INFRARED RADIATION IN DENTISTRY; MEASURING HEAT EMISSION THROUGH PASSIVE METHOD OF THERMOGRAPHY

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Abstract: Medical Infrared thermography is a relatively new medical diagnostic tool, consisting in detection of infrared radiation emitted as thermal energy by the investigated area of the human body. Due a conversion device the thermal radiation transforms first into an electrical signal that can be viewed in real time as visible digital image, called thermogram. So far, the infrared thermography has been applied in many fields of general medicine and increasingly in dental medicine. This article reviews some applications of the method in dentistry specialties such as endodontics, odontology, TMJ pathology, maxillo-facial and oral surgery, periodontology and respectively prosthodontics.

Key words: infrared radiation, infrared thermography, thermogram, dentistry.

1. INTRODUCTION

Current methods used for medical diagnosis include images of the anatomical structures and analysis of functional parameters. The main structural methods include radiography, CT scan, ultrasound, magnetic resonance, mammography, microscopy, and among the most recognized functional methods are electrocardiogram, methods for determining blood pressure, electroencephalogram, lung tests and not least thermography.

Infrared thermography was first introduced in the military field, with the emergence of the first thermographic detector in 1830 [1], not benefiting from accepted medical support until 1956, when it was validated as a method of diagnostic imaging in breast cancer by Lawson [2]. This was due to both past limitations (infrared systems underperforming, absence of software or computer technology and methodology, divergent medical protocols) and the tendency of practitioners to prefer already known structural methods, which had the advantage of an easier association with pathological factor over functional techniques [3].

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Currently, infrared thermography knows a continued grow in modern medicine, explained by the technological advantages of the method in the prevention, the monitoring of some diseases, the selection and evaluation of treatments and its high diagnostic sensitivity and specificity reported by specialized studies [4–9]. The recent paradigm shift of traditional medicine focused primarily on the diagnosis and treatment of diseases, towards a modern approach to medicine aimed at preventing diseases through the identification and elimination of risk factors, thus opened new horizons regarding the applicability of thermography in a number of medical fields.

A series of functional disorders can be identified based on thermographic images, such as metabolic or vascular subcutaneous disorders, acute and chronic inflammatory processes, formation and development of tumor structures, degenerative changes, disturbances within some organs or structures with strong vascularization (including maxillofacial structures). For these reasons, and due the perfecting of image processing techniques, and to the increase of the sensitivity of thermal sensors and spatial resolution, the medical fields in which thermography has proven itself as a diagnostic method have become more numerous.

Thus, diagnostic thermography has been recognized and successfully applied so far in specialties such as rheumatology, dermatology, oncology, orthopedics, cardiology, neurology, angiology, occupational medicine, forensic medicine, general surgery, endocrinology, pediatrics, ophthalmology, and to an ever-increasing extent in dentistry [3]. In the case of dental medicine, infrared thermography appeared and grew as a necessity for the correlation of oral health with general health, opening new diagnostic directions along with conventional paraclinical investigations practiced in this area. Although small in applicability compared to general medicine, studies have been conducted in dentistry and reproducible results registered in endodontics, odontology, temporo-mandibular joint (TMJ) pathology, oral and maxillofacial (OMF) surgery, anesthesia, implantology, prosthodontics and beyond.

2. PRINCIPLES AND TECHNIQUE

But what is infrared thermography? Medical Thermography (MT) is a non-contact process that consists in capturing the surface temperature of various skin areas or mucous membranes of the body and changing it into visible images with diagnostic value, called thermograms. In turn, the surface temperature is closely related to the local metabolism and physiological or pathological changes of various tissues and underlying systems (nervous, vascular, muscular), allowing the images to be interpreted in a much broader sense. Pathological processes and their evolution materialize by changing the surface temperature, making not only a diagnosis but also real-time monitoring possible through the thermographic method.
The method consists in the remote detection of infrared radiation emitted as heat by the investigated area. Heat flow is generated from the living body, no external heat sources being needed for thermal recording, the medical field thus involving a strictly passive, non-invasive assessment, also known as the non-destructive thermography technique [10].

The skin temperature of the human body is approx. 5°C lower than the internal temperature and is determined by the vascular supply, the degree of vascularization of the skin tissue (venous blood) and the metabolism of the underlying tissue, the regulation of heat being achieved through the sympathetic nervous system. In thermography, the human body heat released as electromagnetic radiation invisible to the human eye, is collected and processed by special detectors, represented by sensors sensitive to infrared radiation, able to measure the heat pattern of the skin and mucous membranes, which have an emissivity close to 1.

Infrared detectors – thermographic cameras – can detect emitted thermal radiation, and transform them, with maximum accuracy, into a visible digital image, called thermogram. The first heat signal conversion into an electrical signal, easy to register, is done with a conversion device, and thermal images can be viewed in real time and then computer-processed [1, 11]. Because it can detect the earliest and slightest metabolic disruptions in form of thermal signals, thermography is currently the only method that is able to predict clinical manifestations of inflammation [11]. The details provided by thermography therefore exceed the anatomical (structural) ones, the principle of this method being simple, painless, and noninvasive [3].

The basic principle for the medical assessment by thermography is assuming a symmetrical distribution of temperature for both sides of the body in a healthy human [12], whilst asymmetrical thermal fields are considered pathological. Thus, thermograms are evaluated comparatively, in the right and left half of the body, and any deviations from symmetry have diagnostic value. Differences up to 0.2°C can quickly be detected and a 1°C difference to the surfaces of the corresponding healthy organism, is considered significant from a pathological point of view [1, 13, 14].

Thermograms thus render the thermal profile of the surface of the skin or the mucous membrane of interest, by illustrating a code of colors allocated to thermal values, whereby the colors of the thermograms strictly represent a quantitative coding of temperature, not a qualitative one. In order to standardize the analysis of thermograms, the International Organization of Standards (ISO) recommended the norm ISO/TR 13154: 2009 on medical equipment such as thermographic cameras, the use in the diagnosis of pyrexia, of the rainbow temperature scale, which encodes high temperatures in the color red and low temperatures in the color blue [15]. The thermal differences between corresponding tissues or structures may also be viewed by using a rainbow color scale with stark contrast, while for the analysis
of the vascular system, a grayscale is preferred, some software packages allowing 
the operator to generate a custom color scale, when the clinical situation calls for it. 
Modern technology has led to thermography becoming a method of temperature 
measurement with guaranteed results, but for its use in diagnostic procedures a few 
basic criteria must be met. The quality of the thermal images depends on both the 
technical equipment and on the experience of the examiner [16]. A number of factors 
can negatively influence the thermographic results, compromising the real thermal 
values, beginning with patient related ones (before and during the investigation), to 
the ambient environment in which the test is conducted, to the calibration of the 
infrared camera, to the analysis and interpretation of the images. The thermographic 
companies, although there is no general standardized consensus regarding the 
procedural protocol, release technical specifications and recommendations related 
to the thermographic examination itself through instructions for each medical field 
[1, 16, 17, 18].

3. APPLICATIONS IN DENTAL MEDICINE

3.1. ENDODONTICS

In dentistry, one of the first thermographic studies undertaken in endodontics 
[19], Mc. Cullagh et al. (1997), investigated the thermal changes occurring on the 
root surfaces of extracted premolars (Table 1) during the thermomechanical filling 
of root canals by warm condensation of gutta-percha. The result suggested an 
increase of the root temperature with higher reduction speed, higher thermal values 
requiring an amplified local blood supply for heat dissipation. At the time of the 
study, the harmful biological effects of thermal condensation at the root and 
periodontal space (interruption of blood flow and bone necrosis given by the raise 
of local temperature values over 60°C) were not yet recognized [20].

Another thermographic study on morphological changes and temperature effects 
caused by the irradiation of tooth roots with an 810 nm emission wavelength laser 
diode in order to sterilize them, demonstrated the possibility of using this laser in 
compliance with certain thermal thresholds (every 10°C) and with radiation time, 
taking into account the marked heating of the interradicular areas and the areas 
close to apex, where the root walls are thinner [21].

Thermographic assessments were also performed for assessing the level of 
periodontal harm when filling root canals using systems such as Thermafil Plus 
[22], for the preparation for the application of endodontic pins [23], but also for 
diagnostic purposes for testing the vitality of dental pulp [24], or for monitoring the 
distribution of the hydraulic flow during the irrigation of the canals, with different 
irrigating endodontic needles [25].
### Table 1
Thermographic studies in dental medicine

<table>
<thead>
<tr>
<th>Authors</th>
<th>Year</th>
<th>Field</th>
<th>MT Camera</th>
<th>Room Temperature</th>
<th>Investigation Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>MC Cullagh et al. [19]</td>
<td>1997</td>
<td>Endodontics</td>
<td>Thermovision 900; (Agema, Danderyd, Sweden)</td>
<td>unspecified</td>
<td>in vitro</td>
</tr>
<tr>
<td>da Costa Ribeiro et al. [21]</td>
<td>2007</td>
<td>Endodontics</td>
<td>SC 3000 (Boston, MA)</td>
<td>21°C</td>
<td>in vitro</td>
</tr>
<tr>
<td>Hsieh et al. [25]</td>
<td>2007</td>
<td>Endodontics</td>
<td>ThermaCAM (National Instruments Co., Austin TX, USA)</td>
<td>unspecified</td>
<td>in vitro</td>
</tr>
<tr>
<td>Kabbach et al. [29]</td>
<td>2008</td>
<td>Odontology</td>
<td>SC 3000 (Boston, MA)</td>
<td>20°C</td>
<td>in vitro</td>
</tr>
<tr>
<td>Rodrigues-Bigaton et al. [30]</td>
<td>2013</td>
<td>TMJ Pathology</td>
<td>T 360 (Flir Systems, Danderyd, Sweden)</td>
<td>22°C± 1°C</td>
<td>in vivo</td>
</tr>
<tr>
<td>Batinjan et al. [44]</td>
<td>2014</td>
<td>OMF Surgery</td>
<td>T335 (Flir Systems Pty, Ltd, Australia)</td>
<td>unspecified</td>
<td>in vivo</td>
</tr>
<tr>
<td>Scarano et al. [51]</td>
<td>2011</td>
<td>Implantology</td>
<td>SC3000 QWIP, Flir Systems, Danderyd Sweden</td>
<td>23°C-24°C</td>
<td>in vitro</td>
</tr>
<tr>
<td>Degidi et al. [53]</td>
<td>2012</td>
<td>Implantology</td>
<td>Thermal camera (Series A, FLIR Systems Inc., Boston, MA, USA)</td>
<td>23°C-24°C</td>
<td>in vitro</td>
</tr>
<tr>
<td>Preoteasa et al. [58]</td>
<td>2010</td>
<td>Prosthodontics</td>
<td>ThermaCam PM 350 (Flir, Inframetrics, USA)</td>
<td>unspecified</td>
<td>in vivo</td>
</tr>
<tr>
<td>Iosif et al. [59]</td>
<td>2011</td>
<td>Prosthodontics</td>
<td>ThermaCam PM 350 (Flir, Inframetrics, USA)</td>
<td>20°C-24°C</td>
<td>in vivo</td>
</tr>
</tbody>
</table>

### 3.2. ODONTOLOGY

Thermographic diagnosis of caries dates back to 1998, as described by Matsuyama [26] and a year later by Kaneko [27] primarily as a method for quantifying the lesion activity and less for the presence or absence of the caries process. Energy transmitted by thermal radiation propagates in the form of electromagnetic waves,
changes in emissivity becoming quantifiable when dehydration occurs through the evaporation of water from the structure of hard dental crown tissue (4% in enamel, 13% in dentin), as it occurs in the case of caries processes.

In 2005, Al Quadal et al. [28] signaled differences in temperature release during light-curing for different permanent dental restorative materials. Using thermography, a flowable and a packable composite, a conventional hybrid composite, one compomer, and a modified resin glassionomer material were analyzed, the maximum thermal values being found in the case of the flowable composite (43.1°C), followed by medium thermal values in the conventional composite and RMGI (32.8°C), with minimum temperatures being registered for the compomer (23.3°C) respectively for the packable composite (22.4°C). Differences of up to 20°C between materials raised discussions regarding possible implications for the pulp vitality in the high temperature cases.

Teeth whitening techniques also benefit from infrared thermography for identifying the harmful action of the energy source which accelerates the decomposition of the bleaching agent (hydrogen peroxide), to the body's nerve. According to Kabbach et al. (2008), LED lighting sources generate less heat increases on the surface of the root and pulp, compared to halogen lamps, thus being less harmful to dental tissues [29].

3.3. TMJ PATHOLOGY

Temperomandibular dysfunctions (DTM) have a complex plurifactorial etiology, and are manifested in multiple forms through a predominantly painful symptomatology, while it is possible for the masticatory muscle, the TMJ and the articular disc to simultaneously be part of pathological presentation [30]. All of these factors encumber the establishment of an optimal method of diagnosis, despite various initiatives undertaken hitherto [31–35]. Of these methods, infrared thermography can be used in the diagnosis of some DTM, such as osteoarthrosis [36], the correlations between TMJ arthralgia and the thermal changes of the surrounding regions, initially refuted by a study conducted in 2004 [37] being subsequently demonstrated in 2013 [30].

Other recent studies [38, 39] have identified the correlation between the severity of TMJ disorders and the temperature of the corresponding facial skin, as well as the association with thermal changes in the corresponding areas of the masseter muscle and the temporal anterior fascicle.

3.4. ORAL AND MAXILLO-FACIAL SURGERY

Thermographic comparative research with other pathological conditions (acute inflammation, chronic, benign tumors, cystic formations) in the same region [40] has shown some features of thermal array in the case of malignant processes in
the oral and maxillofacial region. These were highlighted by a markedly elevated
temperature of the skin and mucous membranes superjacent to the carcinoma, the
thermal values being exceeded only in cases of acute inflammation. Another
specific feature of these malignancies consisted in increased thermal values of the
facial skin irrigated by the carotid artery of the affected side, values which can be
explained by the acceleration of the basal metabolism due to the faster cell division
of neoplastic cells, thus causing, through an increase of the vascularization of the
area, also an increase of the thermal gradient.

Although it cannot substitute for routine imaging techniques, infrared
thermography can serve in the diagnosis of malignant tumors, in conjunction with
radiological and histopathological examinations, as Košutić et al. demonstrated as
early as 1978 in a case study [41] on a lower labial carcinoma, own later research
(2012) [42] allowing the highlighting of neoplastic infiltration of the mucosa of the
lower lip, in the case of localized skin basal cell carcinoma (Fig.1a, b).

![Thermographic imaging enables the monitoring of the toxicity of chemotherapy for neoplasms of the OMF region, the prevention and assessment of the severity of radiumucositis, as an intense inflammatory response to radiotherapy [43] and generally in the case of any inflammatory phenomena after surgery, such as teeth extractions [44] or posttraumatically, as part of the healing process, as they've been recorded in mandibular bone fractures [45]. In addition, infrared thermography has proven to be an extremely useful method of diagnosis in inferior alveolar nerve damage, as it sometimes occurs during sagittal osteotomies on the mandibular ram, conducted between Spix’s spine and the sigmoid notch, in patients with class III-type skeletal abnormalities [45].](image_url)
Minor labial salivary gland functionality, commonly investigated by scintigraphy, sialography, chemical analysis and histochemical analysis, has also successfully been tested through the thermography method. Labial mucosa areas wet by saliva, stood out on the thermograms because of an increased opacity, compared to areas marked by hyposialy [46], the result owing to the opacity of saliva for infrared radiation, being, like water, a transparent fluid for visible light.

3.5. PERIODONTOLOGY

Thermal rebalancing after cooling with air for the diagnosis of the inflamed gum, compared to the undamaged one, was successfully thermographically tested as early as 1986 by Barnett et al. Thus, the thermograms for the marginal fixed, the papillary, and the free gingiva, indicated, by a strong coloring of tissue inflammation depending on its severity (normal, moderate, severe), the feasibility of the method [47].

Also in the field of periodontology, thermographic research on some young patients [48], affected by rapidly progressing, aggressive periodontitis, reveal thermodynamic behaviors with diagnose value, regarding periodontal superficial vascularization and its regulating ability, infrared thermography also assuming an important role in the diagnosis of tumor infiltrates, that are found in the superficial marginal periodontium, within certain malignancies such as leukemia [49]. Along with its diagnostics capability, thermography enables the monitoring of periodontal treatments performed by laser, in order to limit the harmfulness of the thermal effects on the marginal superficial periodontium [50].

The peri-implant bone healing process is complex, the success of dental implants largely depending on the primary healing stage. For this to proceed as positively as possible, the preparations of the implant pocket should be the least traumatic, both mechanically and thermally. The thermal values in the region near the perforation hole of the bone, usually reach around 56°C during the preparation for the implant insertion, a temperature at which alkaline phosphatase is distorted, having an effect of slowing the rate of bone healing, sometimes even osteonecrosis, which is why the use of external irrigation systems with saline solution (physiological saline at 4°C) of the type of physiodispenser becomes indispensable.

Using infrared thermography, it was possible to identify the role of the design of the drilling reamers [51] in producing heat in surrounding tissues, with higher temperatures being recorded in the case of cylindrical cutters, compared to conical ones. The method of intraoral welding of titanium clips, introduced in 1981 by Mondani and Mondani [52], also benefited from the infrared thermography technique. Thus, thermal dissipation and heat transmission in peri-implant tissues were thermally evaluated, the authors of the study not recording thermal values higher than 39°C in
the potentially harmful areas of interest, provided the recommended flow rates for the welding procedure were respected [53].

3.6. PROSTHODONTICS AND IMPLANTOLOGY

Data from specialty literature showing thermography studies undertaken in the field of dental prosthetics are quite limited so far. Among these, in the case of fixed prosthetics, thermography has been found useful in assessing the heat generated during the preparation of abutments for the purpose of fixed coronary restorations, as is the case with whole ceramic crowns, where the sacrifice of dental hard substance is a much more important one. Such a study [57] allowed comparisons to be made on the aggressiveness of the different grain size of grinds and cutters, but also related to the specificity of reduction (continuous vs. intermittent).

Other thermographic tests in implantology followed the thermal changes occurring in the cortical bone during low-speed drilling [54] the irrigation systems during drilling vs. internal irrigation systems and generally most of the factors responsible for the apparition of a thermic peak during bone preparation (the pressure, duration, drilling speed, milling design, drill sharpness, implant system, cortical thickness, depth of drilling, bone density and so on) can generally also be thermographically tested [56].

In the case of removable dentures, conventional or on implants, the first studies date back to 2010 [58] and 2011 [59] respectively. Thus, the first study discussed the possibility of a rapid imaging of the mucosa covered by the prosthesis, other than through routine microscopic examinations – such as infrared thermography – after the visualization of the different appearances of the thermograms in the various clinical forms of denture stomatitis (DS) (Figs. 2, 3), the results of which were successfully reproduced some years later [60].

Fig. 2 – Maxillary mucosa in DS type I [58].
The second study used infrared thermography to demonstrate the low thermal resistance of the polymeric material from which most of the removable dentures are made [59]. The material takes over and stores the temperature of the contact surface for a significant period (thermal retention), creating true negative fingerprints of the supporting mucosa, as demonstrated by the thermograms of the denture after its removal from the oral cavity at different time intervals (Figs. 4–6).

Furthermore, thermography can be used as a diagnostic test for structural changes of the oral mucosa such as Candida-associated DS, with a high sensitivity and specificity, similar to the culture-based microbiological analysis method [61], possessing the potential to also be used for the diagnosis of structural changes of teeth, that can be assessed microscopically [62].
4. CONCLUSIONS

The major technological progress recorded by the new generations of infrared detectors has led to an increase in the degree of accuracy offered by thermal imaging, as an alternative method of medical diagnosis, that allows the assessment and quantification of abnormal, pathological heat fields. Moreover, the improved thermal sensitivity of the thermographic chambers, the increase of the spatial resolution, along with the non-invasive, non-contact character of the investigation, contributed to its extension in all medical fields, including dentistry, in specialties such as endodontics, odontology, TMJ pathology, periodontics, oral and maxillofacial surgery, prosthetics, implantology and beyond.
Thermal images (thermograms) can be stored digitally and then processed with different software packages to optimize the analysis of the thermal field. The interpretation is quicker and easier in the case of color coded thermograms. Compared to existing diagnostic methods, infrared thermography also prevails through other advantages, such as the speed of realization, the comfort for the patient, the lack of contraindications and side effects, through quantitative and qualitative evaluation of the investigated affection, which allows the progression of the diseases to be estimated in a systematic manner, so that its use in dentistry in the near future as a highly successful method of research and diagnosis is easily foreseeable.

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