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STUDY AND DESIGN OF A COOL CAP USING PELTIER EFFECT

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Abstract. *Cool cap is a device used in newborns with perinatal asphyxia until six hours after birth. Several researches have pointed that localized hypothermia can decrease the metabolism of brain, which would reduce the sequelae on the brain due to the absence of oxygen. The system for cooling of conventional cool caps is based on the recirculation of a cold fluid around the head of the newborn. The main disadvantage of this system is the size of device, which is large because of the reservoir for the fluid and the mechanical devices for the cooling of fluid. In this work, it is proposed to design a cool cap using Peltier effect in the cooling system. The use of plates with Peltier effect could decrease significantly the size of apparatus. For the correct design, a thermodynamic model of the skull of newborns was developed in order to determine the thermal load of the system. In this model, the temperature of brain should be around 34.5 º C for a mild localized hypothermia. The model of Yablonskiy, which is based on adult head, was adapted in this work for the case of newborns. The mechanical structure of cool cap was designed using the average values of the dimensions of heads of newborns. Also, the average geometry of heads of newborns was evaluated and considered in the mechanical design. A proper control of the plates of Peltier was also developed using microcontrollers and thermal sensors (LM35). This paper presents the method to evaluate the heat transfer of the cool cap to the brain and the firsts impressions with the prototype of cool cap.*

Keywords: *cool cap, peltier, hypothermia*

1. INTRODUCTION

The cool cap is a device used for localized hypothermia in cases of perinatal asphyxia of newborns until six hours after birth. This device aims to reduce the sequelae due to the absence of oxygen in the brain. The cooling of the brain could reduce the metabolic activity of the brain, which would be the responsible for the decrease of sequelae due to the hypoxemic-ischemic encephalopathy (HIE). There are several researches about the cool cap in the world and also, some devices are already commercially available. The most part of cool cap is comprised by a unit for the cooling of refrigerant fluid, a pump for the circulation of fluid and a control system for the regulation of temperature of the fluid and hence, of the surface of head of newborns.

Although several researches have been done using cool cap, there is no consensus about its efficiency as a therapy for the perinatal asphyxia. Kirpalani *et al.* (2007) have been concerned about the use of cool cap without more experimental tests in terms of quantity, which could validate the efficiency of this therapy. However, they also consider that to wait for optimal results could be unreasonable because of the positive evidences reported by other authors, as Eicher *et al.* (2005), Gluckman *et al.* (2005) and Perlman (2005). Barks (2008) has also pointed that there are several controversies about the efficiency of cool cap. In other words, more tests must be accomplished and more data need to be collected. This concern was also the conclusion of work analysis of the Committee on Fetus and Newborn of the American Academy of Pediatrics (Blackmon *et al.*, 2006) about the use of hypothermia in cases of perinatal asphyxia.

In order to evaluate the efficiency of cool cap, Ancora *et al.* (2009) have presented an interesting method to evaluate the effects of the cool cap on the asphyxiated newborns. Their method is based on Amplitude Integrated EEG (Electroencephalogram) and NIRS (Near Infrared Spectroscopy), which were used to evaluate the brain activity (EEG) and the levels of oxygenation and hemoglobin (NIRS). This method allows a continuous evaluation of the effect of cool cap on the physiological conditions of the patient.

As it can be seen, it is necessary to carry out more tests and also in order to understand more about the parameters of the localized hypothermia in perinatal asphyxia. Another point to be considered is the fact that the conventional cool cap has a considerable size, which makes difficult to use it for first aid and emergencies. This fact is quite relevant because in NICU (Neonatal Intensive Care Unit), there are already several types of large equipment. Also, there is no much space in the delivery room, which would be essential for the application of conventional cool cap device.

For this reason, this work proposes the design of a cool cap using Peltier effect. The reason to use the peltier effect is to try to reduce the size of cool cap, which would not require the use of an auxiliary system of refrigeration. Herewith, the whole cooling system could be assembled directly in the cap. In addition, the cool cap could be used for further researches in order to verify the efficiency of localized hypothermia in treatments for perinatal asphyxia.

2. THERMODYNAMIC MODEL

The fundamental equation for the heating transfer in biological system is the equation of Pennes. This equation has been used in several research, which involve the variation of temperature in tongues (Kai *et al.*, 2004) and other parts of human body (Ferreira and Yanagihara, 2009). In a previous work (Barrios *et al.*, 2009), a thermodynamic model was proposed and based on the model of Sukstanskii and Yablonskiy (2004), where the temperature distribution was simulated from the surface of head until the brain of an adult. Since some biological changes take place during the growing of human beings, the thermal parameters and the dimensions of tissues were changed to those of the newborns.

The model was based on a system divided into four layers, which are from outside to inside: scalp, skull, cerebrospinal fluid and brain. The most important advantage of this model is its dependence on the variables that could be measured, or in the least case, could be estimated.

The data about density, specific heat, thermal conductivity, metabolic rate and perfusion of the heads of newborns were obtained from the work of Van Leeuwen *et al.* (2000) and Ferreira and Yanagihara (2009). The most part of dimensional parameters of the head of newborns had to be estimated. For instance, the thickness of the scalp was considered as between 40 % to 60 % of the thickness of that of an adult (Siegfried, 1998). Thus, the thickness of scalp was estimated about 1.5 mm, since the thickness of the scalp of an adult is around 3.0 mm (Sukstanskii and Yablonskiy, 2004). The same consideration was adopted for the cerebrospinal fluid. For the skull, the thickness was 1.3 mm, in accord to the work of Wang *et al.*, 2008.

Simulations were carried out in *MatLab* environment and it was considered a situation of mild localized hypothermia. For this condition, the temperature of the brain should be around 34.5 °C in accord to Gluckman *et al.* (2005) and Battin *et al.* (2003). The results were presented in Barrios *et al.* (2010) and they are reproduced in the graph of Fig. 1.

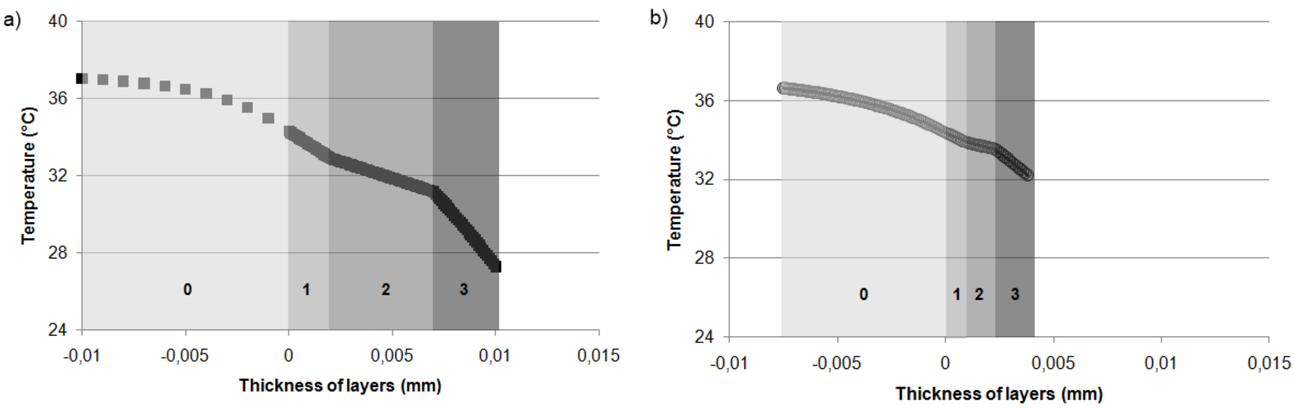

Figure 1. Distribution of temperature along the head of an adult (a) and a newborn (b). The regions 0, 1, 2 and 3 correspond to brain, cerebrospinal fluid, skull and scalp, respectively. (Barrios *et al.*, 2010)

The results have indicated clearly the large difference between the temperatures required for a mild localized hypothermia for an adult and a newborn. The temperature required for a newborn is around 32.5 °C, which is easier to reach than for an adult, which should be about 27.5 °C. This result is important in order to design the thermal load of the cooling system of cool cap and also to control the optimal temperature on the surface of scalp. In summary, the temperature should be around 32.5 °C at maximum. Moreover, some care should be taken in order to avoid injuries due to the low temperatures, since the critical temperature is around 15 °C (Geng *et al.*, 2006).

As mentioned before, more details about the equations of thermodynamic model can be found in the previous work (Barrios *et al.*, 2010).

3. MECHANICAL DESIGN OF COOL CAP AND PELTIER PLATES

The project of the cool cap was developed in the *AutoCAD 3D* environment. The dimensions of the cap were based on a research of statistical data about the anthropometry of newborns. As main dimensions, the length of fronto-occipital and the diameter of biparietal (P3 in Fig. 2) were considered, which is the length from the frontal side until the backwards. Further dimensions were also used and are shown in Fig. 2 and Tab, 1. These data were obtained from the works of Mota *et al.* (2004) and Pereira *et al.* (2008).

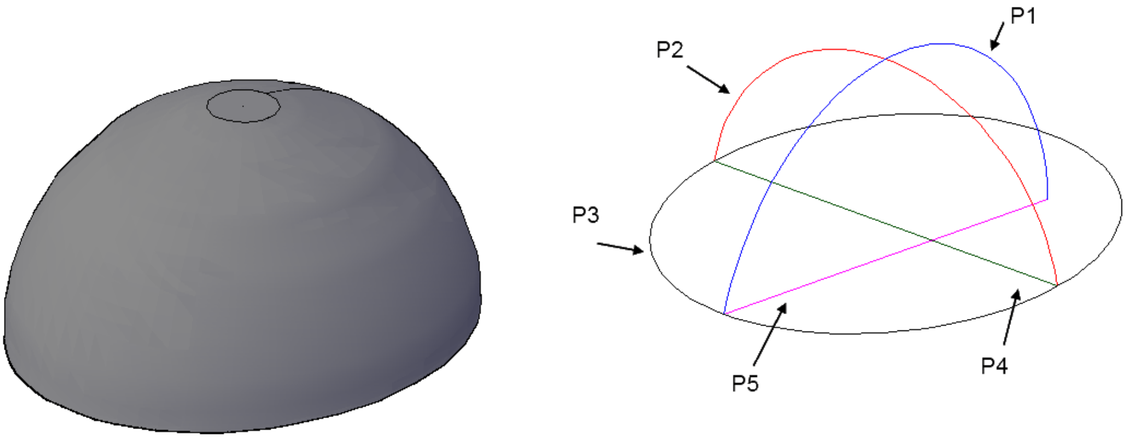

Figure 2. Tridimensional model of skull in contact to the cool cap

Table 1. Dimensional values of the parameters shown in Fig. 1.

Parameter	*Length (mm)*
P1	201.53
P2	200.00
P3	409.02
P4	119.00
P5	139.00

A drawing of the cool cap is presented in Fig. 3. At left side, an external view of cool cap is shown and at right side, an exploded view is presented. The yellow part of the drawing represents the structure to support the cooling system that also would be used as a holder for the head of newborn.

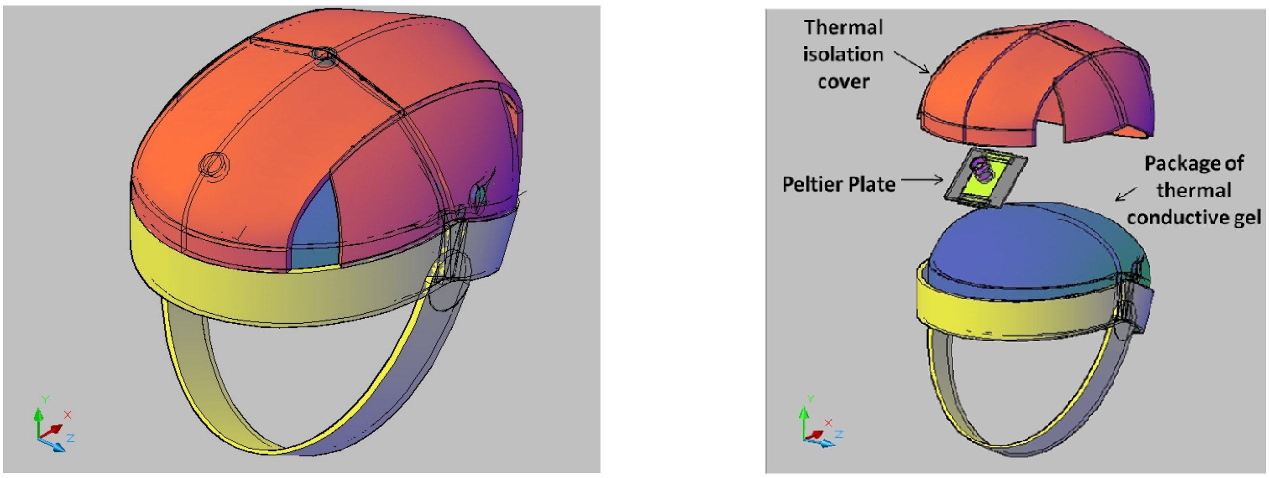

Figure 3. Drawing of cool cap. At left side, an external view and at right side, an exploded view of cool cap.

The support was built with aluminum sheets and it is shown without the package of thermal conductive gel in Fig. 4. This package of gel will be used in order to obtain a homogeneous distribution of temperature on the head surface. The gel that would be used in this project was obtained from a thermal package provided by Mercur (Model BC 0130). The package provided by Mercur could not be used in its original format because of its size and shape. Then, a new package has been developed and it still has to be finished. The aluminum sheet was chosen because of the light weight and also the high thermal conductivity, which is important for the thermoelectric plates, as it will be discussed following. The specification of aluminum sheet is 6061.

Figure 4. The support of cool cap.

For the cooling system of cool cap, thermoelectric plates were used. These plates operate under the peltier effect. The peltier effect is based on heating and cooling in both opposite sides of a module or plate, when a differential of voltage is applied on the sides. In other words, if a side of plate is hot, the other side will be cold. There are many application of peltier effect, such as compact cooler for beverages, cooling of netbooks and others. The greatest advantages of the cooling system that works with peltier effect are the compactaness and rapid response to electrical activation.

The peltier plates were provided by Equipamentos Danvic Ltda and the model used in this project was DV40-06-15.4, which has the maximum thermal power of around 53.1 W. At this configuration, the peltier plate can work up to a current of 6 A and a voltage of 15.4. The dimensions of the plates were of 4.0 mm x 4.0 mm and a thickness of 1.5 mm. The thermoelectric plate used in this project is shown in Fig. 5. For a properly use of peltier plates, a control system was developed, which is described in the next section of this paper.

Figure 5. Peltier plates.

In Fig. 3, it was shown the structure of cool cap with one of the three peltier plates that would be used in cool cap. In Fig. 6, the structure to be used to hold the peltier plates into the cool cap is shown. The green part corresponds to the base of the support of peltier plate. Around the purple part, a spring will be used in order to press the peltier plate against the packet of thermal conductive gel. This pressure is important because the gap between the peltier plate and the package of conductive gel will be filled with air, which could impair the efficiency of the cooling.

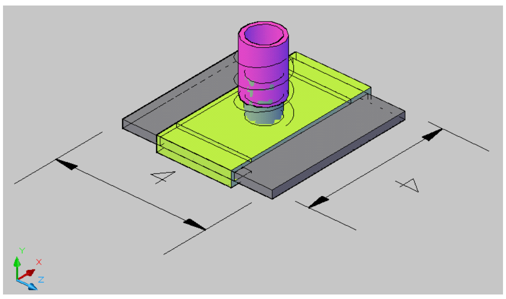

Figure 6. Holder for peltier plates.

4. TEMPERATURE CONTROL

For the controlling of the temperatures and the activation of thermoelectric plates, the microcontroller 8051 was used. The 8051 was chosen because of its compactness and the possibility to connect all devices that would be necessary for the properly use of cool cap.

The sensors of temperature used in this project were the LM35, which is often used in personal computer. Basically, LM35 is a kind of precision integrated-circuit temperature sensor. The output voltage is linearly proportional to the variation of temperature in Celsius degree (°C), which is one of the most important advantage of this sensor. The graph of Fig. 7 shows the experimental measurement of LM35. The temperature was measured using a thermocouple and the output voltage of the LM35 was measured using a multimeter (MD-5770, Icel Manaus).

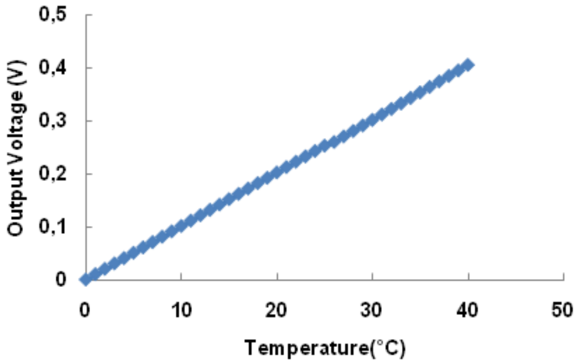

Figure 7. Linearity between output voltage and temperature of LM 35.

Other advantages of LM35 in comparison to others sensors are related to the size (compact), cost and operation, which are quite simple. The Fig. 9 shows a LM 35 and it can be seen that the dimension of this sensor is very small: 15 mm of length and 8 mm of width.

Figure 8. Sensor LM 35.

Another important issue is the positioning of the temperature sensors at the head surface of newborn, which would depend on their functions. There are two general roles for this sensor in cool cap, that is, the measurement of the temperature on the scalp and the temperature of the brain. The last is more difficult than the first, but there is an interesting approach based on the work of Haddadin *et al.* (2005). In accord to their work, there is a specific site on the human face that is thermally connected to the brain, that is, the temperature is quite close of that of the brain. This region is called as BTT (Brain Temperature Tunnel) and is located at a bridge of the nose and the cavernous sinus around the hypothalamic thermoregulatory center. In other words, this site is located at the inner corner of the eye.

For the measurement of temperature on the head surface, it was adopted three specific sites for the sensors, which were close to the Peltier plates. In Fig. 9, it is shown the position of the three peltier plates. The role of these sensors is to control the temperature of head surface, which could not be below the critical temperature of 15 °C. Below this temperature, the risk of injuries due to the burning of skin of scalp increases significantly (Geng *et al.*, 2006).

Figure 9. Peltier plates inside the cool cap.

The control system was firstly designed using the software Proteus (demo version), as can be seen in Fig. 10. Thus, the peltier plate is activated when the temperature is above 32° C and it is turned off when the temperature reaches around 16° C. These temperatures were selected as a parameter for a pre-test of the control system. The correct limit of temperature should be defined after the calculation of heat transfer with the packet of conductive gel, which will be done in the next steps of this work.

The first test of performance of peltier plate has shown a rapid response for cooling. The peltier plate cooled from 25 °C to 8 °C in less than 10 seconds. However, when the activation of peltier plate is turned off, the plate starts to be warmed immediately and reaches a temperature around of 50 °C. This high temperature is not appropriate for the cool cap and it should be minimized. In the next section, this issue is discussed.

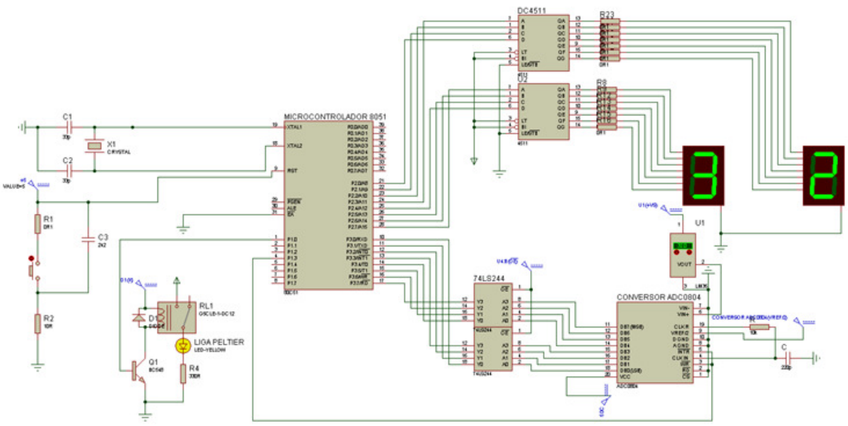

Figure 10. Schematic illustration of the system for the control of temperature of cool cap.

5. DISCUSSION AND CONCLUSION

The cool cap designed in this work is still in development. Further tests are necessary before to start the animal experiment, which would be the next step of this work before the application in newborns. In despite of the good characteristics of peltier plates, some restrictions must be considered. The hotter side of peltier plate is the most important restriction for the application in cool caps. When the peltier plate is turn off, the heat from the hotter side flows to the colder side, which must be kept at low temperature. At this moment, the development of this project is focused in how to solve this problem in the best way. For instance, the effect of this restriction could be minimized by using a properly fan to increase the effect of convection on the hotter side.

There are several attempts in order to improve the COP (coefficient of performance) of the refrigerator system based on the peltier effect. Vián and Astrain (2007) have presented a device called as TPM (Thermosyphon Porous Media), which decreases the thermal resistance of thermoelectric refrigerator. This model is good for small refrigerators; however and unfortunately, it is still large for a cool cap. Another interesting attempt is based on the use of cascade of peltier plates (Metzger and Huebener, 1999). This approach is interesting for the cool cap because it can keep the small size of the device. However, it is important to consider that this approach is more interesting when the temperature of the cold side should be very low, which is not the case of cool cap. In despite of this observation, it is still interesting to consider the use of cascade in order to minimize the effect of heat flow from the hot side to the cold one.

Thus, the next steps will be focused on to optimize the performance of peltier plate by cooling the hotter side. One possibility that will be tested soon is the use of peltier plate in cascade.

6. ACKNOWLEDGEMENTS

The authors would like to demonstrate their gratitude to UCDB, for the financial support for the project and scholarships. Also, they would like to thank CNPq for the scholarship and FUNDECT (Fundação de Apoio ao Desenvolvimento do Ensino, Ciência e Tecnologia do Estado de Mato Grosso do Sul) by the financial support.

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