Thermal Imaging for Increasing the Diagnostic Accuracy in Fetal Hypoxia: Concept and Practice Suggestions

N.A. Urakova and A.L. Urakov

Abstract We developed a method for diagnosing fetal cerebral hypoxia with a thermal imaging camera. The method is based on the following detected principle: hypoxia and ischemia reduce the intensity of thermal radiation from tissues. Infrared thermography was performed in 35 pregnant women with a ThermoTracer TH9100XX thermal imaging camera (NEC, USA) in the temperature range of 26–36 °C. The research results showed that the local temperature of the skin in the parietal head part in live fetuses during delivery and immediately after birth ranged from 31.6 to 36.1 °C. It is found that normally an area of local hyperthermia might be observed on the top of the fetal head, and the temperature in this area might be 0.5–4.0 °C more than the temperature of the areas close to it. This area is located above the central suture of the skull, and has oblong shape. Monitoring the dynamics of temperature in the central suture allows us to evaluate the oxygen supply to fetal brain cortex during delivery. In this context, if the temperature drop areas are not observed in fetal head skin during his passing through the birth canals, it indicates the possibility of giving birth to a healthy child. In its turn, the occurrence of local hypothermia over the central suture of the skull indicates the hypoxic and ischemic damage to the fetal brain cortex and requires immediate hyper-oxygenation of the fetus blood. To increase the oxygen delivery to the fetus, we suggested giving the mother oxygen through a face mask and instruct her to breathe it in until "feeling drunk". We also suggest putting oxygen face mask on the fetus inside the mother's womb for artificial intrauterine ventilation of fetus lungs with breathing gas. In addition, in order to prevent fetal brain cortex cells from dying from hypoxia we suggested cooling the fetal head as soon as it comes out of the birth canal. We also propose to document the child health status in the final stage of childbirth by recording the dynamics of local temperature in the head skin area over the gap between the parietal skull bones with infrared thermography.

Keywords Physiological birth · Intrauterine hypoxia · Thermal imaging diagnostics · Newborn · Obstetric care

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1 Introduction

Hypoxia during childbirth is a major cause of perinatal damage to the cerebral cortex and is a leader in morbidity, disability and mortality rates in infants in the neonatal period [1]. Therefore, the threat of intrauterine fetal hypoxia in pregnancy and childbirth should be of great concern to obstetricians and gynecologists [2]. However, this problem remains unsolved, and the doctors lack safe methods for the diagnosis and monitoring of intrauterine fetal hypoxia.

With this aim in view, monitoring of the fetal heart rate is used to evaluate fetal status. Fetal heartbeat is monitored by cardiac heart murmur detection device or by measuring potential difference [1]. The murmur is detected during auscultation using a stethoscope and/or hand-held Doppler device. Ultrasound examination can also be used [3]. Electrical forces of fetal heart are detected by electrocardiograph with special sensors [4].

The informative value of these methods is reduced during labor due to the fact that the contractions of the uterus and other skeletal muscles cause electrical noise [5, 6]. This increases the error in monitoring sound and electric waves and results in the situation when sensors need to be replaced.

The study of the amniotic fluid collected by intubation is another common method for assessing fetal health [3]. This method is based on spectral changes of amniotic fluid associated with fetal excretion during severe hypoxia. It is monitored with an amnioscope or by visual observation after amniotomy. Such changes in amniotic fluid transparency are rare and exceptional [4]. Therefore, the diagnostic value of amniotic fluid transparency is limited and narrow.

At the same time, fetal hypoxia is dangerous not only for the heart, but also for the whole body. Moreover, the oxygen consumption in fetal brain is greater than in fetal heart [7–9]. The status of fetal brain cells defines future mental abilities [10]. Therefore, adequate oxygen and arterial blood supply to the fetal brain is an evidence of adequate obstetric support [1, 4, 11, 12].

In case of hemorrhagic shock in adult patients, this problem is solved by measuring the local temperature in fingertips with IR thermal imaging camera [13, 14]. However, this method is not applicable to neonates [15, 16]. In this case, the neonate's head can be used instead of the fingertips. Indeed, heat production by the neonate's brain is associated with aerobic metabolism intensity [17]. This allows us to use the dynamics of local temperature of fetal head for evaluating oxygen supply [4, 17]. However, monitoring the fetal head temperature in the delivery room and childbirth thermal imaging were not used previously for documentation of the labor process [1, 3, 10].

Nowadays continuous infrared thermal imaging of the visible part of the fetus's head skin after its appearance is not included in the list of compulsory procedures in childbirth control. As for methods for diagnosing hypoxia and/or ischemia of the fetal cerebral cortex during childbirth bearing down period, they are also unknown [18–22]. Based on the well-known role of general and local temperature in the preservation of life and health in warm-blooded mammals and humans [8, 9], recently we demonstrated high diagnostic value of infrared thermal imaging of various body parts surface for evaluating hypoxic, ischemic and drug damage in adults [5, 13, 23] and children [7, 16]. On this basis, we developed a method for assessing the degree of hypoxic damage to the cerebral cortex and resuscitation efficacy in adults during clinical death [24]. However, this method is not suitable for diagnosis of hypoxia and/or ischemic brain injury in fetuses during bearing down labor stage. It was assumed that infrared thermography of the fetal head will reveal symptoms of hypoxic damage to the cerebral cortex in the fetus. Due to the fact that hypoxia and ischemia of any part of a human body is associated with local cooling and change in color of infrared radiation from multicolor palette of red-orange-yellow-green-blue to monocolor blue palette, the occurrence of local cooling in the skin area above the suture of fetal skull fontanel during the second labor stage may be a diagnostic symptom for brain hypoxia. Therefore infrared thermography of fetal head can be used to diagnose fetal brain hypoxia and/or ischemia in bearing down labor period and after head appearance out of the birth canals.

2 Results

Before beginning our research, we considered the following assumptions. Sudden fetal hypoxia can occur in case of placental abruption, uterine inertia and umbilical cord compression in the final stage of labor. This is due to the physiological characteristics of this stage of labor such as periodic muscular uterus contractions. When the uterine wall contracts, the uterus increases the pressure in the amniotic fluid inside it. Uterine muscles compress not only the fetus, but also the uterine blood vessels. This evacuates blood from the uterine vessels, thereby inducing hypoxia of uterus, placenta and fetus.

In the final stage of labor, there is a danger of mechanical compression of the umbilical cord. This is due to close mechanical contact between the fetus and the birth canal walls. The umbilical cord can sometimes be pressed against the birth canal wall by hard fetal body parts. This can lead to its mechanical compression, devascularization and result in fetal hypoxia.

In physiological childbirth, the fetus passes through the birth canal headfirst. Thus, during birth the fetal head comes first. The fetal head temperature is higher than ambient temperature (25–26 °C), which causes rapid evaporation of fluid. As a result of evaporation, the fetal head temperature decreases. The temperature decrease rate depends on the intensity of blood circulation in fetal head and brain. The dynamics of the head skin temperature depends on the oxygen supply to brain tissues. Local temperature of fetal head can be monitored using IR thermal imaging. This method is contactless and valid at a distance of 1–2 m. In addition, this method for monitoring fetal head temperature is virtually instantaneous.

Infrared thermography was performed in a maternity hospital in 35 pregnant women admitted for physiological birth. Preliminary ultrasonic examination of women and fetuses health status was performed before childbirth. The tests were performed using ultrasonic scanners ALOKA SSD—ALPHA 10 and Medison SonoAce_600_C with standard convex transducers with frequency 3–7 MHz in a conventional way. The pregnant women were tested for fetal hypoxia using the Haussknecht method [25–29].

In this group, in 20 women in 30–32 weeks of pregnancy, fetuses demonstrated high adaptation to intrauterine hypoxia, which was confirmed by Gauskhneht test results (more than 30 s). In other 15 pregnant women in 30–32 weeks of pregnancy, fetuses demonstrated low adaptation to intrauterine hypoxia, which was confirmed by Gauskhneht test results (less than 10 s). Infrared thermometry was performed using Thermo Tracer TH9100XX thermal imager (NEC, USA) in the temperature range of +26 to +36 °C. The ambient temperature in the delivery room was in the range of +24 to +26 °C.

In our opinion, fetal health should be evaluated using digital parameters saved and stored as a document which can be accessed for 18 years after childbirth. In our study, this was achieved through recording digital IR images. For this purpose, we consider fetal head temperature to be the most informative parameter because the cortex has the highest intensity of oxygen metabolism and emits sufficient amounts of heat to the skin covering the skull fissures.

During our study, we found that infrared thermography of fetal head surface during labor ensures immediate delivery of accurate information on the dynamics of its local temperature values in the infrared radiation spectrum. It is shown that individual values of local skin temperature in the parietal scalp of live fetuses during labor and immediately after it were observed in the range of +31.6 to +36.1 °C. If the placental insufficiency symptoms are not observed, and the fetus has high resistance to hypoxia, then the infrared image of the parietal part of the head rarely has significant variations in colors.

In the absence of fetal hypoxia, the fontanel temperature is on the average 2.8 ± 0.21 °C ($P < 0.05$, $n = 20$) greater than cranium skin temperature. In case of severe hypoxia, the fontanel temperature is on the average only 1.5 °C greater than in the absence of hypoxia.

It was found that in normal pregnancy and normal physiological delivery, the head of live fetus is displayed on the thermal camera screen mostly in yellow-orange-red color palette. Besides, normally the temperature of infants' scalp is high (Figs. 1, 2, 3, 4, 5 and 6).

However, the scalp and body temperature in infants born with meconium-stained amniotic fluid was low. Moreover, normally an area of local hyperthermia might be observed on the top of the fetal head, and the temperature in this area might be 0.5–4.0 °C more than the temperature of the areas close to it. This area is located above the central suture of the skull, and has oblong shape (Figs 7, 8 and 9).

In the group of 15 pregnant women with placental insufficiency symptoms and with low fetal adaptation to hypoxia, the dynamics of temperature in the visible head surface during the bearing down labor stage in 10 fetuses had no fundamental differences from the dynamics of the temperature in the fetuses in the control group of mothers. But in other five fetuses we observed short periods of temperature drop in the central suture area of the scalp. The duration of these periods ranged from 30 to 120 s.

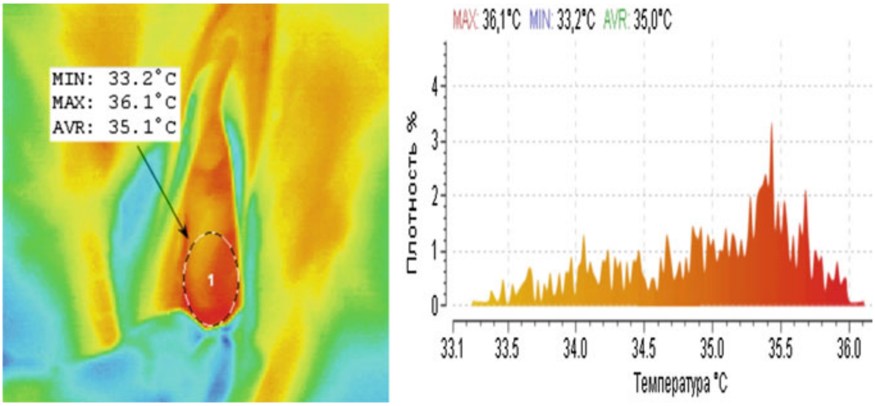


Fig. 1 Thermal camera image of perineum of mother P. and parietal part of the head surface of a live fetus at the beginning of his coming out of the birth canal in the norm

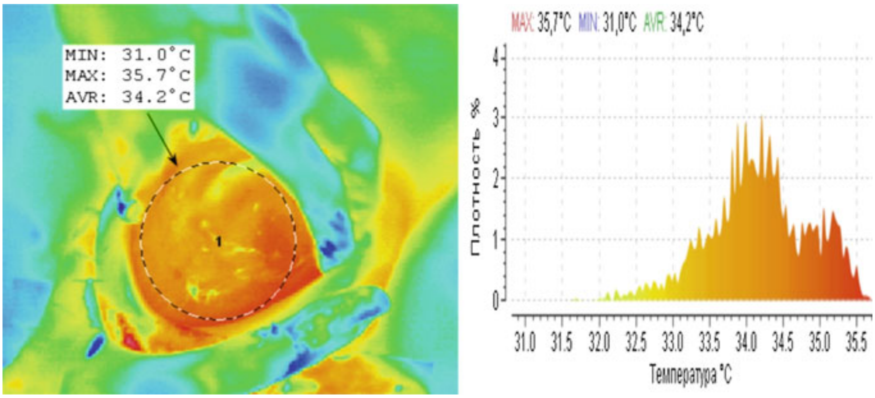


Fig. 2 Thermal camera image of perineum of mother P. and parietal part of the head surface of a live fetus at the delivery from the birth canal in the norm

We analyzed the circumstances of local hypothermia occurrence. It was found out that the immobile position of the fetus in the birth canal induced local hypothermia in the fetus' head above the central suture, whereas spontaneous labors induced rapid temperature increase (in 2–3 s) in five mothers.

The results showed that the immobility of the fetus in the birth canal enhances hypothermia in central suture area. We found that temperature image of the head in these fetuses was normalized only by artificially induced pushing of the fetuses inside the birth canal.

In addition, high informative value of thermal imaging was demonstrated during the first period after childbirth. For instance, in newly born infants the temperature during hypoxia was 32.2 ± 0.08 °C ($P \leq 0.05$, $n = 5$), while after 5 min of

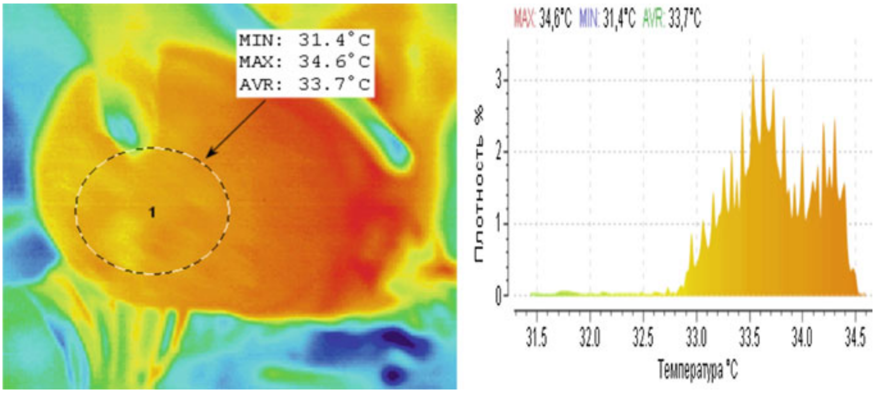


Fig. 3 Thermal camera image of parietal part of the head surface of a live fetus after delivery from the birth canal in mother P. in the norm

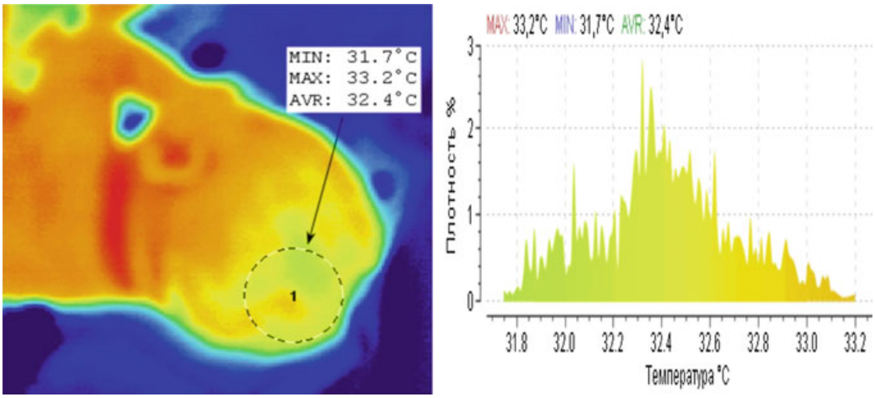


Fig. 4 Thermal camera image of the live newborn head immediately after birth from mother P. before cutting off the umbilical cord in the norm

artificial ventilation it was 34.15 ± 0.09 °C ($P \leq 0.05$, $n = 5$). In addition, neonatal hypoxia was associated with local hypothermia in their fingertips. This effect was observed together with blue skin in hands. The nose was the coolest area in the neonate's body. The average nose temperature was 30.85 ± 0.15 °C ($P \leq 0.05$, $n = 5$). The occurrence of local hypothermia in the nasolabial triangle was observed in one infant (Fig. 10).

We monitored neonates' health status during the first week after birth. From 20 neonates demonstrating high tolerance to hypoxia before birth and no signs of local hypothermia of the head skin area over central suture during labor, only one was found to have cerebral ischemia I. On the other hand, in five of 15 neonates with intrauterine hypoxia and local hypothermia of the head skin area over central suture

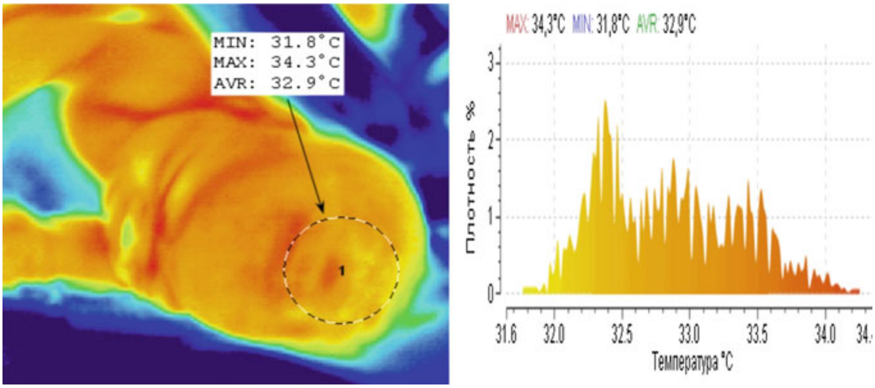


Fig. 5 Thermal camera image of the live newborn head after birth from mother P. after cutting off the umbilical cord in the norm

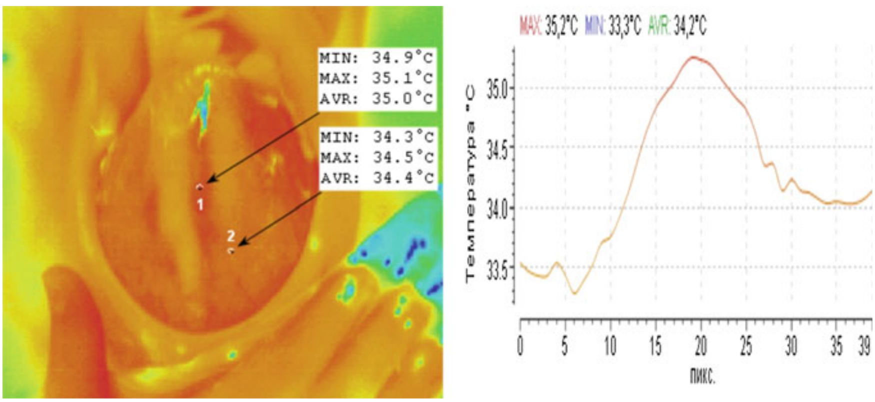


Fig. 6 Thermal camera image of perineum of mother C. and fetus head during the bearing down stage of labor. Before birth the fetus had a low resistance to intrauterine hypoxia. *Curve line* in the graph corresponds to the local temperature of the fetus head between the selected measurement points

cerebral ischemia I and II was observed. The five neonates were born with meconium-stained amniotic fluid and acrocyanosis.

Therefore, IR thermal imaging of neonate's head and body after delivery provides an informative approach to health monitoring and obstetric care quality control. Thermal imaging of the fetal head surface, performed with thermal imaging camera in the final period of labor, allows us to detect the occurrence and development of relative local hypo- and hyperthermia in the area of open central suture. In our opinion, the image of exposed and wet surface of the fetal head during its delivery surrounded by dry air at ambient temperature allows us to make conclusions about the intensity of oxidative metabolism in the brain cortex, as it is

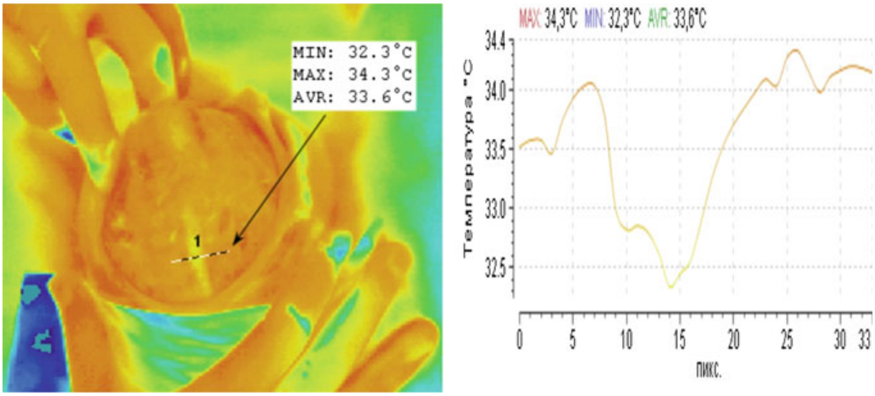


Fig. 7 Thermal camera image of perineum of mother C. and fetus head in 35 s after the termination of the uterus activity in labor. *Curve line* in the graph corresponds to the local temperature of the fetal head surface between the selected measurement points

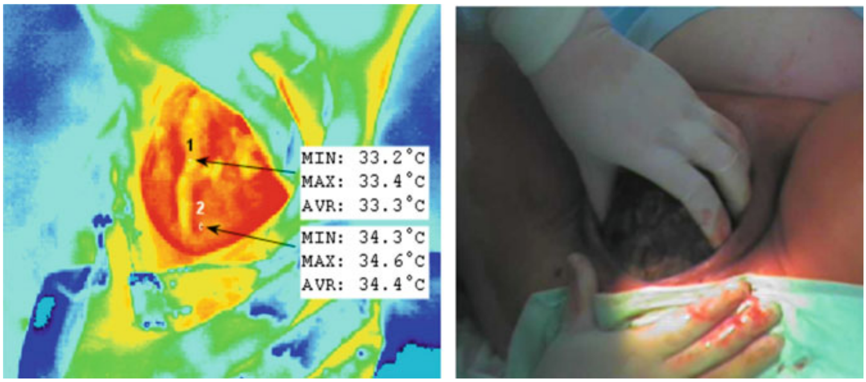


Fig. 8 Perineum of mother B. and the surface of fetal head at its coming out from the birth canal in 30 s after the termination of uterus activity during labor and the process of fetus passing through the birth canal in the infrared (**a**) and visible (**b**) ranges of the spectrum

associated with heat radiation. In its turn, the intensity of aerobic metabolism and thermal radiation enable us to make conclusions about the oxygenated arterial blood supply to cerebral cortex. Therefore, normal- and hyperthermia of the entire surface of the fetal head give bases for assuming that there is no threat of hypoxia and ischemia of the brain cortex.

Prolonged intrauterine hypoxia is the most probable cause of fetal death during abnormal labor and mental disability in newborns who underwent hypoxia and remained alive. The cells of cerebral cortex are known to be the most vulnerable to lack of oxygen, and the first to lose their functional activity and die. Nevertheless, modern standards of obstetric care still do not include methods for controlling the

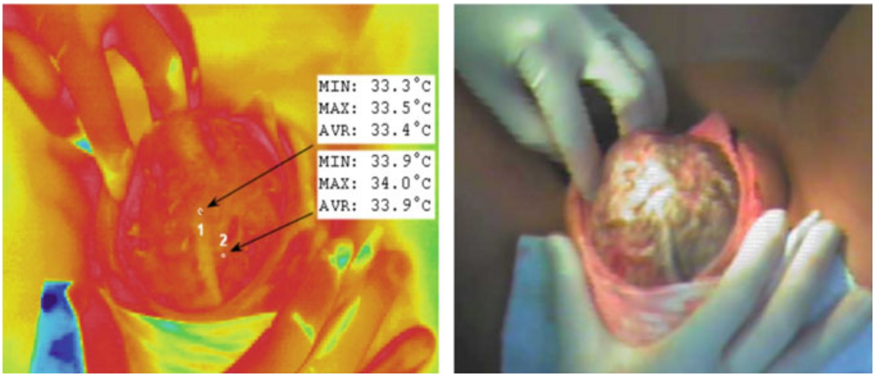
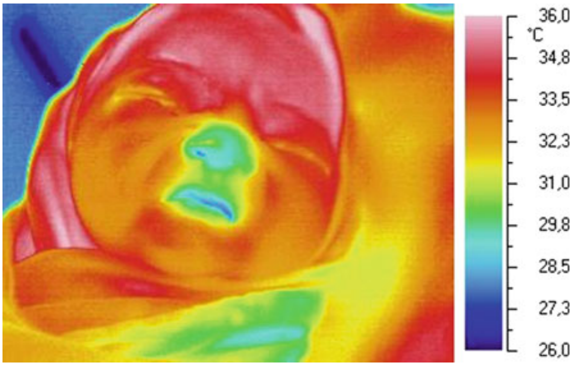


Fig. 9 Perineum of mother C. and the surface of fetal head at its coming out from the birth canal in 30 s after the completion of the uterus activity during labor and the beginning of the spot of the fetus in the birth canal in infrared (**a**) and visible (**b**) ranges of the spectrum

Fig. 10 IR image of neonate's face diagnosed with hypoxia in 30 min after birth



intensity of aerobic metabolism in fetal brain cortex in the final stage of physiological labor in real time.

Recently, with infrared thermography and thermal imaging cameras being introduced in medical practice, it has been revealed that monitoring the dynamics of local temperature of the body surface in humans and animals with a thermal imaging camera allows us to diagnose the occurrence and development of local hypothermia areas due to hypoxia and ischemia in a safe and contactless manner. We were the first to establish that the temperature of the parietal area of the head in newborns after coming out of the birth canal decreases in case of hypoxia and increases in case of hyperoxia.

At the same time, we found that the temperature of the head surface in adults with burr hole in the skull also depends on the efficiency of oxygen supply in real time. We found that local temperature drop is observed in 11–13 s in finger pads and in 50–60 s in the trepanation area after the beginning of voluntary apnea. The recovery of respiration begins to raise the local temperature in finger pads and in the area of burr hole in the skull simultaneously after 2–5 s. Then, after 1–2 min, the local temperature returns to its initial value, and then continues to increase and may exceed its initial value by 0.1–1.5 °C. As a result, the area of local hyperthermia occurs in the former local hypothermia area (Figs. 11 and 12).

Thus, by monitoring the local temperature of the head surface over open suture and skull fontanelle in newborns and over the burr hole in adults, we can carry out inference about the sufficiency of oxygen supplied by the arterial blood to the cerebral cortex, and about the efficiency of lungs ventilation with breathing gas. Therefore, our data creates hope that monitoring local temperature of fetal head after its coming out of the birth canal and adult head with a burr hole with infrared imaging camera may become a new radiology method for evaluating oxygen supply to the cells of cerebral cortex.

Based on these results and on the theoretical concepts about the relationship between aerobic metabolism and the local temperature, we presented several inventions aimed at saving fetal brain cells from hypoxic damage during pregnancy and childbirth. To increase the oxygen delivery to the fetus, we suggested giving the mother oxygen through a face mask and instruct her to breathe it in until "feeling drunk" [21]. We also suggest putting oxygen face mask on the fetus inside

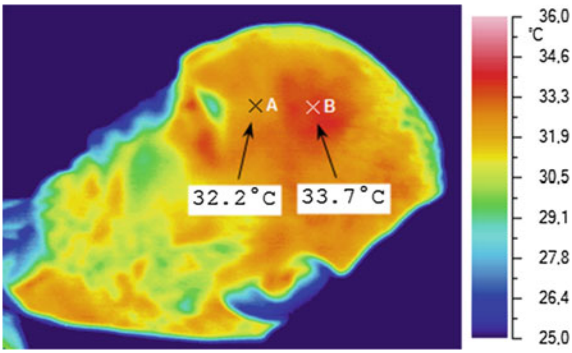


Fig. 11 The head of the patient V., 56 y.o., in 12 days after trepanation at normal blood oxygenation level (control). *Arrows* indicate the values of scalp surface temperature at point *A*—over the intact surface and at point *B*—over the burr hole

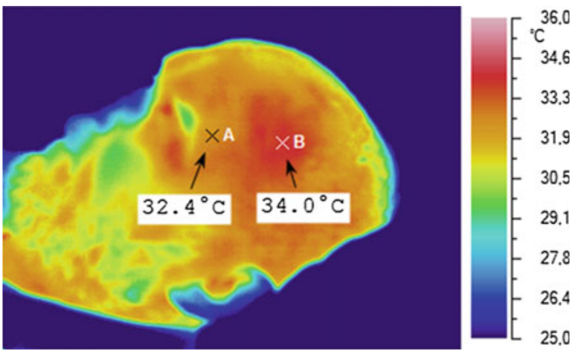


Fig. 12 The head of the same patient V., 56 y.o., with a burr hole in the skull in 60 s after voluntary apnea and in 3 min after the intensive recovery of respiration. *Arrows* indicate the values of scalp surface temperature at point *A*—over the intact surface and at point *B*—over the burr hole

the mother's womb for artificial intrauterine ventilation of fetus lungs with breathing gas [12]. In addition, in order to prevent fetal brain cortex cells from dying from hypoxia we suggested cooling the fetal head as soon as it comes out of the birth canal [20]. We also propose to document the child health status in the final stage of childbirth by recording the dynamics of local temperature in the head skin area over the gap between the parietal skull bones with infrared thermography [10]. Finally, we developed lymph substitute agent injected into the cerebral cortex and aimed at preserving cells viability during hypoxia and ischemia [30].

3 Conclusion

Out findings showed that infrared thermal imaging provides real-time monitoring of delivery process as well as the dynamics of local body temperature of the neonate; it is insensitive to acoustical, mechanical and electrical noises caused by sudden muscular contractions and electrical forces variation in the labor process. This technique allows monitoring the temperature variations in different areas of the fetal head skin, providing timely diagnosis of sudden intrauterine hypoxia and controlling its duration. Detecting local hypothermia areas over the central suture or frontal fontanel also contributes to prognosis of neonatal encephalopathy.

IR thermal imaging provides contactless monitoring of the neonate's head temperature, thereby providing real-time quality control of obstetric care during labor and immediately after delivery. The occurrence of local hypothermia area above the central suture and fontanel can be regarded as an evidence of oxygen deficiency and intrauterine hypoxia. In normal labor and in the absence of intrauterine hypoxia, the head skin temperature over the suture should not be lower than the temperature of the areas close to it. Local hypothermia over the central suture and/or fontanels is an evidence of insufficient arterial blood and oxygen supply to the brain, i.e. brain hypoxia and/or ischemia. Long-term local hypothermia increases the danger of neonatal encephalopathy.

Thus, IR thermal imaging of the neonate's head during the labor and immediately after delivery provides a new approach to labor monitoring and obstetric care quality control. During the final labor stage, this technique provides safe diagnosis of intrauterine hypoxia and its danger to the neonate's brain, and involves obstetric care correction. We believe this method might have favorable prospects in decreasing the neonatal mortality and neonatal encephalopathy.

Infrared thermal imaging also enables taking digital videos and photographs of the fetus, which can be saved and stored in USB flash drive.

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