Application of Infrared Monitoring for Personalization of Obstetric Aid

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The aim of the study was to determine the possibility of infrared monitoring of dynamics of the local temperature in the fetal head skin at the final stage of physiological delivery in order to assess the degree of arterial blood and oxygen supply to the fetus brain.

Materials and Methods. Infrared temperature monitoring of the fetus head surface was carried out at Maternity Hospital No.6 of the Republic Clinical and Diagnostic Center (Izhevsk, Russia) in 35 women at the final stage (sometimes called the stage of bearing-down or pushing, or transitional labor) of physiological delivery and immediately after childbirth. Infrared tomography was used to control the dynamics of the local fetal head surface temperature. The values obtained in the region of the cranial bone projection were compared with those in the region of the sagittal suture or fontanelles.

Results. All fetuses which demonstrated high tolerance to apnea in their mothers during pregnancy have been found to maintain high tolerance to the factors of physiological delivery as well. At the final stage of delivery, the temperature in the skin over the cranial bones, in the region of the anterior fontanelle, and the sagittal suture in these fetuses was relatively stable and did not have any significant differences. All fetuses were born healthy and did not show symptoms of encephalopathy during the first postpartum week.

The fetuses which demonstrated low tolerance to apnea period in their mothers during gestation displayed low tolerance to the factors of physiological delivery as well. At the bearing-down stage with weak contractions, the local temperature in the skin over the cranial bones in these fetuses was relatively stable whereas in some fetuses it decreased periodically over the anterior fontanelle and sagittal suture. It has been established that immediate artificial induction of contraction providing the transition of the fetus along the birth canal by several centimeters or immediate hyperventilation of maternal lungs with the breathing gas till a slight dizziness increased the temperature of the fetus skin over the sagittal suture and anterior fontanelle. During the first postpartum week, symptoms of cerebral ischemia grade I and II appeared in 100% of neonates of this group.

Conclusion. Infrared local temperature monitoring of the fetus head surface at the final stage of delivery and in the first minutes after birth allows for the assessment of blood and oxygen supply to the fetus brain, timely detection of hypoxia symptoms, correction of obstetric aid and its efficiency.

Key words: physiological delivery; personalized obstetrical aid; newborn; infrared tomography; hypoxia; postpartum encephalopathy.

Introduction

The development of the technologies assessing fetus condition inside the uterus made it possible to look at the effectiveness of the existing standards of rendering gynecological and obstetric aid. One of the trends of personalized gynecological and obstetric aid is studying the dynamics of individual morphofunctional structure of the fetus and its behavior under conditions of artificially induced hypoxia using ultrasound and infrared monitoring. The point is that the results obtained enable the assessment of fetus tolerance to intrauterine hypoxia during pregnancy and physiological delivery [1–3].

It should be noted that constitutional (individually typological) anatomy is one of the main approaches of clinical and diagnostic paradigm of personalized medicine

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which is now dynamically evolving [4, 5]. To diagnose correctly the state of health and detect the signs of previous intrauterine fetal asphyxia by visual criteria is part of the educational program on anatomy of the fetus and newborn [6]. However, first-hand visual experience and standard diagnostic methods are not always successful in timely revealing of intrauterine fetal hypoxia during delivery and assessing tolerance of the fetus to it, which reduces the effectiveness of the gynecological and obstetric aid [7].

The reasons for the late diagnosis of intrauterine hypoxia are individually typological characteristics of topographic anatomy of the brain, cranial bones and fetal head skin, location of its arms and cord inside the uterus and birth canal concealed from the eyes of medical personnel and also unawareness of the dynamics of lung capacity and thoracic cavity values [8]. Additionally, the problems of late detection of hypoxia signs in the fetus may be aggravated by relatively small dimensions of its body (e.g. in prematurity and/or dystrophy, cachexia) or, on the contrary, large dimensions (e.g. in acromegaly and diabetes mellitus). The diagnosis of intrauterine hypoxia is also impeded by the changes in the fetal properties caused by intoxication (e.g. alcoholism, drug or toxic substance addiction of their mothers) and presence of anesthetic, myorelaxant, psychotropic, soporific, and some other agents in maternal blood [9].

Intrauterine fetal hypoxia is one of the most frequent causes of perinatal morbidity and occupies 21–45% of all cases of perinatal pathology [7, 9]. Most vulnerable to oxygen deprivation are cortical neurons which are destroyed first as they do not endure hypoxia [10, 11]. To avoid or reduce distressing outcomes of hypoxia and fetal asphyxia, various methods of diagnosing the signs of fetal intrapartum hypoxia have been developed and suggested for clinical application. Acoustic and/or electrocardiographic monitoring of the fetal heart rate, detecting of heart murmurs with the help of stethoscopes, manual Doppler device, or ultrasound [2, 3]; biochemical blood tests for the assessment of metabolism in the fetal body; diagnosis of asphyxia by changes in the color and transparency of the amniotic fluid and appearance of meconium in it which is detected visually using amnioscope are referred to these methods [3, 7]. Each of the mentioned methods is known to have not only advantages and but limitations too.

Unfortunately, at the final stage of delivery these methods are not informative.

To define hypoxia in adults, we have previously proposed to register the dynamics of the local temperature on the palm finger-cushions using infrared tomography [12, 13]. However, fetal arms are not accessible for diagnosing [14]. Therefore, it was decided to explore a local temperature in the skin of the fetal head as it is the first part of the body available for direct visual investigation [15].

In recent years, owing to the advent of thermal imaging, infrared monitoring of local temperature dynamics on the human body surface is being actively implemented into medical practice. It enables safe and contact-free diagnosis of the emergence and development of hypo- or hyperthermal zones in various body areas which may be symptoms of ischemia, hypoxia, inflammations, and malignant neoplasms [8, 12]. Thermal imagers differ from other radiodiagnostic systems by their full safety and ability to obtain images of the selected open region of the body in different rainbow colors depending on its local temperature [14]. Positive results of using infrared imaging in adults allowed us to suppose that similar temperature measurements on the fetal head surface will make it possible to reveal symptoms of hypoxic damage of its cortex. Lack of arterial blood (ischemia) or oxygen (hypoxia) is known to reduce the temperature in many other parts of the body [8, 14, 15]. And therefore, it is natural to suppose that the decrease of temperature in the skin in the area of the anterior fontanelle and sagittal suture in the fetal head may serve as a diagnostic sign of cortical hypoxia. Consequently, infrared monitoring of dynamics of fetal local head temperature may become a novel medical technology in assessing the degree of oxygen supply and detecting hypoxia and/or cortical ischemia at the final stage of vaginal delivery (after the appearance of the presenting head from the birth canal).

The aim of the investigation was to determine the possibility of infrared monitoring of dynamics of the local temperature in the fetus head skin at the final stage of physiological delivery in order to assess the degree of arterial blood and oxygen supply to the fetus brain.

Materials and Methods

The study was carried out at Maternity Hospital No.6 of the Republic Clinical and Diagnostic Center (Izhevsk, Russia) by the personnel of the Department of Modeling and Synthesis of Technological Processes of Udmurt Federal Research Center, Ural Branch of the Russian Academy of Sciences (Izhevsk), the Department of Human Anatomy of I.M. Sechenov First Moscow State Medical University, and the Department of Normal and Topographic Anatomy of the Faculty of Fundamental Medicine of Lomonosov Moscow State University.

The local temperature of the fetal head skin was measured at the final transitional stage of physiological vaginal delivery at 37–41 weeks of pregnancy in 35 women. Written informed consent to participation in the study was obtained from all patients. The investigation design was approved by the Ethical Committee of Izhevsk State Medical Academy.

Monitoring of the fetal head local temperature after its disengagement was performed using a TH91XX infrared thermal imager (NEC, USA) at a distance of 1.5–2.0 m. The temperature range of the imager screen was 26–36°C. The temperature in the delivery room was 24–26°C. The temperature was measured in separate points of the head skin in the projection of the parietal bones, sagittal fissure and/or anterior fontanelle [14, 15]. The data obtained were processed using Thermography Explorer and Image Processor software (NEC, USA).

Long before delivery at 30–32 weeks of gestation, the pregnant women and their fetuses underwent US examination in compliance with the existing standards of rendering medical aid. Additionally, tolerance of the fetus to hypoxia was determined during their mothers' voluntary breath-holding using Haussknecht test [1, 2]. Sonographic examinations of the fetuses were conducted using premium ALOKA SSD-ALPHA 10 US scanner (Aloka, Japan) supplied with the convex 3–7 MHz probes. The fetuses in 20 pregnant women have been established to have values over 30 s according to the score of the Haussknecht test (i.e. were highly tolerant to hypoxia) while 15 women had values below 10. In the latter group with low values of the test, cord entanglement around the neck and chest was revealed in one of the fetuses.

After birth, all newborns were examined by the specialists and underwent the necessary laboratory and clinical diagnostic investigations.

The results were statistically processed by analysis of variance using applied software package Statistica 6.0. Statistical significance of the results was determined using Student's t-test for unpaired samples [16].

Results

Before planning the investigations, we proceeded from the fact that the fetal head goes outwards first and its surface becomes also first available for visual examination. However, the association of the local temperature of the head surface with adequate oxygen supply to the fetus at this stage of delivery remains insufficiently studied.

Cooling of the fetal head skin is known to occur due to convection, evaporation of the fluid from its surface, and due to inhibition of aerobic metabolism in the skin and cortical neurons whereas heating is the result of increased supply of arterial blood and oxygen to the skin and brain. With other things being equal, the local temperature of the skin in the area of the anterior fontanelle and sagittal suture of the fetal skull can be largely determined by the intensity of oxygen metabolism in the neurons of the brain cortex since in this case a sufficient amount of heat is released [17, 18].

The results of our investigations showed that infrared thermography of the fetal head surface performed at the final stage of delivery enables instantaneous real-time acquisition of reliable information about the local temperature of the head surface. Individual values of the local temperature in the skin of the parietal part of the head in the living fetuses in the process of childbirth and immediately after it were in the range of 31.6–36.1°C. It has been established that in case of normal pregnancy and physiological delivery the head surface of the living fetus is visualized in yellow-orange-red colors on the imager screen during the entire delivery process (Figure 1).

Besides, in norm in some fetuses, there may found a zone of local hyperthermia in the skin of the parietal part of the head after its disengagement, where the temperature is 0.5–4.0°C higher than that of the skin over the adjacent areas. As a rule, this zone has a prolate form and is located over the cranial sagittal suture (Figure 2).

Fetuses with a high tolerance to hypoxia which has been determined long before the term of delivery during pregnancy endured easily the period of childbirth and did not have symptoms of hypoxia. In the fetuses of this group, the local temperature of the skin in the area of large fontanelles at the time of birth was higher by 2.80±0.21°C ($p<0.05$; $n=20$) than that of the adjacent areas of the skin. Immediately after delivery and cutting the umbilical cord, the local temperature on the surface of the head equalized and did not have significant differences (Figure 3).

Fetuses with low tolerance to hypoxia detected long before delivery demonstrated symptoms of heavy hypoxia

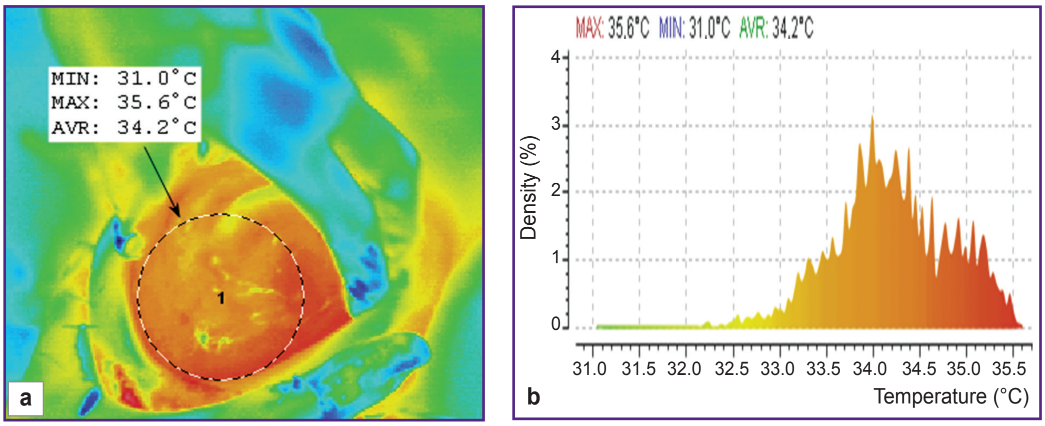

Figure 1. IR image of the fetal head in the process of its disengagement and passing outwards on the imager screen (a) with indication of the range of some local temperature values and density of its location (b); (*1*) the range of temperature measurement (center–perimeter)

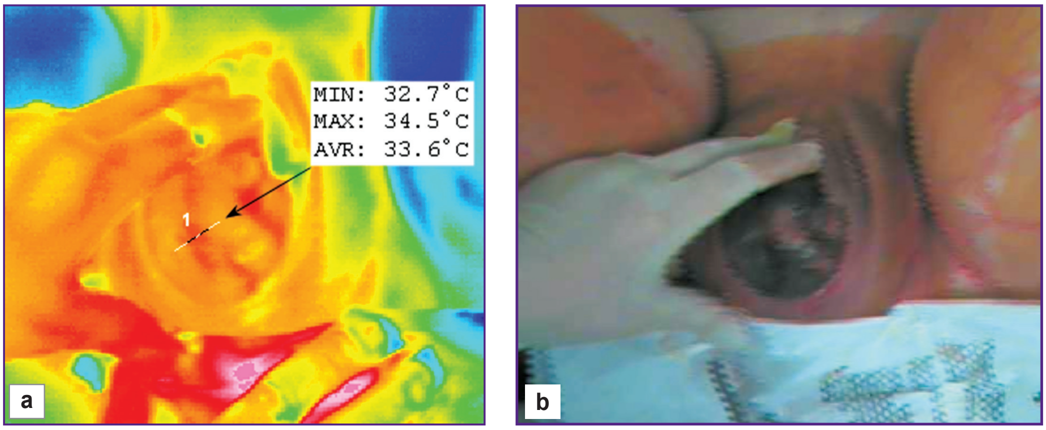

Figure 2. IR image of the fetal head in the process of its disengagement and passing outwards in infrared (a) and visible (b) range of tissue radiation spectra with indication of the local temperature in the area of the sagittal suture; (*1*) the range of temperature measurement (center–perimeter)

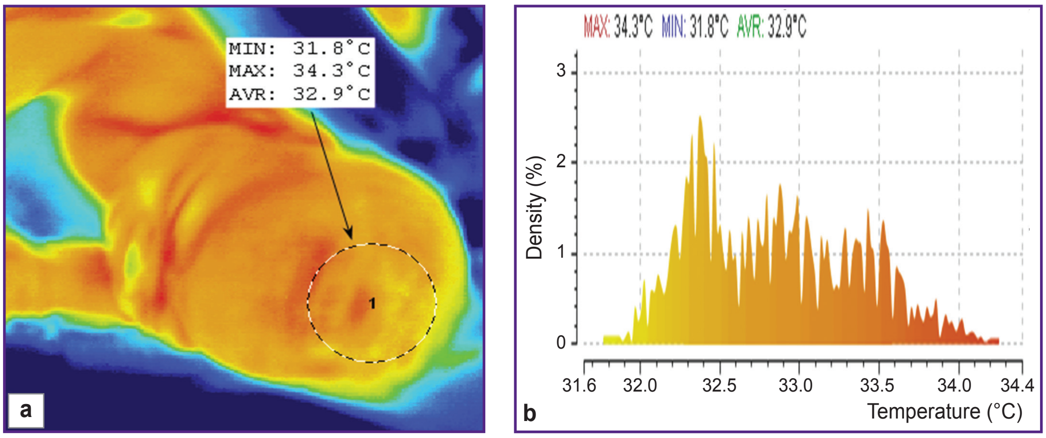

Figure 3. A living healthy newborn in the IR range of radiation spectrum immediately after cutting its cord (a) with indication of the range of values of the local temperature and its density in the skin of the parietal part of the head (b); (*1*) the range of temperature measurement (center–perimeter)

and asphyxia at the final stage of delivery. The local temperature of the head skin in the region of projection of the anterior fontanelle and frontal bone was 0.5–1.5ºC lower in the neonates with the signs of intra-partum asphyxia just after birth relative to the fetuses with high tolerance to hypoxia and born healthy. Besides, the low-tolerance fetuses had the temperature in th e skin over the large fontanelles lower than the temperature of the adjacent skin areas over the frontal bones of the skull by 0.50±0.05°C ($p<0.05$; $n=15$).

Maximal decrease of the local temperature in the head skin was observed in fetuses with low tolerance to hypoxia born in the turbid amniotic fluid with meconium. After birth, they were noted to have low values of the local temperature of the head skin and general body temperature as well. In the group consisting of 15 pregnant women with the signs of placental insufficiency and low tolerance of their fetuses to hypoxia, the dynamics of the temperature values on the visible surface of the head during the final stage of the labor period in 10 fetuses did not differ significantly from that in the group of mothers with a high tolerance of their fetuses to hypoxia. But in the rest 5 low-tolerance fetuses, periodically appearing prolate zones of local hypothermia were registered in the head skin over the anterior fontanelle and sagittal suture at the final pushing stage which lasted for 30–120 s (Figure 4).

We have analyzed the reasons causing the appearance of these zones of local hypothermia in the projection of the sagittal suture. A combination of several factors may lead to the development of local hypothermia in the fetal head skin: low tolerance to hypoxia, weak uterine contractions, protracted labor, and long-term immobile position of the fetus in the birth canal. Increase of time till the next contraction and the period of immobile position in the birth canal enhances local hypothermia whereas

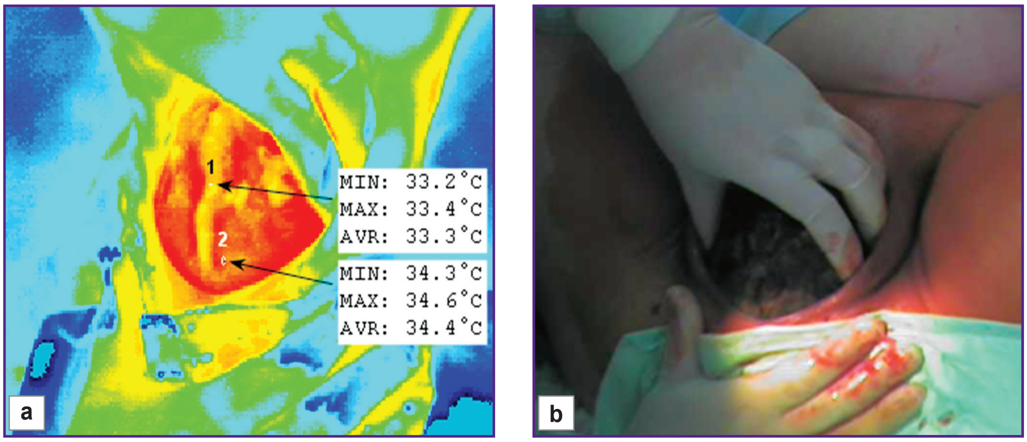

Figure 4. Head surface of the fetus with low tolerance to hypoxia at the moment of coming out from the birth canal 30 s after the completion of contraction and immobility of the fetus in the birth canal in infrared (a) and visible (b) ranges of radiation spectrum with indication of the local skin temperature values over the sagittal fissure between the bones (*1*) and over the skull bones (*2*)

Infrared monitoring of the local temperature of the head skin at the moment of fetal head disengagement and immediately after its birth (°C)

At the moment of head disengagement		Before cutting the cord in the newborn		5 min after cutting the cord in the newborn	
Over the anterior fontanelle	Over the frontal bone	Over the anterior fontanelle	Over the frontal bone	Over the anterior fontanelle	Over the frontal bone
In 20 neonates with high tolerance to intrauterine hypoxia determined at 30–32 weeks of gestation					
34.70±0.08*	34.40±0.07	34.0±0.08*	33.90±0.07*	34.20±0.08*	34.20±0.09*
In 5 neonates with low tolerance to intrauterine hypoxia determined at 30–32 weeks of gestation and born with the signs of intra-partum asphyxia					
33.4 ± 0.1*	33.9±0.1	33.7±0.1*	34.1±0.1*	34.2±0.1	34.3±0.1

* Statistical significance of value differences with the temperature in the area of frontal bone projection in fetuses with high tolerance to hypoxia at the moment of head disengagement (p<0.05).

acceleration of the next contraction and fetal movement in the birth canal, and/or immediately started hyperventilation of the mother's lungs with a breathing gas cause a quick elevation of the temperature in the zone of hypothermia and normalization of the temperature portray of the fetal head on the imager screen. Findings of our investigations also showed that induced contractions pushing the fetus several centimeters forward in the birth canal elevate the local temperature in the cooled area of the skin over the sagittal suture by 0.3–0.5ºC in 2–3 s after the successful movement of the fetus through the birth canal.

The comparative study of the fetal head skin temperature over the anterior fontanelle and sagittal suture after delivery showed that the skin temperature over the open anterior fontanelle and sagittal suture was on average 2.80±0.21°C (p≤0.05) higher than over the frontal and/or parietal bones in the group of 20 fetuses with high tolerance to hypoxia.

The local temperature of the skin over the large fontanelle in the neonates with high tolerance to hypoxia immediately after head disengagement was on average higher by 1.30±0.05°C than in the group of fetuses with low tolerance to hypoxia. In all highly tolerant babies born without the signs of intra-partum asphyxia, the skin over the anterior fontanelle had the temperature of 34.70±0.08°C whereas 5 low-tolerant newborns with the signs of intra-partum fetal asphyxia had the temperature of the skin over the anterior fontanelle equal to 33.4±0.1°C (p≤0.05) (see the Table).

The newborns with intrauterine intra-partum hypoxia and born with clinical signs of hypoxia (had cyanotic skin, acrocyanosis in the hand fingers and at the tip of the nose) were found to have the body temperature of 32.20±0.08°C (p≤0.05; n=5) and the local temperature of the nose 30.85±0.15°C (p≤0.05) immediately after birth. One baby had additionally the local zone of hypothermia in the area of nasolabial triangle [14, 15]. Since symptoms of hypoxia in the babies of this group persisted in the first hours after birth, they required artificial lung ventilation (AVL) with a breathing gas and oxygen. Five minutes after starting AVL, the general body temperature elevated and reached 34.15±0.09°C (p≤0.05).

The analysis of the newborns' health during the first week of life showed that in the group of 20 neonates, who were highly tolerant to hypoxia during gestation and born without zones of local hypothermia appearing in the skin of the head, only one baby had the signs of cerebral ischemia. In the other group composed of 15 newborns with low values of Houssknecht test and low tolerance to hypoxia, the local hypothermic zones appeared in 5 babies in the head skin over the sagittal suture and these 5 babies were born in turbid amniotic fluid with meconium. Symptoms of ischemia grade I and II were found in these neonates during the first week after birth.

Discussion

The findings of our investigations showed that monitoring of the local temperature on the fetal head surface over the anterior fontanelle and sagittal suture between the cranial bones provides the possibility to control the sufficiency of oxygen supplied with arterial blood to the brain cortex. This method can also confirm the normal course of physiological delivery, timely reveal the exhaustion of adaptive resources of the fetus to intrauterine hypoxia, and assess the effectiveness of the rendered obstetric aid [19–23]. Therefore, the data obtained by us have convincingly showed that application of infrared thermal imaging to monitor the local temperature of the fetal head after its appearance from the birth canal can become a novel method of radiological diagnosis of the adequacy of arterial blood and oxygen supply to the cells of the fetal brain [24].

Image of the bear and wet surface of the fetal head on the imager screen during its disengagement and coming outwards to the environment with dry air at room temperature makes it possible to judge about the intensity of oxidative metabolism in the brain cortex as it is accompanied by heat release which is in line with the data of the research literature [15, 17, 18]. The intensity of aerobic metabolism and thermal radiation, in its turn, enables one to judge the adequacy of oxygenated arterial blood supply to the brain cortex. If delivery goes on normally and there is no intrauterine hypoxia, the temperature of the fetal head skin over the anterior fontanelle and sagittal suture is never lower than that in the adjacent skin areas. Local hypothermia in the region of the anterior fontanelle and sagittal suture signifies insufficient supply of arterial blood and oxygen to the brain and is the symptom of hypoxia and/or ischemia of the fetal brain. Long-term hypothermia increases the danger of encephalopathy development in a newborn.

Thus, presence of normothermia and/or hyperthermia over the entire surface of the fetal head may indicate absence of threatening hypoxia and ischemia of the brain cortex whereas presence of general hypothermia and/or zone of local hypothermia over the anterior fontanelle and sagittal suture signifies exhaustion of fetal adaptive reserves to hypoxia [8].

Conclusion

Infrared thermography carried out by means of thermal imagers provides real-time registration of local temperature of the fetal head surface and the neonate body. This method is not sensitive to acoustic, mechanical, and electric disturbances arising due to jerky muscular contractions and electric biopotentials in the organism of the woman in the process of physiological delivery. This method provides also the control of temperature differences between various segments of the fetal head surface. Such monitoring can timely diagnose sudden manifestations of intrauterine hypoxia and control its duration. Zones of local hypothermia detected by thermal imagers in the region of the anterior fontanelle and sagittal fissure between the bones of the skull provide the opportunity not only to diagnose fetal hypoxia but to predict the development of encephalopathy in the neonate in future.

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Conflicts of interest. The authors have no conflicts of interest to declare.

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