A Study On Avoiding Burn Injuries When Treating Patients With Needle Cupping

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***Abstract*—Needle cupping is a treatment that involves the use of heat and may cause burns if not performed carefully. Burn injuries in skin tissue result from exposing the skin to a temperature or temperatures above a threshold value for a certain period of time. In this study, we used ANSYS software to investigate heat transfer in a newly designed electro-thermal cup, the cup has an aspect ratio of AR=1.033 and that the ratio of the control temperature to the ambient temperature is T_O/T_∞<7.5. The results revealed that the gradual heating via the electro-thermal cup completely conforms to the human body's ability to adapt. Moreover, the results of the study can be used as a reference in estimating burn injuries for cupping therapy in the future.**

Keywords—burn injuries; heat equation; cupping; electro-thermal cup

I. INTRODUCTION

Cupping therapy is a simple, effective, economic, and time-saving treatment that utilizes the principles of heat transfer to affect biological tissues by changing their temperature [1-3]. Cupping therapy is a process that consists of suctioning or vacuuming sections of the body's meridian system for the purposes of drawing out toxins, managing pain, increasing blood flow, and promoting a healthier flow of chi energies [4]. These concepts and theories regarding the mechanisms of cupping therapy are theories from traditional Chinese medicine, but these theories need to be revised in light of modern medical scientific knowledge [5].

Needle-retention cupping, sometimes referred to as needle cupping for short, consists of applying a cup over the center of the site where an acupuncture needle has been inserted [6,7]. Needle cupping is mostly used for red and painful knee and elbow joints, where there is a need to simultaneously stop the pain and remove the excess pathogenic heat. The practitioner should administer the acupuncture treatment as intended under normal circumstances, leaving the needles in place as long as necessary. The acupuncture treatment time can be reduced, however, by 10-15 minutes if needle cupping will be applied following the acupuncture.

Understanding the biothermomechanics of skin tissue requires knowledge of biomechanics, bioheat transfer, and physiology. In a study by Xu et al. [8], a scheme was introduced to investigate the coupling between thermal and mechanical behaviour of skin tissue. A precise analysis of the thermal responses of biological tissues is difficult because of the complexity of the mechanisms that maintain body temperature, such as blood flow and metabolic heat generation [9,10]. Therefore, different bioheat transfer models have been proposed [11]. The most commonly used model for simulating the thermal behaviors of tissues is usually expressed by the thermal process described by the Pennes' bio-heat transfer equation [12].

The Pennes' model is used for predicting the effects of thermal physical properties and geometrical dimensions on the transient temperature and damage function distributions [13]. The results show that the thickness of the epidermis and dermis layers significantly affects the temperature and burn injury distributions, while variations in the initial temperatures and blood perfusion have little effect on these distributions. Using a one-dimensional model of metabolic heat generation, Okajima et al. [14] calculated the time and the thermal penetration depth required to reach a steady state.

Heat therapy involves exposing parts of body or the entire body to high temperatures at various thermal penetration depths [14,15]. However, it is essential that burn injuries be avoided when administering heat therapy. Burn injuries in tissue result from exposing the tissue to a temperature or temperatures above a threshold value for a specific period of time. Both the temperature and the exposure duration considerably affect the extent of a burn. Generally, a burn injury begins when the tissue temperature increases to a value greater than 44°C [13], whereas during hyperthermia for cancer treatment, the cancer cells are killed when the temperature reaches 42°C [16,17]. Human in vivo studies have demonstrated that the lipid bilayer of a cell membrane may be damaged if human tissue cells are kept at 50°C for more than 3 minutes [18]. Under such conditions, the proteins inside the cells will mutate, and this will eventually lead to coagulation necrosis, which is a type of accidental cell death. Therefore, it is necessary to control the temperature inside an electro-thermal cup.

Although extensive studies have been performed regarding the effects of blood perfusion and metabolic heat generation on temperature changes in biological tissues, few studies have been conducted to investigate the issue of skin tissue burn injuries due to elevated temperatures during thermal therapies. Therefore, establishing a simplified model will increase our knowledge of the association between elevated temperatures and burn injuries and thus help promote the efficient use of cupping therapy.

II. MODELS AND METHODS

In this study, we used ANSYS software [19] to investigate heat transfer in a newly designed electro-thermal cup. The most commonly used model for simulating the heat transfer through gas in an electro-thermal cup as shown in Figure 1 is the heat equation. The two-dimensional form of the heat equation can be written as follows:

$$\frac{1}{r}\frac{\partial}{\partial r}\left(k_a r\frac{\partial T_a}{\partial z}\right)+\frac{\partial}{\partial z}\left(k_a\frac{\partial T_a}{\partial z}\right)+\dot{q}=\rho_a c_a\frac{\partial T_a}{\partial t} \quad (1)$$

where k_a is the thermal conductivity, ρ_a is the density, c_a is the specific heat, and $\dot{q}$ is the heat generation of the thermofoil heater. For simplicity, all thermal properties are treated as constant and are based on the average of the control temperature of the thermofoil heater (T_o) and the ambient temperature (T_∞).

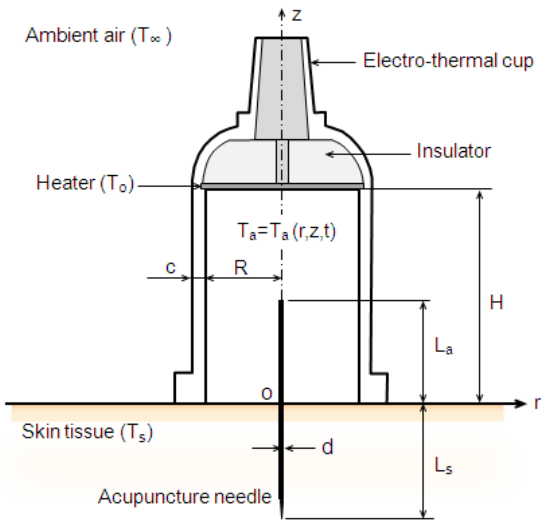

Figure 1 - Theoretical model of the electro-thermal cup.

A two-dimensional heat equation is described for the skin tissue as shown in Figure 1. The analysis assumes that the skin tissue is isotropic and homogeneous. To simplify our mathematical model, metabolic heat generation is assumed to be zero with respect to the heat generation of the thermofoil heater, and blood perfusion is neglected due to the fact that it has little effect on thermal damage [8,20]. Based on the above assumptions, the two-dimensional form of the heat equation can be written as follows:

$$\frac{1}{r}\frac{\partial}{\partial r}\left(k_s r\frac{\partial T_s}{\partial z}\right)+\frac{\partial}{\partial z}\left(k_s\frac{\partial T_s}{\partial z}\right)=\rho_s c_s\frac{\partial T_s}{\partial t} \quad (2)$$

All the thermal physical properties are assumed to be constant in the skin tissue despite the temperature elevation. The typical thermal physical properties of the skin tissue considered in this study were density ρ_s=1200kg/m3, specific heat c_s=3300J/kg-K, and thermal conductivity k_s=0.45W/m-K. [13,14,21]

The thermal effects are specified using the following initial conditions:

$$T_a(r,z,0)=T_{a,i} \qquad for\ t=0\,, z>0 \quad (3)$$

$$T_s(r,z,0)=T_{s,i} \qquad for\ t=0\,, z\le 0 \quad (4)$$

where the initial temperature of gas inside the electro-thermal cup ($T_{a,i}$) is equivalent to the ambient temperature (T_∞), the initial temperature of the skin tissue ($T_{s,i}$) is constant at 37°C [22], the control temperature (T_o) is constant, and the skin temperature (T_s) can be obtained by solving Equation (1) and Equation (2) with the following boundary conditions:

$$T_a(r,H,t)=T_0 \qquad for\ t=H \quad (5)$$

$$T_a(r,0,t)=T_s(r,0,t)=T_{s,0} \qquad for\ z=0 \quad (6)$$

$$h_c\Delta T_a=k_a\frac{\partial T_a(R,z,t)}{\partial r} \qquad for\ r=R=\frac{D}{2} \quad (7)$$

$$k_a\frac{\partial T_a(R+c,z,t)}{\partial z}=h_c\Delta T_a \qquad for\ r=R+c \quad (8)$$

where h_c is the convection heat transfer coefficient of air.

Since acupuncture and cupping are done in the same place by applying the needle first and then applying the cup over the needle, L_a and L_s are length values representing the length of the portion of the needle in the air and the length of the portion inserted into the skin tissue, respectively. Therefore,

$$T_n(0,L_a,t)=T_a(0,L_a,t) \qquad for\ z=L_1 \quad (9)$$

$$k_n\frac{\partial T_n(d/2,z,t)}{\partial r}=h_c\Delta T_a \qquad for\ z\ge 0 \quad (10)$$

$$-k_n\frac{\partial T_n(d/2,z,t)}{\partial r}=-k_s\frac{\partial T_s(d/2,z,t)}{\partial r} \qquad for\ z<0 \quad (11)$$

where k_n is the thermal conductivity of the acupuncture needle, and d is the diameter of the needle.

In practice, the cups used in cupping therapy typically come in a variety of bell shapes, for which the ratio of the height (H) to the inner diameter (D), known as aspect ratio (AR), is between 1 and 3.75. The physical properties of the electro-thermal cup considered in this study are height H=31.5mm, inner diameter D=30.5mm, thickness c=3mm, aspect ratio AR=1.033, and thermal conductivity k_g=14W/m-K. The acupuncture needle used was made of stainless steel, the physical properties of which are diameter d=1mm, length L=30mm, and thermal conductivity k_n=14.9 W/m-K.

Burn injuries can be predicted by calculating the skin temperature (T_s). A burn injury caused by temperatures higher than the threshold can be calculated using the thermal damage function (Ω), which is the Arrhenius burn integration proposed by Henriques and Moritz [23], as follows:

$$\Omega = \int_0^t A \cdot \exp\left(-\frac{E}{R_0 \cdot T_s}\right) dt \quad (12)$$

where A is the pre-exponential factor, E is the activation energy, R_0 is the universal gas constant, and T_s is the absolute skin temperature. The value of universal gas constant R_o=8.314J/mol-K. Because of the ethical and immunological issues associated with the use of human skin for testing, pig skin was chosen as a substitute because of its high degree of structural and functional similarities to human skin. Hence, the values of A and E used in this study were 2.126×10^{81} /s and 5.255×10^5J/mol [24], respectively.

The thermal damage function *Ω* is the dimensionless indicator of thermal damage, so the calculation of *Ω* enables us to compute damage due to burn injuries. Generally, *Ω*=0.53 can cause irreversible epidermal damage, *Ω*=10 would cause complete transepidermal necrosis [25], and third-degree burn injuries would occur at *Ω*=10,000 [26].

III. Results and Discussion

The numerical computation in this study included the air above the skin away from the electro-thermal cup and the skin tissue underneath the cup. The element meshes used were N=36,163, and the transient temperature change time interval was Δt=1 second. Because the heat source was set using a digital thermostat, the thermofoil heater temperatures chosen were 50°C, 100°C, and 150°C, and the outside temperature T_∞ was a constant 20°C.

In the cupping therapy of traditional Chinese medicine, needle cupping consists of a combination of cupping and acupuncture used for patients who require both acupuncture and moxibustion. In practice, after determining the appropriate needle depth based on the deficiency and excess of the particular illness, the cup is placed over the needle; the heat conductivity of the needle introduces heat into the acupuncture point to produce a therapeutic effect. To understand the impact of heat transfer while the needle is left in situ, the needle length was assumed to be 18mm (z/H=0.57) and the depth to which the needle was stuck into the skin tissue was 12mm (z/H=-0.38).

The first example calculation investigated the temperature variation between the air inside the electro-thermal cup and the skin tissue when the cup was placed over the needle during moxibustion. Figure 2 shows the skin temperature at the central axis inside the cup (r=0). The curve distribution in the figure clearly shows that as the thermofoil heater began to warm, because the initial air temperature inside the electro-thermal cup was 20°C, the skin surface temperature decreased during the first 60 seconds and then proceeded to increase rapidly. At 304, 349, and 352 seconds during heating, the temperature increase slowed, $(T_t-T_{t-1})/T_{t-1}<1\%$, implying that the temperature inside the cup was approaching a steady state. The curve also shows that at different thermofoil heater control temperatures, the skin surface temperature inside the cup was higher than body temperature (T_s>37°C); this occurred at 624, 231, and 129 seconds, respectively, showing that this time can be shortened by adjusting the control temperature. Chinese medicine practitioners use flames to quickly remove the air from inside the cup in order for it to adhere to the skin; this often causes the patient to feel a burning sensation and discomfort. The electro-thermal cup developed in this study uses low temperature moxibustion from a thermofoil heater, with the skin detecting gradual heating in order to stimulate and activate the acupuncture points, in contrast to the traditional method of burning moxa (*Artemisia argyi*, Chinese mugwort), which can generate temperatures up to 140°C and lead to a risk of burns.

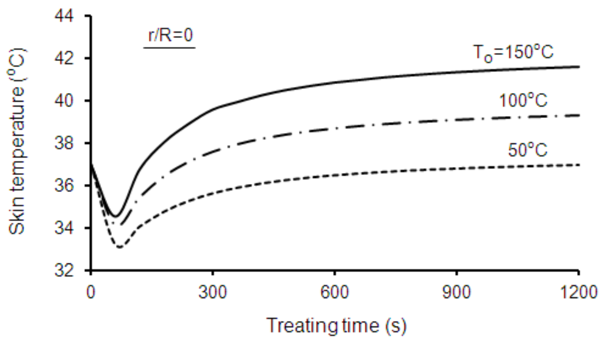

Figure 2 - Skin temperature elevation under different control temperature

Figure 3 shows the radial heat distribution of the skin surface inside the cup when the outside temperature T_∞ was 20°C and the thermofoil heater heated for 1200 seconds. With the exception of T_o=50°C, a temperature at which the insufficient heat transfer did not change the temperature of the skin surface, the other two curves clearly show that the central axis inside the cup had the highest temperature, and the temperature decreased as the radial distance increased. This is mainly due to the boundary conditions in Equations (7) and (8), where the heat generated by the thermofoil heater was transferred through the cup walls and dissipated to the outside. The curves show that the temperature differences between the electro-thermal cup central axis and the cup interior at T_o=100°C and 150°C were 2.7°C and 5.1°C, respectively.

If cup interior air temperature obtained from Equation (1) is used to calculate heat flux, then

$$q" = -k_a \frac{\partial T_a}{\partial z} \quad (13)$$

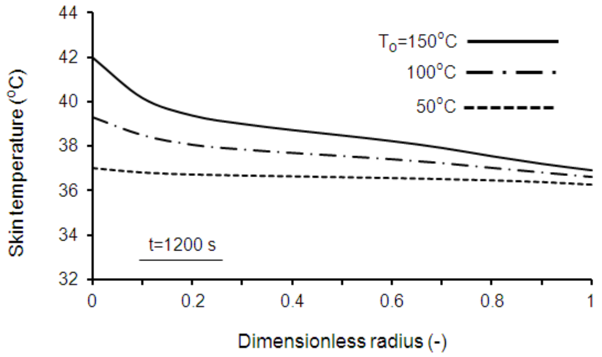

Figure 3 - The radial heat distribution of the skin surface

Thus, we can obtain the heat flux ($q_H^{"}$) generated by the thermofoil heater and the heat flux ($q_s^{"}$) borne by the skin surface. Figure 4 shows that both $q_H^{"}$ and $q_s^{"}$ show linear increases. The calculation results show that when the temperature To is raised from 50°C to 150°C, heat flux generated by the thermofoil heater increases 6.4 times from 2.34×10^{-3}W/cm2 to 15.14×10^{-3}W/cm2. Raising To enhances the thermal efficiency of the electro-thermal cup; however, this requires increasing the heat flux of the thermofoil heater which, in turn, affects safety and costs. By contrast, increasing To from 50°C to 150°C increases the $q_s^{"}/q_H^{"}$ ratio from 1.71% to 3.92%; yet the heat flux borne by the skin surface $q_s^{"}$ is only 0.59×10^{-3} W/cm2. This shows that the heat generated by the thermofoil heater is mostly dissipated to the outside through the cup walls and, at most, 3.92% is transfered to the skin, implying that the cups should be made from a material with better thermal insulation in order to increase the effectiveness of cupping.

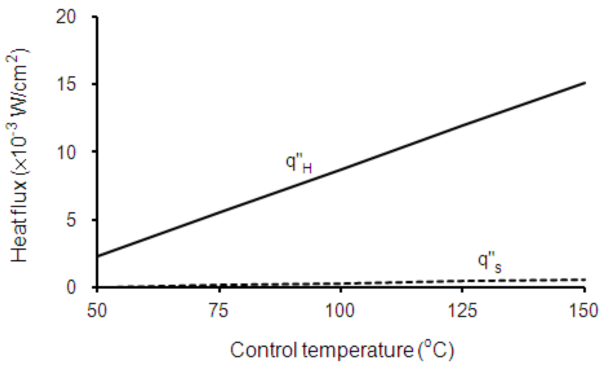

Figure 4 - Heat flux elevation under different control temperature

This study used ANSYS software to establish a mathematical model and provide color isothermal contours to show transient temperature variations. The use of color makes the heat transfer more visible, which can in turn enhance the capacity to evaluate whether the needle cupping method is appropriate; this aids in the design of the electro-thermal cup. As the thermofoil heater was attached to the top of the cup, the basic principles of heat transmission state that the top of the cup will be hotter than the bottom ($\partial T/\partial z$ >0); therefore, the air density inside the cup shows an increasing trend in the direction of gravity ($\partial \rho/\partial z$ <0). Thus, the air weight of the less dense air at the top of cup is less than the air weight of the more dense air at the bottom of the cup. As such, the air inside the cup is in a stable state and there is no bulk fluid motion. Figure 5 shows the temperature variations inside the cup at a control temperature of T_o=150°C, and outside temperature of T_∞=20°C and heating for 1200 seconds. The image shows that the isothermal lines near the thermofoil heater at the top of the cup are nearly horizontal. Lower, the acupuncture needle creates a lower temperature in the middle, whereas to the sides, the temperature is higher. Close to the end of the needle (z/H≒0.65), the colors indicate a more prominent curve. The metal acupuncture needle is highly heat conductive which helps transfer heat through the needle to the skin. Traditional moxibustion ignites balls of moxa; if direct moxibustion is used, the fire often first or second degree burns to the skin. Indirect moxibustion, while removing the risk of burns, the thermal insulation greatly reduces the amount of heat felt by the skin, hindering the therapeutic effects. The small area of skin that is heated also reduces the therapeutic effects. Traditional moxibustion is a temporary heating therapy; heat and pain are often felt after the procedure which may result in skin infections or, in serious cases, bacteremia. Figure 5 shows that the gradual heating via the electro-thermal cup completely conforms to the human body's ability to adapt.

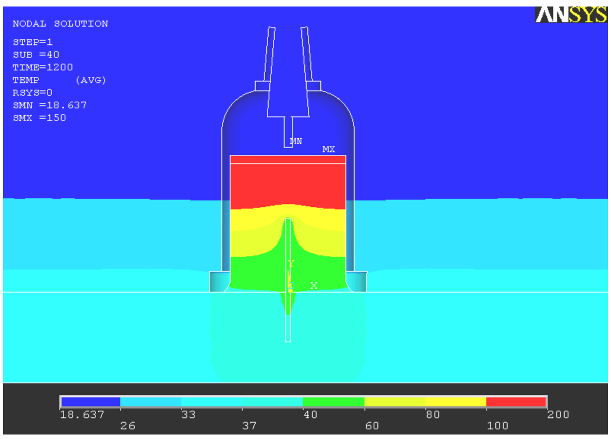

Figure 5 - Transient-state temperature profiles in the electro-thermal cup

Figure 6 shows the thermal damage function curves at different control temperatures, T_o. The Y-axis shows the thermal damage function and the X-axis shows the heating time. The curve distributions show that at the beginning of heating, Ω increases rapidly and that even after 1200 seconds, Ω still continues to increase. The increases are 7.5%, 8.1%, and 8.6%, respectively, where the amount of increase is defined as $(\Omega_t - \Omega_{t-1})/\Omega_{t-1}$. Thus, where the temperature is higher than body temperature, prolonged times continue to raise the Ω value. As Ω is a dimensionless secondary index that measures burn injury and the thermal conductivity of the electro-thermal cup was excellent (thermal conductivity k_g=14 W/m-K), despite not reaching the critical value for irreversible epidermal damage (Ω=0.53), there was still a large variation; however, this also implies that there is room to improve the thermal efficiency of the electro-thermal cup.

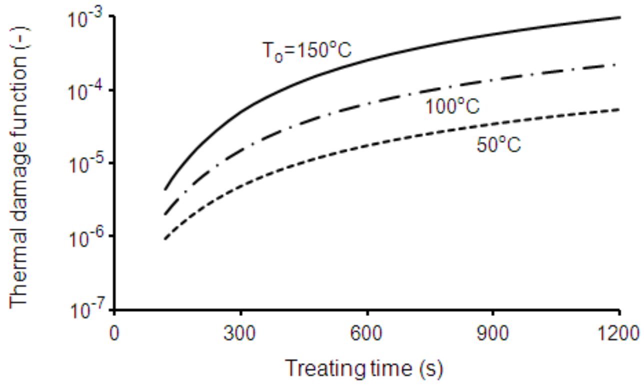

Figure 6 - Thermal damage function under different control temperature

IV. Conclusions

Needle cupping is typical therapy employed in traditional Chinese medicine. The technique is characterized by amazingly rapid results, which appear to be aided in part by the application of heat. But during needle cupping treatment, it is difficult to quantitatively estimate the threshold for skin surface burn injuries because the degree to which temperatures are elevated during the therapeutic process is sometimes ignored. In order to study the heat transfer associated with needle cupping, it is necessary to determine the relationship between the heating performance of the instrument and the degree to which heat is transferred to the skin during thermal treatment.

This study used ANSYS software to study the heat transfer capabilities of electro-thermal cups in general, and, more specifically, to investigate the heat transfer characteristics of a newly designed electro-thermal cup. The results indicated that the cup's aspect ratio H/D=1.033, and the temperature ratio $T_0/T_\infty<7.5$. Moreover, the results of the study can be used as a reference in estimating burn injuries for novel electro-thermal cup designs in the future.

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