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# Experimental setup and measurements of heat transfer rate during newborn brain cooling process

**DOMINIKA BANDOŁA**[a]
**MAREK ROJCZYK**[a]
**ZIEMOWIT OSTROWSKI**[a]
**JOANNA ŁASZCZYK**[b]
**WOJCIECH WALAS**[c]
**ANDRZEJ J. NOWAK**[a*]

[a] Institute of Thermal Technology, Biomedical Engineering Lab, Silesian University of Technology, 44-100 Gliwice, Konarskiego 22, Poland

[b] C&C Technology Sp. z o.o.,40-692 Katowice, Malinowa 8, Poland

[c] University Clinical Hospital in Opole, Department of Children Intensive Care, 45-418 Opole, Witosa 26, Poland

**Abstract** This work discusses the heat transfer aspects of the neonate's brain cooling process carried out by the the device to treat hypoxic-ischemic encephalopathy. This kind of hypothermic therapy is undertaken in case of improper blood circulation during delivery which causes insufficient transport of oxygen to the brain and insufficient cooling of the brain by circulating blood. The experimental setup discussed in this manuscript consists of a special water flow meter and two temperature sensors allowing to measure inlet and outlet water temperatures. Collected results of the measurements allowed to determine time histories of the heat transfer rate transferred from brain to the cooling water for three patients. These results are then analysed and compared among themselves.

**Keywords:** Brain cooling; Experimental stand; Heat transfer rate

*Corresponding Author. Email: andrzej.j.nowak@polsl.pl

# 1 Introduction

According to the data provided by the World Health Organization, perinatal hypoxemia is still a relatively frequent problem encountered during childbirths (2–4 cases for every 1000 births). The problem starts with improper blood circulation which causes insufficient transport of oxygen to the brain. At the same time, insufficient cooling of the brain by blood causes an increase of brain temperature. Question how serious are consequences of these dangerous conditions certainly depends first of all on how long neonate's brain was not sufficiently provided with the oxygen and how much its temperature raised. In many difficult situations, the hypoxic-ischaemic encephalopathy (HIE) can be developed. The selective brain cooling can be nowadays considered as a hypothermic therapy which allows significant reduction or even elimination of results of the hypoxic-ischaemic encephalopathy. It is, however, absolutely crucial that brain cooling of the neonate is initiated within 6 hours after delivery and that the body temperature of infants is kept in a consistent hypothermic range of 34 °C to 35 °C for at least 72 h. At the same time, in order to mitigate the side effects of rapid change of tissue temperature during hypothermal therapy, deep body temperature should still be kept at a constant and secure level. This frequently requires thermal irradiating the rest of the body of the baby while its head should be cooled. Particularly important and difficult to maintain is the moment when the internal body thermoregulation centre is ready to intercept the control over the body temperature. An extensive review of those processes and relevant literature is offered by Łaszczyk and Nowak [1,2].

Although this hypothermic therapy is already being applied for some years, it is still not quite clear how big should be the heat flux received by the cooling device from the newborn's head to maintain suitable temperature field inside the newborn's brain and throughout the entire body during the entire therapy period. Many doubts are also associated with a question what is the proper time of the hypothermic therapy. It should also be noticed that in case of cooling by use of the Olympic Cool-Cap System (Natus Medical Inc.), [3], the guidelines for rewarming phase are still not standardised and cooling parameters during this stage of treatment are set only manually. Therefore it is advisable to develop a reliable computational model of a typical newborn brain cooling process which after tuning could represent hypothermic therapy reasonably well and would offer possibilities of testing various therapeutic scenarios. It should be stressed that results of this kind of simulations could help, in a longer term, to identify the specific parameters to optimally tailor hypothermia therapy for individual newborns, and as a consequence – protect the life of neonates.

Very important in this context are boundary conditions, and particularly information on a heat transfer rate in the cooling system. In this paper, the volume flow rate and temperatures of a cooling fluid flowing through a cooling cap are measured and recorded. To the authors' best knowledge, this is the first attempt to monitor and to record the time history of the heat flux rate transferred from the patient head to the cooling fluid during brain cooling process. This should help to understand the physics of the process better and fully control it.

## 2 Hypothermic therapy and measurements

As already mentioned, the hypothermic therapy should be initiated at most within 6 hours after delivery. Patient being prepared for the treatment is naked and he/she is losing heat to the ambient environment as it is visible in Fig. 1. It can be expected that temperature at the abdomen/torso is typically quite even and approaches 34 °C whilst at limbs values of temperatures are lower and equal to about 28 °C. This fairly big temperature difference might be a surprise, but even for the perfectly healthy neonate, the temperature of his/her skin is not uniform. All protruding elements of the body like fingers at palm and foot, nose, shanks etc. are much colder than the skin of remaining parts of the body. Temperature differences are absolutely noticeable and may even reach 3–4 °C. This is confirmed by infrared (IR) picture displayed in Fig. 2.

Then neonate's head is cooled using the cool cap supplied with cold water prepared by the cooling centre as schematically shown in Fig. 3. The rest of neonate's body is generally heated by the heating mattress and being irradiated by radiant warmer. The cooled head is at the same time protected from being irradiated by the special thermal screen (see Fig. 4). As a result temperature of the head decreases to about 28 °C, whilst the temperature of the torso increases a little and on the limbs rises even to about 37 °C. It should be remembered that if the temperature on the skin surface of the head is such low, the temperature inside the neonate's brain is considerably higher but still at the required level. It is caused by the high thermal resistance of the bones, the high metabolic heat production of the brain and the current flow of the warm blood. This is confirmed by a


Figure 1: Patient with applied brain cooling therapy. Courtesy of the Univ. Clinical Hospital in Opole. Used by permission.

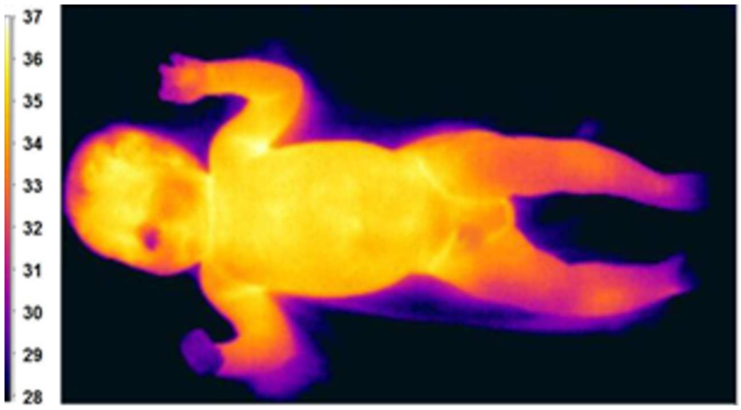


Figure 2: Temperature field of the baby's skin measured by thermographic camera.

number of computer simulations, e.g. [2], and neonatologists' observations.

The heat flux transferred from the brain to the cooling water flowing through the cooling cap is certainly not constant during the therapy but depends on the water flow rate and its temperatures. The Olympic Cool-Cap system originally controls only the average temperature of the cooling fluid and this is set by the neonatologist. Any other information about the performance of the system is not available. The value of the volumetric water flow rate is rather low. This is why dedicated water flow meter equipped also with the temperature sensors has been designed and manufactured. This flow meter, shown in Fig. 5, is supported by the standard telecommunications system (GSM) system and allows one to monitor fluctuations of the heat flux in the brain cooling process even remotely using

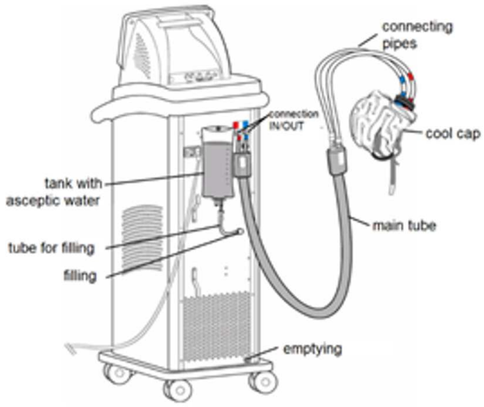


Figure 3: Accessories of Olympic Cool-Cap system [3]. Courtesy of Olympic Cool-Cap. Used by permission of the Polish representative office.

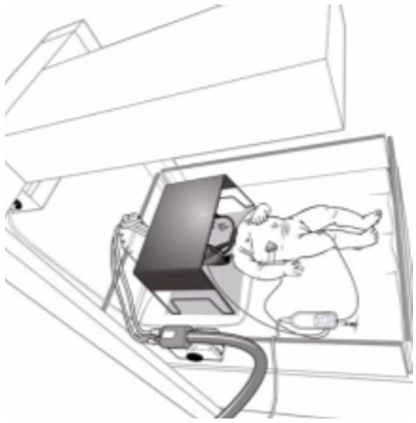

Figure 4: Thermal protection of the head. Courtesy of Olympic Cool-Cap. Used by permission of the Polish representative office.

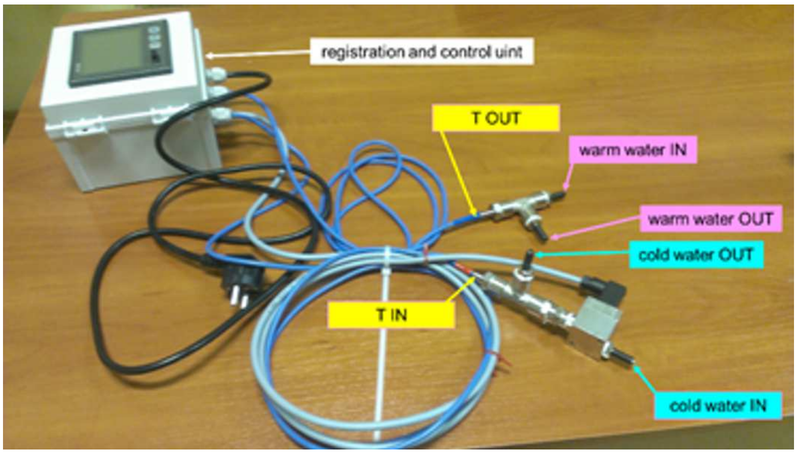


Figure 5: The water flow meter equipped with temperature sensors to monitor fluctuations of heat flux in the brain cooling process remotely.

internet browser. However, data are secured by user account and password. In this way all computational analyses carried out during therapy can be made without any disturbance to the medical personnel.

Figure 6 demonstrates how this special water flow meter equipped with the temperature sensors has been connected to one of in/out ports of the cooling device. Hence, from the operation point of view, there are no differences for the nurses. There are no differences in the treatment process as well.

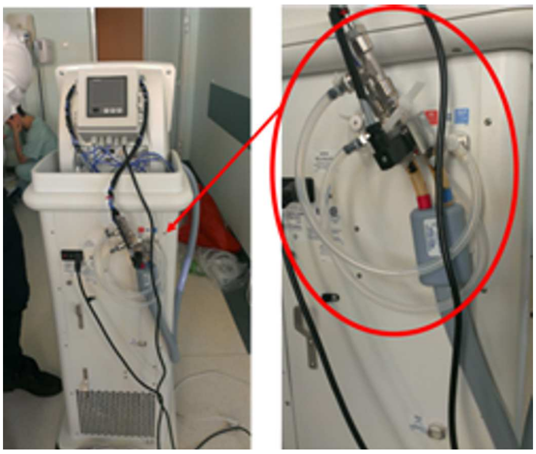

Figure 6: Cool-Cap system equipped with the water flow meter and temperature sensors.

Utilising the water flow rate and associated inlet and outlet water temperatures, recorded remotely as described above, calculations leading to the values of heat flux have been carried out and recorded. They are discussed briefly in the next section.

## 3 Selected results and discussion

The water flow rate and temperatures of the cooling water have been measured in course of three hypothermic therapies, see Tab. 1.

Table 1: Basic data for considered three patients.

| ID | Date of therapy start | Time of therapy start | Actual mass of neonate in kg |
|---|---|---|---|
| N1 | 17.03.2017 | 7:00 | 2.79 |
| N2 | 24.06.2017 | 3:53 | 2.90 |
| N3 | 02.07.2017 | 18:57 | 2.14 |

The recorded time history of variations of the cooling water temperatures (dashed and dotted line), water flow rate in liters/min (solid gray line and scale on the right side) and heat rate in wats (solid black line and scale on the left side) for patient N1 are presented in Fig. 7. Simultaneously, variations of the neonate's core temperature (solid line), the temperature of the skin over the abdomen (dashed line) and temperature of the forehead (dotted line), have also been recorded and are shown in Fig. 8. Curves in Fig. 7. and 8 are plotted as one-hour time average of measured values.

Figures 9 and 10 demonstrate analogous results for patient N2 while results for patient N3 are presented in Figs. 11 and 12. It should be noticed that core temperature is at the level of 34 °C for all three patients, which was a desirable/expected temperature. The skin temperature is at the normal level, i.e., it is around 36 °C, again for all three patients. Some small disturbances can be observed for patient N3 between 15th and 25th hour of the therapy resulting in small overcooling of the lower part of the body. This was then compensated by radiant warmer.

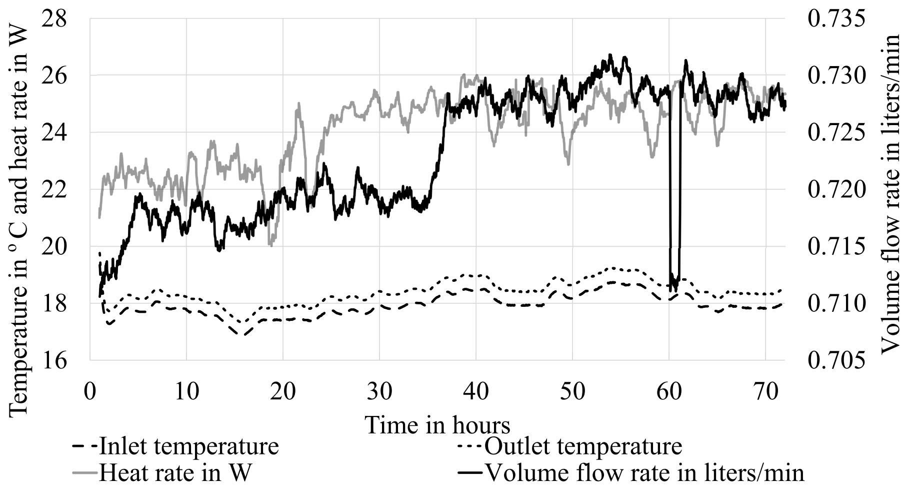


Figure 7: Measured temperatures and volume flow rate of the water in cooling cap together with heat rate – patient N1 .

The temperature of the forehead for patients N1 and N2 are very similar while this temperature for patient N3 is essentially different. Reason for this different character of temperature variations is up to now not known,

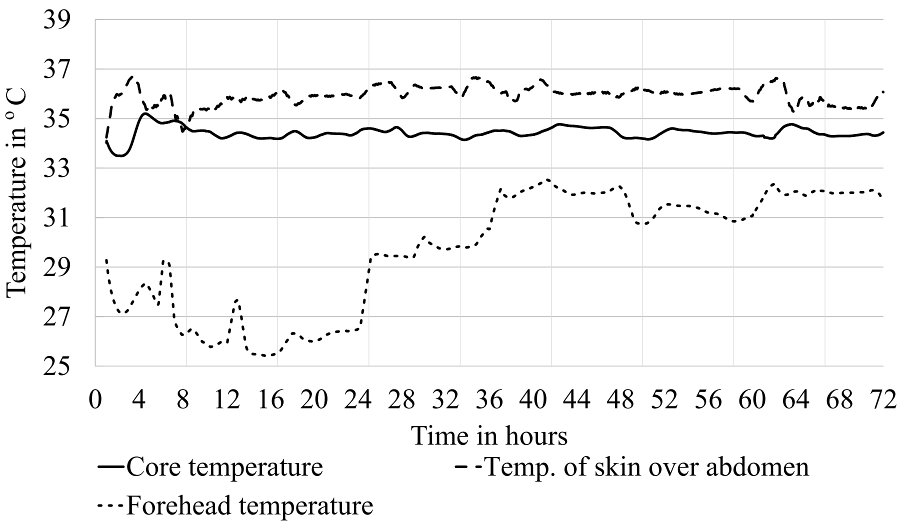


Figure 8: Variations of measured temperature during hypothermic therapy (one-hour mean) '– patient N1.

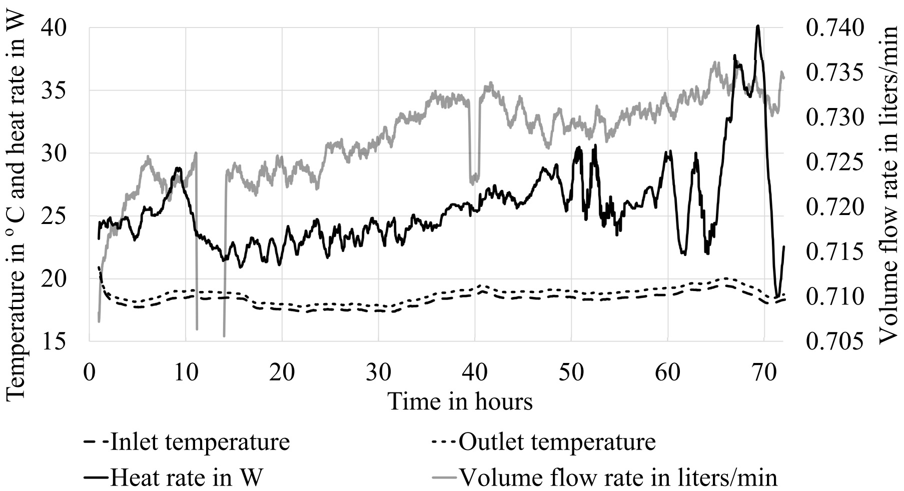


Figure 9: Measured temperatures and volume flow rate of the water in cooling cap together with heat rate – patient N2.

the more so the heat rate for this patient is only slightly bigger than for patient N1 and visibly smaller than for patient N2. The only possible explanation can be associated with the clearly smaller weight of this patient, (see Tab. 1).

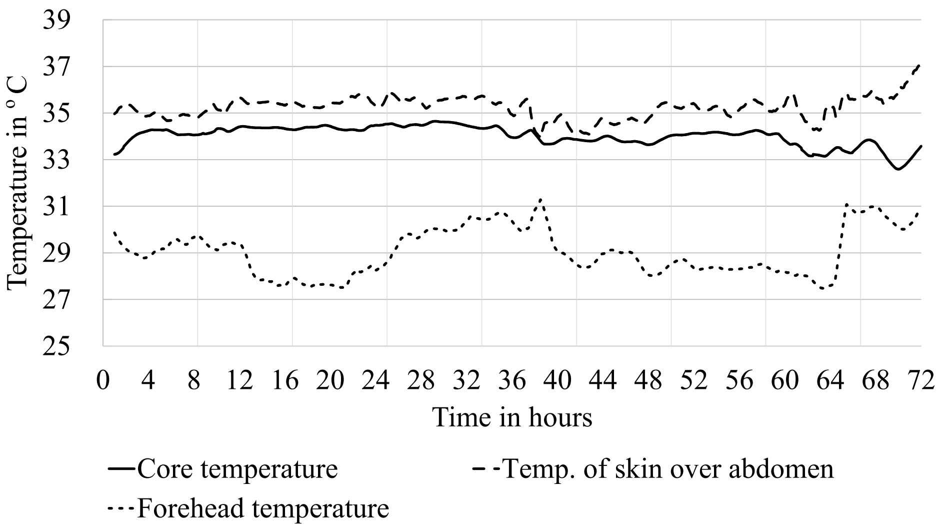


Figure 10: Variations of measured temperature during hypothermic therapy (one-hour mean) – patient N2.

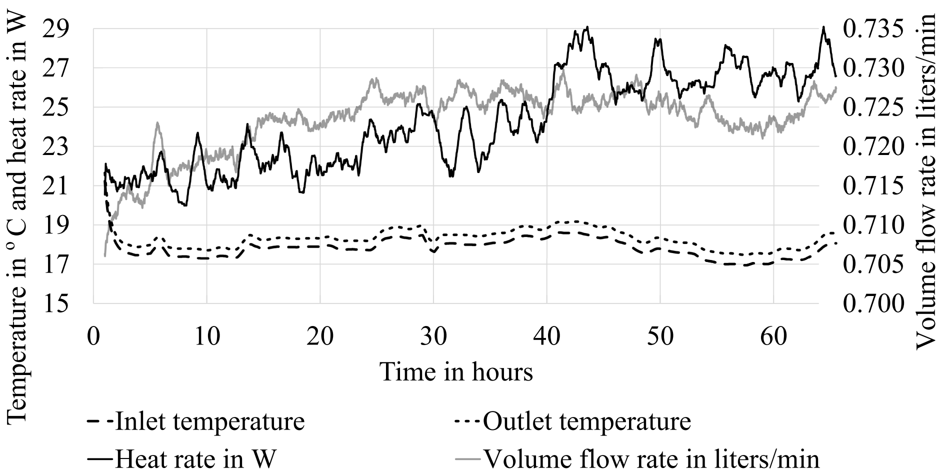


Figure 11: Measured temperatures and volume flow rate of the water in cooling cap together with heat rate – patient N3.

The rate of heat for all three patients is compared in Fig. 13. It should be noticed that the range of this quantity within the course of therapy is fairly similar for all three cases, at least between 10th and 45th hour of the therapy. Some more clear differences can be observed at the be-

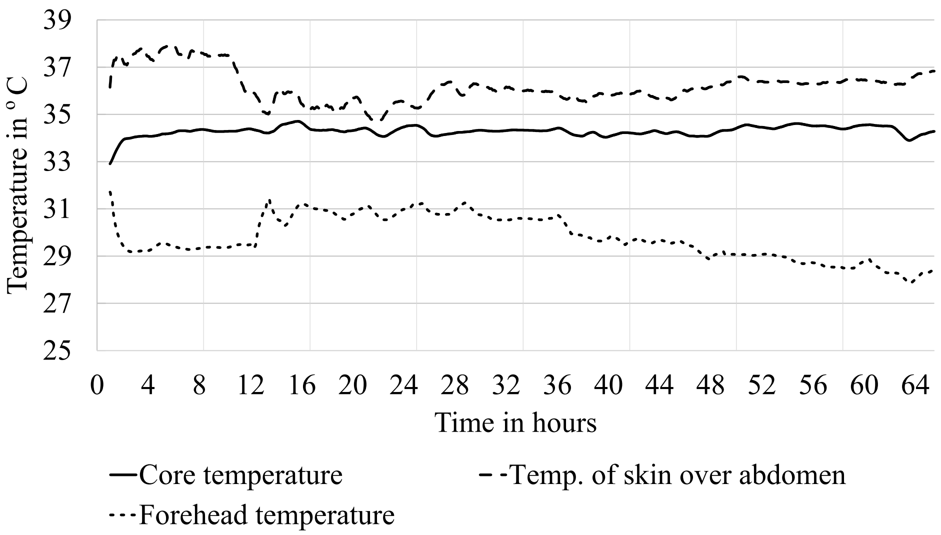


Figure 12: Variations of measured temperature during hypothermic therapy (one-hour mean) – patient N3.

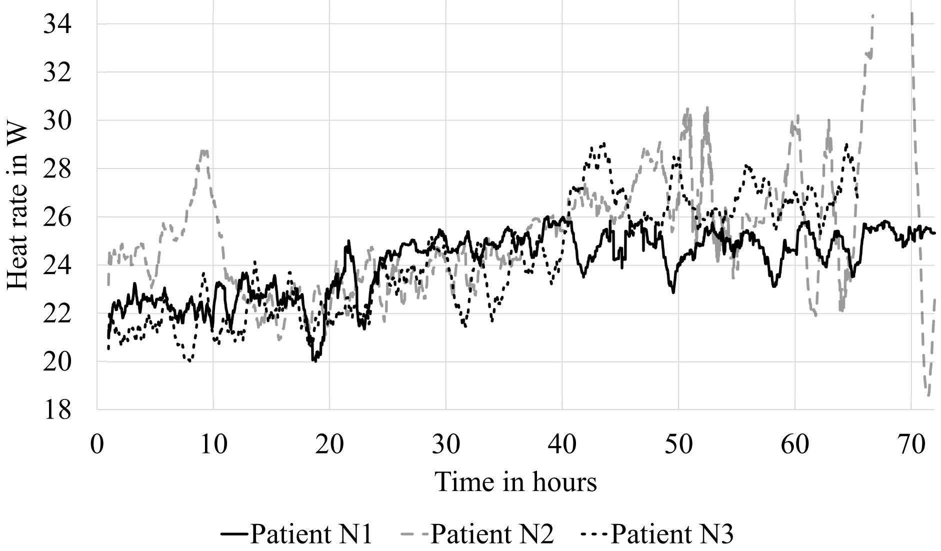


Figure 13: Comparison of the heat rate for all three patients.

ginning of therapy. This is absolutely understandable since infants are brought/transported to the hospital at different medical states. Much more difficult is to understand and explain those substantial fluctuations at the end of therapy. They will be analysed when more measurement data will be obtained.

The measured values presented above will be utilised to formulate in the future a convective boundary condition on the neonate's head. To make such boundary condition reliable many more experiments, as well as medical tests, are required.

## 4 Conclusion

The newborn's brain cooling can be considered nowadays as therapy to considerably reduce or even fully eliminate results of the hypoxic-ischaemic encephalopathy. The computer model of this therapy developed in the previous works requires reliable boundary conditions. The most important boundary condition, i.e., the heat flux transported from a newborn's head to a cooling liquid was measured using specially designed measuring equipment. Identical measurements should certainly be repeated with subsequent patients and analysed from the statistical point of view.

No doubts, the therapy itself and its computational model still require a lot of medical trials due to some open questions such as the proper time of the cooling stage of the therapy, precise scenario of rewarming stage, the total time of rewarming, etc. Coupling developed a computational model with the series of experiments and processing results of measurements recorded during brain cooling treatment of real babies should allow verifying numerous research hypotheses related to that therapy. Such thorough examination of the newborn's brain cooling process and its analysis from different perspectives will allow deepening knowledge about hypothermic therapy.

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