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Dental Applications of Thermography
Termografinin Diş Hekimliğindeki Uygulamaları

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ABSTRACT
Thermography is a technique which utilizes imaging and visual evaluation of the thermal changes. The amount of blood circulation varies at different layers of the skin and hence, there is a change in temperature accordingly. This is the basis behind the principle of thermography. This technique is utilized in diagnostics. In this review article, we have made an attempt to highlight the applications of thermography in dentistry.
Key words: Thermography; temperature; thermal image.

ÖZET
Termografi, termal değişikliklerin görüntülü ve görsel değerlendirilmesinde kullanan bir tekniktir. Kan dolaşım miktarı derinin farklı katmanlarında değişkenlik gösterdiği için sıcaklıkta buna göre değişir. Bu kural termografinin temel prensibidir. Bu teknik teşhislerde kullanılır. Bu derleme, diş hekimliğinde termografi uygulamalarını vurgulamak için yapılan bir çalışmadır.
Anahtar Kelimeler: Termografi, sıcaklık, termal görüntüleme

Introduction

The study and implementation of biothermal processes for assessing well being or disease is called thermology. The term thermography involves imaging and visual examination of those thermal changes[1].When the mother handles her new born, the body warmth detection and touch can be the earliest conscious sensation, which is perceived by the newborn. Heat has a deep cognitive impact on human beings. There have been firm connections of life with warmth. Temperatures of the human body, which are moderate have been associated with well being and increased body temperature with ill health[2].

The concept behind such an implementation was incorporated on the fact that, as the quantity of blood circulation at various parts of the skin differs, the temperature also shows a change in accordance. Therefore diseases affect the flow of blood also result in irregularities in distribution of temperature and when assessed, they will yield genuine diagnostic data[1]. From the ancient past, bodily heat was considered as a major symbol of health and implementation of temperature determination along with thermal imaging had been involving. As the years passed, an array of devices have been employed such as thermometers, thermistors, thermocouples and liquid crystal imaging systems for determining the body temperature[3]. In this review, we aim to discuss history, types of thermography and also understanding of its working principles. We have also highlighted the probable uses of thermography in dentistry.

History

Good health, according to primitive medicine has been perceived as an equilibrium among the elements. Around 600-400 BC, the measurement of temperature of human body was an essential feature of pre Hippocratic medicine of Greeks. During 400 BC, body temperature was utilized as a diagnostic symbol[4]. Hippocrates measured the skin temperature of his ill patients by using his right hand[5]. Galen (130-210 AD) emphasized that body heat was created due to the bio combustion of food. Also, he reviewed a concept on the feedback among sensory as well as motor nerves which is known today as the primary mechanism of thermoregulation[6].

Galileo's thermoscope was invented in 1592, which was an air thermometer which is semiquantitative and displayed shifts in the temperature. It was altered by Santorio Sanctorius in 1611, who made modifications in the thermoscope and created a thermometer which displayed the variations in core humans body temperatures in case of well being as well as illness[7,8]. In Germany,1872, Wunderlich brought in measurement of fever to be a habitual procedure in diagnostics[4,9].

In 1928, the earliest infrared image of a human subject was documented by Czerny in Frankfurt[10]. The diagnostic application of infrared thermography began in Germany, 1952. A single detector infrared bolometer was developed for diagnostics by Schwamm and Reeh for consecutive thermal measurement of specified body locations. The first medical association of thermography was founded by them in 1954 which is still operating as German Society for Thermography and Regulation Medicine[11].

In the earlier days, single infrared detectors were used. As a result of advancement of additional devices such as contact thermography by electronic thermometers along with liquid crystal plates, they were incorporated in diagnostic methods. Earlier camera, which was used for infrared imaging which was obtained from military systems had limitations due to poor resolution (thermal as well as spatial) along with being expensive. Lack of computer hardware and software added to the disadvantages. Superior technology acceptable for medical causes was accessible since around 1980 which was then used globally mostly LN2 cooled MCT (HgCdTe) scanners. Uncooled microbolometer Focal Plane Arrays (FPA) systems emerged economical after 2000. They were frequently used in medicine despite some methodological problems leading to misinterpretation[11].

Types

Depending upon the type of operation, thermography can be categorized as follows,

1. Contact Method: This is semi quantitative which employs liquid crystals called liquid crystal thermography (LCT),
2. Non-contact method: This is a quantitative infrared-detecting method which is called as Infrared Telethermography (ITT) and Dynamic Area Telethermometry (DAT)[4,12].

Temperature of the skin can be determined by static thermography or dynamic thermography. Temperature measure in a single instance of time is called static thermography. If measured in a series of many consecutive instances, it is called dynamic thermography[13].

Liquid Control Thermography

A liquid crystal thermometer comprises of pliable rubber layers. Inside the layers, cholesteric crystals are ingrained. The crystals are organized in sheets that are seated on a frame. The rubber layers have an arrangement for inflation such that the surface, which is responsive to heat is well conformed to the contour of the body. In order to determine the thermal changes, the crystal sheets are arranged upon the areas to be inspected. A shift is seen in the colour of the crystals from a neutral colour to another colour as a reaction to the temperature of the surface. The conclusive colour presentation is then captured by polaroid photography. It provides an immediate hard copy of the image[12].

Some benefits of LCT are portable systems without any electric requisites. They are considerably economical compared to electronic telethermography units. There are numerous shortcomings which include reduced thermal sensitivity, around 0.3-1ºC. The process, being technique sensitive necessiates meticulously calculated skin contact for recording a consistent distribution of temperature. Furthermore, the liquid crystal display has a poor spatial resolution which is < 5 mm.

The primary limitation is that body surface temperature cannot be precisely determined by any equipment which established contact with the skin.[4] In spite of drawbacks, LCT has yielded purposeful conclusions while assessing thermal irregularities of the face as a result of disorders of the orofacial region[14]. Therefore measuring the skin temperature devoid of numerous artifacts, it is hugely useful to ascertain the temperature of the skin without a contact between the the monitoring device and skin, which is done remotely by determining the infrared black body radiation emitted by it[15].

Infrared Telethermography

ITT also referred as telethermometry, telethermography, digital infrared telethermographic imaging or electronic thermography is a noncontact method of determination of temperature, where the detector is placed at a single spot[12]. It comprises of an amplifier-digitizer, an infrared detector, a microcomputer along with a video clip[16]. The infrared detectors which are used are of various types and include linear array infrared detectors, single element infrared detector and two dimensional array detectors[17]. The single detector infrared radiation thermography functions in a manner such that as the infrared radiation emitted by the face entered the germanium lens, it passed via the mirrors placed perpendicular. The electric signals are converted to digital values by an amplifier. These signals are reconstructed into a digitized thermal image.

An infrared camera having a linear array of detectors requires a mirror. The mirror usually revolves around a vertical axis in order to scan the field of view (FOV). Therefore the vertical resolution is restricted. FPAs or two dimensional arrays comprise of a plate of miniature detectors and a germanium lens. The germanium lens works similarly to a single detector system. Thus it guides in focusing the infrared influxes on the detectors directly. The benefits of the FPA cameras are increased speed, thus allowing to acquire more than100 images per second, maintenance free performance as there are no moving parts and reliability Nonetheless, limited spatial resolution is the drawback[12].

Noncontact clinical thermometry has not turned into a reality with the dawn of quantum physics. Due to reduced energy and radiation intensity emitted by the body at skin temperature, biological telethermometry was not empirical till the evolution of specific and sensitive detectors of infrared radiation[18].

Dynamic Area Telethermometry

DAT is a recent promising branch of infrared imaging which is directed at the quantitative measurement of the time dependence of skin temperature, assessing the modulation of temperature that has direct bearing on the thermoregulation of skin. Temporal behavior of surface temperature is studied using a series of thermal images along with quantitatively assessing the temporal thermal behavior of each subarea as a function of time. The temperature values, pertaining to a subarea unit is obtained from each of a sequence of thermal images, comprises a time sequence of temperatures, the dynamics of which can be analysed quantitatively. If the dynamic thermal action is periodical, fast Fourier transform examination of the time sequences can produce the underlying frequencies of the periodic modulation of temperature. Thus DAT can ascertain the neurogenic mediated thermal changes which pursue autonomic nervous function and can present additional pathophysiological or physiological information[12,16,17,19].

Characteristics of a Thermal Image

There are clinical applications which call for information about the distribution of temperature over a large area of the body's surface. This information is generally displayed as a thermal image which informs the clinician about the temperature of every spot over the area of interest at a certain instance in time.

1. Spatial resolution: The distance between two spots which are closeby, whose temperatures can be determined individually, and due to their thermal resolution. Thermal resolution is the least difference in temperature, which can be determined at two individual spots on the image.
2. Temporal resolution: The lag in time between a temperature difference at a definite spot on the observed area and the resultant change on the thermal image.
3. Time responses: In addition, like temperature measurement at a single location, different thermal imaging devices have their characteristic time responses, i.e., the time taken to obtain a reliable thermal image of a monitored area[12].

Facial Telethermography

There is a normally proportional pattern of dissipation of radiative heat over the human body. In normal subjects, there have been small changes in temperature of the skin at chosen points from side to side, which is around 0.2ºC)[20].

In normal subjects, ITT of the face have revealed that men have increased temperatures when compared to females. The logic behind this is that men have increased basal metabolic rate compared to women and the skin dissipates increased heat per unit area of body surface. In a similar manner, ethnicity and age differences in facial temperature can also happen[21,22,23].

It was found that men have greater temperatures than women over the 25 anatomic areas determined on the various parts of the face, for example orbit, cheek, chin, upper and lower lip[22]. When in fact, temperature differences between the right and left side among several specific regions of the face in symptom free individual subjects were found to be less $<$ 0.3ºC. It was found that the area delta T values were $>$ 0.5ºC among various disorders of chronic facial pain[24].

General Clinical Requirements

The first 7 guidelines are by the Japanese society of Thermology. The latter 5 were added by Koriyama et al.

1. Keep the testing room free of wind. Turn off air conditioners.
2. Keep sources emitting high-temperature infrared away from the subject. Place a screen between any heater and the subject
3. Keep control room temperature at over 25ºC. 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 from smoking 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.25
8. Judge the interoral condition and perform periodontal inspection.
9. Hold the frontal region and chin of the subject and set a thermocamera 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 acquisition26.

The use of ITT in the dental arena has been minimum, mainly as a result of technological insufficiencies of previous thermal imaging systems. Due to ever evolving technological development, present systems have the ability to produce real time extremely sensitive digitized thermal images[27].

Chronic Orofacial Pain Patients

A recent system of classification of the Delta T measurements of the facial area was brought in.[24] Telethermographs were classified as 'normal' by this system when Delta T values of selected anatomic area were ranging from 0.0 to ± 0.25ºC, 'hot' when area Delta T is > – 0.35ºC, and 'cold' when area Delta T was < + 0.35ºC. When a Delta T value of a selected anatomic area is ± (0.26-0.35ºC), the data is then categorized as'equivocal'. Furthermore, they also found that hot thermographs had the clinical diagnosis of

1. Peripheral nerve mediatedpain,
2. Sympathetically maintained pain,
3. Maxillary sinusitis,
4. Temperomandibular joint (TMJ) arthropathy.

Subjects who were categorized with cold subareas on their thermographs were seen having diagnosis of sympathetically independent pain and Peripheral nerve-mediated pain.Subjects categorized with normal telethermographs were inclusive of patients diagnosed with Trigeminal neuralgia, Cracked tooth syndrome, Psychogenic facial pain and Pretrigeminal neuralgia. This recent classification resulted in 92% agreement in categorizing patients with pain, thus regarding it as a chief diagnostic parameter[13,24]. Sickles et al conducted a study which concluded that electronic thermography has a promise as a diagnostic test for atypical odontalgia among patients with toothache, for which the dentist cannot find any convincing dental explanation[28].

TMJ Disorders

Examination of normal temperomandibular joint using thermography had shown thermal patterns which are symmetrical with an average delta T values of 0.1°C[13,21,29]. Asymmetrical thermal patterns were seen in TMJ pain patients with temperatures increased over the involved region of TMJ. Mean area Delta T values were + 0.4°C ,± 0.2°C Standard Deviation[30]. Particularly symptomatic patients with internal derangement and temperomandibular joint osteoarthritis with pain were found having thermal patterns which are asymmetrical along with an increase in area temperatures over the involved area of TMJ. The mean area TMJ Delta T were + 0.4°C, ± 0.2°C Standard Deviation. Additionally a study conducted on patients with mild to moderate temperomandibular disorders depicted that area Delta T values corresponded with the patients level of the symptoms of pain[31].

In 1996, a double-blinded clinical study conducted by Beth and Gratt in order to compare the delta T values among patients undergoing orthodontic treatment, temperomandibular patients and asymptomatic controls of TMJ. The results revealed that the mean TMJ area delta T values were +0.2°C, +0.4°C, and +0.1°C in these groups[32]. The above mentioned results suggested that tele thermography can differentiate patients undergoing active orthodontic treatment and patients with temperomandibular disorders (TMD)[13,32].

In Assessing Pulp Vitality

Infrared thermographic imaging for human teeth is under investigation in order to assess the pulp vitality[33,34]. Temperature determination, as a diagnostic modality for human teeth, has been explained with the usage of infrared thermography, liquid crystals and thermistors. Cholesteric liquid crystals that display various colours while heated have been earlier employed to measure pulp vitality. The basic concept was the tooth having a vital pulp tissue had a warmer tooth surface temperature when compared to the tooth without blood supply[35,36].

Surface temperature of teeth has also been determined over a span of time at intervals of 15 seconds with the help of an electric thermometer, which is attached to a surface probe which is positioned in contact with the tooth. These studies manifested that following cooling, vital teeth displayed a successive increase in surface temperature[37,38].

Thermographic imaging is a non invasive and an extremely precise system of determining the body surface temperature. It has been utilized to reveal that following cooling, nonvital teeth were slower to re warm when compared to vital teeth[39].The limitation of this procedure is that the teeth should be isolated with rubber dam after which a span of acclimatization is required before imaging. The procedure is complex requiring the subjects to rest for an hour before testing[34].

In Quantification of Thermal Insult to Pulp

Pulps of tooth are exposed to various thermal insults during different treatment methods. In the recent times, Electro Thermal Debonding (ETD) method is extensively utilized for debonding brackets in orthodontics. This approach even though has abundant benefits compared to conventional mechanical method can cause serious thermal pulpal damage[3]. In 1999, Cummings and co-workers accomplished an in-vitro study on extracted premolars employing ETD. Examination of Thermal imaging was made utilizing detector of mercury cadmium terullide. It revealed that the pulpal temperature raised from 16.8^0C- 45.6^0C, which can be a threat to pulpal vitality. It can be established from the study that ETD methods required periodic cooling of the teeth along with concurrent thermal imaging to avoid damage to the pulp[40].

Inferior Alveolar Nerve Deficit

Neurosensory deficit is a major complication which is encountered in maxillofacial surgery[41]. The thermal imaging of the chin has proved to be procedure capable enough of assessing inferior alveolar nerve deficit. Subjects who do not have deficit of inferior alveolar nerve will display a proportional thermal pattern having an area delta T of $+ 0.1^{o}$C , $\pm 0.1^{o}$C Standard Deviation, although patients with deficit of inferior alveolar nerve had an area delta T of $+ 0.5^{o}$C , $\pm 0.2^{o}$C Standard Deviation on the affected side[42].

The observed vasodilatation assumed to be as a result of blockade of the vascular neuronal vasoconstrictive messages as an equal impact on the thermological pattern could be elicited in normal subjects. This is achieved by temporarily blocking of the inferior alveolar nerve by using a nerve block containing 2% lidocaine[41].

In 2007, Lee et al conducted a study for evaluating the damage and recovery of the inferior alveolar nerve in orthognathic patients at the first and fourth week following surgery using electronic thermography. They concluded that the infrared body temperature procedure is an objective method which can be applied as a supplemental diagnostic procedure for inferior alveolar nerve damage[43].

Qualitative Evaluation of Nitrous Oxide Concentration

Nitrous oxide is an insoluble gas that is quickly absorbed and removed promptly by the lungs. Thus it is utilized extensively either alone or when combination with other anesthetic agents[44]. Numerous studies have shown results that nitrous oxide leakage into the work area can cause detrimental health issues such as hematologic, nervous and reproductive dysfunctions[45]. Rademaker et al, in his study in 2009 utilizing infrared thermography to assess the efficacy of 2 nitrous oxide scavenging systems- The Safe Sedate Dental Mask (Airgas, Radnor,Pa.) system (System I) and Porter Nitrous Oxide Sedation System (Porter Instrument, Hatfield, Pa.) (System II), concluded that neither of the system was able to curb occupational exposure of nitrous oxide under the National Institute for Occupational Safety and Health Recommended Exposure Limit NIOSH REL. System I met the threshold value put up by American Conference of Governmental Industrial Hygienists of less than 50 ppm during an 8 hour day and accomplished significantly superior to System II[46].

Other Uses in Dentistry

A thermogram offers definite images for bone and neurologic disorder diagnostics, articular pain due to conditions such as rheumatoid arthritis, arthritis, muscular pain – hypo-or hypertonic reactions, osteoarthritis, diagnosis of any kind of inflammation of any kind, periodontitis - acute and chronic, supervision of endodontic treatments, tissues reactions subsequent to usage of new dental materials, diseases of the sinus, malignancies of the maxillofacial region, myofascial pain syndromes and neuralgia[15].

Conclusion

Thermography is useful in dentistry due to the accurate measurements of regional temperature (0.05^0 differences). Following treatment, thermograms can provide significant connections about the methods of treatment and their efficacy. Thermograms can be secured in a database, a compact disc or printed on regular or special paper[15]. Thermography helps in the evaluation as well as staging of different dysfunctions of the head and neck region. The exclusive significance of thermography is both quantitative as well as qualitative appraisal which aids in assessment of advancement of the disease in an orderly manner[1].

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