



Original Research Article

Fetal hypoxia: Temperature value for oxygen exchange, resistance to hypoxic damage, and diagnostics using a thermal imager

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ABSTRACT

Modernization of obstetric care for fetal hypoxia is proposed by hyperventilating the mother's lungs with oxygen before the first symptoms of oxygen poisoning, General hypothermia of her body, and local hypothermia of the fetal head in the final period of delivery. The review shows the possibility of indirectly estimating the rate of oxygen exchange in the fetal cortex of brain by monitoring the local temperature of the head surface above the crevices and fontanels of the skull. It is shown that progress was achieved by using new data from ultrasound and infrared monitoring of fetal health.

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1. Introduction

Preservation of fetal health and life in case of sudden intrauterine hypoxia is still not a completely solved problem of obstetrics and gynecology.^{1,2} Unfortunately, generally accepted standards for the diagnosis and treatment of hypoxia do not exclude its harmful effect on the fetus.^{3–5} In this regard, in order to accelerate progress and discover completely new solutions, it makes sense to draw the attention of researchers to technical solutions that can only be found in inventions today. Among the inventions that have not yet been implemented in obstetrics and gynecology, a special place is occupied by inventions designed to assess and increase the reserves of adaptation to hypoxia.^{6,7}

2. Materials and Methods

A thorough study of scientific literature and inventions was conducted between 2009 and 2019 using the Google Scholar, Google Patent, Scopus, and PubMed databases. The results were analyzed, prioritized, and summarized. Keywords of the search strategy: thermal imager, infrared thermography, local temperature, pregnancy, childbirth, fetus, fetal brain, cerebral cortex, oxygen, aerobic metabolism, hypoxia, ischemia, apnea, blood loss, adaptation to hypoxia, adaptation to blood loss, radiation diagnostic methods, antihypoxants, blood substitutes. Information was limited by the possibility of using during pregnancy and childbirth for the diagnosis of intrauterine fetal hypoxia and increase the stability of the fetus to hypoxia. 19 inventions were evaluated for review.

3. Objective

This review is intended to emphasize the important diagnostic value of radiation properties, functional activity,

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and local temperature of the fingers and toes of a pregnant woman and her fetus in intrauterine fetal hypoxia during pregnancy and childbirth, on the one hand, and the diagnostic value of the natural dynamics of the local temperature of the fetal head surface in the final period of labor, and the role of cranial hypothermia and artificial hyperoxygenation of the fetus in weak labor activity, on the other hand.

4. Results

Today, it can be argued that the development of inventions designed to assess the reserves of adaptation to hypoxia began with the study of the dynamics of the state of fetuses inside the uterus during voluntary apnea in a pregnant woman and comparing it with the dynamics of the state of aquarium fish in a small volume of water after hermetically closing the container with them. The results showed that normally healthy fish and fetuses behave in conditions of acute hypoxia almost the same: at the beginning of the hypoxia period, they take a stationary state, the longer the duration of which is greater, the more they have reserves of adaptation to hypoxia. Then, after exhausting the reserves of adaptation to hypoxia, fish and fetuses suddenly activate their motor activity, and they have respiratory movements of the costal and or gill arches.^{8–11}

Thanks to this, in 2010, the invention "Method for assessment of fetus resistance to hypoxia by M. Y. Gausnekt" (RU Patent 2432118) was created, in which it was first proposed to assess the resistance of the fetus to hypoxia by the duration of its stationary state in uterus in the case of voluntary apnea of pregnant woman.

Then in 2013, the invention "Method of maintenance of live fish during transportation and storage" (RU Patent 2563151) was created, in which for the first time it was proposed to introduce hydrogen peroxide into water to keep fish alive in water without oxygen gas.

A few years later, there were reports that showed that apnea, the imposition of a tourniquet on the forearm and acute massive blood loss cause local hypothermia in the fingertips, which is well diagnosed using a thermal imager.^{12,13}

Thanks to this, in 2016, the invention "Method for infrared evaluation of human resistance to blood loss" (RU Patent 2619789) was created, in which it was proposed to issue a conclusion about high human resistance to blood loss when the fingertips were cooled by more than 1.0 °C at voluntary apnea lasting more than 50 seconds.

In this regard the it was suggested that infrared imaging should be used in obstetrics and gynecology to diagnose fetal hypoxia.¹⁴ The fact is that the exit of the head surface from the birth canal to the outside makes the head available for infrared imaging. In turn, the dynamics of the local temperature of the fetal head surface may reflect the degree of provision of the cerebral cortex with arterial

blood and oxygen.¹⁵ It was hoped that the local skin temperature above the cranial windows might reflect the local temperature and intensity of aerobic metabolism of cortical cells.¹⁶

It was soon shown that with high heat production intensity in the cortex, the skin areas above the natural "windows" of the skull may have a higher temperature than the adjacent skin areas.¹⁷ This skin temperature may indicate a sufficient intensity of aerobic processes in the cerebral cortex and a sufficient supply of arterial blood and oxygen. On the other hand, the development of local hypothermia in the skin areas above these windows of the skull may indicate a decrease in the flow of arterial blood and oxygen to the cerebral cortex.^{6,15}

But the diagnostic capabilities of infrared imaging are still not used enough in modern obstetrics.^{18–20} However, in recent years, it has been reported that infrared imaging of the fingers and toes, performed using a thermal imager in pregnant women with thrombophilia, can help in the diagnosis of fetal hypoxia. The fact is that a pregnant woman can respond to markers of fetal hypoxia as her own markers that appear during her hypoxia. At the same time, a pregnant woman includes adaptation reserves, which are manifested in the form of developing symmetrical local hypothermia in the fingers and toes, which are easily detected using a thermal imager.²¹

It should be noted that in recent years, thermal imaging images are increasingly used in various fields of medicine to visualize areas of local hypothermia in order to diagnose ischemia and hypoxia in real time.²⁰ In particular, the appearance of areas of local hypothermia in the region of the fingertips in adult patients has long been recognized worldwide as a symptom of hypoxia and used for diagnosis of hemorrhagic shock¹³ and also as a method of improving the accuracy of diagnosis of hypoxia using pulse oximetry.²² Moreover, recording the dynamics of local hypothermia in the fingers of an adult with a short-term tourniquet on the forearm is used worldwide as a standard diagnostic test, called the "Cuff occlusion test".¹²

It is shown that the most dangerous for the fetus is the final period of physiological labor. The fact is that at the end of labor, there may be a sudden decrease in the delivery of arterial blood and oxygen to the fetal body. And such a tragedy occurs at the end of childbirth much more often than before childbirth. Sometimes the delivery of oxygen is reduced for a very short period of time. In such cases, the fetus can easily withstand the lack of oxygen and remain practically healthy. But in some cases, during childbirth, oxygen with arterial blood stops coming to the fetus for a long time.^{1,2,5} Normally, the fetus is ready for this situation. It immediately reduces the consumption of oxygen, that is, saves its use.^{7–9} But the oxygen reserves in the fetus are small. Therefore, the fetal body does not have enough oxygen for long. After depletion of oxygen reserves, the

fetus is in a state of hypoxia. However, even in hypoxic conditions, it also remains healthy for some time, but in normal or high temperature conditions, this period is very short. It is shown that in the absence of oxygen, the absence of irreversible hypoxic damage in the fetus is determined by the degree of its hypothermia and the reserves of its adaptation to intrauterine hypoxia.^{9,16,17}

It was found that the direct dependence of the fetus on oxygen develops from the second half of pregnancy.²³ It is shown that during this period, his head develops at a faster pace, in which the main place is occupied by the brain.^{7,19} From this period of pregnancy, the process of development and differentiation of the fetal brain becomes a priority. Therefore, with the sudden development of intrauterine hypoxia, the fetus reacts to it by immediately redistributing blood flow in favor of the brain. This adaptive response is aimed at optimizing the delivery of oxygen to the fetal brain. It is known as the "fetal brain preservation phenomenon".^{3,7,19}

The fetal brain differs from other parts of the body by its maximum dependence on oxygen, since the main intracellular metabolic processes occur in brain cells with the participation of oxygen with the maximum intensity.^{6,19} In this regard, other things being equal, the fetal brain cells are the first to fail hypoxia and die. However, most often hypoxia is not prolonged, so it is not deadly for the fetus during physiological childbirth. Simply, the fetus is forced to include its reserves of adaptation to oxygen deficiency. That is why after birth, such a newborn child seeks to immediately inhale air, since the air contains the life-giving gas oxygen, which is absorbed into the blood through the lungs and enters the brain with blood.

To protect tissues from hypoxic damage in hypoxia and ischemia in 2015-2016, several solutions were invented, enriched with oxygen in the form of oxygen gas and/or in the form of oxygen salt with hydrogen, namely:

1. Lympho-substitute for local maintaining viability of organs and tissues in hypoxia and ischemia" (RU Patent 2586292). Solution for injection containing 0.88% sodium chloride, 0.06 - 0.1% glucose and 0.01 - 0.02% hydrogen peroxide.
2. Agent for increasing resistance to hypoxia" (RU Patent 2604129). This is a solution of 0.3-0.5% hydrogen peroxide in drinking water, which additionally contains oxygen gas at an excess pressure of 0.2 ATM at a temperature of +8 °C.
3. Energy drink" (RU Patent 2639493). This is an energy drink intended for enteral nutrition of children, made in the form of a sterile solution that includes glucose, ethyl alcohol, 0.3 - 0.5% hydrogen peroxide, containing oxygen gas at an excess pressure of 0.2 ATM at +8 °C.
4. Means for physical endurance increase" (RU Patent 2634271). This is a solution 7% glucose, 3% hydrogen

peroxide and oxygen gas at an overpressure of 0.2 ATM at +8°C.

Today it becomes clear that the body temperature of a woman and her fetus determines the intensity of oxygen consumption as follows: the higher the body temperature, the higher the speed of aerobic processes and the faster oxygen is consumed. Therefore, there is no alternative to lowering the temperature of organs, tissues and the body as a whole to slow down the expenditure of oxygen in the body.

Therefore, it is no accident that in 2016 was created the invention "Method for time of day determination for Caesarean section" (RU Patent 2626302). The essence of this invention is that in order to prevent hypoxic damage to the fetal brain, it is proposed to perform a planned Caesarean section in a certain part of the day. To do this, choose the time of day at which the body temperature of the pregnant woman has a minimum value. A similar value for protecting the fetal brain from hypoxic damage may be a cold object that reduces the temperature of the head along with the fetal brain.

It is established that viability of the brain cells of the fetus inside the uterus depend on many factors: the age of the fetus and the general state of his health, the health of the pregnant woman, the oxygen content in the inhaled air, the oxygen content in the arterial blood of a pregnant woman, the condition of the placenta, of ensuring its arterial blood from the gas exchange between fetal blood and maternal blood in the placenta, the processes of oxygen consumption in the body of a pregnant woman and the fetus, and the body temperature of a pregnant woman and the body temperature of the fetus.^{19,23} The latter factors become the most important in the conditions of sudden intrauterine fetal hypoxia, since it is the lowering of the temperature of the mother's body and her fetus that most reliably and safely reduces the intensity of aerobic metabolism in the fetal head and its need for oxygen, which ultimately increases resistance to hypoxia and lengthens the period of viability of brain cells in the absence of oxygen.²⁴ It is shown that similar problems were successfully solved due to local hypothermia in adult patients with acute lower limb ischemia,^{25,26} acute intestinal ischemia,^{27,28} as well as in children and adults with cardiac arrest during surgical operations on the heart and large main vessels.²⁹ In this case, surgeons use specially designed devices, drugs and methods that provide an emergency reduction in the temperature of organs in the ischemic area (i.e. due to local hypothermia) and / or cooling of the entire body (i.e. due to general hypothermia).³⁰ In addition, hypothermia has long been successfully used to preserve organs and tissues for their subsequent transplantation.^{31,32} Finally, hypothermia started within the first 6 postpartum hours has been shown to be a therapy that reduces the risk of death or deterioration in children with hypoxic-ischemic encephalopathy.³³

In recent years, thermal imagers have been used for this purpose.

The fact is that, the results of several studies around the world have shown that in adults, hypoxia, ischemia, and massive blood loss cause similar adaptive changes that manifest as local hypothermia in the fingers of hands.¹³ Based on this pattern, the development of methods for infrared diagnosis of hypoxia began with the invention of a method for detecting local hypothermia of the fingertips.

Based on this data, the “Method of determining stage of hypoxic injury and probability of reanimation by A. L. Urakov” (RU patent 2422090) was invented in 2009. The essence of this invention is reduced to monitoring the dynamics of local temperature in the patient’s hands using a thermal imager and issuing a conclusion about the progression of hypoxia, about the development of the stage of irreversible hypoxic damage in cells of cortex and about the onset of biological death when the size of the local hypothermia zone increases sequentially from the hands to the forearms and shoulders of both hands, and then to the patient’s torso.

Then in 2010 it was invented «Method for labor by N.V. Sokolova» (RU patent 2441592). The essence of this method is to conduct an ultrasound examination of the fetus when it is inside the uterus, and monitor the echogenicity of the fingertips of its hands during natural childbirth. The results are evaluated and if the degree of echogenicity of subcutaneous fat in the fingertip decreases during contractions, a conclusion is issued about hypoxia, which threatens the viability of the cells of the cerebral cortex in the fetus.

At the same time in 2010 it was invented «N. A. Urakova’s intrauterine scuba and ventilation method of fetal lungs with respiratory gases» (RU Application for invention N 2010134466) and in 2011 it was invented «The way of saving the fetus in case of sudden intrauterine hypoxia» (RU Application for invention N 2011109952). The essence of these inventions is reduced to the timely diagnosis of intrauterine fetal hypoxia, immediate hyperventilation of the lungs of a pregnant woman with oxygen gas up to the appearance of symptoms of oxygen poisoning while simultaneously ventilating the fetal lungs with respiratory gas using an intrauterine scuba tank and performing an urgent Caesarean section.

In 2011 it was invented «Method for assessing fetus resistance to obstetric hypoxia» (RU Patent 2511084). The essence of the method is that the condition of the fetus inside the uterus is controlled by ultrasound. When the fetus has an act of breathing movements of the ribs, multiple flexion-extension movements of the limbs and unclenching of the fists that occur during contractions, the duration of the immobile state of the fetus is determined from the beginning of this period. When the duration of the fixed position of the fetus during labor is approaching zero, it is concluded

that the fetus has poor adaptive stability to physiological childbirth.

In 2012 it was invented «Method of protecting fetus from hypoxic damage in labour» (RU Patent 2503414). The essence of the method is that ultrasound is used to monitor the ultrasonic echogenicity of the skin of the fetal finger pads. Reduction of ultrasonic echogenicity of skin of finger-pads in labour testifies to presence of acrocyanosis in fetus. In this case woman in childbirth is asked to start deep and frequent breathing. If the woman is unconscious, artificial hyperventilation of lungs with breathing gas is carried out up to appearance of first symptoms of oxygen poisoning in the woman, with continuation of hyperventilation until lung respiration in the newborn baby begins and umbilical cord is cut. State of the newborn baby’s health is performed by means of thermovision camera. Analysis of the newborn baby’s thermal radiation intensity by means of thermovision camera is started simultaneously with beginning of its body contact with atmospheric air. Birth of newborn baby with normal temperature testifies to absence of cyanosis in it. In this case labour is finished in accordance with general rules. Identification of section of local hypothermia in newborn baby’s skin testifies to cyanosis and acrocyanosis. In case if newborn baby after its birth does not breath independently, after removal of content of airways and appearance of local hypothermia of skin in peripheral sections of newborn baby’s body, its reanimation is started by interrupted double compression of chest. Reanimation is stopped when newborn baby starts crying and chest starts to perform respiratory movements. If baby is immobile, respiratory mask, connected with breathing apparatus is applied on its face, and artificial lung ventilation is carried out by them. When temperature in zone of local hypothermia increases, umbilical cord is clipped and dissected.

In addition, an invention was created in 2012 «Method of obstetric assistance in travails» (RU Patent 2502485). The essence of this invention is that for this purpose continuous infrared thermography of fetus. Presence and localisation of fissure between skull bones is detected on open part of fetus’s head. Estimation of presence and degree of hypoxia and ischemia of cerebral cortex of fetus is carried out by level of temperature of head skin in the area of skull fissure projection. If temperature remains in the standard range at all stages of fetus advancement inside birth canal, the level of intrauterine hypoxia and ischemia is estimated as safe. In this case physiological labor is performed. If starting local hypothermia is identified, conclusion about intrauterine hypoxic and ischemic injury of fetus’s cerebral cortex is made Fetus’s body is imparted forward movement by means of travails until it takes position, at which temperature of skin above skull fissure starts to become normal. If further beginning local hypothermia of skin in area of skull fissure projection is identified, impact is repeated. If normal temperature is identified when fetus advances in

birth canal, possibility of healthy child birth is predicted and if parameters do not change physiological labour is carried out.

In 2012 it was invented «Method for assessing body compensatory response to acute hypoxia» (RU Patent 2531924). The essence of this invention lies in the fact that the subject of an adult temporarily stop breathing, record the dynamics of the local temperature at the finger pad and determine the length of time since the cessation of respiration to reduce the local temperature at the finger pad of 0.1 °C. At time interval less than 15 seconds, give the conclusion of goods adaptation to hypoxia, and the period of time longer than 15 seconds to make a conclusion about poor adaptive capacity to hypoxia.

In 2013 it was invented «N.A. Urakova's method for antenatal assessment of foetal adaptation to repeated hypoxia» (RU Patent 2529377). The essence of the method is reduced to ultrasound monitoring of fetal motor activity inside the uterus and to determining the duration of its motionless state during repeated apnea in a pregnant woman. At the same time, if the time interval exceeds 15 or 30 seconds, the fetus' adaptation to repeated hypoxia is evaluated as satisfactory or good, respectively.

Then in 2014 it was created the invention «Method of midwifery allowance» (RU Application for invention N 2014110156). The essence of this invention is that natural childbirth is carried out under the control of the dynamics of the local temperature of the fetal head using a thermal imager. When a zone of local hypothermia is formed in the scalp above the skull window, the visible surface of the fetal head is immediately irrigated with tap water at a temperature of 18°C until the entire visible surface of the head is cooled to a temperature of 20-18 °C and the irrigation is maintained with the specified efficiency until the beginning of pulmonary respiration in the newborn.

In the same period of time, it was reported that immediately after the fetal head leaves the birth canal, the normal surface of the head has a uniform temperature within +36°C. However, then the temperature begins to decrease. The fact is that the air temperature in the birth hall is within +24 - +26°C, and the head of the fetus remains naked and wet. This creates conditions for intensive cooling of the surface of the open part of the fetal head due to heat convection and evaporation of water from its surface. At the same time, the intensity of cooling of the head surface depends not only on the intensity of convection and evaporation of water, but also on the intensity of warming of the skin from the brain. Moreover, the temperature of the skin over the crevices of the skull depends to a large extent on the radiation of heat coming to it from the cerebral cortex. At the same time, the intensity of heat release in the cerebral cortex depends not only on the delivery of warm blood to it, but also on the provision of oxygen to the cortical cells. In this regard, for the first time, attention was drawn to the

fact that the dynamics of the local temperature of the fetal head in the area of the central crevice of the skull, carried out under conditions of moderate and uniform cooling, may reflect the provision of oxygen to the cells of the cerebral cortex.^{10,11}

In 2015, it was invented «Infrared diagnostic technique for neonatal fetal hypoxia» (RU Patent 2622594). The essence of this invention is as follows: at first, mother's body temperature is determined. At body temperature above 37.2°C an increased fetal need for oxygen is predicted. Further, continuous dynamic thermal imaging video recording of the fetal head surface temperature during the act of delivery in the temperature range from 32 to 42°C using a thermal imager with the function of imaging of its visible on the screen in colors varying from red to purple. When the fetal head surface leaves the birth canal, it is immediately blown with a stream of dry air at a temperature of 25°C. A household hair dryer with the function of creating a uniform flow of cold air is used as a blowing device. The hair dryer is placed above or below the fetal head without shielding the infrared image of the head on the thermal imager screen. The head is blown from a distance of 10-15 centimeters with air flow intensity ensuring a decrease in the head surface temperature by several degrees in 3 to 5 seconds. With a uniform temperature, or with local hyperthermia above the arrow-shaped suture or fontanel, no hypoxia is concluded. If the temperature in one of these areas decreases by 0.1°C compared to the surface temperature over adjacent areas of the head, a conclusion is made on fetal hypoxia. Fetal head blowing by air and thermal video recording of temperature dynamics is continued until the birth. The video is archived in the digital form on an individual USB flash drive.

In 2019, it was reported that when hypoxic damage to the cells of the fetal cortex occurs in the final period of labor, the skin temperature over the skull "window" decreases. However, immediate hyperventilation of a pregnant woman's lungs with oxygen can normalize the skin temperature in this area. Therefore, infrared monitoring of the dynamics of the local temperature of the fetal head surface in the final period of delivery can be used to assess the quality of obstetric care.⁶

Therefore, it is hoped that the provision of obstetric care with infrared monitoring of the dynamics of the local temperature of the fetal head surface can inform medical staff in real time about the provision of oxygen to the fetal brain in the final period of physiological delivery. This makes it possible to diagnose fetal hypoxia in a timely manner, evaluate the effectiveness of oxygen delivery, and prevent hypoxic brain damage. A review of known inventions has shown that this requires a thermal imager that allows you to monitor the dynamics of the local temperature of the fetal head surface in the area of natural bone slits and fontanels. Most likely, the appearance of a zone of local

hypothermia in these areas of the fetal head surface will be recognized as a symptom of hypoxia. Most likely, the means to prevent hypoxic damage to the fetal brain will be oxygen gas, which will be recommended to immediately hyperventilate the lungs of a pregnant woman until she has a symptom of oxygen poisoning, and a cooling package, which will be recommended to immediately apply to the entire accessible part of the surface of the fetal head. This method will increase the oxygen content in the blood of the mother and fetus and will reduce the need for oxygen in cells of fetal brain cortex.

5. Conclusion

The local body temperature of a pregnant woman and her fetus during pregnancy and childbirth plays a very important role in regulating the intensity of aerobic processes in cortical cells of fetuses due to the high dependence on the functional activity of their mitochondria on temperature. Therefore, in conditions of intrauterine hypoxia, if it is impossible to immediately deliver the necessary amount of oxygen to the fetal brain, the brain cells can be saved from hypoxic damage by immediately cooling the fetal brain. This area of research requires the involvement of various specialists. However, infrared and temperature midwifery allowance is a realistic goal that can be achieved in the near future. Advances in this area can reduce infant mortality during childbirth, improve the health of newborns, and reduce the cost of obstetric care.

6. Source of Funding

None.

7. Conflict of Interest

None.

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