INFRARED THERMOGRAPHY – COMPARISON OF INNER CANTHUS OF THE EYES AND FOREHEAD SURFACE TEMPERATURES IN HEALTHY ADULTS

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Abstract

Infrared thermography (IRT) is a non-invasive method for surface temperature measuring. The use of the contactless IRT method is comfortable for the patient, fast and hygienic. However, this method does not provide information about the core body temperature because the temperature is measured indirectly from the surface of the human body. There are several places on a human body from which surface temperature is commonly measured; the methods of measurement and application of the device is inconsistent. The aim of this article is to show the difference between the temperature measured on the forehead and on the inner corner of the eye in healthy persons, with reference to the recommendations of ISO standard. This is mainly due to the fact that compliance with the ISO standard is not always met, as shown by the personal experience of the authors. The body surface temperature was measured by use infrared camera WIC 640 under control of calibrated model of a black body. The data from 59 different volunteer subjects show statistically significant difference in measured temperature from both selected positions. The obtained median temperature values were 35.04 °C from forehead area and 35.85 °C from canthus of eyes. The observed difference was more than three-quarters of a degree Celsius for the median value. The maximum observed temperature difference within the observed group was almost 1.94 °C. The present study defines surface temperature from canthus of eye and undoubtedly shows how important it is to comply with the standards and recommendations of professional thermology societies.

Keywords

contactless thermography; forehead temperature; inner canthus of eye; surface temperature; temperature screening

Introduction

Infrared thermography (IRT) is a non-invasive method for measuring the surface temperature. Presented study focuses on measuring temperature of the human face with implications of using the tool for febrile screening [1]. The paper comes out from the ISO standard [2] and recommendations by team of experts from European Association of Thermology (EAT) [3] where the key point of IRT measuring is the area selection for purpose of the temperature recording. Both of the sources state the inner canthus of the eye as the only site on the face suitable for fever detection. Despite of this still the most used region for measuring is the forehead area. That fact does not pose a big problem when using IRT, as automatic highlighting of the maximum temperature can be set as one of the functions in most infrared cameras [4, 5]. A measurement error and therefore a false temperature value could be measured when using the infrared thermometer [6]. As shown the study of Hausfater, the temperature measured by infrared thermometer on the forehead doesn't correlate with tympanic temperature in patient with fever [7]. The question is what the difference and accuracy of results will be when using only the infrared thermometer with variable measuring area position without monitoring human core temperature by another temperature sensor. This is the case of most screening temperature control points implemented around the world (e.g. Vaccination Center, University Hospital Brno).

The aim of this article is to show the difference between the temperature measured on the forehead and on the inner corner of the eye in healthy persons, with reference to the recommendations of ISO standard and EAT. The study may be useful particularly in connection with the personal temperature screening process, for example for the detection of febrile diseases.

Based on physical principles of IRT, many quantities and parameters have to be taken into account during the

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measurement. IR cameras can detect infrared radiation emitted by an object and transform it into electronic signal [8]. Any object with temperature above absolute zero (-273.15 °C) emits infrared radiation. This radiation is formed by electromagnetic waves and belongs to electromagnetic spectrum, specifically into infrared (IR) spectral band which is defined by wavelength from approx. 0.8 μm to 1000 μm. The IR region is generally subdivided into narrower four bands [9].

The IRT detectors are most commonly sensitive in the bands from 3 μm to 15 μm, with the exception of the region between 5 μm and 7.5 μm which is related to the atmospheric absorption [10]. When the IR radiation hits an object it may be partially absorbed (described by an absorptivity α) and reflected (described by reflectivity ρ) by a body, or even pass through it (described by a transmissivity τ). These three parameters are wavelength-dependent. The sum of these three parameters must be one at any wavelength as stated in the first Kirchhoff´s law [11]:

$$\alpha + \varrho + \tau = 1 \qquad (1)$$

Materials in which the transmission and the reflection are zero are called black bodies. In such bodies all the incident IR radiation is absorbed by the body (α =1).

The law that allows calculating the amount of electromagnetic radiation ($W_{\lambda b}$) emitted by a black body into the hemisphere outside its surface, is the Planck´s law of radiation [12]:

$$W_{\lambda b} = \frac{C_1}{\lambda^5 \left(e^{\frac{C_2}{\lambda T}} - 1 \right)} \qquad (2)$$

where C_1 = 3.7413·10^{-16} (W·m^2) and C_2 = 1.4388·10^{-12} (K·m) are universal radiation constants, λ is the wavelength (m) and T is the absolute black body temperature (K). The result of the calculation is the power emitted per unit area per unit wavelength, which is a function of λ and T. The equation (2) defines an inverse relation between the temperature and the wavelength of the emission maximum. By differentiating the Planck's law equation with respect to λ the peak of radiation intensity at a given temperature in appropriate wavelength band can be determined by Wien´s law [10]:

$$\lambda_{peak} = \frac{2897.8}{T} \qquad (3)$$

The total hemispherical radiation intensity of a black body is obtained by the integration of Planck´s law through all wavelengths (λ from zero to infinity) and is called the Stefan-Boltzmann law [13]:

$$W_b = \sigma \cdot T^4 \qquad (4)$$

where σ is the Stefan–Boltzmann constant, which is equal to 5.6704·10^{-8} W·m^{-2}·K^4. It has to be stated that real objects almost never comply with the above-described laws even if they may approach the black body behavior in certain spectral bands and conditions. Real body generally emits only a part W_λ of the radiation emitted by a black body $W_{\lambda b}$ at the same temperature and wavelength. Therefore, the emissivity has to be introduced. It is the rate at which an object emits energy compared to that of a black body at a given temperature and wavelength. In the case of constant and wavelength-independent emissivity, the body is called grey body. Emissivity can be expressed as [12]:

$$\varepsilon_\lambda = \frac{W_\lambda}{W_{\lambda b}} \qquad (5)$$

To obtain the radiation intensity in the case of the grey body, emissivity needs to be substituted in the Stefan-Boltzmann law (6). Thus we obtain the equation for the grey body [12]:

$$W_b = \varepsilon \cdot \sigma \cdot T^4 \qquad (6)$$

Based on the Kirchhoff´s law, the value of the emissivity is one and reflectivity is zero for a black body. All radiation hitting a black body is absorbed and must be emitted consequently. The grey body emits only a fraction of thermal energy and the emissivity is always less than one and reflectivity greater than zero [12]. It has been shown that the emissivity of human skin is 0.98 and is independent of the wavelength and without difference between dark or white skin [14]. Therefore, human skin can be measured almost as a true black body when considering the clean and cover-free skin surface [15].

Measuring the temperature of objects using non-contact thermometers is generally a technically complex procedure, as shown by the simplified physical basis in the previous text. It is even more difficult to measure the temperature of the human body, and therefore the human core, when it is measured indirectly with the help of surface temperature. Another variable is added here, which is the choice of the position of the surface for the temperature measurement. As already mentioned, the aim of the study is to determine the value of the surface temperature on the forehead and inner canthus of the eyes position and to compare these with each other.

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Material and methods

Faces of 59 different volunteer subjects were measured in this study. All the persons were measured one after the other in a short period of time under stable room conditions and after their sufficient temperature acclimatization. All the persons were in the same position relative to the IRT device and the black body simulator device. The monitored subjects consisted of both men and women aged 18–23 years. All persons declared feeling healthy at the time of the measurement and did not show signs of febrile illness. All participants gave written, informed consent. The IRB waived the requirement for its approval based on the characteristics of the study. The persons wore a face mask FFP2 class and they had no makeup or other cosmetics on their face skin.

The face of persons was measured from 2 meters distance from the IRT device in the frontal plane. Room temperature was 22 °C, additional sources of heat radiation were not present. The IRT images were recorded with infrared camera WIC 640 (Workswell, Prague, Czech Republic) equipped with Flir focal plane array microbolometer thermal detector, 640×512 IR resolution, and spectral range from 7.5 µm to 13 µm. The absolute accuracy of the measurement is declared at ± 2 °C or ± 2% of reading and thermal sensitivity of device is 0.03 °C, according to the technical data list provided by the manufacturer. The thermoimages are presented in the so-called rainbow palette. The calibrated model of a black body (Pyrotherm CS 120, Dias Infrared GmbH, Dresden, Germany) was used with defined temperature of 37 °C and defined emissivity (0.98).

The maximal temperatures were measured from two different ROIs (region of interest) for each monitored person (Fig. 1). First ROI was rectangular selection from the forehead (ROIfh), second ROI was rectangular selection from the root area of the nose and inner canthus of the eye (ROIce). The temperature of black body simulator device was checked each time to determine the temperature stability of the IRT device. The emissivity was set at the value 0.98 during IRT image evaluation.

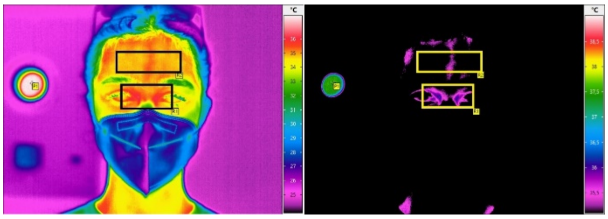

Fig. 1: Example of face and black body simulator IRT image with forehead area and inner canthus of the eyes ROI selection. Left IRT image: temperature range 24–37 °C, right IRT image: temperature range 35–39 °C with highlighted temperature maxima.

The obtained data represent maximal temperature from selected ROIs. These data were statistically tested for normality by using Kolmogorov-Smirnov test. Data were subsequently tested for statistical difference by means of a paired t-test on significance level of $p = 0.05$ (set of maximal temperature values from foreheads versus maximal temperatures from inner canthus of eyes).

The obtained IRT images were processed by IRBIS 3.1 professional (InfraTec, Dresden, Germany). The obtained data were processed by Excel (Microsoft Corporation, Redmond, Washington) and statistically evaluated by Statistica 12 (Microsoft Corporation, Redmond, Washington) software.

Results

The main aim of study was comparison of temperature measurement from the selected ROI—forehead area and area of inner canthus of the eyes (Fig. 1). Temperature maxima were determined and compared from both ROIs and a mutual numerical difference was expressed.

All 59 measured persons provided valid data which was further subjected to analysis, these are shown in Table 1 with analyzed maximal temperatures from selected ROIs of all persons.

Obtained data was expressed by using box-plot graphs (Fig. 2) with representation of median, quartile values and maxima. Graphical and numerical results show different temperature distribution in the area of the forehead and the inner canthus of the eyes. The performed statistical evaluation showed statistical significance difference at the level $p = 0.05$. The lower temperatures were observed in the case of forehead, the higher temperatures were observed in position of inner canthus of the eyes.

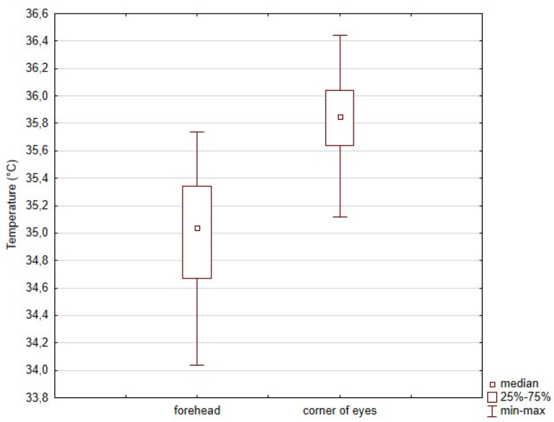

Fig. 2: The graph of temperature distribution (°C) for selected ROI – forehead and inner canthus of eye.

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Statistical temperature values from analyzed data obtained from forehead ROIs were for median 35.04 °C, 25% quartile 34.67 °C and 75% quartile 35.34 °C. Data obtained from inner canthus of eyes ROIs were for median 35.85 °C, 25% quartile 35.64 °C and 75% quartile 36.04 °C.

ΔROI values (determined as temperature difference ROIce – ROIfh) showed the following (Fig. 3): Except for one case, the temperature difference was in the positive value range, which means a presence of higher temperature in the area of inner canthus of the eye; median value was determined as 0.78 °C; maximal difference was determined as 1.94 °C (as outliers value) or 1.6 °C (as nonoutliers value). Data ΔROI are not affected by the possible IRT accuracy errors because of difference value form, calculated as the temperature difference.

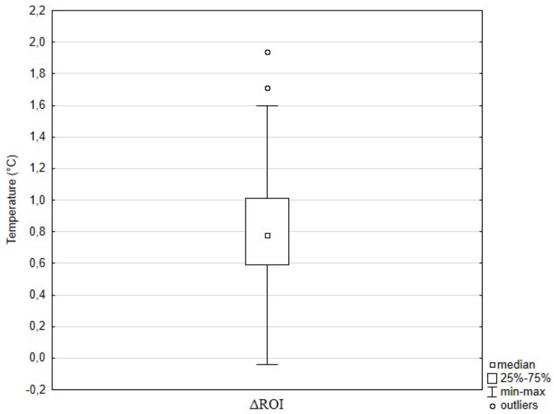

Fig. 3: The distribution of temperature values (°C) obtained as difference value from ROI forehead temperatures – ROI inner canthus of eyes temperatures.

Table 1: Table of maximal temperature from selected ROIs; ROIfh – position on forehead, ROIce – position on inner canthus of eyes, ΔROI – temperature difference ROIce – ROIfh.

Pers. (-)	ROIfh (°C)	ROIce (°C)	ΔROI (°C)	Pers. (-)	ROIfh (°C)	ROIce (°C)	ΔROI (°C)	Pers. (-)	ROIfh (°C)	ROIce (°C)	ΔROI (°C)
1	35.19	36.14	0.95	21	35.46	36.03	0.57	41	36.06	36.42	0.36
2	35.42	36.08	0.66	22	36.05	36.30	0.25	42	34.81	36.15	1.34
3	34.96	35.93	0.97	23	35.22	36.07	0.85	43	35.47	35.94	0.47
4	34.59	35.67	1.08	24	34.91	36.85	1.94	44	35.45	36.12	0.67
5	35.41	36.25	0.84	25	35.97	36.37	0.40	45	35.30	35.93	0.63
6	36.25	36.83	0.58	26	36.07	36.65	0.58	46	35.59	36.54	0.95
7	35.25	36.09	0.84	27	34.79	36.35	1.56	47	35.40	36.73	1.33
8	35.44	36.36	0.92	28	35.37	36.06	0.69	48	34.86	35.68	0.82
9	35.65	35.87	0.22	29	34.43	35.28	0.85	49	35.75	36.50	0.75
10	34.77	36.48	1.71	30	34.84	36.03	1.19	50	35.56	36.38	0.82
11	35.61	36.79	1.18	31	35.27	36.14	0.87	51	35.91	36.65	0.74
12	35.33	36.31	0.98	32	35.53	36.14	0.61	52	35.63	36.15	0.52
13	35.70	36.71	1.01	33	35.44	36.13	0.69	53	35.70	36.48	0.78
14	35.74	36.41	0.67	34	35.77	36.03	0.26	54	35.05	36.31	1.26
15	36.33	36.29	-0.04	35	35.31	35.90	0.59	55	35.60	36.31	0.71
16	35.58	36.13	0.55	36	34.97	36.26	1.29	56	35.83	36.47	0.64
17	36.25	37.02	0.77	37	35.11	36.30	1.19	57	35.89	36.31	0.42
18	35.29	36.39	1.10	38	34.60	36.20	1.60	58	35.43	36.43	1.00
19	35.49	36.79	1.30	39	35.42	36.24	0.82	59	35.50	36.28	0.78
20	35.94	36.55	0.61	40	35.75	36.01	0.26				

Discussion

The measurement of human body temperature is not an easy task, although it might seem so at first glance.

And this statement is even more true for non-contact measurements. This method is very specific and requires a prudent approach. There are many scientific studies that focus on this topic. However, many questions are still unanswered. Practice shows that there is no unity of opinion or real adopted measurement procedure.

A big problem is insufficient acclimatization in the case of temperature measurement in the forehead area, as the authors Kistemaker et al. [16] or Liu et al. [17] point out. The minimal time 15 minutes for acclimatization is suggested. The same authors [17] voiced the opinion that measuring of human core temperature in connection with fever screening as the auditory meatus temperature is a superior alternative when compared with the forehead body surface temperature due to its close approximation to the tympanic temperature.

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The area of the body surface from which the temperature is measured is one of the key parameters for successful and credible temperature measurement, as is shown by this study and by studies of other authors too. In our actual case, the temperature from forehead area and area of inner canthus of eyes were compared. The most published studies presented comparison of gold standard core temperature measurement with other alternatives. The authors Shann and Mackenzie [18] compared rectal, axillary, and forehead temperature measurement in their published article. Conclusion of this study stated that axillary and rectal temperatures are in good agreement in contrast with forehead temperature. A similar study was presented by Mogensen et al. [19], where rectal temperature measurement (as the gold standard) was compared with forehead and ear temperature measurement. These authors claim that measuring the temperature on the forehead or ear cannot replace the gold standard for the exact measurement of temperature, the rectal method is still recommended by them. Authors of another thermal study where oesophageal, tympanic, and forehead skin temperatures in adult patients were monitored remark, that the obtained data suggest that forehead skin temperature is not interchangeable with standard core temperature measurements [20].

It is clear from the published results that the often-used measurement of human body temperature from the forehead position may not correspond to real body temperature. The authors of the cited works mostly point to the gold standard of measuring the temperature in the rectum. However, this represents a contact measurement method and therefore it is appropriate to pay attention to contactless methods as well.

Here the following questions arise in connection with contactless method—where and how much? These basic questions address the issues of what the best body surface position is to realize contactless measurement and what is the temperature of such body surface position corresponding to the physiological temperature state.

The answer to these questions seems more than clear if we follow the recommendations of leading experts in the field of contactless thermography and the current measurement standards.

There are several other studies supporting the use of inner canthus of eyes position on human face. The authors Perpetuini et al. [21] in their overview clearly state, based on the evidence of the analysis performed, that the evaluation of the maximum temperature from the eye inner canthus seems to be the most reliable method to assess fever.

However, there are also expert studies of the opposite opinion. The phenomena of inner canthus temperature contactless measurement in relationship to direct temperature measurement was investigated by Fernandes et al. [22] The authors brought the knowledge that inner canthus of the eye temperature measurement is not a valid substitute measurement to gastrointestinal temperature telemetry pill in sports and exercise science settings. The results are mainly related to traditional methods of core temperature assessment used in sports and exercise science settings, as authors noted in their conclusion. Similar results were reported by Teunissen and Daanen [23], when they compared temperature of the inner canthus of the eye to oesophageal temperature with results, that observed temperatures differed significantly during different physiological conditions (rest, exercise, recovery and passive heating) and their relationship was inconsistent between used conditions. This poses doubts on the use of temperature of the inner canthus of the eye as a technique for core temperature estimation.

As can be seen from the literature research, there is a double view of the possibility of measuring body temperature by location the ROI in position of inner canthus of the eye. This was the main reason for doing our proposed comparative study. The temperature on the forehead and in the inner canthus of the eye was compared under the same conditions on a sufficiently robust sample of people of the comparable age and occupation. In the presented study, the temperature of a healthy individual was evaluated, i.e. the normal physiological temperature and its variance within the studied group.

Some of the obtained data can be compared with other authors. The authors Ng et al. [24] published the study, where the mean value of forehead contactless temperature was measured. The value 35.6 °C was determined as maximum limit temperature of a healthy person. This is fully corresponding with data from our measurement, where median value of forehead contactless temperature was under 35.1 °C.

In the studied group the observed temperature value data from the inner canthus of the eye were higher than the forehead temperature values and certainly with comparable variability. From this observed fact, the authors conclude the suitability of measuring the surface temperature from the inner canthus of the eye and determined the median temperature in this surface position as 35.85 °C. The authors consistently point to a significant statistical difference between the temperature distribution obtained from the forehead ROI and from inner canthus of the eye ROI. It is important to emphasize that the measurement was performed with FFP2 class respirators, which positions the study to be close to reality in situations of screening used for temperatures associated with respiratory disease.

Conclusion

The present study undoubtedly shows how important it is to comply with the standards and recommendations of professional thermology societies. Although these recommendations have been into validation for several

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years, there are still institutions or persons that do things purely on their own. The significant difference between surface temperature measured in position of forehead and inner canthus of eyes was observed and numerically expressed. The results of this implemented study draw attention to the possibility of unnecessary data variability and bias of the measured results, if a standardized uniform approach to measurement of surface temperatures is not observed.

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