circumference with variable reduction factor at each sections for the body parts (Salleh, Acar, & Burns, 2011). In addition, the application of variable reduction factor and computer aided design had assisted the fabrication process towards an optimal PG with a specified targeted pressure.

Meanwhile for the head segment, there has been less information or study conducted for pressure therapy treatment. Most studies referred more to limbs and other parts regarding the application of PG (Ng & Hui, 1999; Nguyen et al., 2007; Leung et al., 2010). The management of facial burn injuries at the rehabilitation stage still use the normal head garment (HG) and face mask as the acceptable standards for nonsurgical methods. HG is made from the same fabric used to fabricate PGs, while the face mask is made from a thermoplastic material. Both methods have been claimed to generate pressure to the scar areas, but limited studies reported the exact amount of pressure generated.

1.3 Problem Statements

The effects caused by burn injury in the facial area mostly disrupt the anatomical and functional structures, thus creating pain, deformity, swelling, and contractures that may lead to lasting physical and psychological effects on patients. These patients commonly lose their confidence with the community due to their injuries and appearances (Villapalos, Jeschke, & Herndon, 2008; Arno, Gauglitz, Barret, & Jeschke, 2014; Thakrar et al., 2015). At the rehabilitation stage, it has been reported that few methods were being used in managing burn injuries in the facial region. Face mask and PG are required to be worn up to one year or longer until the scar has matured, and can only be removed for hygiene and cleaning purposes (Villapalos, Jeschke, & Herndon, 2008). However, limited studies were conducted for the head segment in terms of pressure generated from the current treatment methods. Most of these studies were conducted based on lower and upper limb body parts, which are characteristically cylindrical in shape without much complexity (Ng & Hui, 2001; Macintyre, 2007; Yildiz, 2007). Silon face mask has been claimed to be an application of the method that is capable of increasing the healing process, but no measurement on the exact amount of pressure exerted had been reported (Nakamura, Niszezak, & Molnar, 2011).

As for the head garment fabrication process, the current HG fabricated in local hospital mostly used single reduction factor at 20% for the whole body segment. However, according to several studies, graduated reduction factor should be used for better pressure performances. Laplace`s Law and reduction factor equation was being used for the pressure garment fabrication. Unfortunately, the parameters in the reduction factor equation was not being evaluate to be used in HG fabrication.

Modulus elasticity of the fabric is a vital information if Laplace's Law was used in PG construction. However, the problem is that no information of fabric properties is supplied to the local hospital. This problem have been reported by a previous research (Macintyre & Baird, 2005). A standard tensile test was used in order to establish the material properties if Laplace's Law was subjected for the PG fabrication. Therefore, most of local hospital don't apply the Laplace`s Law to calculate the reduction factor and simply used single reduction factor of 20% from the original circumferences. Moreover, the pressure output was not measured and only gauged from the patient`s feedback.

1.4 Research Objectives

This study focuses on the pressure exerted from nonsurgical methods in pressure therapy treatment. Pressure measurement is conducted to measure the pressure exerted from currently practised HG and face mask therapy. Both methods are mostly used to treat scars located in the facial area. As for this study, the targeted wounded area is shown in Figure 1.3, where the hypertrophic scar exists. The red area will be the main focus for the investigation of the pressure exerted from the current practised methods used for pressure therapy treatment. The investigation involves fabrication, pressure measurements, and data analysis of the current practised methods used in the treatment.