ARTYKUŁ PRZEGLĄDOWY REVIEW ARTICLE

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The role of thermography in ophthalmology

Anna Modrzejewska

I Chair and Clinic of Ophthalmology, Pomeranian Medical University in Szczecin
Head: Prof. Anna Machalińska, MD, PhD

HIGHLIGHTS

Thermography is used for the evaluation of the ocular surface in dry eye syndrome, severity of inflammation, detection of intraocular tumours or retinal ischaemia.

ABSTRACT

Thermography is used to assess the extent and intensity of local hyperaemia and tissue metabolism based on the emitted radiation in the infrared range. In ophthalmology, it is used for the diagnosis of ocular inflammatory conditions. Increased ocular surface temperature is observed in tumours such as melanoma and uveal naevus. Reduced temperature as a result of blood flow disorders is detected in patients with vascular occlusion, glaucoma, diabetic retinopathy or AMD. Lower emission of infrared radiation on the ocular surface was observed in dry eye syndrome due to tear film instability and faster tear evaporation. Thermography is a non-invasive, fast and objective technique, and in the future it may complement the diagnostic process of many ophthalmic diseases.

Key words: thermography, thermal imaging camera, ophthalmology, ocular surface temperature, infrared, thermal emission

INTRODUCTION

Infrared radiation is a type of electromagnetic radiation with a wavelength in the range of 0.78–1000 μm, which was discovered in 1800 by William Herschel [1]. Every object and every living organism emits and reflects infrared radiation, which can be recorded by thermal imaging cameras as a temperature map or thermogram. Images are usually visualized using the rainbow colour order, where white or red indicates higher, and blue or green indicates lower temperatures. The analysed object is compared to the perfect black body (with a coefficient equal to 1.0), which absorbs 100% of radiation, and to the perfect white body that reflects 100% of radiation [2]. Measuring devices have been improved for more than 100 years since the first thermograms were acquired. Thermography in medicine was first used at the end of the 19th century for the early detection of breast cancer [1]. A thermal imaging camera visualized the area of the skin covering the tumour as a warmer area than that of normal tissue, so it was possible to determine the margin of the affected tissue [3]. Further studies revealed that higher temperature was positively correlated with greater blood flow and more severe inflammation in the region of interest. Increased metabolic activity of tissues is associated with the accumulation of carbon dioxide, prostaglandins and other proinflammatory factors, which leads to vasodilatation and hyperaemia, and thus to an exothermic reaction and the release of heat to the environment [4, 5]. The increase in local temperature can be quantified with a thermal imaging camera [6].

EXAMINATION TECHNIQUE

In recent years, significant progress has been made to improve the standardization of this diagnostic technique and refine clinical protocols. The accuracy of thermal imaging depends on a number of factors, and clinicians have to be aware of them to correctly analyze the images. Researchers have emphasized the influence of different environmental conditions, posture, as well as the angle and distance from the camera during examination on the repeatability of measurements. Conditions in the room, i.e. air temperature, air currents and humidity may significantly affect measurements taken with the thermographic camera. It is recommended that the images should be acquired after resting for 15 minutes in the examination room, perpendicularly to the examined area, and at a distance of 1 m from the camera [7, 8]. The influence of variability in the same patient on the acquired measurements is eliminated by comparing symmetrical areas of the body surface. The patient's age and appearance, e.g. body hair, amount of subcutaneous tissue or skin changes may also disturb local heat transfer, which should be taken into account in thermographic analysis [9–11].

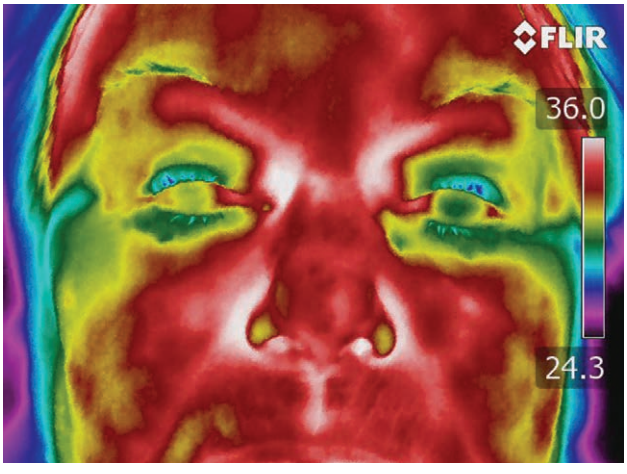
The ocular surface, however, is unaffected by the above-mentioned confounders. No differences in temperature were found between male and female subjects. However, the ocular surface temperature decreases with the time point after blinking and with the age of the studied patients [12, 13]. The ocular surface temperature decreases by 0.01–0.02°C per year throughout life, and the rate of change increases after middle age [14]. The mean ocular surface temperature at the corneal centre is 34.3°C ± 0.7 and it does not depend on corneal thickness or the depth of the anterior chamber [15]. The highest temperatures were measured in the nasal field of the conjunctiva and around the corneal limbus, and they were about 0.45–1°C higher than those measured in the centre of the eye [16, 17]. Lower temperatures at the corneal centre are probably associated with the absence of blood vessels and the presence of a thin layer of the tear film in this area, which is prone to faster evaporation [18–20].

OCULAR APPLICATIONS OF THERMOGRAPHY

There are a number of papers reporting potential applications of a thermal imaging camera in the diagnosis of ocular diseases. Most studies on the use of thermography in ophthalmology concern the diagnosis of dry eye syndrome (fig. 1). Tear film abnormalities result in low thermal emission and reduced ocular surface temperature [21]. The degree of temperature reduction correlates with the results of the Schirmer test, the tear meniscus height (TMH) and the tear breakup time (TBUT) [22, 23]. The increased instability and evaporation of the tear film is particularly common in the elderly. Many researchers have found a negative correlation between the patient's age and the ocular surface temperature, which may result in symptoms of dry eye that worsen with age [14, 18].

FIGURE 1

Dry eye syndrome in the left eye (on the right side of the thermogram).



Studies on the use of thermography in cataract surgery began in 1994. Rise in corneal temperature after extracapsular cataract extraction [24] and corneal burns induced by phacoemulsification [25] have been reported. To assess the effect of phacoemulsification on the ocular surface temperature, researchers took intraoperative measurements on the corneal surface and in the anterior chamber [26]. The highest temperature measured at the corneal surface was 44.9°C. Studies have revealed that thermography may be useful in the operating room to assess the corneal surface temperature during cataract surgery performed with different techniques and phacoemulsification ultrasonic tips [27, 28]. For example, Giannaccare et al. used a thermal imaging camera to examine patients on days 7 and 28 after cataract phacoemulsification, and compared to preoperative measurements they found cooling in the central cornea, but heating in the temporal limbus. Measured temperature was inversely related to the OSDI (Ocular Surface Disease Index) and directly related to TBUT. Warming in the temporal region was associated with aseptic inflammation, which developed in response to perioperative tissue injury [29]. This observation was also confirmed by Shih et al. Temperature in this area normalized one month after surgery [30]. Many studies have indicated an increased incidence of dry eye syndrome after cataract surgery. This procedure involves incision of the cornea and disruption of the tear film, which may aggravate previously existing symptoms. A decrease in the tear meniscus height, TBUT elongation, squamous metaplasia and decreased corneal sensation after surgery have also been reported [31, 32]. Modrzejewska et al. used a thermal imaging camera to measure temperature in the ocular region in patients one month after cataract surgery, and compared the obtained values to those measured one day before the surgery. The reported mean ocular surface temperature was lowest on day 14 after surgery, then increased and normalized on day 28 [33] (fig. 2).

Microbiological assay is the gold standard in the assessment of the aetiology of ocular inflammation but it is not used routinely [34, 35]. The diagnosis is usually based on the examination of the eye using a slit lamp and the assessment of symptoms reported by the patient [36–38]. Both tests are subjective. For many years clinicians have been trying to find objective and quantitative techniques for the assessment of ocular inflammation. Studies have demonstrated that in scleritis, uveitis or keratitis, the ocular surface appears warmer on thermograms compared to normal tissues. The ocular surface temperature in patients with corneal bacterial ulcer was 0.8°C higher than in the normal eye [39, 40]. Modrzejewska et al. measured ocular temperature in patients with various inflammatory conditions of the eye. An increase in the mean temperature at the central point of the cornea, the ocular surface and in the orbital cavity was found in patients with conjunctivitis, keratitis, anterior uveitis and endophthalmitis (fig. 3, 4). The greatest difference in temperature between the affected and normal eyes was found for endophthalmitis (1.23°C higher compared to temperature measured at the central point of the cornea and on the ocular surface). Endophthalmitis is characterized by significant damage to the ocular membranes and increased catabolism, and thus a strong exothermic reaction. The lowest gradient was found in keratitis (0.11°C at the central point of the cornea and 0.19°C on the ocular surface). For all inflammatory conditions temperature measured at the corneal centre was lower than the mean ocular surface temperature: conjunctivitis (34.72°C vs. 35.47°C), keratitis (34.19°C vs. 34.92°C), uveitis (34.40°C vs. 35.20°C), and endophthalmitis (35.27°C vs. 35.80°C). This phenomenon can be explained by the previously described morphological features of the cornea. If corneal structures are not translucent, potential endophthalmitis and its advancement are assessed by ultrasonography, which is a subjective test that depends on the quality of equipment and the examination technique. It was concluded that the thermographic examination may in this case be used as an additional diagnostic tool [41].

FIGURE 2

A thermographic image of a patient's face 1 day before (A) and 1 (B), 14 (C), 28 (D) days after cataract surgery of the right eye (on the left side of the thermogram).

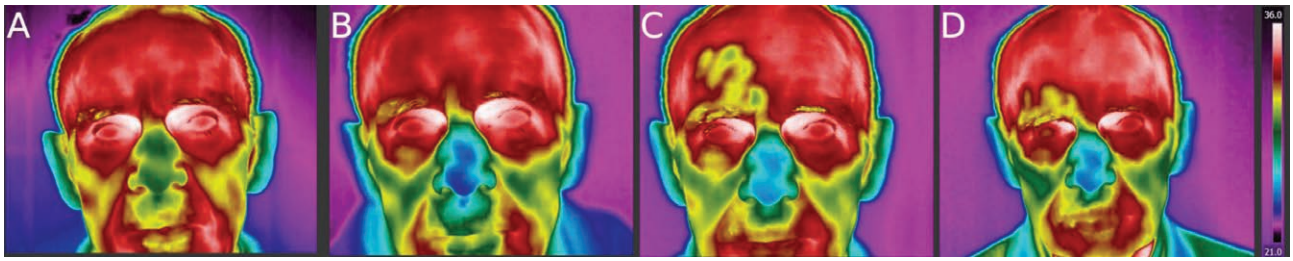


FIGURE 3

Endophthalmitis of the left eye.

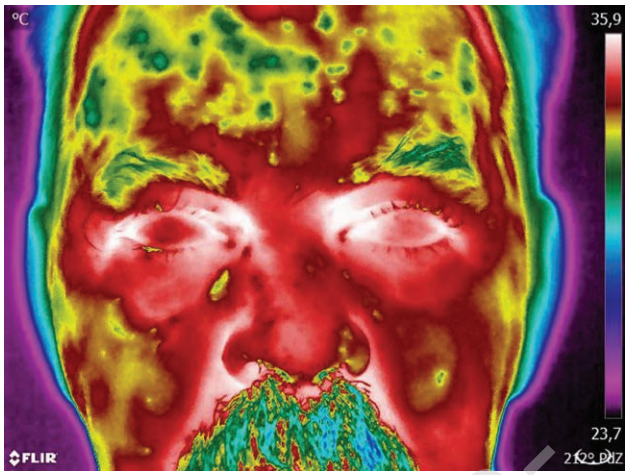
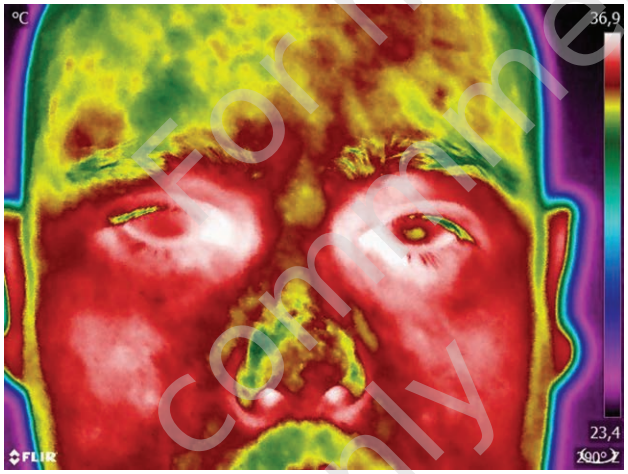


FIGURE 4

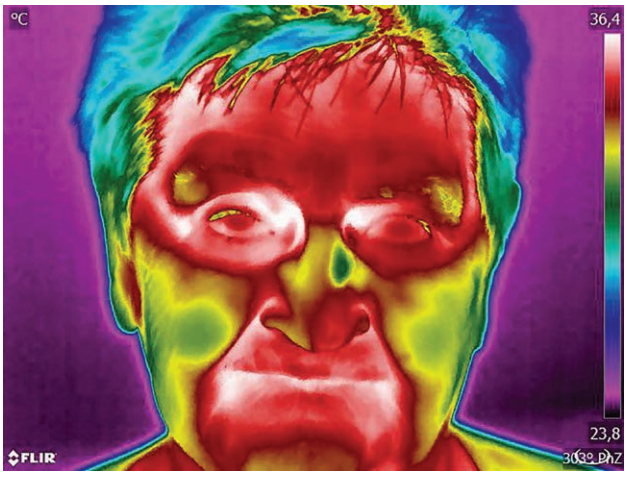
Conjunctivitis of the right eye.



In the case of intraocular tumours, diagnostic difficulties are caused by amelanotic changes and those accompanied by retinal detachment, or the lack of insight into the fundus caused by corneal opacity, narrow pupil or vitreous haemorrhage. The diagnosis and qualification for treatment largely relies on the experience of the clinician analysing the results of additional tests, such as type A or B ultrasonography, Doppler ultrasound, fluorescein angiography or optical coherence tomography. Histopathological examinations prior to eye removal surgery are extremely rare [42]. In 1971, Kruszewski reported that ocular tumours such as melanoma or uveal naevus are visualized in thermography as hot regions [43]. Wittig et al. also noted warming of the ocular surface in melanoma of the conjunctiva and uvea [44]. According to researchers, melanomas are malignant cancers with significant thermal activity, which results from abnormal vascularisation of the tumour mass [45]. This hypothesis has been confirmed in other studies revealing that uveal melanoma is characterized by a greater mean maximum blood flow in the central retinal artery, in the posterior ciliary arteries, and total choroidal flow measured by Doppler ultrasound compared to normal eyes [46, 47]. The role of the immune response and metabolic activity of melanomas was also discussed [48]. These tumours secrete pro-inflammatory and pro-angiogenic cytokines, causing chronic tissue inflammation that promotes tumour growth [49–51]. The thermal imaging camera can detect areas with increased metabolism and blood flow as warmer regions. Modrzejewska et al. found that eyes with uveal melanoma and retinal capillary hemangioblastoma had higher mean temperatures measured at the corneal centre, ocular surface and orbital cavity compared to the patient's other healthy eye (fig. 5).

FIGURE 5

Uveal melanoma of the right eye.



Ocular temperature was higher in the group of patients with uveal melanoma after unsuccessful brachytherapy compared to patients with tumour regression [52] (fig. 6).
It is believed that this may indicate positive changes in the tumour area, i.e. vascular occlusion, ischaemia and scarring of the retina [53]. Mean temperature was also lower in eyes with a focal metastasis to the uvea compared to unaffected eyes [52] (fig. 7).
According to Konstantinidis et al., metastatic tumours are poorly vascularised and use the blood supply existing in the local tissue. Moreover, some metastatic tumours may be vascular with extensive necrotic foci [54], which may be responsible for their lower temperature.

FIGURE 6

A. Uveal melanoma in the left eye after unsuccessful brachytherapy. B. Uveal melanoma in the left eye after successful brachytherapy.

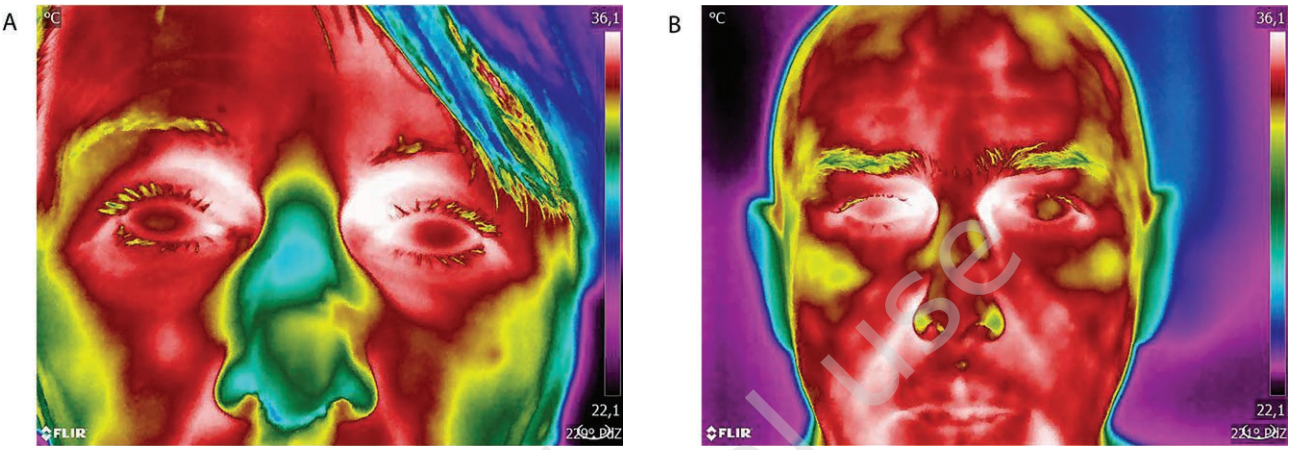
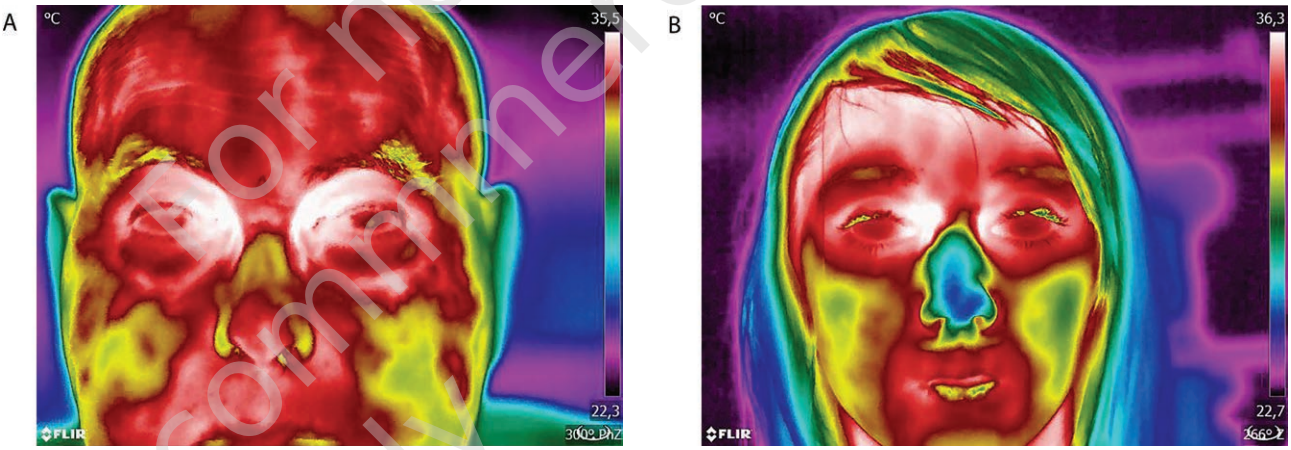


FIGURE 7

A. Focal metastasis to the uvea in the left eye. B. Retinal capillary hemangioblastoma in the right eye.



Other studies on the use of thermography in ophthalmology indicate the potential applicability of this method for the detection of occlusion in the central retinal vein. Ocular surface temperature in eyes with central retinal vein occlusion, especially those with ischaemic CRVO, was lower than in unaffected eyes [55].

Thermography showed a lower temperature in eyes with nonproliferative and proliferative diabetic retinopathy and in dry and wet AMD (age-related macular degeneration) compared to eyes without these pathologies [56, 57]. This highlights the role of ischaemia in the pathogenesis of these ophthalmic diseases.

The thermographic camera was also used for the monitoring of the filtering bleb function after glaucoma surgery. A greater temperature gradient was found between a properly functioning bleb and the surrounding conjunctiva compared to the bleb in the eyes with a higher postoperative intraocular pressure [58].

CONCLUSION

Ocular thermography is a fast, non-invasive and safe procedure that shows real-time temperature distribution on the ocular surface. Because it provides objective and quantitative data, it can be used as a complementary diagnostic tool for the differentiation of ophthalmic diseases or evaluation of treatment outcomes. As in many imaging techniques, computerization and the development of telemedicine have significantly improved the availability and ease of use of thermal imaging cameras. Compact thermal imaging cameras that can be connected to a smartphone via a USB port are popular for industrial applications. Currently, images of the eye fundus can be acquired using a smartphone application or a portable fundus camera in many physicians' offices and opticians worldwide. Dedicated advanced software is used to analyse images for any abnormalities and, if necessary, results are reported to the ophthalmologist.

Apparently, future advances in ophthalmology are associated with the further miniaturization of measuring devices, the development of telemedicine, and greater availability of specialist diagnostic procedures, including thermography.

Figures: from the author's own materials.

CORRESPONDENCE
Anna Modrzejewska, MD, PhD
I Chair and Clinic of Ophthalmology,
Pomeranian Medical University in Szczecin
70-111 Szczecin, al. Powstańców Wielkopolskich 72
e-mail: ania_modrzej@o2.pl

ORCID
Anna Modrzejewska – ID – http://orcid.org/0000-0002-0393-1041

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