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LONG TERM TESTS AND FAILURE SIMULATION A DEVICE FOR HEAD COOLING OF NEWBORNS

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Abstract. *Devices to cooling the head been used to reduce cerebral metabolism and also to prevent future brain damages in newborns with perinatal asphyxia. The treatment for a mild hypothermia takes about 72 hours. Thus, the cooling system efficiency of this device as well as the safety are very important aspects. This work presents the results of the authors of this work. Long-term tests were also done to simulate a clinical application. A structure of temperature sensors was created to measure room temperature and also the temperature between the skin of the newborns and the thermoelectric plates of the device. Failures were simulated in order to evaluate the behavior of the thermal plates. The security system prevented the heat flows to the cold side, since it would create a contrary result, the heating of the newborns head. Preliminary tests show the confiability of the device for clinical application and the safety system has proved itself efficient.*

Keywords: *cool cap, long term tests, thermoelectric plates.*

1. INTRODUCTION

Cool cap is a device used for the cooling of the head of newborns with perinatal asphyxia. The aim of this cooling is to reduce the cerebral metabolism and consequently, damages caused due to the lack of oxygen (Thoresen, 2011; Fairchild *et al.*, 2010). Between the sequels of the perinatal asphyxia, Hypoxia Ischemic Encephalopathic (HIE) is considered as the major cause of permanent neurological damage in newborns (Guinsburg *et al.*, 2008). A mild hypothermia, which has presented good results (Rutherford *et al.*, 2010), requires a temperature around 34,5ºC (Battin *et al.*, 2003), which means that the temperature for this treatment is not so critical and hard to be reached. Also, the treatment must be done during the next 72 hours after the birthing (Ancora *et al.*, 2007).

The equipment presented in this work is based on cool caps that are already commercially available. It is known that such devices work with cooled fluids, which are circulated around the head of newborns through tubes made of polymers. These devices require a large physical area and their weight becomes high. Hence, the transportation is almost impracticable, that is, it is not allowed to move them between rooms or in ambulances. Therefore, the development of a device able to have weight and size reduced becomes interesting and this is the purpose of the device developed on this work.

In the device of this work (Naka et *al.* 2011), the cooling is done with the use of thermoelectric plates and can thus improve the portability of the equipment, which is one of the aims of the design of the device presented in this work. These thermoelectric plates are based on the Peltier effect, which suffer cooling in one of its sides, while the other is heated, when an electrical potential differential is applied on them. In order to improve the performance of these plates, a heat dissipator on the hot side of the Peltier plate is usually assembled. That is, the heat dissipation can be improved and it is possible to obtain the maximum performance of these plates, since the difference of temperature can decrease the temperature of the cold side.

For clinical application, it is very important the monitoring of the variations of temperature in each thermal plate because a reversion of the heat flow can occur. In other words, the cold side can be heated due to the reversion of the heat flow, which means that the result will be completely opposite in comparison to the desired effect. Thus, it is important to analyze these variations during a clinical application. To this end, in this work, an experimental network of temperature sensors has been designed, where the environmental temperature and the temperature of the interface of contact between the skin of patients and the cooling device can be measured. The sensors have been located on different sites of cool cap. Thus, an evaluation of the stability of temperature could be carried out in long-term tests.

Other important issue is the implementation of a security system, that is, a system that can turn off the thermoelectric plates when some abnormality is detect. However, it is important to consider that a sudden interruption of the system can invert the flow of heat and the cold side can be heated, which is an opposite effect in relation to the aim of this device. Thus, in this work, it is presented the results from a simulation of the failures of the cool cap.

In summary, the focus of this paper is on the demonstration of the behavior of a cool cap that uses a cooling system with thermoelectric plates, which are based on the Peltier Effect. Furthermore, the stability of the temperature of the thermoelectric plates and the automated security system has been also considered. The long-term tests were performed with duration of 48 and 72 hours.

2. MATERIALS AND METHODS

2.1. Temperature Monitoring System

In order to analyze the performance of a cool cap, a system for the acquisition of temperature data has been developed. This system contains five temperature sensors (LM-35), an Arduino UNO and a notebook. Three sensors (S1, S2 and S3) were distributed on the surface of a mold, which imitates the shape of a head of a child, as can be seen in Fig.1. Two sensors (S4 and S5) were used for the measurement of environmental temperature. All sensors were connected to an Arduino controller, which was responsible for the acquisition of data and to plot the data in a HyperTerminal installed in the notebook. In Fig. 1, it is shown how the sensors were distributed on the surface of the mold and also, the sensors used to measure the environmental or room temperature. The mold was made with plaster and the dimensions were obtained from the technical literature (Mota *et al.*, 2004) The measurement of environmental temperature is quite crucial, since the performance of the thermoelectric plates depends on the speedy of dissipation of the heat on the hot side of plate. Thus, a high environmental temperature can decrease the performance of the cooling system of cool cap.

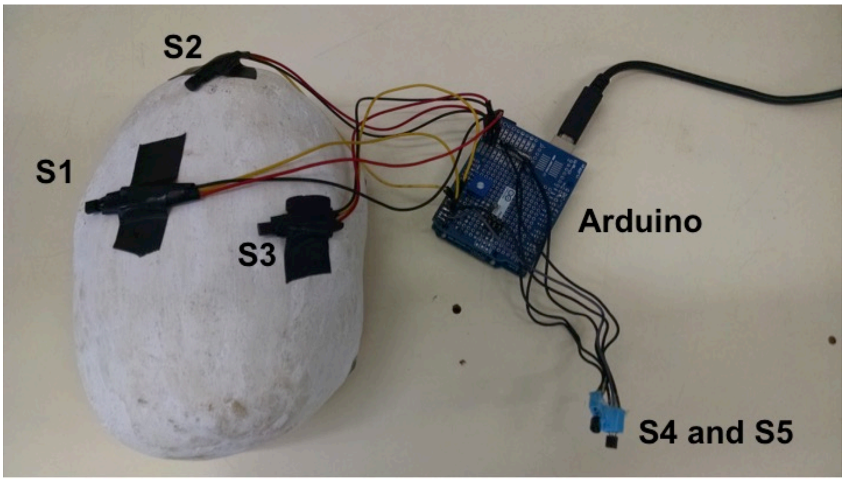

Figure 1. Distribution of sensors on the surface of the mold.

2.2. Long-term Test

With the measuring system designed and assembled, a thermal conductive gel bag was placed on the surface of the mold and the sensors, and the bag was also attached to the structure of cool cap, as shown in Fig. 2. The role of this bag is to assure that the temperature could be better distributed on the surface of the mold. This bag will be also used in the clinical applications of this device. The voltages applied on the thermoelectric plates were previously adjusted and the system was kept activated for a certain period in order to observe if some wrong connection could affect the stability of the measurements.

The tests were carried out in a room with air conditioner in order to keep the environmental temperature constant. The duration of the test was 48 and 72 hours, which represents a real clinical case of application of a cool cap in a mild hypothermia on the head of newborns.

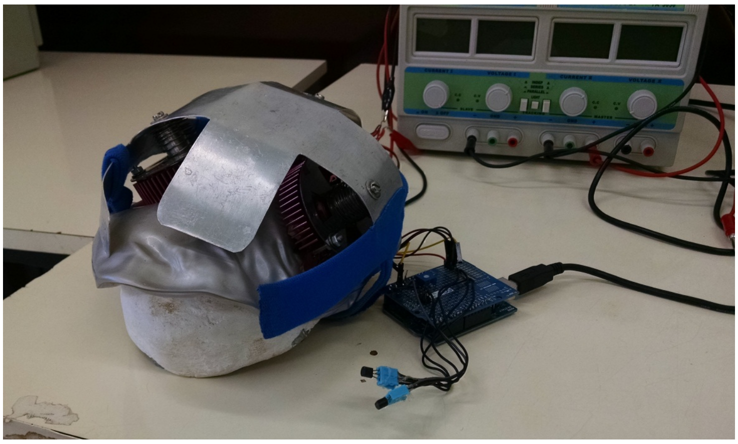

Figure 2. The system used for the long-term tests of cool cap.

Before the start the long-term tests, it is necessary to choose a proper and stable electrical potential to be applied on the thermoelectric plates. The reason is based on the fact that the commercially available cool cap works with a cooled fluid at an average temperature around of 12º C (Gluckman *et al.*, 2005). Since the temperature of cold side depends on the electrical potential, it is not necessary to apply a high electrical potential to reach a temperature around 12º C.

Thus, tests in order to determine the proper electrical potential were carried out, where the variation of relative temperature (ΔT) in relation to the time was observed, as can be seen in Fig. 3. The ΔT is the difference of temperature between the environmental temperature and the temperature of each sensor (S1, S2 and S3) place on the surface of the mold, as described by the Eq. (1).

$$\Delta Ti = \text{Environmental Temperature} - \text{Temperature Sensor (Si)} \quad (1)$$

where the index i means the number of sensor (1, 2 and 3).

The environmental temperature was obtained by the average of the measurement obtained from the sensors S4 and S5. It was defined that a difference of temperature around 8 ºC to 10 ºC would be enough for the clinical application. Since at a room temperature between 22 ºC and 20 ºC, the temperature of the sensors should be indicated temperatures around 12 ºC.

Based on the tests, it was decided to use an electrical potential around of 5 V and an electrical current around of 3,97 A. The variation of the temperature of sensors (S1, S2 and S3) using these parameters can be seen in Fig. 3. For higher electrical potential, the results were not so stable. Thus, the value of 5 V was defined as a limit of operation of the cool cap. The sensor S1 was placed far from the thermoelectric plates, which results in lower difference of temperature in comparison to the environmental temperature and others sensors (S2 and S3).

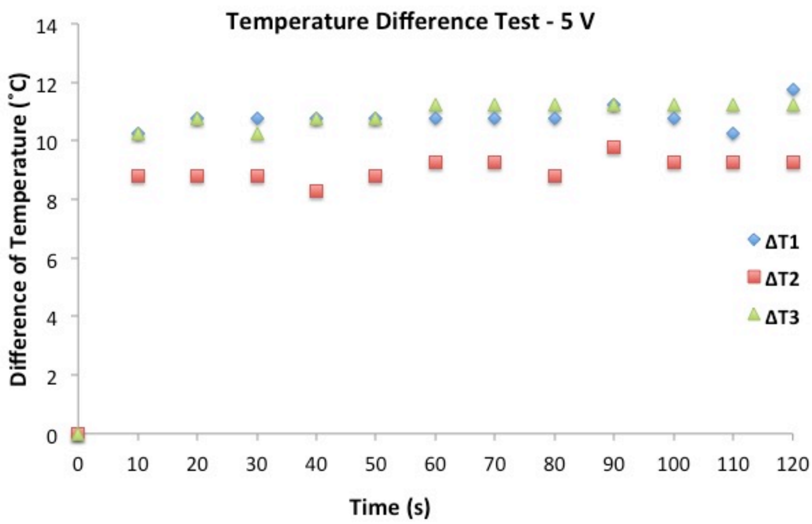

Figure 3. Test with 5 V and 3,97 A. Sampling rate: 1 Hz.

It is important to notice that these preliminary tests were done in a short time (two minutes), because it was only done to observe the behavior of the difference of temperature in relation to the time. Also, the aim of these test was to define a parameter for the long-term tests, which are one the focus of this work.

2.3. Security System

For the clinical application of the prototype presented in this work, it was necessary to develop a security system for the cool cap. In summary, this system should be responsible to collecting and analyzing data, in order to verify if the cool cap is working as expected. In order to design and assembly this system, the following materials were used:

- 1 Arduino UNO;
- 5 Temperature Sensors (LM-35);
- 1 Relay Module;
- 1 Red LED;
- 1 Potentiometer of 10 KΩ.

The design of the safety system was initiated by the definition of the position of the sensors. Three sensors were distributed over the thermoelectric cooler of each plate and two sensors were used to measure the environmental temperature. The electrical potential applied on the thermoelectric plates was measured using an analog channel of the Arduino, which required the use of a potentiometer to reduce the electrical current and to calibrate the voltmeter. The relay module is responsible for the input electrical potential of the switching in the thermoelectric plates, which were controlled by the Arduino. The red LED was used to indicate any technical problem in the cool cap. In Fig. 4, it is shown the assembly of the security system installed at the cool cap.

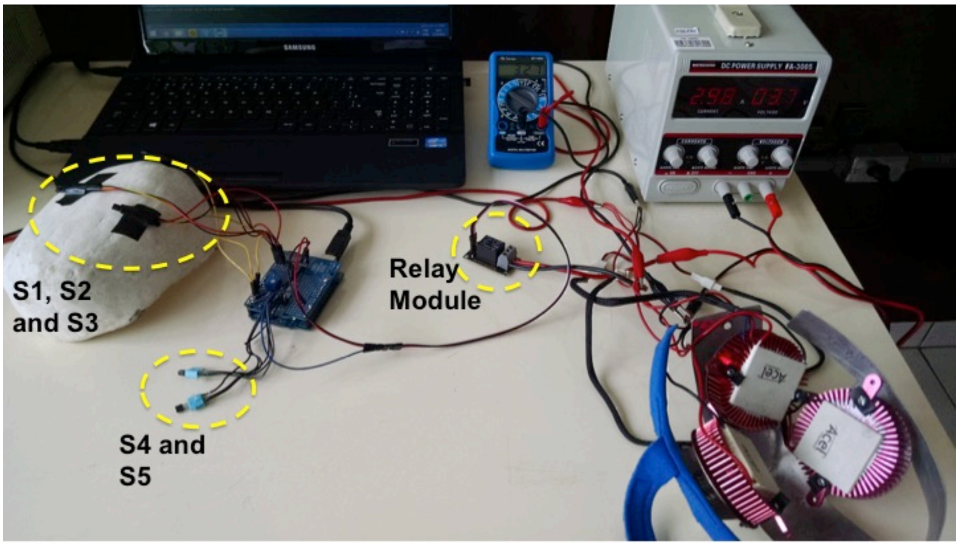

Figure 4. System used for the security tests of the cool cap.

The system was designed in a way that the Arduino acquires data from the all temperature sensors. Afterwards, the system compares the temperatures of the cold surfaces of the thermoelectric plates and the environmental temperature. If the temperature in the thermal plates were lower than the environmental temperature, the relay module remained closed and the cool cap was kept in the activated mode. On the other hand, if the temperature is higher than the environmental temperature, the system is turned off due to a possible reversion of heat flow.

In addition, the Arduino was also able to read the electrical potential applied on the thermoelectric plates. The electrical potential measured by the Arduino was compared with the previously programmed value for the electrical potential. Therefore, if the electrical potential applied on the thermoelectric plates of the Cool Cap is less than the programmed value, the device remains powered. On the other hand, if the values is higher, the system automatically turn-off the activation of the cool cap. Thus, if any of these conditions is broken, the relay opens the power circuit immediately and the cool cap will be turned off and the red LED is triggered indicating a technical problem.

3. RESULTS

The result of long-term tests for 48 hours is presented in Fig. 5. In this test, an electrical potential of 5 V was applied on the thermoelectric plates. The best performance, or the highest difference of temperature between the sensors placed on the surface of the mold and the environment was of 9 ºC and the sensor S2 measured it. As can be seen in Fig. 1 and mentioned before, the sensor S1 was placed far from the thermoelectric plates in comparison to others sensors, which is the reason for the lowest difference of the temperature detected for this sensor (Δ1), as can be seen in Fig. 5. The temperature was quite stable during the tests and small variations were detected. These variations can be associated with the oscillations of temperature in the room, during the night and the day, despite of the use of air conditioner.

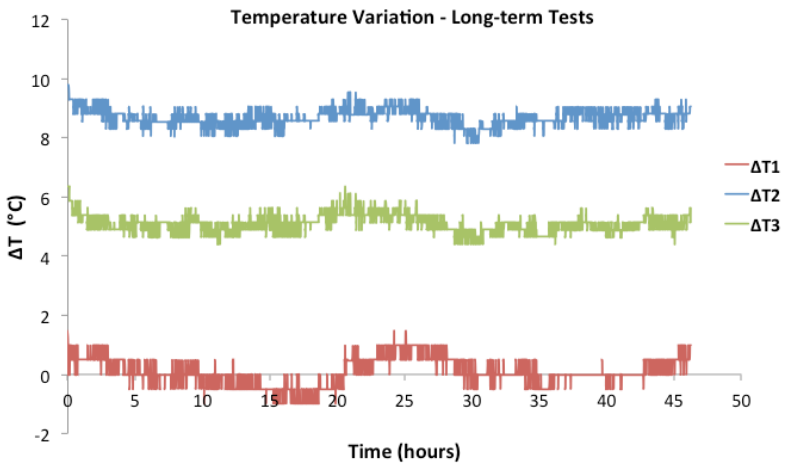

Figure 5. Long-term results (48 hours) for an electrical potential of 5 V on the thermoelectric plates.
Sampling rate: 1 Hz.

For the test with duration of 72 hours, an electrical potential of 4 V was applied on the thermoelectric plates. The results are presented in Fig. 6. The decrease of the electrical potential was done in order to observe the effect of this decrease on the difference of the temperature. The highest difference of temperature has been observed on the sensor S2, similar to the result showed in Fig. 5, and the values were around of 8 ºC to 9 ºC. The temperature was stable in comparison to the previous result, as it shown in Fig. 5.

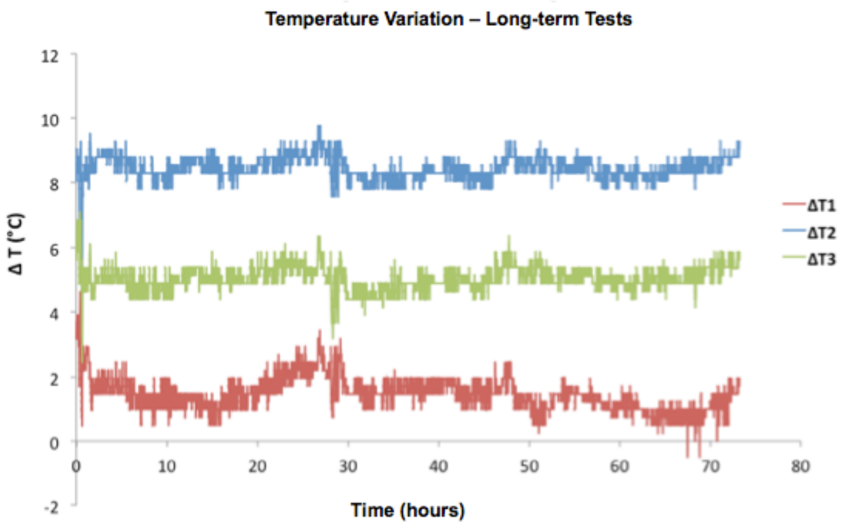

Figure 6. Long-term results (72 hours) for an electrical potential of 4 V on the thermoelectric plates.
Sampling rate: 1 Hz.

In order to check the performance of the security system, tests were carried out with a simulation of a technical problem of the cool cap. The failure was simulated by means of the withdrawal of one sensor from the cold side of the thermoelectric plates. Then, this sensor (S3 and Δ3 in Fig. 7) was manually heated at a temperature higher than the environmental temperature. When the temperature of this sensor was higher than the environmental temperature, the relay interrupted the power supply and the cool cap was turned off. The temperature of the thermoelectric plates changed to the level of the environmental temperature, as can be observed in Fig. 7 (ΔT equals to zero). In Figure 7, the ΔT (1,2 and 3) represents the difference between the environmental temperature and the temperature at each sensor (S1, S2 and S3), according to the Eq. (1), as mentioned before.

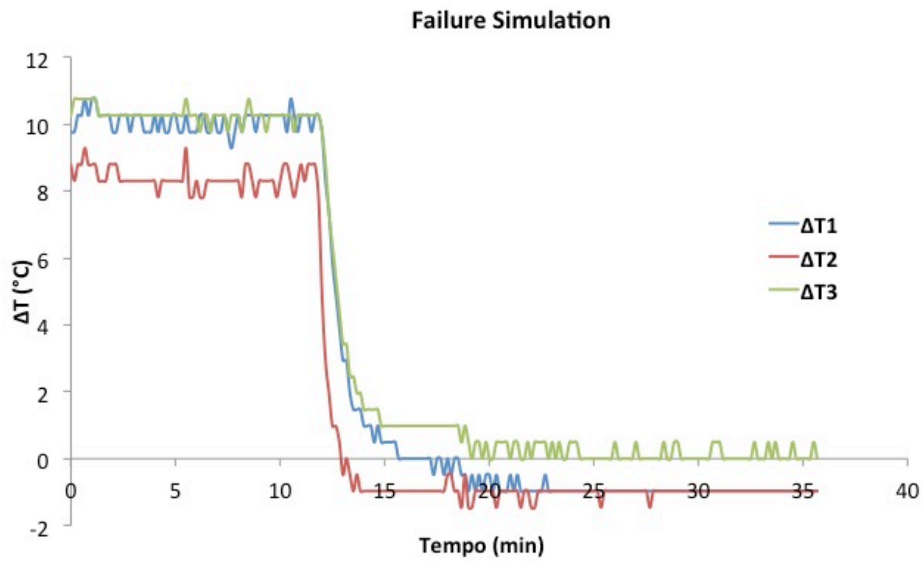

Figure 7. Simulation of a failure due to the heating of thermoelectric plate
Sampling rate: 1 Hz.

It is important to notice that after the system is turned off due to the some abnormality, the difference of temperature is almost close to zero, which means that the temperature on the surface molds reaches the environmental temperature. For the sensor 1 and 2 (ΔT1 and ΔT2), as can be seen in Fig. 7, the difference was negative and close to -1 ºC, which means an increase of 1 ºC in comparison to the environmental temperature. For the sensor S1, it makes sense because this sensor was used to create the abnormality in the system, that is, it was removed from the surface of the mold and it was heated. In the case of the sensor S2, as mentioned before, it was placed far from the thermoelectric plates and this increase of the temperature in relation to the environmental temperature could be related to the position of this sensor or the reversion of the heat flow of the thermoelectric plates. In the future, further tests should be done in order to take a more refined set of data by the increase of the number of sensors.

Other important issue of this test was how the temperature on the surface of mold would behave after the shut down of the system. In Fig. 7, it is possible to observe that the decrease was not so abrupt and takes around 2 minutes to stabilize. Also, the increase of temperature was not so high (around 1 ºC), which means that a simple control system in closed-loop using an "ON-OFF" controller would be enough. That is, if the increase of the temperature had been significantly, it means that the reversion of the heat flow was playing an important role on the security system. Then, it would be necessary to use another strategy of control, such as a PID (Proportional Integrative and Derivative) controller.

4. CONCLUSIONS

Based on the results obtained experimentally, it was clear in the long-term test that the temperature in the interface between thermoelectric plates and the scalp of the newborn, maintained a difference with the environmental temperature at about 8 °C, which is enough for the application of cool cap in a room at 20º C. Furthermore, it is possible to observe a quite stable temperature along of the test, which means that the cool cap could be used on clinical applications.

About the tests with simulation of failures, the decrease in the temperature variation was not so negative, which would mean a reversion of the heat flow (heat flowing from the hot side to cold side, increasing the temperature of cold side). Also, a simple control system in closed loop using an "ON-OFF" controller was enough for this application.

An Ethics Committee is already evaluating this project, in order to be used in NICU (Neonatal Intensive Care Units) of the University Hospital of UFMS (Federal University of Mato Grosso do Sul).

5. ACKNOWLEDGEMENTS

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7. RESPONSIBILITY NOTICE

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