Thermography: A New Diagnostic Tool in Dentistry

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ABSTRACT

The various biochemical processes in the human body generate heat, which must be dissipated. Skin is the major route for heat dissipation using blood as the heat exchange fluid. Skin temperature is an indicator of aberrations in metabolism, hemodynamics or in neuronal thermoregulatory processes. Since most of the heat dissipation of skin is by infrared black body emission, skin temperature should be measured without contact, by monitoring the emitted infrared radiation. This has been the basis of telethermography. Thermography is being used to detect various pathological conditions in the medical field. There are also various orofacial conditions in which thermography can be used. This paper deals with the history of thermography and its various uses in dentistry.

Keywords: Telethermography, Liquid crystal thermography, Infrared thermography, Facial telethermography, Black body radiation.

INTRODUCTION

The detection of body warmth, along with touch, may be the first conscious sensation a newborn baby perceives when handled by mother. Heat (or warmth) has a profound cognitive impact on humans. Even the most primitive humans knew that the body of a dead person is always cold. There are strong associations of life with warmth, of moderate body temperature with health, and of high body temperature (fever) with disease. Body heat is generated by metabolism and by muscular activity, and keeps the core body temperature at a defined slightly oscillating level (about 37ºC). 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. Thermography 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.

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. Galileo Galilei is credited with inventing the semiquantitative air thermometer (Galileo’s ‘thermoscope’). In 1611, Santorio Sanctorius, developed the first thermometer. It took, however, another 300 years before Wunderlich introduced fever measurements as a routine clinical diagnostic procedure (Germany in 1872).

Czerny documented the first infrared image of a human subject in Frankfurt in 1928. 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 für Thermographie und Regulationsmedizin eV).

CHARACTERISTICS OF THERMAL IMAGES

Thermal images are characterized by their spatial resolution, i.e. the separation between two nearby spots (the temperatures of which can be assessed distinctively), and by their thermal resolution, i.e. the minimum temperature difference that can be measured at two distinct spots on an image. Another related parameter is the temporal resolution, i.e. the time delay between a change in temperature at a certain spot on the monitored area and the corresponding change on the thermal image.

There are two commonly used methods of obtaining thermal images. A relatively inexpensive semiquantitative contact method that uses liquid crystals and is named liquid crystal thermography (LCT), and a quantitative infrared-detecting noncontact method known as area telethermometry, electronic thermography, infrared
telemetherography (ITT), or digital infrared telethermographic imaging (DITI). Infrared thermography can be measured at a single instance in time (static telethermography) 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 periodical 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.

LIQUID CRYSTAL THERMOMETRY

Liquid crystal area thermometers use 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 contours. Those liquid crystal elastic sheets are applied to the surfaces of the body. After placement, the crystals change from their neutral color at room temperature, in response to the surface temperature of the body with which they are in contact. The color distribution over these sheets represents the temperature distribution over the area of skin in contact with the sheet. The resultant color display is then photographed (usually 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.

Some advantages of liquid crystal thermography are systems being portable with no electric requirements, and are considerably less expensive than electronic telemetherography units. But there are various disadvantages, including low thermal sensitivity (0.3-1°C). In addition, the process is technique sensitive, requiring carefully timed skin contact to record a reproducible temperature (0.3-1ºC). In addition, the process is technique sensitive, requiring the sheet. The resultant color display is then photographed (usually 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.

In spite of its severe 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 skin can be measured without contact is by remotely measuring the infrared black body radiation that it emits.

INFRARED TELETHERMOGRAPHY

Thermal or infrared energy is an energy, not visible because its wavelength is too long for the sensors in our eyes to detect. It is the part of the electromagnetic spectrum that we perceive as heat. Unlike visible light, in the infrared spectrum everything with a temperature above absolute zero emits infrared electromagnetic energy. Even cold objects, such as ice cubes, emit infrared radiations. The higher the temperature of the object the greater the infrared radiations emitted. In 1899, Max Planck suggested that the energy emitted by any object is quantized. Planck formulated a theoretical function to quantitatively describe the spectrum of black body radiation. Planck’s basic assumption was, that the energy (0) of each emitted quantum is a product of some universal constant (h) and the frequency (λ) associated with it (0 = h×υ). The frequency is equal to the speed of light (c) divided by the wavelength (λ) (υ = c/λ). The value of that universal constant, h, could be derived from the experimental data.

Thermography is a noncontact, nondestructive test method that utilizes a thermal imager to detect, display, and record thermal patterns and temperatures across the surface of an object. Since infrared radiation is emitted by all objects based on their temperatures, according to the black body radiation law, thermography makes it possible to “see” one’s environment with or without visible illumination. The amount of radiation emitted by an object increases with temperature; therefore thermography allows one to see variations in temperature.

Planck’s quantitative treatment has permitted us to calculate the black body photon fluxes of any energy for any temperature, or to determine temperature by measuring the black body radiation. Since the maximum flux of black body radiation at human skin temperature (30-36°C) is in the infrared part of the spectrum (about 9-10 μm), clinical black body radiative thermometry, or telemetherometry, must preferably use detection systems, sensitive in that region of the infrared spectrum. An additional important reason for using 8 to 12 μm detectors is the fact that, unlike in other regions of the infrared spectrum, skin is > 98% emissive in that region. When skin is partly reflective, as it is below 8 μm, the detected infrared emission may represent artifacts due to reflected infrared radiation that originated from some environmental source.

Noncontact clinical thermometry did not become a reality with the advent of quantum physics. Because of the low energy and low intensity of the radiation emitted by the body at skin temperature, biological telemetherometry was not practical until the development of sensitive and precise detectors of infrared radiation.

INFRARED DETECTORS

Because of the low intensity of human skin’s black body radiation, precise measurement (< 1% precision) of the infrared emission from small areas of skin (e.g. 1 mm²) within a reasonable short time period (say, 30 msec) requires photon (quantum) detectors (e.g. rapidly responding photoconductive devices), which produce electrical pulse each time they absorb infrared photon. These pulses can be amplified and counted individually, or they can be integrated into an instantaneously measurable electric current. Detectors that require thermal equilibrium with the measuring device (bolometers) are inadequate for clinical use. Although modern bolometers with a very low heat capacity can be fabricated into...
two dimensional arrays and produce high resolution thermal images at a rate of 30 per second,\textsuperscript{15} they cannot operate adequately at skin temperature,\textsuperscript{16} especially when neuronal response times, involved in rapid thermoregulatory processes are to be studied.\textsuperscript{17}

Photoconductive quantum detectors are analogous to thermoressive electronic thermometers. The photoconductive semiconductors most commonly used for photon detection in the 8 to 14 μm region are ‘three-metal alloys’, such as mercury-cadmium-telluride (HgCdTe).\textsuperscript{18} HgCdTe detectors have high efficiency combined with a low noise (low ‘dark current’), allows the determination of skin temperature of areas less than 10 mm\(^2\) at a distance of 100 cm from the camera with a precision of a millidegree.\textsuperscript{18}

**Infrared Radiation Measurement in Medical Field**

Using an appropriate detector, skin temperature can be measured remotely at a single spot (telethermometry or radiation thermometry), or provides quantitative information on the temperature distribution over a large area of skin (telethermometry or telethermography). Clinical telethermography systems consist of infrared detector with its appropriate amplifier-digitizer and readout electronics, a microcomputer, and a video display.\textsuperscript{18}

The detectors must be sensitive to infrared radiation in the 8 to 12 μm region. Three configurations of infrared detectors can be used for telethermography: A single element infrared detector, a linear array of infrared detectors and a two-dimensional array of detectors.

Infrared radiations emitted by the face enters the lens of the camera, passes through a number of rapidly spinning prisms (or mirrors), which sequentially reflect the infrared radiations emitted from different subareas of the field of view onto the infrared sensor. The sensor converts the reflected infrared radiations into electrical signals. An amplifier receives the electric signals from the sensor and boosts them to electric potential signals of a few volts, that can be converted into digital values. These values are then fed into a computer. The computer uses this input, together with the timing information from the rotating mirrors, to reconstruct a digitized thermal image from the temperature values of each subarea of the field of observation. These digitized images can be analyzed with appropriate image analysis software or stored on a computer disk for later reference.\textsuperscript{8}

**FACIAL TELETHERMOGRAPHY**

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 are small (about 0.2°C).\textsuperscript{19} 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.\textsuperscript{20} Whereas the right-versus-left-side temperature differences (termed static area DT values) between many specific facial regions in asymptomatic individual subjects were shown to be low (< 0.3°C). The area DT values were found to be > 0.5°C in a wide variety of chronic facial pain disorders.\textsuperscript{21}

There are certain guidelines to be followed while taking a facial telethermography as advised by Japanese Society of Thermology.

1. Keep the testing room free of wind. Turn off air conditioners.
2. Keep sources emitting high-temperature infrared away from the subject.
3. Keep control room temperature at over 25°C. Record room temperature and humidity when taking each thermal image.
4. Stabilize the environment for at least 20 minutes before examination in the winter.
5. Instruct the subject to refrain for at least 4 hours before thermographic examination.
6. Note the following items as subject-related information in the medical record including name, sex, age, chief complaint, history of tobacco use, history of alcohol consumption, handedness, painful position, abnormal position, region of cold sensitivity, past medical history, present clinical history, presence of medical treatment and detail of medical treatment, diagnostic entity, body temperature, time when the thermal image is taken, room temperature, room humidity, and wall temperature.
7. Check the first thermal image again at the end of the sequence to confirm the reproducibility of images and changes over time.
8. Judge the interoral condition and perform periodontal inspection.
9. Hold the frontal region and chin of the subject and set a thermo-camera at a consistent distance from the subject.
10. Instruct the subject to remain seated during image acquisition.
11. Inform the subject to keep water in mouth for 5 seconds before image acquisition.
12. Instruct the subject on edge-to-edge occlusion and on the prohibition of mouth respiration during image acquisition.\textsuperscript{22}

**Applications of Thermography in Dentistry**

**Detection of Infra-alveolar Nerve Deficit**

The thermal imaging of the chin has been shown to be an effective method to assess inferior alveolar nerve deficit.\textsuperscript{23} Subjects with no inferior alveolar nerve deficit show a symmetrical thermal pattern, with an area DT of + 0.1°C (± 0.1°C SD) w (μ), while patients with inferior alveolar nerve deficit had an area DT of + 0.5°C (± 0.2°C SD) on the affected side.\textsuperscript{23} The observed vasodilation 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.\textsuperscript{24}

**TMJ Disorders**

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 + 0.4°C (± 0.2°C SD).\textsuperscript{25} 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 + 0.4°C (± 0.2°C SD). In addition, a study of mild-to-moderate TMD
After 72 hours of treatment with acyclovir cream, majority of the patients returned to normal with no clinical or thermographical evidence of infection.27

**Chronic Orofacial Pain Patients**

A new classification system of facial area DT measurements was introduced.23 This system classifies telethermographs as ‘normal’ when selected anatomic area DT values range from 0.0 to ± 0.25°C, ‘hot’ when area DT is > – 0.35°C, and ‘cold’ when area DT is < + 0.35°C. When a selected anatomic area DT value is ± (0.26-0.35°C), the finding is classified as ‘equivocal’. The results have been tabulated in Table 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 (Dt°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.27

**COMPARISON OF THERAPEUTIC MODALITIES**

Infrared thermography promises to become a research tool for an objective assessment of anti-inflammatory treatment efficacy. A double-blind, placebo-controlled study was done to evaluate the effect of GaAlAs diode laser on wound healing and pain reduction in patients after extraction of impacted lower third molars by infrared thermography. The patient treated by active laser reported more pain and swelling during the first week after tooth extraction than the patient treated by placebo laser. However, the comparison of thermograms of patients treated by placebo and active laser showed the acceleration of wound healing after extraction in the patient treated with GaAlAs diode laser.28

**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. Tissues 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**

The various advantages of thermography are:
1. Noninvasive technique
2. Easy seating examination
3. Minimal examination time (2-3 minutes)
4. Nonexpensive technique
5. Obvious differences in color changes (gradient – 0.05°C).
6. Its real time enables very fast scanning of stationary targets and capturing of fast changing thermal patterns.

**CONCLUSION**

In dentistry, thermography can become important because of accurate measurement of regional temperature (0.05°C differences). Thermography may be useful in elaborating of a right diagnosis on an inflammatory reaction from maxillofacial territory. 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.

**REFERENCES**

3. Thermography www. techalone.com