Thermoelectric heat patch for clinical and self-management of post melanoma excision wound care

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Abstract. Thermodynamics as a physical and healing therapy is considered to have potential beneficial effects when applied to soft tissue. Normothermia is the state of a body being at a normal temperature and is essential to healthy cell functioning and wound healing. This article presents the application of thermoelectric elements on a conductive textile; focusing on the heat transfer of five elements over varied areas. By setting the temperature of the thermoelectric elements relative to skin temperature, a thermal camera captured the heat transfer. An increase in heat transfer was created by lining the conductive textile with commercial polyester wadding forming a quilted patch. Thus, by adapting this patch, the maximum distance between the elements relative to a minimum heat loss was observed at 3 cm. Any distance less than 3 cm covers a small area, whilst an increase in heat loss occurs above 3 cm. Further research can be conducted by implementing a pulse width modulating (PWM) system to maintain a constant temperature between 32 and 34 °C. With the addition of a temperature sensing device, a preventative system can be developed for chronic wounds essential for diabetic patients.

1. Introduction

Thermoregulation is the process in which the body works to maintain its core body and skin temperature within the required boundaries [1]. The human body achieves thermal balance from heat exchange that occurs between the body and its surrounding thermal environment. Autonomic thermoregulation relates to the autonomic nervous system composed of the hypothalamus that unconsciously controls the body thermal balance.

Perioperative hypothermia caused from anaesthesia has become a major concern in the medical field. In fact by administrating anaesthesia, thermoregulation is impaired; in addition to exposure to a cold environment, administration of intravenous fluids and evaporation from incisions, hypothermia is induced. Associated with major surgical procedures, such as cardiac and spinal surgery [2-5], it is vital to foster normothermia. Normothermia is the state of a body being at a normal temperature essential to healthy cell functioning [6] and wound healing.

Research into normothermia for regional anaesthetised surgical wounds such as melanoma excisions has yet to be studied. Melanoma excisions induce a local wound environment influenced by the anaesthesia for 4 - 6 hours post administration. Post-surgery, the wound is stitched as the site undergoes the healing process. Wound healing consists of four overlapping phases: haemostasis, inflammation, proliferation and remodeling. Haemostasis initiates the healing process preparing the phases that follow. During this phase, the inflammatory phase also begins. Once haemostasis has been completed, regeneration occurs through proliferation and remodeling [7-9]. Skin temperature is vital in
monitoring wound healing; it can be applied to prevention of complications such as infections. Despite unimpaired epidermis layer, in the case of diabetic patients measuring skin temperature in the insensitive foot has been addressed resulting in a relationship between an increase in localized temperature and localized pressure [10].

A skin temperature differential of 1 - 3 °C of the wound bed indicates a healthy healing state. Wounds that do not heal within three months are considered chronic; generally caused by a complication in one or more of the healing phases. In this case, skin temperature of the wound bed can increase up to 4 - 5 °C accounting for an infected wound. Postinfection temperature increases range only 0.8 - 1.1°C [11].

Skin acts as a thermal sensor for the body giving rise to the thermoregulation process; moreover, a variation of core body and skin temperature exists around the body [12]. Thus for normothermic wound therapy, temperatures approaching the skin temperature when the body is thermally balanced are ideal. Zhan et al. [13] identifies 33.4 °C as the ideal skin temperature (Tsk) where the human body is unaware of the temperature change with a 1.5 - 3 °C allowance. Discomfort is felt by the human body when the temperature increases or decreases more than 4.5 °C. Thomas et al. [14] reported the importance of duplicating normal physiological conditions in order to provide an optimum wound environment to improve wound healing. Current approaches into normothermic wound management apply heat to the wound inducing a moist environment whilst preventing hypothermia. However, the applied temperature is relative to the body core temperature and not the skin temperature [14-17]. Moreover, the materials and methods adapted are inconvenient requiring regular wound cover changes.

This study aims to provide a basis for development of an efficient wearable normothermic wound therapy patch by applying thermoelectric elements to electrical and thermal conductive textiles. This paper identifies the optimum positioning of thermoelectric elements for an even temperature distribution on a conductive patch. By applying this patch onto a wound, the temperature is distributed to the wound bed and periwound area maintaining thermophysiological skin temperature post anaesthetic administration thus preventing hypothermia. Subject to the results of this project, the proposed outcome is to effectively construct a single patch that can be applied to wounds of various sizes. Analysis of the heat distribution across the patch relative to the patch size is performed by identifying the optimum distance between the thermoelectric elements and patch size. The textile patch offers adaptability, providing a customised or patient-specific solution for improved wound management practice. This research has taken into consideration extensive wound sizes by positioning the thermoelectric elements in a matrix that is repeatable; thus, enabling versatile tailored textile patches for wounds of various sizes that can be place on any part of the body. Moreover, it has the potential for use in clinical or home settings.

2. Materials and Methods

To perform the experiment with precision, the thermophysiological skin temperature of about 33 °C was adapted as a reference model; thus, analysis of heat transfer on conductive textiles in the form of a patch was studied by setting the thermoelectric elements at 30, 32, 34 and 36 °C. To follow, a description of the materials selected is presented including the methodology of the experiment.

2.1. Materials

2.1.1. Thermoelectric Elements

Thermoelectric elements (product number QC-17-1.0-3.0) were purchased from Quick-Ohm Küpper & Co. GmbH of dimensions (l×w×h) 12×12×4 mm. To ensure optimum performance of the thermoelectric modules, the maximum current and voltage should not surpass 70% of the specifications. The specifications for the module are as follows; I_{\text{max}} = 3.3 A, V_{\text{max}} = 2 V, Q_{\text{max}} = 3.9 W with a \Delta T_{\text{max}} of 71 °C.
2.1.2. Textiles and Materials

For efficient thermal diffusion, conductive metalized nylon textile was purchased from SHIELDEX. Its rip stop weave is beneficial for commercial use due to its ideal properties, such as strength, durability and resistance to wear and tear; having an abrasion resistance of 500,000 cycles, one hundred times better than most conventional fabrics. Consisting of three fully plated metalized layers of 99% pure silver and coated with copper and tin, it is lightweight weighing 77 gsm with a thickness of 0.1 mm; in addition, it has a low surface resistance measuring at less than 0.02 Ω and an operating temperature ranging between -30 to 90 °C. It possesses electromagnetic and radio frequency-interference (EMI/RFI) shielding properties whilst eliminating passive static and minimising infrared radiation (IR) in addition to its antimicrobial properties; thus, it is well suited to wearable biomedical garments, where interference is common in medical centres. To improve the thermal diffusion, a thermal insulating textile was used as to line the conductive textile. This textile, a traditional polyester non-woven fabric purchased commercially, was selected for its high thermal diffusion value [18]. Aluminium tape was selected to fix the thermoelectric elements onto the nylon textile. It was adapted for this study due to its thermal properties and its common use as a heat sink.

2.2. Method

A thermal pocket consisting of five layers was prepared. Top and bottom layers were formed by folding the conductive metalized nylon fabric; thus creating the first and fifth layer respectively, to house the thermoelectric elements. Adding the polyester non-woven textile to the first layer produced the second layer. By applying the hot side of the thermal elements onto the polyester non-woven fabric, this third layer formed the basis of the experiment. The fourth layer of aluminium tape provided a heat sink for the system in addition to keeping the thermoelectric modules fixed.

Five thermoelectric elements were selected and positioned on a conductive textile as presented in figure 1 (a) and (b). Four thermoelectric elements were positioned in a square array with a fifth in the middle. Varying the distance (d) equally between the four outer elements deduced a set of six samples: sample 1, \(d = 1\) cm; sample 2, \(d = 2\) cm; sample 3, \(d = 3\) cm; sample 4, \(d = 4\) cm; Sample 5, \(d = 5\) cm and sample 6, \(d = 10\) cm. This pattern permits repeatability relative to any textile surface area whilst a middle node assists in an evenness of heat transfer through the textile. Figure 1 (c) presents the repeatability horizontally. Thermal images were captured using the Keysight Technologies U5855A Thermal Imaging Camera and its software TrueIR Analysis and Reporting Tool was used to analyse the heat transfer of line and segment and produce histograms.

![Figure 1](image.png)

**Figure 1.** Positioning of thermoelectric elements: (a) thermal photograph showing the working elements, (b) the matrix setup where the distance \(d\) varies and (c) horizontally repeated pattern.

3. Results and Discussion

To determine the position of the thermoelectric modules for optimum heat diffusion within the conductive and insulating textiles, samples 1 and 6 were initially made with the thermoelectric
elements electronically connected in parallel. By using the boxed analysis feature for samples 1 and 6 at the temperature of 34 °C, the sample range was determined. Boxed analysis is the method by forming a box over the area under study in which the temperature distribution across this selected area is represented using a histogram. By evaluating the histograms for these samples (refer to supplementary document), it was concluded that for sample 6 the thermoelectric peltiers were not efficiently utilised, with the temperature of the conductive patch ranging from 29 to 34 °C and a slightly left skewed distribution. By contrast sample 1 represented by a trimodal distribution, possesses a wider distribution approaching the desired temperature through the patch and a restricted temperature range of approximately 2.5 °C, relatively half of sample 6. From this, samples 2 to 5 were built for further study using line segment analysis at the predetermined temperatures 30, 32, 34 and 36 °C. A current of 3A was supplied for samples 1 to 5 for temperatures of 30 and 32 °C whilst 5A was supplied for 34 and 36 °C.

3.1. Line Segments

By varying the distance between the thermoelectric elements, ΔT_{max} was calculated across the vertical and horizontal line segments measured from the middle of two elements and diagonally, L1, L2 and L3 respectively, refer to figure 2 (a). Measurements were also taken and the ΔT_{max} was recorded across line segments between the outer and inner elements, L1 and L2, refer to figure 2 (b).

Line segmental analysis was identical for L1 and L2 in figure 2 (a) and in figure 2 (b); thus, a single ΔT_{max} was recorded for each set. These results along with ΔT_{max} recorded for L3 in figure 2 (a) were compared and presented as a percentage difference from the smallest ΔT_{max} to the largest ΔT_{max} in order to verify the optimum distance between thermoelectric modules, refer to figure 2 (c).

![Figure 2](image_url)

**Figure 2.** Line segment analysis: (a) connecting elements, (b) between elements and (c) graph of % increase from min to max ΔT_{max} of line segments.

From the results presented in figure 2 (c), it can be deduced that sample 3 with a 3 cm distance between the thermoelectric elements appears to be ideal relative to the distance. For example, the percentage difference across the line segments is comparable to samples 1 and 2, contrast to samples 4 and 5. Taking into account that the heat spreading across a larger surface area is desired, samples 1 and 2 are relatively small. For samples 4 and 5 ΔT_{max} varies greatly with an increase in temperature. By taking the average of the percentage increases, sample 3 performs better than samples 2, 4 and 5. Sample 1 proved to be the most efficient. Thus, further analysing the system, the power per square meter was calculated for each distance. Taking sample 1 as a reference, a comparison of the samples is shown in figure 3: presenting the power in W.m\(^{-2}\) and the percentage difference of the samples in comparison to sample 1. Comparing the samples to sample 1, sample 3 appears to be more efficient relative to the surface area.
Figure 3. Power dissipation (a) measured across surface area (W.m\(^{-2}\)) and (b) % increase of samples 2-5 relative to sample 1.

3.2. Histograms

Analysing sample 3, histograms were produced for all studied temperatures. It can be seen from figure 4 that for the distance of 3 cm, a wide normal distribution occurs implying a constant heat spread. Although at 34 and 36 °C the heat spread is slightly skewed to the left and right respectively, the distribution is still wide. Comparing sample 3 to the other samples (refer to supplementary document), the distribution shows more symmetry and is closer to a uniform distribution.

Figure 4. Histograms for sample 3: (a) at 30 °C, (b) 32 °C, (c) 34 °C, and (d) 36 °C.

4. Conclusion

Thermoelectric elements, when applied to attire, can provide thermophysiological comfort to humans maintaining normothermia around locally anaesthetised wounds. Equations governing thermophysiological comfort depend on skin temperature and not core temperature; thus, for this study the temperature setting for the thermoelectric elements are ideal to restore the skin temperature to its physiological state. By building a thermal pocket using five thermoelectric elements, the optimum distance between the elements was analysed. This was completed via recording the temperature distribution through a conductive textile, in the form of line segment analysis and power dissipation.
per square meter. It can be concluded that by applying thermoelectric elements to provide thermal comfort, a distance of 3 cm was ideal to cover a patch $55 \times 55$ mm, whilst providing a constant heat spread. However, this setup required a large amount of current giving rise to ergonomic issues of powering this wearable patch. Further research will require the implementation of a pulse width modulator (PWM) system in order to maintain a constant temperature between 32 and 34 °C to provide a portable and cost effective normothermic patch. Moreover, a temperature sensing device can be incorporated as a preventative feature for chronic wounds essential for diabetic patients. Heat distribution is vital to many applications; thus, this study can be adapted by researches from a vast variety of fields.

**Supplementary Document**

![Figure 5](image)

**Figure 5.** Histograms at 34 °C for samples (a) 1, $d = 1$ cm and (b) 6, $d = 10$ cm.
Figure 6. Histograms for sample 1: (a) at 30 °C, (b) 32 °C, (c) 34 °C, and (d) 36 °C.

Figure 7. Histograms for sample 2: (a) at 30 °C, (b) 32 °C, (c) 34 °C, and (d) 36 °C.
Figure 8. Histograms for sample 4: (a) at 30 °C, (b) 32 °C, (c) 34 °C, and (d) 36 °C.

Figure 9. Histograms for sample 5: (a) at 30 °C, (b) 32 °C, (c) 34 °C, and (d) 36 °C.

References

[1] Zhongping L and Shiming D 2008 Build Environ 43 70-81.
[2] Kurz A 2008 Best Pract Res Clin Anaesthesiol 22(1) 39-62.
[3] Kurz A, Sessler DI and Lenhardt R 1996 N Engl J Med 334(19) 1209-15.
[4] Teodorczyk JE, Heijmans JH, van Mook W, Bergmans D and Roekaerts P 2012 Open J Anesthesiol 2(3) 65-9.
[5] Allen TK and Habib AS 2018 Anesth Analg. 126(1) 7-9.
[6] Buggy DJ and Crossley AWA 2000 Br J Anaesth 84(5) 615-28.
[7] Ud-Din S and Bayat A 2016 Exp Dermatol 25 579-85.
[8] Gurtner GC, Werner S, Barrandon Y and Longaker MT 2008 *Nature* **453** 314-321.
[9] Rivera AE and Spencer JM 2007 *Clin Dermatol* **25(1)** 39-48.
[10] Houghton VI, Bower VM and Chant DC 2013 *J Foot Ankle Res* **6(31)**
[11] Chanmugam A, Langemo D, Thomason K, Haan J, Altenburger EA, Tippett A, Henderson L and Zortman TA 2017 *Adv Skin Wound Care* **30(9)** 406-414
[12] Romanovsky AA 2014 *Acta Physiol* **210** 498–507
[13] Zhang X 2001 *Smart Fibres, Fabrics and Clothing* vol 1, ed Tao X (Elsevier) 34-57
[14] Thomas RT, Diebold MR and Eggemeyer LM 2005 *J Am Med Dir Assoc* **6(1)** 46-9.
[15] Alvarez OM, Rogers RS, Booker JG and Patel M 2003 *J Foot Ankle Surg* **42(1)** 30-5.
[16] Whitney JD, Salvadalena G, Higa L and Mich M 2001 *J Wound Ostomy Continence Nurs* **28(5)** 244-52
[17] Altura D 2003 *US Patent No. US 6,613,953 B1*.
[18] Matusiak M 2006 *Fibers Text East Eur* **14(5)** 98-102