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A Qualitative Research on the Heat Transfer of Cupping Therapy

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***Abstract*—This study investigated heat transfer of cupping therapy using ANSYS software for numerical calculations and color imaging in order to examine changes in the transient temperature field and velocity field of the skin due to the heated air within the cup. This study focused on the flash-fire cupping method and used an initial cup temperature of 150°C. The calculation results indicated that the air temperatures of the skin surface after 600 and 1200 seconds of adiabatic cupping was 59.5°C and 47.2°C, respectively, and the hot air within the cup serves as superficial heat therapy. No natural convection occurs within the cup, implying that heat transfer in the cup is conducted through the air. For a adiabatic cup, the temperature within the cup decreases to 40°C after 65 seconds and heat transfer in the cup is conducted through air convection.**

Keywords—cupping therapy; heat transfer; flash-fire cupping; adiabatic cup

I. INTRODUCTION

Mankind has always been skillful at controlling and using heat, including its applications in medical therapies. Using heat to treat illnesses and aid in physical recuperation is a fundamental part of traditional Chinese medicine (TCM) and essential to traditional medicine in all ancient cultures [1-4]. However, there are few academic analyses of heat as used in TCM, including the thermal effectiveness of cutaneous devices or the thermal responses of skin tissue.

Heat is commonly used in medical practice; heat therapy uses temperature changes to soothe and repair cellular tissue. Cupping in TCM is a therapy that applies heat. When the temperature inside the cup is higher than the body temperature, heat is transferred, conducted, or radiated into the body. When the temperature of the tissue rises, the blood vessels expand, increasing blood flow to the area, and metabolism in quickened.

Cupping uses an open cup to heat a specific area of the body [5]. combustion or a vacuum is used to create negative pressure within the cup so that it attaches to the skin causing passive hyperemia, or congestion, within the superficial tissue to help the tissue heal or improve circulation, thus promoting metabolism [6]. Skin becomes injured at temperatures above 42-44°C [7]. Contact time is another important factor determining burn injury, with a temperature of 58°C sustained for three minutes destroying the lipid bilayer of the cell membrane [8]. Heating the cup increases the temperature inside, after which it is placed on the skin. The heat from the air is transferred to the skin while some of the heat escapes from the walls of the cup into the outside air. Cups with superior thermal insulation allow less heat dissipation; assuming a completely adiabatic cup, all heat would be transferred to the skin. As such, the choice of cup used is an important factor determining the effectiveness of cupping.

During treatment, the amount of heat used to best meet the patient's needs is mainly determined by the physician's experience. An excessive amount of heat may cause flash burns when the cup comes in contact with the skin [9]. Modern cupping has mostly moved away from heat and has opted to use vacuum cups such that traditional cupping methods are gradually being forgotten.

This study advocates retaining the essence of traditional cupping to prevent the loss of these techniques. The mathematical model developed using Pennes' bioheat equation [10-13] and numerical analysis were used to study heat transfer in cupping therapy to serve as a reference for TCM clinicians in order to help revive the use of traditional techniques.

II. THEORETICAL MODEL AND METHODS

The numerical methods used in this study applied ANSYS software. Appropriate boundary conditions were set so that changes in the temperature field and velocity field were used to investigate heat transfer during cupping. To simplify the mathematical model, this study made the following assumptions:

1. The area of skin was isotropic and homogenous.

2. The thermophysical properties of the air and skin were not influenced by temperature variations.
3. Heat radiation between the cup and the outer environment was not considered.

The geometrical model used for numerical calculations (Figure 1) was a circular cylinder (r,θ,z) with an axially symmetric cup so that the azimuth angle θ can be ignored and the equation can be simplified using the coordinates (r,z). The cup dimensions were diameter D=50mm, height H=80mm, and wall thickness c=5mm.

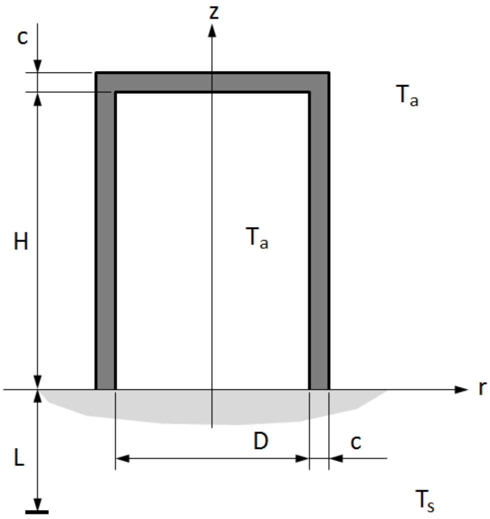


Fig. 1. *Theoretical model of the therapeutic cup*

The governing equations for the air were the continuity equation, momentum equation, and energy equation. The governing equation for the skin was Pennes' bioheat equation and the governing equation for the cup was a separate energy equation. The thermal equation for the air inside the cup and the skin was transient; therefore, the initial conditions were set as follows:

$$T_a(r,z,0) = T_{a,0} \quad \text{for } t=0,\ z>0,\ r=R=\frac{D}{2} \tag{1}$$

$$T_a(r,z,0) = T_a \quad \text{for } t=0,\ z>0,\ r>R \tag{2}$$

$$T_a(r,0^+,0) = T_s(r,0^-,0) \quad \text{for } t=0,\ z=0 \tag{3}$$

$$T_s(r,z,0) = T_{s,i} \quad \text{for } t=0,\ z<0 \tag{4}$$

The initial air temperature inside the cup was equal to the temperature of a lit alcohol lamp ($T_{a,0}$) and the initial skin temperature ($T_{s,i}$) was assumed to be 37°C. With these given parameters, the skin temperature (T_s) can be found using the boundary conditions and governing equation.

The boundary conditions for the cup walls and bottom (*r=R* and *z=H*) were assumed to be adiabatic, implying that heat flux (q") was zero. Thus, the air at the skin surface and the skin must be in thermal equilibrium:

$$\frac{\partial T_a(r,z,t)}{\partial z} = 0 \quad \text{for } z=H \tag{5}$$

$$\frac{\partial T_a(r,z,t)}{\partial r} = 0 \quad \text{for } r=R=\frac{D}{2} \tag{6}$$

$$T_a(r,0^+,t) = T_s(r,0^-,t) \quad \text{for } z=0 \tag{7}$$

$$h_a(T_a - T_s)\ |_{z=0^+} = -k_s \frac{\partial T_s}{\partial z}\ |_{z=0^-} \quad \text{for } z=0 \tag{8}$$

If the cup walls and bottom did not provide complete thermal insulation, thermal equilibrium must be considered between the cup and the outside air as well as the skin and the inside air.

$$h_a(T_a - T_c)\ |_{z=H^-} = -k_c \frac{\partial T_c}{\partial z}\ |_{z=H^+} \quad \text{for } z=H \tag{9}$$

$$-k_c \frac{\partial T_c}{\partial z}\ |_{z=(H+c)^+} = -h_a(T_c - T_a)\ |_{z=(H+c)^-} \quad \text{for } z=H+c \tag{10}$$

$$h_a(T_a - T_c)\ |_{r=R^-} = -k_c \frac{\partial T_c}{\partial r}\ |_{r=R^+} \quad \text{for } r=R \tag{11}$$

$$-k_c \frac{\partial T_c}{\partial r}\ |_{r=(R+c)^-} = -h_a(T_c - T_a)\ |_{r=(R+c)^+} \quad \text{for } r=R+c \tag{12}$$

$$T_a(r,0^+,t) = T_s(r,0^-,t) \quad \text{for } z=0 \tag{13}$$

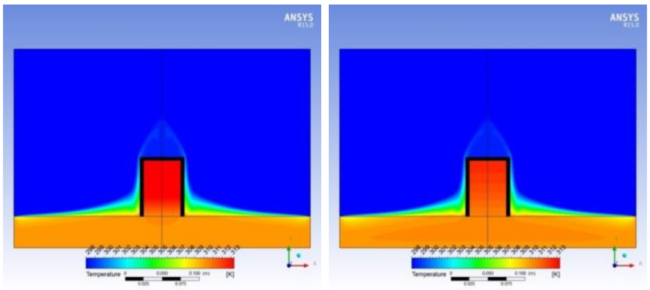
$$h_a(T_a - T_s)\ |_{z=0^+} = -k_s \frac{\partial T_s}{\partial z}\ |_{z=0^-} \quad \text{for } z=0 \tag{14}$$

The parameters required for numerical calculations in this study included the element partitions for each region and the transient time interval Δt; the regions were considered to be the area above, left, and right of the cup three times the diameter. The skin comes to thermal equilibrium with the air inside the cup and the air outside the cup; the deepest skin depth (L) was set at the core body temperature of 37°C. The value of L was calculated using trial and error and the area where $\partial T_s/\partial z = 0$ was calculated. Jiang et al. [7] pointed out that the skin thickness of the human back was 4.208cm; thus, this was used for the value of L.

III. Results and Discussion

This study focused on the widely used flash-fire cupping method and set the temperature inside the cup ($T_{a,0}$) at 150°C to investigate the heat transfer inside the cup. Figure 2 shows the temperature variations for an adiabatic cup with the initial temperature inside the cup at 150°C. When the cup is heated and quickly pressed onto the skin, the heat is transferred into the skin tissue, lowering the air temperature inside the cup. As heat is transferred from areas of high temperature to areas of low temperature, the hotter air inside the cup is at the top and the lower temperature air is at the bottom. Thus, the density of the air at the top of the cup is lower than the density of the air at the bottom. This implies that natural convection is impossible within the cup; therefore, thermal convection currents are not present and heat transfer is mainly though conduction. Figure 2 shows that as the cup is adiabatic, the temperature gradient of the walls is zero $\partial T_a/\partial r = 0$; thus, through heat conduction, the isothermal line inside the cup is nearly horizontal.

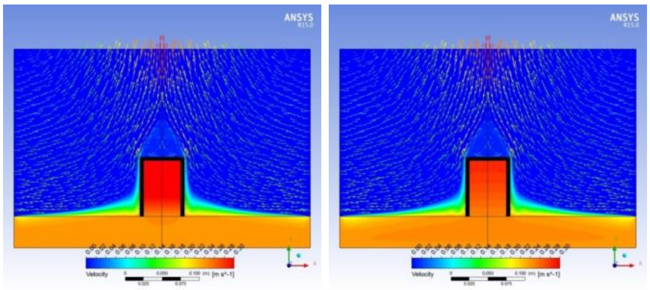
Figure 2 also shows a clear color change between the air temperature inside the cup and the skin. Numerical calculation shows that after 600 and 1200 seconds of treatment, the temperature at the top of the cup reduced to 70.1 and 52.5°C, respectively, while the air temperatures at the skin surface were 59.5 and 47.2°C, respectively. After 1200 seconds, the air temperature at the skin surface was still greater than 37°C, indicating that cupping is a continuous thermal stimulus for local section of skin. The thermal stimulus can help expand blood vessels, improving local blood circulation and metabolism. The color changes for the skin tissue indicate that heat from inside the cup slowly transferred into the skin and expands outwards to the sides quicker than it does deeper into the skin. In general, superficial heat therapy is defined as heat that penetrates less than 10mm deep into the skin; whereas, heat penetration of 30-60mm is considered deep heat therapy. The calculation results show that while the initial temperature was 150°C, the heat only provided superficial heat therapy. Therefore, as widely used in TCM hospitals, depending on the patient's condition, physicians may consider using several or tens of cups. During treatment, arranging the cups in rows is referred to as cupping alignment.



(a) t=600seconds (b) t=1200seconds

Fig. 2. *Transient-state temperature profiles in the adiabatic cup*

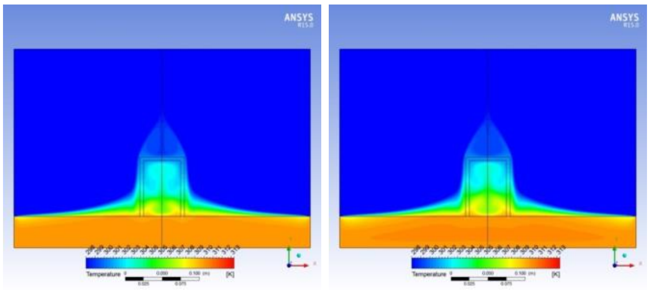
Figure 3 shows the changes in the velocity field inside an adiabatic cup with the initial air temperature outside the cup at 20°C. As the human core temperature is higher than the outside air temperature, heat dissipates from the skin surface into the outside air. The temperature of the skin surface is lower than the internal body temperature as the thermal current from the skin heats up the surrounding air. The figure shows that the air temperature near the skin surface is higher and the density is lower; whereas the air temperature away from the skin is lower and the density is higher. This causes natural convection around the outside of the cup. As the convection effect caused by the difference in air temperatures is not strong, the heat lost through the thermal convection current only heats up the air close to the skin surface. The figure shows that as the temperature difference in the outside air is very small, the natural convection velocity vectors were between 0.1-0.3m/s. At approximately 48mm above the cup, nearly as high as the diameter of the cup (D=50mm), the velocity vectors from both sides combine to create an updraft and slightly increase to 0.32m/s. It is worth emphasizing that with no natural convection within the cup, this result implies that heat transfer inside the cup is mainly conducted through the air.



(a) t=600seconds (b) t=1200seconds

Fig. 3. *Transient-state velocity profiles in the adiabatic cup*

Figure 4 shows the temperature variations inside a diabatic cup. As the cup conducts heat, a traditional bamboo cup was used in this calculation for which the thermal conductivity coefficient is k=0.1959W/m·K. Therefore, the initial high air temperature inside the cup is not only transferred to the skin, but also partially through the cup and into the outside air. In this example, the cup was placed on the skin after being heated, after which the heated air dissipates through the walls and top of the cup. Thus, the air temperature inside the cup rapidly declines. The figure clearly shows that the temperature inside the cup had already declined to below 37°C at 600 seconds; as time continues, heat from the skin is transferred into the air above the skin, including both the air inside and outside the cup. As metabolism maintains a skin temperature of 37°C, the color variation is only noticeable at the skin surface. The heat transfer rate along the cup is clearly quicker than that for the thermal convection current in the air; as such, the colors for the air at the skin surface inside the cup created an arc.

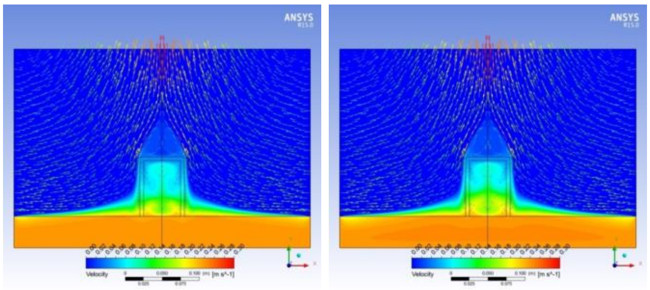


(a) t=600seconds (b) t=1200seconds

Fig. 4. *Transient-state temperature profiles in the diabatic cup*

Figure 5 shows the velocity field changes inside the diabatic cup. The velocity vector results for the air outside the diabatic cup were similar to those for the adiabatic cup. As the temperature difference caused density variations leading to natural convection, the velocity vectors were more apparent above the cup. Similarly, the velocity vectors on either side of the cup came together in an updraft at 48mm above the cup and the velocity vectors slightly increased to 0.32m/s. However, in this calculation, the lower temperature air was at the top and the warmer skin was at the bottom.

As the air density was lower at the bottom of the cup, natural convection occurred; however, the small temperature difference inside the cup only resulted in velocity vectors smaller than 0.03m/s. This shows that in this situation, the heat transfer inside the cup is mainly conducted through air convection.



(a) t=600seconds (b) t=1200seconds

Fig. 5. *Transient-state velocity profiles in the diabatic cup*

IV. CONCLUSIONS

In practice, cupping uses heat to create negative pressure inside the cup which is then placed directly on the skin causing passive hyperemia to achieve the treatment objectives. However, excessive or improper use of heat may cause serious burns. In particular, the flash-fire cupping method often uses alcohol lamps with flame temperatures of up to 463°C as a heat source. After being heated by the flame, the cup is immediately placed on the treatment area, where burns may occur shortly after the cup comes in contact with the skin.

The numerical calculation results showed that with an initial temperature inside an adiabatic cup of 150°C, the air temperature at the skin surface after 600 and 1200 seconds of treatment was 59.5°C and 47.2°C, respectively, and the hot air within the cup provides superficial heat therapy. As the temperature inside the cup is higher at the top and lower at the bottom, no natural convection occurs within the cup, implying that heat transfer in the cup is conducted through the air. For a diabatic cup, the temperature within the cup decreases to 37°C after 600 seconds and heat transfer in the cup is conducted through air convection. If the cup is made of diabatic materials, some of the heat will be transferred to the outside air, implying that the heat from the hot air inside the cup will quickly dissipate; thus, the temperature will fall and the heat therapy will not be effective.

The essence of traditional cupping is the use of heat to soothe and repair cellular tissue; however, the temperature and length of time used lacks scientific verification and support. Therefore, this study makes up for this shortcoming while maintaining the traditional value of cupping by using a modern theoretical model to analyze the heat transfer of cupping therapy to ensure that TCM physicians can provide safe treatment.

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