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Theory and Design

Diagnosis of Intrauterine Brain Hypoxia Using Thermal Imaging Video Monitoring of the Fetus

N. A. Urakova* and A. L. Urakov

Diagnosis of intrauterine brain hypoxia using thermal imaging video monitoring of the fetus was implemented using local recording of temperature dynamics of the skin of the neonate's head in the region of projection of the cranial fissure during the end of labor. In the norm, this temperature is equal to or higher than the temperature of skin above the cranial lobe. Local temperature decrease in the region of projection of the cranial fissure can be regarded as evidence of cerebral hypoxia.

Introduction

Intrauterine fetal hypoxia is a very frequent cause of perinatal diseases (21-45% of the total number of perinatal pathologies) [1, 2]. Fetal hypoxia was earlier suggested to be diagnosed using pregnancy and labor monitoring [3-6]. However, this problem is unresolved, and obstetricians are lacking a safe method of fetal hypoxia monitoring [7-10].

Monitoring of fetal heart is used for this purpose. Fetal heart rate is monitored by detection of heart murmur or electric potentials [1]. Murmur is detected by auscultation using a stethoscope and/or a manual Doppler apparatus. Ultrasonic examination can also be used [8]. Fetal cardiac biopotentials are detected using an electrocardiograph with special sensors [11].

The information value of these methods decreases during labor. During labor, the skeletal muscles of the parturient undergo maximal contraction, thereby inducing electrical noise [8, 12]. This increases the error of monitoring of sound and electric waves and leads to the necessity of replacing the sensors.

Izhevsk State Medical Academy, Izhevsk, Russia; E-mail: urakovanatal@mail.ru
* To whom correspondence should be addressed.

Amniotic fluid probing is another frequently used method of estimation of fetal health [1, 8]. This method is based on spectral changes of amniotic fluid associated with excretion of the fetus during severe hypoxia. Such monitoring is done using an amnioscope or visual observation upon dissection of the fetal bladder. Such changes in amniotic fluid transparency are rather rare and are an exception from the rule [11]. Therefore, the diagnostic value of amniotic fluid transparency is limited and narrow.

Nevertheless, fetal hypoxia is dangerous not only for the heart but also for the whole body. Oxygen consumption in the fetal brain is greater than in the fetal heart [13-15]. The state of fetal brain cells determines future mental ability [16-18]. Therefore, adequate supply of the fetal brain with oxygen and arterial blood is evidence of adequate obstetric support [1, 7, 8, 11].

In the case of hemorrhagic shock in adult patients, the similar problem is solved by detection of the local temperature of fingertips by IR thermal vision device [19]. However, this method is not applicable to neonates [12, 17]. However, 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 [20-22]. This allows the use of dynamics of local temperature of the fetal head for diagnosis [9-11]. However, monitoring of temperature in the delivery room and thermal vision recording of childbirth have not been used previously for documentation of labor [1, 8, 11, 23].

The goal of this work was to describe a method of X-ray diagnosis and digital documentation of fetal health in labor.

Materials and Methods

Sudden fetal hypoxia can occur in case of mazolysis and weak labor weakness at the final stage of labor. This is due to the physiological characteristics of this stage of labor manifesting itself in periodic muscular activity of the uterus causing increased pressure in the amniotic fluid and uterine wall. Uterine muscles compress not only the fetus, but also blood vessels of the uterus. This evacuates blood from the uterine vessels, thereby inducing hypoxia.

At the final stage of labor, there is a danger of mechanical collapse of the umbilical cord. This is due to close mechanical contact between the fetus and the labor pathways. As the fetus moves towards the birth canal outlet, dry pressure on the fetus increases. The umbilical cord can be occasionally pressed against the walls of the labor pathway. This can lead to its mechanical compression and result in fetal hypoxia.

In physiological childbirth, the fetus is transported along the birth canal headfirst. Thus during birth, the head of the fetus comes first. The temperature of the head of the fetus is higher than ambient temperature (25-26°C), which causes rapid evaporation of fluid. As a result of evaporation, the temperature of the fetus' head decreases. The rate of the temperature decrease depends on the intensity of blood circulation in the fetus' head and brain. The dynamics of the head skin temperature depends on the oxygen supply to brain tissues. Local fetal head temperature can be monitored using the IR thermal vision method [9, 10, 12, 17]. This method is contactless and valid at a distance of 1-2 m. In addition, this method of fetal head temperature monitoring is virtually instantaneous.

Fetal head skin temperature dynamics was tested in 35 women (pregnancy weeks 37-41) in labor at the stage of labor pains in Maternity House No. 6, Izhevsk, 2012. Preliminary ultrasonic testing of the health state of the women and fetuses was determined before childbirth. The tests were performed using ultrasonic scanners ALOKA SSD – ALPHA 10 and Medison SonoAce-600-C and standard probes of convex type with frequency 3-7 MHz using a conventional method [3]. The pregnant women were tested for fetal hypoxia using the Haussknecht method [4].

In 20 pregnant women the fetuses were found to be tolerant to hypoxia at 30-32 weeks (Haussknecht test was >30 sec). In 15 pregnant women the fetuses exhibited low tolerance to hypoxia (Haussknecht test was <10 sec). In addition, in one pregnant woman coiling of the cord around the fetus' neck and chest was observed.

The research design of this work was approved by the Izhevsk State Medical Academy. The principles of the Helsinki Declaration were taken into account [24].

IR thermometry was implemented in the TH91XX (NEC, USA) thermal vision meter. Ambient temperature was maintained within the range 24-26°C.

The temperature of the thermal vision screen was maintained within the range 26-36°C. The distance between the thermal vision meter and the pregnant woman was 1.5-2.0 m. The area of interest was exposed to vision. The IR pattern was fixed first. Local temperature of the mother was determined. The initial temperature was regarded as the basic temperature of the fetus.

The local fetal temperature dynamics was monitored throughout the labor. Mean temperature, standard deviation, and threshold values of 34, 32, 30, 29, and 25°C were determined as recommended in the literature [19]. Local temperature of the fetus' cranium was also monitored [25]. Skin temperature was averaged over five neighboring zones. The test results were processed using the Thermography Explorer and Image Processor software.

All of the neonates were examined by skilled physicians and subjected to laboratory assay.

Test results were statistically processed using STATISTICA 6.0 software on a LG LW65-P797 personal computer. Statistical confidence was monitored using the Student *t*-test criteria.

Results

In our opinion, fetal health should be estimated using digital parameters and stored in a document accessible for 18 years after childbirth. In our study, this function was implemented in digital IR vision records. Fetal cerebral temperature is most informative for this purpose because the cortex has the highest intensity of oxygen metabolism and emits sufficient amounts of heat to the skin covering the skull fissures.

The results of IR vision monitoring provide information about fetal head temperature. Head skin temperature during labor is from 27.5 to 36.1°C. In 20 children tolerant to hypoxia, the temperature was from 36.1 to 33.9°C, while in 15 children intolerant to hypoxia it was from 35.1 to 27.5°C. The lowest temperature was

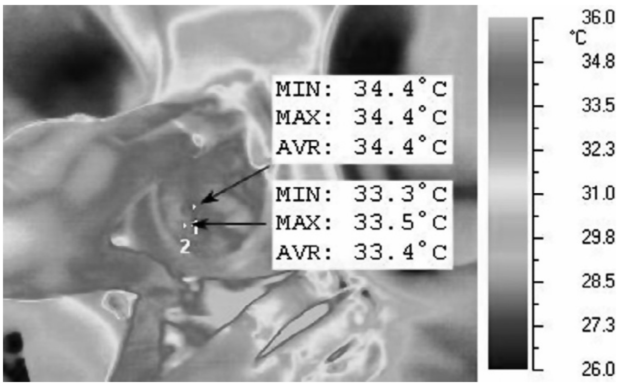

Fig. 1. IR image of fetal head for maternal patient P. Local temperature at central fissure (1) and parietal bone (2) is indicated.

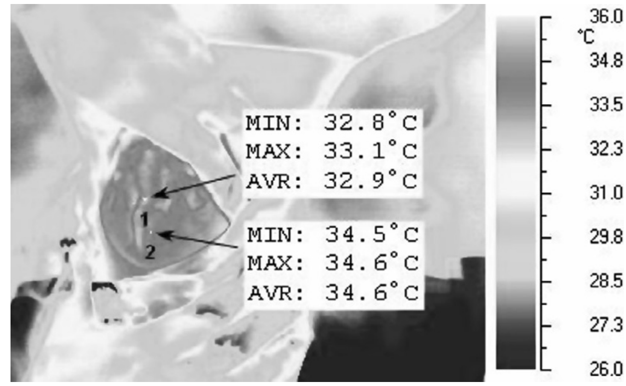

Fig. 2. IR image of fetal head in maternal patient B. 30 sec after the end stage of labor. Temperature at central fissure (1) and parietal bone (2) is indicated.

observed in five children with hypoxia and born in meconial water.

The normal fetal head is visualized as yellow–orange–red pattern with local hyperthermia (from 0.5 to 4.0°C above surrounding temperature). This segment is located above the central fissure between the parietal bones (Fig. 1).

In the absence of fetal hypoxia, the fontanel temperature is on average 2.8 ± 0.21°C ($P \leqslant 0.05$, $n = 20$) greater than cranium skin temperature. In the case of heavy hypoxia, the fontanel temperature is on average only 1.5°C greater than in the absence of hypoxia (Table 1).

In five neonates with hypoxia and born in meconial water, modified dynamics of cranium skin temperature was observed. This effect was present for 30-120 sec, whereas skin temperature above the central fissure decreased, thereby providing local hypothermia (Figs. 2 and 3).

Immobile position of the fetus in the birth canal induced local hypothermia in the fetus' head above the fissure, whereas spontaneous labor induced (in 2-3 sec) a temperature increase observed in five mothers. Skin temperature was equal to the temperature of neighboring areas (or, in some cases, higher).

In addition, the information value of the thermal vision records was demonstrated during the initial period after childbirth. For instance, neonate temperature during hypoxia was 32.2 ± 0.08°C ($P \leqslant 0.05$, $n = 5$), while after 5 min of artificial ventilation it was 34.15 ± 0.09°C ($P \leqslant 0.05$, $n = 5$). In addition, neonatal hypoxia caused local hypothermia in the fingertips. This effect was observed together with blue skin. The nose was the coldest place on the neonate's body. The nose temperature was 30.85 ± 0.15°C ($P \leqslant 0.05$, $n = 5$). One neonate demonstrated local hypothermia in the nasolabial triangle (Fig. 4).

TABLE 1. Local Temperature (°C) in Area of Frontal Bone Projection and Same Value 5 min after Birth in Norm and Hypoxia

Moment of head emergence		Before cutting of funiculus		5 min after childbirth	
At frontal bone	At fontanel	At frontal bone	At fontanel	At frontal bone	At fontanel
Group of 20 healthy neonates					
34.4 ± 0.07	34.7 ± 0.08*	33.9 ± 0.07*	34.0 ± 0.08*	34.2 ± 0.09*	34.2 ± 0.08*
Group of 15 neonates with hypoxia					
34.4 ± 0.08	32.9 ± 0.10*	33.8 ± 0.09*	34.0 ± 0.07*	34.3 ± 0.09	34.3 ± 0.09

* Confidence level at $P < 0.05$, $n = 15$ and $n = 20$ relative to temperature in area of frontal bone projection in norm.

a b

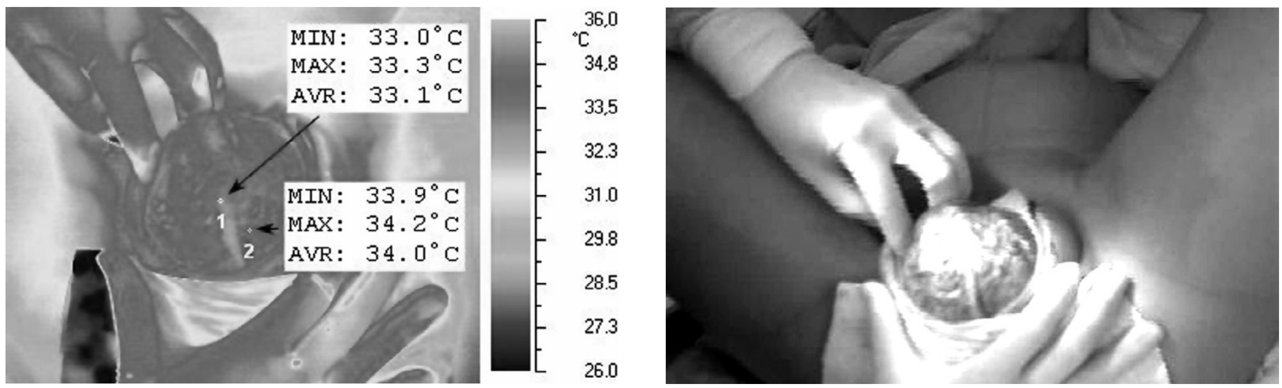

Fig. 3. IR image of fetal head in maternal patient S. 30 sec after the end stage of labor in IR (a) and visible (b) spectral ranges. Local temperature at central fissure (1) and parietal bone (2) is indicated.

We analyzed health state of the neonates at the first week after birth. Among 20 neonates with high tolerance to hypoxia before birth and absence of local hypothermia of the skin of the head at the site of the fissure projection during labor, only one was found to have cerebral ischemia I. On the other hand, 5 of 15 neonates with intrauterine hypoxia and local hypothermia of skin at the site of the fissure projection demonstrated cerebral ischemia I and II. The five neonates were born in meconial water with acrocyanosis.

Therefore, IR thermal vision of neonatal head skin after labor and thermal vision of the neonate's body provide an informative approach to health monitoring and quality control of obstetric care.

Fig. 4. IR image of neonate's face 30 min after birth accompanied by hypoxia.

Conclusion

Thermal IR vision provides real-time monitoring of labor and dynamics of local body temperature of the neonate that is insensitive to acoustical, mechanical, and electrical noise caused by sudden muscular contractions and electrical biopotential variation. This method also provides monitoring of temperature difference between the head skin segments. Such monitoring provides timely diagnosis of sudden occurrences of intrauterine hypoxia and determines the duration of the disease. This also provides prognosis of neonatal encephalopathy.

IR thermography provides contactless monitoring of the neonate's head temperature, thereby providing real-time quality control of obstetric care during labor. The zone of local hypothermia above the fontanel can be regarded as evidence of oxygen deficiency and intrauterine hypoxia. In the case of normal labor and the absence of intrauterine hypoxia, the head skin temperature above the fissure should not be lower than the temperature of the adjacent areas. Local hypothermia above the fissure and/or fontanels is evidence of insufficient supply to the brain of arterial blood and oxygen, i.e. hypoxia. Long-term local hypothermia increases the danger of neonatal encephalopathy.

Thus, IR thermography of the neonate's head during labor provides an new method of labor monitoring and obstetric care quality control. During the final stage of labor, this method provides safe diagnosis of intrauterine hypoxia and degree of its danger to the neonate's brain, and provides for correction of obstetric care. There is a prospect for the use of this method worldwide leading to a decrease in the neonatal mortality and neonatal encephalopathy.

IR thermal vision record and photographs of the fetus can be stored in digital form on a USB flashcard.

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