Temperature and blood rheology in fingertips as signs of adaptation to acute hypoxia

A Urakov¹,², N Urakova¹, A Kasatkin¹, V Dementyev²

¹Department of General and Clinical Pharmacology, Izhevsk State Medical Academy, Izhevsk, Russia
²Department of Thermal Deformation Processes, Institute of Mechanics, Ural branch of RAS, Izhevsk, Russia

E-mail: urakoval@live.ru

Abstract. It is found that the absolute values of temperature and color infrared image of the fingers and palms in healthy volunteers and in patients with hemorrhagic shock are in the same range, so they don’t represent precisely their condition. It turned out that what really matters is the dynamics of temperature and color infrared image of the palms after cuff occlusion test. In healthy volunteers and in patients with high resistance to shock, there is a rise in temperature and change in color from blue to red in the infrared image of the fingers and palms for 1 - 1.5 minutes after elimination of ischemia, but in patients with low resistance to shock there is a decrease in temperature and expansion of blue color in the palm surface in the infrared image. On the other hand, to assess the resistance to hypoxia in a fetus inside a mother's womb it is proposed to determine the duration of the period of the fetus stationary state during apnea period in pregnant women by using ultrasonography or during period of uterus tonic contractions during childbirth. We found that if fetus has high resistance to hypoxia, the duration of stationary state during the apnea or uterus contraction is greater than 20 seconds, and after exhaustion of reserves for adaptation to hypoxia it approaches zero. It is shown that growing hypoxia causes decrease in the local temperature of the central area of the skull and vice versa.

1. Introduction

It is very difficult to diagnose the beginning of hemorrhagic shock and recovery from it in each patient based on generally accepted ideas about the danger of massive blood loss and the body response to it. Nevertheless, the concept of hemorrhagic shock can be significantly changed today. In this regard, we propose the following amendments:

1. Clinical manifestations of effects of massive blood loss and their dynamics are individual for each patient.
2. The same amount of blood loss results in different response in different patients depending on many internal and external factors.
3. Hemorrhagic shock is a condition that people inherited from warm-blooded animals that developed it in the process of evolution as a defense (adaptive) mechanism aimed at preserving life after blood loss.
4. Massive blood loss and hemorrhagic shock are not the direct causes of biological death in warm-blooded animals and humans.
5. Hypoxic brain injury is the immediate cause of death in all patients regardless the cause of circulatory arrest.
6. Maintaining sufficient reserves for adaptation to hypoxia is a measure for favorable recovery from blood loss and protective role of hemorrhagic shock at any stage of its development.
7. The results obtained from diagnostic test for the patient’s reserves for adaptation to hypoxia, can greatly improve the forecast accuracy concerning blood loss danger, hemorrhagic shock diagnosis and successful recovery.

To test predictive validity of finger temperature for survival in adult patients with hemorrhagic shock, we conducted a research to study the dynamics of fingers and hands temperature by means of infrared thermography. At the same time we studied the dynamics of the local temperature of fingers pads in healthy adults during voluntary apnea and cuff occlusion test. Along with this, we studied the dynamics of the rib cage and fins activity in aquarium fish with acute hypoxia and monitored the dynamics of the motor activity of the chest and limbs in adults and fetuses in the mother’s womb. We also monitored the local temperature of fetal head during labor using infrared thermography.

As a result, we have developed new functional tests that have been tested in a pilot clinical trial [1-7]. We showed the importance of infrared technology for the detection of ischemia, hypoxia and hypoxic damage to the cerebral cortex in a number of scientific reports and academic articles. In this research we studied the relationship between the duration of ischemia and hypoxia of organs and tissues and their local temperature [8]. We were able to find out that the use of infrared thermography and ultrasound improves the diagnostic accuracy. Besides, well-timed application of new functional testing provides information about the patients’ resistance to hypoxia and hemorrhagic shock, improves forecast accuracy, facilitates evaluation of the degree of hypoxic damage to the cerebral cortex, and enables the detection of vital signs during clinical death with the possibility of surviving and the treatment effectiveness assessment [9, 10].

2. Materials and methods
We studied blood rheology in 24 adults healthy volunteers, 5 blood donors, in 35 patients diagnosed with traumatic hemorrhagic shock. Blood rheology was studied through visual observations in vivo (inside peripheral vessels) by ultrasonic and infrared thermography before and after voluntary apnea, cuff occlusion test and blood donation 400 ml. In the period from 2009 to 2015 we studied the dynamics of local temperature of body surface using infrared thermal images in healthy adult volunteers, pregnant women, women in labor, babies during delivery, newborns immediately after birth, in adult blood donors after 400 ml of blood loss and in adult patients after massive blood loss.

Dynamics of local body temperature in adult volunteers was studied prior to, during and after voluntary apnea lasting from 15 to 90 seconds in 10 healthy volunteers (Group 1); after 2 minutes of provocative ischemia in the right hand (shortened cuff occlusion test) in 14 healthy volunteers (group 2); in 5 blood donors after 400 ml of blood loss (group 3); and in 35 patients diagnosed with traumatic hemorrhagic shock who were treated at the anesthesiology and intensive care department (group 4). Hemorrhagic shock was classified with the use of ATLS system. In order to induce ischemia, a cuff was placed on the arm and inflated to a pressure 30 mmHg above systolic blood pressure; this pressure was held for 2 minutes. Occlusion was performed within 3 hours after the patient’s admission to intensive care. The infrared thermal images of the palm and fingers surface were recorded prior to, during and after the occlusion test with a time interval of 30 seconds.

At the same time we studied the dynamics of local temperature in hands in 10 healthy volunteers prior to and 30 minutes after cold test application. The cold test implied that the hand was immersed in melting snow water for 2 minutes. In the first series of observations, study was conducted in sober volunteers. In the second series of observations, study was conducted in the same volunteers, but in 30 minutes after they took 40° ethyl alcohol solution at a dose of 0.4 g/kg body weight (Russian vodka “Stolychnaya”) on an empty stomach.
Another series of observations were carried out in pregnant women in their 20-24 and 30-34 weeks of pregnancy in women's clinics. We studied the dynamics of the local temperature in pregnant women fingers during voluntary apnea, which lasted from 15 to 30 seconds. At the same time, we also examined the motor activity and radiation properties of fingertips of the fetuses in mothers’ wombs. The dynamics of the women fingers temperature was studied using a thermal imaging camera, while the dynamics of fetal movement and his fingers radiation properties was studied using ultrasound investigation. In the study, 100 pregnant women had normal pregnancy (control group) and the other 25 pregnant women (study group) had signs of placental insufficiency of 1B degree. Later, 35 of 125 women were admitted to maternity hospitals in their 37 - 41 weeks of pregnancy for term labor. The dynamics of the local temperature of the fetal head skin during labor and the newborns body temperature after birth was studied by means of thermal imaging device.

Ultrasound examination of pregnant women and fetuses was performed by means of ALOKA SSD - ALPHA 10, Medison SonoAce-600-C, which is the expert class medical device, and standard convex sensors with the frequency of 3–7 MHz [1,3,6]. After completing the standard ultrasound examination, and taking voluntary informed consent from a pregnant woman, apnea test was applied using M.Yu. Gauskneht method for assessing the fetus resistance to fetal hypoxia [1].

Local skin temperature changes were documented with photographs. Infrared monitoring of hands temperature was performed by using ThermoTracer TH9100XX (NEC, USA) thermal imager. Ambient temperature of the examination room was 24 - 25°C, the temperature window of the thermal camera was set to the range of 25 to 36°C. The obtained data were processed using the Thermography Explorer and Image Processor software. A region of interest was defined over the entire hand using the outline of the hand to separate the hand temperature from the background. From this region of interest, we determined the mean temperature, standard deviation and distribution of isotherms at the thresholds of 34, 32, 30, 29 and 25°C. In addition, spot temperatures of the finger tips were measured. Mean finger temperature was calculated by averaging the finger tips temperature of the 2nd to the 5th finger. The thumb was excluded from temperature measurements as it usually carried a pulsometer.

At the same time, we studied the dynamics of fins color, motor activity and lifetime in aquarium fish, including 150 blue tetras and 150 guppies with acute hypoxia. In addition, their defecation time, water color change, and water clarity were recorded. Acute hypoxia was achieved by placing the fish in water inside a sealed container at a certain temperature without access of air. Before the beginning of the research, its protocol was approved by the Ethics Committee of Izhevsk State Medical Academy, based on the principles set in the Declaration of Helsinki of the World Health Organization. All volunteers signed an informed consent for voluntarily participation in the study.

3. Results
As no similar studies had been carried out before, we had high hopes that the monitoring of the motor activity and the local temperature of the peripheral parts of the body would arm us with new information that would allow to develop methods for evaluating the patients’ resistance to the effects of acute massive blood loss, and increase the accuracy of diagnosis and forecasts. To check these assumptions, we conducted initial experiments with aquarium guppies and blue tetras. In order to identify the patterns we simulated acute and potentially fatal hypoxia resulting in aquarium fish death. The research was carried out at different temperatures. In several series of experiments, we investigated the dynamics of fish motor activity continuing until its biological death. We also measured their life duration after cutting off air supply to water in which they were held. At the same time we studied the dynamics of fetal movement inside pregnant women wombs during voluntary apnea. Studies were conducted by means of ultrasound examination in pregnant women in their 20-24 and 30-34 weeks of pregnancy.

The results revealed the perfect analogy between the dynamics of motor activity in fish and fetuses under the conditions of acute hypoxia; they also made it possible to find out diagnostic symptoms of the exhaustion of their reserves for adaptation to hypoxia. In particular, it appears that when cutting off air supply to water with fish and to the respiratory system of pregnant women during their voluntary
apnea, chaotic motor activity of fish and fetuses in the mothers’ wombs is followed by a period of complete and continuous immobility. Our results showed that if fish and fetuses have sufficient reserves for adaptation to hypoxia, their bodies remain still for a longer period of time than in fish and fetuses with insufficient reserves for adaptation to hypoxia. Besides, we found out that when the reserves for adaptation to acute hypoxia are exhausted, both fish and fetuses suddenly increase their motor activity, which is manifested as follows. Fish spread out its pectoral fins, and its oscillating fins movement becomes more frequent and increased to the maximum, its mouth is widely open, and there is also quickening and increase in ventilating movement of gill arches. Fetuses spread their arms away from the body, unclench their fists, straighten their fingers, and demonstrate sudden chest rise.

In addition, in experiments with fish, we found out that as soon as the reserves for adaptation to hypoxia were depleted, the fins color changed. To explain this phenomenon, we assumed that the color of the fish fins during hypoxia changes because of the changes in its blood color. The matter is that in normal conditions the blood which is delivered to the fins is oxygenated, but under the conditions of lack of oxygen and after the reserves for adaptation to hypoxia are exhausted the blood, which is delivered to fins, lacks oxygen. At the same time, the blood enriched with oxygen is bright red and the blood which lacks oxygen is dark cherry red. The dependence of fish fin color on oxygen level in its blood was demonstrated by experimental results which were obtained while introduction of hydrogen peroxide in water with fish. It showed that the introduction of hydrogen peroxide in water with fish after they have exhausted its reserves for adaptation to hypoxia restores its fins color, prevents heavy motor activity and prolongs fish survival under the conditions of total lack of oxygen in water [67]. In addition, we carried out laboratory experiments studying dynamics of color and ultrasound echogenicity of preserved donor blood. It was shown that introduction of hydrogen peroxide solution into donor venous blood enriched it with oxygen and, in fact, turned it into arterial blood. The blood lost its dark cherry color and became bright red. At the same time the ultrasound echogenicity of the blood was increased.

Based on these data, we assumed that a similar change in the color of blood and hands soft tissues might be observed in fetuses with intrauterine hypoxia. In consequence, fetuses’ skin color and ultrasound echogenicity of their fingers soft tissue might be changed. Since today there are no safe methods for studying the dynamics of color of fetus fingers skin inside his mother’s womb, we decided to investigate fetuses’ fingers using ultrasound examination. For this purpose the ultrasound examination was done using conventional transabdominal techniques. Ultrasound echogenicity of fingers was studied during voluntary apnea in pregnant women in the second half of pregnancy and during pushing contractions in women in the last stage of labor. Our results showed that in normal conditions fetuses are highly resistant to intrauterine hypoxia and can easily withstand a period of voluntary apnea in pregnant women and pushing contractions in labor for 20 seconds. At the same time their fingertips preserve stable ultrasound echogenicity. In particular, in pregnancy the fetuses don’t move during apnea, their fingers are clenched into fists, and their fingertips preserve stable ultrasound echogenicity.

However, in case of low fetal resistance to intrauterine hypoxia which might be caused by placental insufficiency, fetuses don’t remain calm during voluntary apnea period in pregnant women or the pushing contractions period in labor. In particular, in 5 - 10 seconds after the beginning of apnea period in pregnant women or pushing contractions in women in labor, fetuses started to make breathing movements with their chest and hands; they unclenched their fists and straightened their fingers. At the same time fetuses demonstrated a reduction in ultrasound echogenicity in their fingers pads. Moreover, in several seconds after terminating apnea in pregnant women and pushing contractions in labor, ultrasound echogenicity in fetal fingers pads became normal.

These results allowed us to assume that during hypoxia, some fetuses with low resistance to hypoxia might demonstrate the increase in the reduced haemoglobin in blood up to very high levels. In its turn, it might cause acrocyanosis in fetus’ fingers and become the reason of the heat emission reduction in his fingertips. Moreover, the temperature drop in fingertips might be not just an effect from hypoxia, but also a way to adapt to it. The matter is that the survival of biological objects under acute hypoxia
might be increased by means of hypothermia. The protective effect of cold in hypoxia was proved by experimental results in such cold-blooded animals as fish. It appeared that the life duration in fish after cutting off the air supply to water was more than 2 times longer when the temperature of water was 15°C than when this temperature was 25°C.

Following this, we assumed that local hypothermia may naturally occur in a human fetus after he is expelled out of the mother’s womb. When the baby comes out head first, it is his head that might be the first part of the body to be cooled by the surrounding air. To check this assumption, we studied the dynamics of the local temperature of fetal heads after their passing through the birth canals. The results showed that initially the fetal head had the same temperature as his mother’s body, regardless of his resistance to hypoxia. But later the temperature of the fetal head surface started to decrease. The longer the fetal head was exposed to the surrounding air at room temperature, the lower the temperature was.

At the same time we found out that in normal conditions the head of live fetus was displayed by thermal imager mainly in the yellow, orange and red colors, and an area of local hyperthermia might be observed on the top of the fetal head. The temperature in this area might be 0.5 - 4.0°C more than the temperature of the areas close to it. It is shown that the local hyperthermia area is located above the central suture or frontal fontanel of the skull. If located above the central suture of the skull, the hyperthermia area has oblong shape. In case of complications of pregnancy and labor, and, in particular, when the fetus’ resistance to intrauterine hypoxia is extremely low, the head of a live fetus is displayed on the thermal imager screen in the yellow, orange, and red colors as well, but in some fetal heads a local hypothermia area can be observed. In particular, the newborns with severe hypoxic damage, who were born in meconium-stained amniotic fluid, had areas of local hypothermia over central suture or frontal fontanel of the skull. At the same time the area of local hypothermia over central suture had an elongated.

At the same time we studied the dynamics of the local temperature and ultrasound echogenicity in fingers’ pads in healthy adult volunteers and pregnant women using special functional tests, and in adult patients of both sexes with conditions including acute massive blood loss. The results showed that the dynamics of radiation properties of fingers’ pads reflected the body response (adaptive capacity) to acute ischemia, acute hypoxia and massive blood loss, so it can be used to diagnose the patients’ condition. The results also reveal that infrared thermography, which is done by means of a thermal imaging camera, provides a non-invasive monitoring of the fingers’ pads local temperature and can be considered as an independent method for diagnosing the condition of trauma patients’ with massive blood loss and acute hypoxia.

The results showed that the infrared and ultrasonic monitoring of the radiation properties of fingers’ pads in adults provided urgent information about their body response to the apnea and the compression of the blood vessels in the arm. We found out that in 12 - 15 seconds after the cessation of breathing or blood supply to the hands, the local temperature in fingers’ pads begins to decrease. After that, if the period of ischemia is prolonged by more than 2 times, ultrasound echogenicity in fingers’ pads begins to decrease. In addition, the decrease in local temperature is directly proportional to the duration of ischemia period, and the area of decreased temperature extends proximally.

Consequently, infrared thermography, which is done by using a thermal imaging camera, is more sensitive and much more informative compared to the ultrasound examination of the fingers’ pads echogenicity. Since infrared thermography done by using a thermal imaging camera is safer than the ultrasound examination, further studies of the radiation properties of fingers were conducted only by using a thermal imaging camera. We carried out a series of observations of the dynamics of local temperature in the fingers of healthy adult male volunteers during acute ischemia in their arms caused by compression of blood vessels by applying a tourniquet to their upper arms. The results show that after compression of the vessels, local temperature in the fingertips drops very quickly in all fingers except the thumb. The process of local decrease in temperature in fingers starts with the decrease in temperature in their pads. In particular, a decrease in local temperature by more than 0.1°C in the finger pads was observed within 12 seconds after applying the tourniquet in different men.
It is shown that extending the ischemia period results in a decrease in temperature, at the same time the area of hypothermia increases in each of the 4 fingers, spreading from their tips towards the palm. Hence, the area of local hypothermia is always observed only in the fingertips at the beginning of ischemia period. It is noteworthy that first the decrease in temperature is observed in the pad of the longest finger. Since in most people the middle finger is the longest one, generally it is the middle finger pad that cools down first during ischemia. After that, if the ischemia period is prolonged, the area of local hypothermia can be observed in other fingers’ pads. The area of local hypothermia, which is initially localized in the fingertips, first spreads to the distal phalanges, and then (if the ischemia period continues) to the middle phalanges in 4 fingers. The thermal imaging camera displays the finger phalanges in which the temperature was decreased in blue, while phalanges where no temperature decrease was observed are displayed in yellow and orange colors.

It is important that after removing the tourniquet, the fingers’ areas with decreased temperature demonstrate temperature rise. The temperature in fingers returns to its initial values after 30 - 60 seconds. Later we could observe a steady increase in local temperature in all fingers and in the palm to the values greater than the initial ones. Moreover, an area of local hyperthermia was observed in each finger in the place of the local hypothermia area. We found out that in healthy men, the period of local temperature rise in fingers and palm, observed in 2 minutes after applying the tourniquet to the upper arm, lasted about 5 minutes after its removal. The same dynamics of local temperature in fingers was observed when applying the tourniquet to the upper arm in pregnant women. Later, a series of observations of the local temperature dynamics in fingers was carried out in healthy adult male volunteers and pregnant women during voluntary breath holding. The results showed that apnea, as well as compression of blood vessels resulted in common dynamics of temperature decrease in fingers.

In particular, a decrease of more than 0.1°C in local temperature of fingerpads was observed in a group of healthy pregnant women in 13 seconds after beginning voluntary apnea, and in the group of healthy male volunteers in 15 seconds after it. Concurrently, the images of 4 fingers’ pads (except the thumb pad) in the thermal imaging camera changed their colors from yellow and orange to blue. The other areas of the fingers, as well as the palm and forearm in both men and women remained colored.

After the restoration of breathing, the local temperature in fingers increased in all men and women involved in the study. The temperature in the area of local hypothermia in each finger returned to initial values in 15 - 30 seconds after the restoration of breathing. In the subsequent period of time, the temperature in all the fingers and palm increased to the values greater than the initial ones. The period of local hyperthermia in fingers lasted for about 3 minutes in healthy men and women, after that the temperature in fingers and palms became normal.

These results confirmed our assumption that, all other things being equal, the occurrence of local hypothermia in the distal phalanges of the fingers might be a symptom of not only hypoxia and ischemia, but also of lack of blood in the body, caused by exsanguination, and in particular, by massive blood loss. Now we had to find an explanation for the reason for local temperature decrease in fingers during hypoxia. First we have found the answer to the question of why the compression of blood vessels in the upper arm causes temperature decrease in the fingertips. The matter is that the exposed hands are surrounded by air at a temperature of 25°C. Therefore, a part of the hands heat is continually going into the air. In these circumstances, fingers and palms can only stay warm if they are continuously warmed up. Here, warm blood is a natural heat transport fluid. That is why compression of the blood vessels in the upper arm stops the delivery of warm blood to the hands, and in these conditions they begin to cool down. Along with this, in accordance to the laws of physics, temperature decrease starts from the peripheral areas of the hands.

It was more difficult to answer the question of why the dynamics of temperature decrease in fingers observed as a result of cessation of breathing, was the same as in case of compression of the blood vessels in hands. To answer this question, we referred to the common idea that the cessation of breathing reduces the oxygen level in blood and increases the carbon dioxide concentration. This, in turn, excites specific chemoreceptors in the central nervous system. Excitation of chemoreceptors can reflexively trigger a general protective and adaptive body response aimed at preventing the brain
hypoxia. Reflex spasm of blood vessels in the peripheral parts of the body might be a part of complex adaptive changes, as the body redistributes arterial blood to the benefit of heart and brain. Moreover, reducing blood delivery to hands and other peripheral parts of the body might play a protective role, especially for the brain. Exposed hands continuously radiate the heat to the outside, so reducing the blood delivery to them at an air temperature of 25°C results in their cooling. Here, the temperature decrease begins with the fingers' pads. Consequently, the temperature decrease in fingers observed during apnea is a result of a reflex spasm of blood vessels. Thus, local cooling of fingers' pads may be a diagnostic symptom of the organism response to hypoxia, namely, the ability of the body to cause a reflex spasm of blood vessels in the peripheral parts of the body.

In order to check this assumption, we decided to find out whether the reflex spasm of blood vessels plays a key role in the occurrence of local hypothermia in the fingertips. To simulate the reflex spasm of blood vessels in the fingers we used cold test. In order to reduce the reflexive effect of cold on the muscle tone of blood vessels, we used a food product with a general anesthetic effect, namely, “Stolichnaya” vodka (an ethanol solution with 40% of ethanol). The dynamics of the local temperature in fingers after the cold test was observed in 10 healthy adult male volunteers in normal conditions and in 30 minutes after the intake of ethyl alcohol, at a dose causing mild alcoholic intoxication. The results showed that in normal conditions (in healthy sober men) cold test (immersing hands in cold water at a temperature of +3 - +4°C for 2 minutes) causes cold spasm of blood vessels, strong painfulness and prolonged local hypothermia in the distal finger phalanges. However, cold test does not cause cold spasm of blood vessels, painfulness and prolonged hypothermia in fingers in the same men under alcoholic intoxication (specifically, in 30 minutes after intake of ethyl alcohol at a dose of 0.4 g/kg on an empty stomach).

After that we studied the dynamics of local temperature in the hands during voluntary apnea and cuff occlusion test in the same volunteers under alcoholic intoxication. The results were really amazing! We found out that alcoholic intoxication postpones, slows down and reduces the local hypothermia in the fingers’ pads during apnea and in hands ischemia. Consequently, a spasm of blood vessels in the hands might occur reflexively as part of the body adaptation to hypoxia. Clinically, it can be observed as a decrease in local temperature in the fingers, if they are exposed and surrounded by air at a room temperature. Therefore, monitoring the dynamics of local temperature in the fingers, in the conditions when ambient temperature is below the body temperature, can be used for non-invasive diagnostics of the body response to hypoxia.

At this stage of the research, the study resulted in the following findings. In normal conditions (in healthy and sober volunteers) a sudden stop of lungs ventilation with breathing gas depletes peripheral parts of the body by means of reflex spasm of blood vessels. Avascularization of the peripheral parts of the body reduces the delivery of warm blood and oxygen, which are sent to vital organs instead. Therefore, reflex spasm of blood vessels in the peripheral parts of the body can be considered as a part of the universal protective and adaptive response of the body aimed at preserving arterial blood supply to the brain under the conditions of sudden decrease in oxygen reserves. This response may be observed as local cooling of the fingers. Therefore, local cooling in the fingertips observed during apnea can be considered as a diagnostic symptom of the organism response to acute hypoxia. We assumed further that the protective mechanism that triggered a spasm of blood vessels in the peripheral parts of the body would be universal. The body activates it not only during apnea and ischemia, but also in any other acute critical conditions that might cause hypoxic brain damage. Therefore, acute massive blood loss might trigger this protective response in healthy and sober people.

To check this assumption, we studied the dynamics of the local temperature in the hands of blood donors while collecting venous blood and during 70 minutes after it. The observations were performed during regular donation of 400 mL venous blood in 5 healthy male donors by using a thermal imaging camera. Donors were in the supine position during the entire period of collecting the blood. Blood collection took 10 – 15 minutes. After donating, the donors were kept in the supine position for 15 minutes more. After that, donors stood up and walked or stayed in the sitting or standing position. In other words, their body was held in an upright position.
Our observations showed that the dynamics of the local temperature in the fingertips during the blood collection from the donors was similar to the dynamics of the temperature decrease in fingertips during apnea and cuff occlusion test in healthy and sober volunteers. However, after the blood loss, the fingers’ pads of the donors remained cold for a long period of time, while the fingers’ pads of the adult volunteers after apnea and ischemia became warm very quickly. In particular, we found that the temperature in all fingers’ pads of the right hand in all donors was decreased by more than 0.1 °C after taking approximately 100 ml of blood from the vein (the blood volume which is usually taken in 2-4 minutes after the introduction of the injection needle into the cubital vein of the left hand). Then, in all donors, the temperature in each distal phalanx of the right hand was progressively decreasing together with the increase in the volume of blood drawn from the vein of the left hand. At the same time, the area of local hypothermia was increasing in each fingertip. This increased cooling of fingertips and an increase in local hypothermia areas was observed until 400 ml of blood was drawn from veins.

Later, after the bleeding had stopped, the local temperature, shape, location and size of the local hypothermia area in the fingertips of the right hand remained essentially unchanged for over 60-minute observation period. We observed the dynamics of the local temperature and the size of local hypothermia area in the donors’ fingers up to the moment when 400 ml of blood was drawn and the bleeding stopped. We analyzed the results and found out that in the final stage of blood collection, local hypothermia in the fingertips increased by 1.0 – 1.5 °C, and the size of the hypothermia area in the distal phalanges increased by more than 3 times. However, we continued observing the temperature in the donors’ fingers. Within 60 minutes after the loss of 400 ml of venous blood by each donor, we studied the dynamics of local temperature in the fingers of their right hand during and after the application of shortened cuff occlusion test (occlusion 2 minutes). The results showed that in 1 hour after the 400 ml blood loss, cuff occlusion test resulted in the same dynamics of local temperature in the fingers, as in normal conditions (i.e. prior to the blood loss) in healthy volunteers.

In particular, we found that in 11 - 12 seconds after we started applying the shortened cuff occlusion test, further drop of more than 0.1 °C was observed in the decreased temperature in the fingers’ pads in each donor. At the same time the local hypothermia area in the distal phalanges of the fingers extended. After the cuff occlusion test the dynamics of the temperature in fingers’ pads was diverse: immediately after the cuff occlusion test the temperature rose, and within 1 minute became greater than its initial value (before the cuff occlusion test), then it remained at this level for about 3 - 5 minutes, and then finally returned to its initial value. Thus, an acute blood loss of more than 100 ml triggers an organism’s protective and adaptive response aimed at preserving arterial blood supply to the brain in sober and healthy adult subjects. The fingers are among the first body parts to respond to this signal that triggers a reflex spasm of blood vessels, reduces warm arterial blood delivery and basically causes ischemia and hypothermia of fingers. At a room temperature, reduced delivery of warm blood to the exposed fingers is observed as common dynamics of the decrease in the local temperature in fingers’ pads and distal phalanges. At the same time a local hypothermia area is formed in each finger pad, and after the blood loss it is preserved for more than 1 hour. After observing the donors we found that acute blood loss changed the dynamics of the heat radiation in the fingers’ pads; and infrared monitoring of local temperature performed by using thermal imaging camera provided this information in real time. But that was not our most important discovery. What is more important is that the use of thermal imaging camera and shortened cuff occlusion test allows us to detect the body’s additional reserves for adaptation to acute hypoxia! Using a thermal imaging camera made it easy to reveal them and assess the body’s resistance to hypoxia!

It turned out to be quite simple in reality: after acute but harmless blood loss the availability of unused reserves for adaptation to acute hypoxia is manifested by the following changes in the local temperature in the hands: at the end of the shortened cuff occlusion test we can observe the further drop of the temperature in the cooled fingers’ pads and the increase in the local hypothermia area in the distal phalanges. On the contrary, after the cessation of ischemia, the temperature in the fingertips increases, and the size of the local hypothermia areas in the fingers’ distal phalanges decreases.
After that, we had to detect the lack of reserves for adaptation to hypoxia in trauma patients with acute massive blood loss.

To complete this task, we observed the dynamics of the local temperature in the hands in 35 patients admitted to the hospital with traumatic hemorrhagic shock (average patients’ age was 46 ± 11 years). According to ATLS, 10 patients’ condition was classified as II class haemorrhage, 22 patients’ condition was classified as III class haemorrhage, and the condition of 3 patients was classified as IV class haemorrhage. All patients were provided with medical treatment in accordance with the recommendations. Along with this, surgical haemostasis was achieved in all patients. The results of infrared monitoring of the dynamics of the local temperature in fingers showed that at the admission, the temperature of distal phalanges of the fingers was 3 - 6 °C less than the temperature of proximal phalanges and the palm in all 35 patients. Local temperature of the fingertips was in the range from 25°C to 29°C. In this case, the absolute values of the local temperature of the patients’ finger pads had no prognostic value, because such temperature values were occasionally observed in healthy people without blood loss as well. However, the values of the local temperature in the fingers’ pads observed in these same patients when using shortened cuff occlusion test were quite different.

The results of the observations showed that in 8 patients out of 10 with II class haemorrhage and in 1 patient out of 25 with III class haemorrhage the use of shortened cuff occlusion test caused diverse changes in the fingertips local temperature, which were typical for healthy subjects and blood donors (Figure 1). Therefore they were included in the group of patients who did not completely use their reserves for adaptation to acute hypoxia. That is why, all other things being equal, we predicted a higher probability of their recovery.

In other patients the use of shortened cuff occlusion test did not cause diverse changes in the local temperature in the fingers’ pads. Based on these data, we concluded that the body of these patients completely depleted its reserves for adaptation to acute hypoxia. That is why, all other things being equal, we predicted a low probability of their recovery. The results showed that after receiving treatment in the hospital, all 9 patients in whom the use of shortened cuff occlusion test resulted in diverse changes in local temperature in fingertips, survived. On the other hand, from 26 patients who had no evidence of adaptive response in their fingers when using shortened cuff occlusion test, only 22 patients survived. Thus, four patients died within 48 - 72 hours after admission to the hospital.

![Figure 1. Infrared image of the palmar surface of the right hand of the patient with hemorrhagic shock (L. Male, 28 years) at admission to the hospital (surviving patient):](image-url)
4. Conclusion
By using thermal imaging camera we found out that acute blood loss, as well as the voluntary apnea and cuff occlusion test, result in local hypothermia in the exposed fingers’ pads. At the same time, the increase in the volume of lost blood, as well as an increase in the duration of apnea and hand vessels occlusion, increases hypothermia and local hypothermia area in fingers, which is consistently expanding first to the entire distal phalanx, and then to the middle phalanx of each finger. Therefore, growing local hypothermia and expansion of its area in fingers, detected by a thermal imaging camera, are suggested to use as a diagnostic symptom for increased hypoxia, all other conditions being equal.

It was found that local hypothermia was observed in blood donors’ finger pads after a 400 ml blood loss, and it was preserved for more than 1 hour later. The use of shortened cuff occlusion test after collecting blood from donors first facilitates hypothermia, and then results in postocclusive hyperthermia in their fingers. The similar diverse changes in the local temperature in fingers are observed in healthy people after breathing restoration in 0.5 - 2 minutes after apnea, and after recovery of blood supply to hands when using shortened cuff occlusion test. At the same time, we have shown that in patients with acute massive IV class haemorrhage (30 - 40% of blood loss) the use of shortened cuff occlusion test does not change the dynamics of progressively growing and expanding local cooling in fingers. Therefore, diverse changes in local temperature in exposed fingers detected by a thermal imaging camera after the use of shortened cuff occlusion test (i.e. decrease in the local temperature at the beginning and its increase later) are suggested to be considered as a diagnostic symptom of availability of reserves for adaptation to hypoxia. This diverse change in local temperature in finger pads in a patient after acute massive blood loss allows us to conclude that he has sufficient reserves for adaptation to acute hypoxia and predict high probability of his survival.

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