Thermography: A Review
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Abstract: Thermology is the study and application of biothermal processes to assess health or disease and the word thermography employs imaging and visual evaluation of those thermal changes. It is a noncontact, nondestructive and noninvasive investigative method that utilizes the heat from an object to detect, display and record thermal patterns and temperatures across the surface of the object. For the past four decades, various devices such as thermometers, thermistors, thermocouples, and liquid crystal imaging systems have been used to measure the amount of heat dissipated by the body. More recently, with the advancement in technology the thermography tools had progressed into a beneficiary device in diagnosis. The principle behind such application was built on the fact that, as the amount of blood circulation at different layers of the skin varies, the temperature also changes accordingly. Consequently, disorders that affect the blood flow too results in abnormalities in temperature distribution and these when evaluated will provide valid diagnostic informations. Thermography is being used to detect various pathological conditions in the medical field. There are various orofacial conditions in which thermography can be used. This paper deals with the basics of thermography and its various applications in dentistry.

Key words : Thermography, Telethermography, Infrared Thermography, Facial Telethermography

INTRODUCTION

A new diagnostic modality named medical thermography, involving the assessment of the thermal characteristics of the human body's surface, has evolved over the past four decades.1 Body heat is generated by metabolism and by muscular activity, and keeps the core body temperature at a defined slightly oscillating level (about 37°C). The organisms' heat loss depends on ambient factors and results of conduction, convection IR radiation and of evaporation (sweating) from the surface of the skin despite of breathing and other mechanisms. Inside the organism, heat is transported by convection (blood flow) and by conduction.2 Thermology is the study and application of biothermal processes to assess health or disease and the word thermography employs imaging and visual evaluation of those thermal changes. From antiquity bodily heat is considered as an important indicator of well being and application of temperature measurement and thermal imaging had continued to evolve. Thermography is based on the ability to image the heat emission of the human body. A variety of temperature measurement devices, including thermistors, thermocouples, liquid crystal thermal imaging systems, and infrared detection systems, have been used to measure the amount of heat given off by blood flowing within and beneath the skin. As the amount of blood circulating varies (within and beneath the skin layers), so does the skin temperature. Different disorders affect this blood flow and result in abnormalities in temperature distribution. These thermal abnormalities, therefore, carry diagnostic information. More recently, with the advancement in technology the thermography tools had progressed into a beneficiary device in diagnosis.3 Using conventional medical thermography, only the body surface and a superficial layer a few mm in depth are surveyed, and the temperature distribution is mapped and recorded.4

HISTORY

Ancient medicine perceived good health as a state of balance between the elements. The assessment of body temperature was an integral part of Greek pre-Hippocratic medicine (600-400 BC), and as early as 400 BC, human body temperature was used as a medical diagnostic sign. Hippocrates used his right hand to judge the skin temperature of his sick patients. About 600 years later, Galen (130-210 AD) advanced the notion that body heat is produced by the biocombustion of food. Galen also discussed a theory on the feedback between sensory and motor nerves, which, as we know today, is the primary mechanism of thermoregulation.5 In 1592, Galileo invented the semi quantitative air thermometer called Galileo's thermoscope, which can exhibit temperature changes. In 1611, Santorio Sanctorius modified the thermoscope and invented a thermometer, which demonstrated the variation in core temperatures of humans in both health and disease. In 1911, Wunderlich introduced fever measurements as a routine clinical diagnostic procedure. The modern era of telethermometry was initiated in 1931 by Hardy, who described the physiological role of the infrared emission of human skin and its potential diagnostic importance.6 The medical use of infrared thermography started in 1952 in Germany. The physician Schwamm, together with the physicist Reeh developed a single detector infrared bolometer for sequential thermal measurement of defined regions of the human body surface for diagnostic purposes. They founded the first medical association of thermography in 1954, today still active as German Society for Thermography and Regulation Medicine (Deutsche Gesellschaft fur Thermographie und Regulations medizin eV).7 In 1986, the American Academy of Neuro-Muscular Thermography published basic guidelines for conducting facial thermographic examinations.8
CLINICAL TEMPERATURE MEASUREMENTS

The temperature of a biological system can be measured at a single spot (or in a single cavity), at several spots (small subareas) simultaneously, or at a virtual continuum of spots, over an extended area of the body's surface, such as the human cheek or face. The latter mode of temperature measurement can be displayed as a thermal image which represents the spatial distribution of temperature over an area of interest. Skin temperature can be measured at a single instance in time (static thermography) or in a series of many sequential instances (dynamic thermography). The latter type of measurement represents the dynamics of the thermal behavior of the given spot, spots, or areas of a thermal image. These measurements are named dynamic spot thermometry and dynamic area thermometry, respectively. The dynamic phenomena measured can be of a transient or of a periodic nature. In the former case, we observe a trend of warming or cooling until a thermal equilibrium is reached. Periodic modulation of skin temperature manifests physiological thermoregulation which is characterized by oscillations around a certain average value of temperature.

TYPES OF THERMOGRAPHY

Based on the method of application thermography can be classified into following types. A semi quantitative contact method that uses liquid crystals called liquid crystal thermography (LCT), a quantitative infrared-detecting non-contact method known as infrared telethermography (ITT) and Dynamic area telethermometry (DAT).

LIQUID CRYSTAL THERMOGRAPHY

A liquid crystal thermometer consists of flexible rubber sheets within which cholesteric crystals are embedded. There are several layers of the crystals in the commercial sheet materials, which are mounted in a frame (a thin box) which has a clear side parallel to the sheets. In addition, there may be provision for inflating the sheets while in the frame, so that the heat-sensitive surface conforms better to the body's contour. To measure the thermal changes the crystal sheets are placed over the surfaces to be examined. After placement, the crystals changes from their neutral colour at room temperature into different colour in response to the surface temperature of the body with which they are in contact. The colour display over these sheets represents the temperature distribution over the area of skin in contact with the sheet. The resultant colour display is then photographed using Polaroid photography which gives an instant hard copy of the image. It is this photograph that becomes the thermogram, which is used for diagnostic evaluation.

The advantages of LCT systems are that they are less expensive and portable than electronic telethermography units. On the contrary, they are technique sensitive, requires timed skin contact to record a reproducible temperature distribution. Moreover, the temperatures recorded are not accurate due to the contact of the crystal sheet with the body surface which can cause compensatory warming/cooling of the contact area. The other demerits are low thermal sensitivity (0.3-10C) and poor spatial resolution (the separation between two nearby spots) of about >5 mm.

In spite of its several limitations, liquid crystal thermography has been claimed to yield meaningful results in the evaluation of thermal abnormalities of the face due to orofacial disorders. Thus, to make the measurement of skin temperature free of many artifacts, it is highly advantageous to determine skin temperature without any contact between the skin and the monitoring device. The only way the surface temperature of the skin can be measured without contact is by remotely measuring the infrared black body radiation that it emits.

INFRARED TELETHERMOMETRY

Infrared thermography, telethermometry, electronic thermography, or digital infrared telethermographic imaging (DITI) is a noncontact method of temperature measurement where the detector is kept remotely at a single spot. It consists of an infrared detector, amplifier-digitizer, a microcomputer and a video display. The infrared detectors used here are of different types they include, single element infrared detector, linear array infrared detectors and two dimensional array detectors.

The single element detector consists of a set of rapidly rotating mirrors and a germanium lens which focuses the infrared flux emitted by the subareas of the field of interest onto the mirrors as they are transparent to infrared light and have high refractive index. The single detector infrared radiation thermography works in such a way that, as the infrared radiation emitted by the face enters the germanium lens it passes through the mirrors that are placed perpendicular to each other. These set of mirrors rotates rapidly on a vertical and horizontal axis simultaneously so that every point on the field of view is scanned and reflected onto the detector which converts them into electrical signals. An amplifier then converts these electric signals into digital values which are then fed into a computer which reconstructs a digitized thermal image. An infrared camera with a linear array of detectors requires just one mirror. The mirror generally rotates around a vertical axis, to scan the field of view and hence its vertical resolution is limited.

Two-dimensional arrays or focal plane arrays (FPA) consists of a germanium lens and a plate of miniature detectors. The germanium lens functions in the same way as in single detector system and helps in focusing the infrared influxes directly on to the detectors. The advantages of the FPA cameras are that they have higher speed (allowing to obtain >100 images per second), reliability and maintenance-free performance since they require no moving parts. However, the disadvantage is limited spatial resolution.

DYNAMIC AREA TELETHERMOMETRY

The newly developed dynamic area telethermometry (DAT) promises to become a new diagnostic aid in the assessment of orofacial disease. DAT provides quantitative information on the thermoregulatory frequencies (TRFs) manifested in the modulation of skin temperature. Whereas the static telethermographic studies, demonstrate local vasodilatation or vasoconstriction, DAT can identify the mechanism of these signs and thus it is expected to significantly improve the differential diagnosis. DAT can readily distinguish between occlusive and vasoconstrictive hypothermia, since the latter involves enhancement of abnormal high frequency TRFs, while the former shows diminution of the amplitudes of normal TRFs. Vasoconstrictive hypothermia is also expected to have a minimal effect on micro spatial homogeneity of skin temperature (HST) and will exhibit normal HST modulation, while occlusive hypothermia will show significantly reduced HST modulation. Next, DAT can differentiate between neuronal vasodilatation...
with its characteristic TRF pattern, and vasodilatation due to blockage of neuronal control by a nerve block or by excessive extravascular nitric oxide. Under the latter conditions, maximal HST is associated with minimal modulation. Extravascular overproduction of nitric oxide, often associated with enhanced immune response, can be characterized by abnormal TRFs due to the autocatalytic production of extravascular nitric oxide. The vasodilator effect of extravascular nitric oxide might explain the positive correlation between pain and local hyperthermia, such as is observed in TMD. The inflammation of the temporomandibular joint is associated with hyperactivity of chondrocytes and osteocytes involved in bone remodeling, which are known to produce nitric oxide. Nitric oxide overproduction is also associated with enhanced immune response. Further, atherosclerosis was shown to be associated with excessive nitric oxide production. On the other hand, nitric oxide has been shown to enhance the sensitivity of nociceptors, and intracutaneous injections of NO to humans were shown to induce dose-dependent local pain. Since DAT and HST measurements can identify the involvement of extravascular nitric oxide in local hyperthermia, they offer a unique tool to diagnose and manage dental disorders associated with orofacial pain. In summary, the science of thermology, especially DAT, appears to have great promise as an important new area of dental research, especially as a new diagnostic tool in the assessment of orofacial disease.

**FACIAL TELETHEMOROGRAPHY**

Heat emissions from the human face have been shown to be physiologic indicators of underlying health or disease. Heat emission is directly related to cutaneous vascular activity, yielding enhanced heat output on vasodilatation and reduced heat output on vasoconstriction. Infrared telethermography of the face may serve, therefore, as an utterly harmless, non-invasive diagnostic technique that can help to differentiate selected clinical problems. The pattern of radiative heat dissipation over the human body is normally symmetrical. It has been shown that in normal subjects, differences in skin temperature on selected points from side-to-side is small (about 0.28°C). The significant difference between the absolute facial temperature of men vs. women has also been observed. Men were found to have higher temperatures over the 25 anatomic zones measured on the face (e.g. orbit, upper lip, lower lip, chin, cheek, etc.) than women. The rationale behind this is that men have more basal metabolic than women and his skin dissipates more heat per unit area of body surface. Similarly age and ethnicity variations in facial temperature can also occur.

**CLINICAL APPLICATION OF THERMOGRAPHY IN DENTISTRY**

In chronic orofacial pain patients

Gratt and his colleagues in 1996 developed a classification system using telethermographs for patients with chronic pain. They classified them as normal when selected anatomic area (ΔT) values range from 0.0 to +0.25°C, hot when it is >0.35°C, and cold when it is <0.35°C. When a selected anatomic area value is 0.26–0.35°C, the finding is classified as equivocal. Moreover they also found that hot thermographs had the clinical diagnosis of (1) sympathetically maintained pain, (2) peripheral nerve mediated pain, (3) TMJ arthropathy, or (4) maxillary sinusitis. Subjects classified with cold subareas on their peripheral nerve-mediated pain (2) sympathetically independent pain. Subjects classified with normal telethermographs included patients with the clinical diagnosis of (1) cracked tooth syndrome (2) trigeminal neuralgia (3) pretrigeminal neuralgia (4) psychogenic facial pain. This new system of thermal classification resulted in 92% agreement in classifying pain patients making it as an important diagnostic parameter.

In TMJ disorders

It has been shown that asymptomatic TMJ subjects have symmetrical thermal patterns with mean area TMJ DT values of 0.18°C (+0.18°C s.d.). On the other hand, TMJ pain patients were found to have asymmetrical thermal patterns, with increased temperatures over the affected TMJ region of their face and mean area DT values of +0.48°C (+0.28°C s.d.). Specifically, painful TMJ patients with internal derangement and painful TMJ osteoarthritis were both found to have asymmetrical thermal patterns and increased area temperatures over the affected TMJ region of their faces, with mean area TMJ DT of +0.48°C (+0.28°C s.d.). In other words, the correlation between TMJ pain and hyperperfusion of the region seems to be independent of the etiology of the TMJ disorder (osteoarthritis vs internal derangement).

In addition, a study of mild-to-moderate TMD patients indicated that area DT values correlated with the level of the patient's pain symptoms. A most recent double-blinded clinical study compared active orthodontic patients vs TMD patients, vs asymptomatic TMJ controls, and showed average TMJ area DT values of +0.28°C, +0.48°C, and +0.18°C; for the these three groups respectively. This study showed that telethermography can distinguish between patients undergoing active orthodontic treatment and patients with TMD.

In quantification of thermal insult to pulp

Dental pulpal tissue is exposed to variety of thermal insult during various dental treatment modalities. Of late for debonding of orthodontic brackets electro thermal debonding (ETD) method is widely used, this technique although has many advantages than the conventional mechanical method can pose serious thermal damage to pulp. Cummings and his colleagues in 1999 performed an in-vitro study on extracted human premolar teeth applying ETD. Thermal imaging analysis was done using mercury cadmium terullide detector showed that the pulpal temperature increased from 16.80°C- 45.60°C, which can pose serious threat to pulpal vitality. It can be stated from the study that, ETD methods needs intermittent cooling of the teeth with simultaneous thermal imaging to prevent pulpal damage. Similarly the use of ultra high speed air-driven instrumentation during cavity preparation can result in serious thermal insult to the pulp. To overcome this, it is believed that various coolants (airwater spray or air/water alone) can be used to reduce the intrapulpal temperature and prevent subsequent damage to the pulp. It was only until 1979, when Carson and his colleagues performed a study employing thermography to determine the pattern of heat distribution and dissipation during ultra-speed cavity preparation using both an air-water spray and air only coolants to determine if a point heat source is generated. This study stated that the mean magnitude of temperature increases with both types of coolant, 2.80°C and 3.670°C, probably does not exceed the physiologic limits of the pulp.
Assessing inferior alveolar nerve (IAN) deficit

The thermal imaging of the chin has been shown to be an effective method to assess inferior alveolar nerve deficit. Whereas subjects with no inferior alveolar nerve deficit show a symmetrical thermal pattern, with an area DT of +0.18°C (+0.18°C s.d.). While patients with inferior alveolar nerve deficit had an area DT of +0.58°C (+0.28°C s.d.), on the affected side. The observed vasodilatation seems to be due to blockage of the vascular neuronal vasoconstrictive messages, since the same effect on the thermological pattern could be invoked in normal subjects by temporary blockage of the inferior alveolar nerve, using a 2% lidocaine nerve block injection.¹

Detection of Herpes Labialis in prodromal phase

During the prodromal phase, all patients showed an increase in temperature with the mean localized change in temperature (Δt°C) being 1.1°C ± 0.3°C over a mean thermographically positive area of 126 mm² ± 34 mm² even when the patient was asymptomatic. After 72 hours of treatment with acyclovir cream, majority of the patients returned to normal with no clinical or thermographical evidence of infection.¹⁰

Other uses in Dentistry

A thermogram can offer precise images for:

1. Diagnosis of bone and nerve disorders
2. Articular pain in arthritis, osteoarthritis, rheumatoid arthritis
3. Muscular pain, hyper or hypotonic reactions
4. Monitoring endodontic treatments
5. Tissue reactions to new dental materials
6. Diagnosis of any kind of maxillofacial inflammation
7. Chronic and acute periodontitis
8. Sinus disease
9. Cancers in maxillofacial territory
10. Myofascial pain syndrome
11. Neuralgia

ADVANTAGES OF THERMOGRAPHY

- non-invasive technique
- easy seating examination
- minimal examination time (2-3 minute)
- non-expensive technique
- obvious differences in color changes (gradient=0.05°C)

In order to store thermograms, we can use many methods:

- printing on paper, Xerox paper or coated with a material that changes color on heating; this is the thermal printing
- magnetic device (CD, Disc or computer database, archive)²

CONCLUSION

The science of thermology appears to have great promise as an important new area of dental research, especially as a new diagnostic tool in the assessment of orofacial disease.¹ The unique significance of thermography is both qualitative and quantitative assessment which helps in estimation of progression of the disease in a systematic manner. With the innovation of novel equipments and the state of the art facility, thermography in the near future will certainly reemerge as a unique research tool in dentistry.¹ After treatment thermograms can give important relations about the treatment methods and their efficiency. Thermograms can be saved in a database, on compact disc or printed on a special or regular paper.¹⁰

REFERENCES


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LIST OF PHOTOGRAPHS

Figure 1: Facial imaging

- Left facial findings are consistent with the appearance of an oral or sinus infection.
- Outer jaw warming is consistent with the appearance of inflammation to the TMJ and possible oral infection.

Figure 2: Electromagnetic spectrum