# Thermography in dentistry: a bibliometric review

# Termografia em odontologia: uma revisão bibliométrica

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## ABSTRACT

Infrared thermography is an imaging exam present in the scope of diagnosis, evolutionary monitoring, and prognosis in the health area. Over the years, thermography has been studied in medicine, and it is a technique recently used in Dentistry. In this sense, the objective of this work was to carry out a literature review with a bibliometric approach to the use of thermal images for the diagnosis/monitoring of dental treatments. Studies that relate thermography to dental specialties were analyzed, considering the use of thermography as a diagnostic aid and monitoring of dental treatments in its wide range of activities. Searches were performed in the following databases: PubMed, Web of Science, Embase, Scopus, Scielo, from 1985 to 2020, with a search phrase including thermography and Dentistry specialties. The results show the trends in publications relating thermographic images to dental specialties by year of publication, journals, country, type of study, manufacturer of cameras used, resolution, and ambient temperature, totaling 119 publications in 83 journals. Temporomandibular Dysfunction and Orofacial Pain was the specialty with the highest concentration of publications relating thermography to Dentistry (27 articles). Endodontics was the second specialty (23 articles),

Restorative Dentistry was the third specialty (18 articles) followed by Surgery (17 articles). It can be concluded that thermography is indicated as an auxiliary diagnostic method in Dentistry specialties. The main indications for thermography in Dentistry are in the context of diagnosis of Orofacial Pain (dysfunctions temporomandibular disorders of the muscular and articular types, noninflammatory odontalgias and neuropathies), Endodontics (inflammatory odontalgias), Implantology (osseointegration), and follow-up evolution of the postoperative surgeries.

**Keyword:** infrared thermography, thermal images, dentistry, dental care.

**RESUMO**

A termografia infravermelha é um exame de imagem presente no âmbito do diagnóstico, monitorização evolutiva, e prognóstico na área da saúde. Ao longo dos anos, a termografia tem sido estudada em medicina, e é uma técnica recentemente utilizada na Odontologia. Neste sentido, o objectivo deste trabalho foi a realização de uma revisão bibliográfica com uma abordagem bibliométrica da utilização de imagens térmicas para o diagnóstico/monitorização de tratamentos dentários. Foram analisados estudos que relacionam a termografia com especialidades dentárias, considerando a utilização da termografia como auxiliar de diagnóstico e monitorização de tratamentos dentários na sua vasta gama de actividades. As pesquisas foram realizadas nas seguintes bases de dados: PubMed, Web of Science, Embase, Scopus, Scielo, de 1985 a 2020, com uma frase de pesquisa incluindo termografia e especialidades de Odontologia. Os resultados mostram as tendências em publicações relacionadas com imagens termográficas a especialidades dentárias por ano de publicação, revistas, país, tipo de estudo, fabricante de câmaras utilizadas, resolução, e temperatura ambiente, totalizando 119 publicações em 83 revistas. Disfunção Temporomandibular e Dor Orofacial foi a especialidade com a maior concentração de publicações relacionadas com termografia para a Odontologia (27 artigos). Endodontia foi a segunda especialidade (23 artigos), Odontologia Restaurativa foi a terceira especialidade (18 artigos) seguida de Cirurgia (17 artigos). Pode concluir-se que a termografia é indicada como método auxiliar de diagnóstico nas especialidades de Odontologia. As principais indicações para termografia em Odontologia estão no contexto do diagnóstico da Dor Orofacial (disfunções temporomandibulares dos tipos musculares e articulares, odontodontias não inflamatórias e neuropatias), Endodontia (odontias inflamatórias), Implantologia (osseointegração), e evolução do seguimento das cirurgias pós-operatórias.

**Palavra-chave:** termografia infravermelha, imagens térmicas, odontologia, cuidados dentários.

## 1 INTRODUCTION

Infrared thermography is an imaging examination present in the scope of diagnoses, evolutionary monitoring, and prognosis in the health area, first described in 1956 by R.N Lawson, to diagnose breast cancer [1]. Many devices that enable measuring the body temperature, like thermistors, thermocouples, liquid crystal imaging system, and thermometers, were described with the advancement of thermography [2]. In 1987, the American Academy of Medical Infrared Imaging recognized the medical infrared thermography [3].

Any person can have the infrared imaging examination done, including children and pregnant, because it is a painless method that does not rely on ionizing radiation, therefore helpful as an advanced supplementary diagnosis [4, 5, 6, 7, 8]. Throughout the years, medicine has been using thermography, and it is a recent technique in Dentistry. Scientific research shows that this exam is accurate and reliable as a tool in diagnosis, according to the theory of the musculoskeletal system, which claims that structures must be in thermal equilibrium and symmetric, when in a healthy state [9].

Although Dentistry already uses thermography, the subareas in dental treatments in which this tool could bring the most benefits to diagnosis and monitoring are still not clear. Besides that, the research centers, authors and journals in this field are not yet formally established. Therefore, the objective of this study was to conduct a literature review with a bibliometric approach about thermal imaging to diagnose and monitor dental treatments.

## 2 METHODOLOGY

### 2.1 SYSTEMATIC REVIEW

#### 2.1.1 Eligibility criteria

The main objective of this systematic review was to analyze studies that relate thermography to dental specialties registered in the Federal Dentistry Council, considering the use of thermography as a diagnostic aid and monitoring of dental treatments in its wide range of activities.

#### 2.1.2 Search strategy

The searches included the following databases: Pubmed, Web of Science, Embase, Scopus, Scielo, from 1985 to 2020. The search phrases contained thermography and the specialties recognized by the Federal Dentistry Council, as shown in Table 1.

Exclusion criteria were thermography in animals, thermography as a descriptive variable (not considered for diagnosis or monitoring), thermography not linked to specialties recognized by the Federal Dentistry Council, studies that did not use thermal cameras to measure the temperature, and clinical case reports.

Table 1. Search phrases used in the databases.

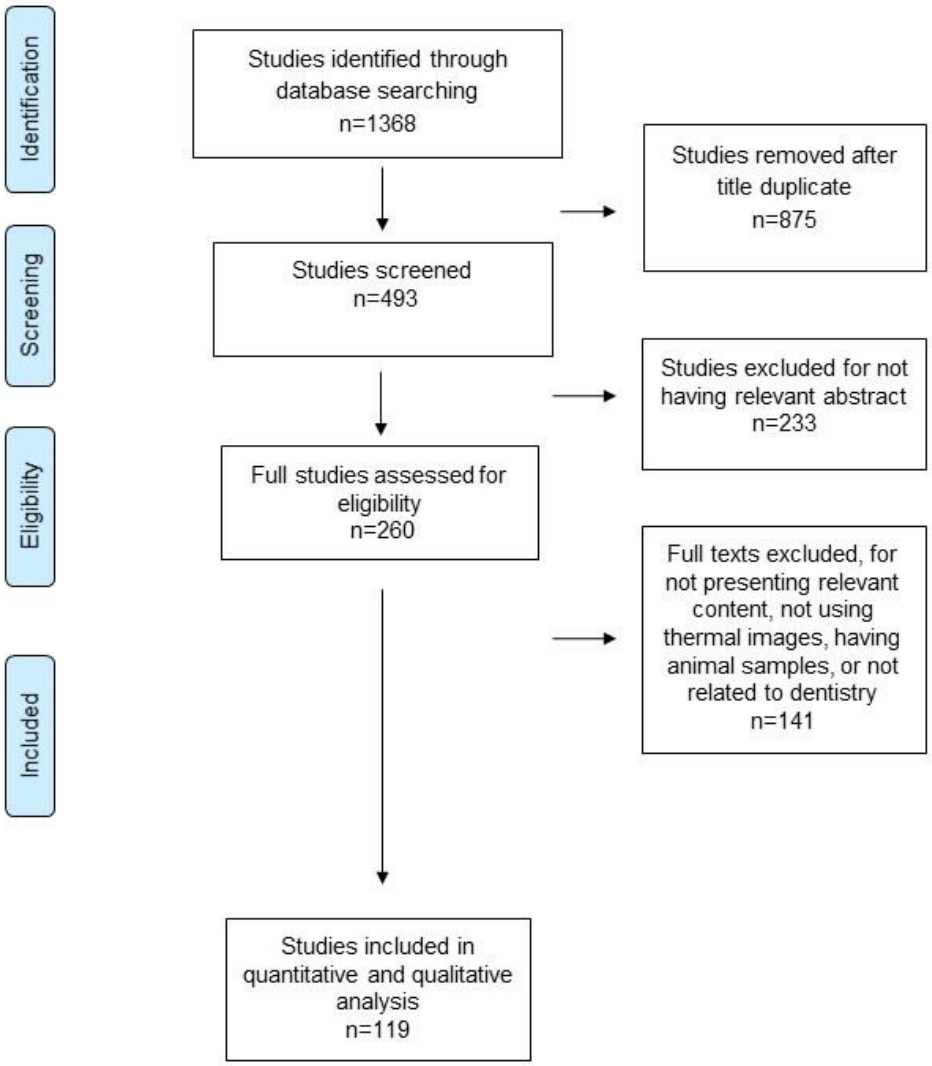
| Database | Search phrase | Total |
|---|---|---|
| PUBMED | (“Thermography” OR “Temperature Mapping” OR “Mapping, Temperature” OR “Mappings, Temperature” OR “Temperature Mappings” OR “Skin Temperature” OR “Skin Temperatures” OR “Temperature, Skin” OR “Temperatures, Skin” OR “Skin thermal” OR “Infrared imaging” OR “Infrared thermography” OR “Infrared Camera” OR “Thermographic pictures” OR “Thermographic images” OR “Thermographic imaging” OR “Thermal images” OR “Thermal image” OR “Thermal imagers” OR “Thermal imaging”) AND (“General practice, dental” OR “Dental General Practices” OR “Dentistry” OR “Medicine, Oral” OR “Oral and Maxillofacial Pathology” OR “Neoplasms, Oral” OR “Fever Blister” OR "Temporomandibular joint dysfunction syndrome" OR "Temporomandibular joint disorders" OR “Facial Pain, Neuralgic” OR “Maxillofacial Surgery” OR “Paresthesias” OR “Endodontology” OR “Dental Pulp Necroses” OR “Odontalgia” OR “Odontalgias” OR “Periodontic” OR “Periodontal Disease” OR “Salivary Gland Diseases” OR “dental implant” OR “Geriatric Dentistry” OR “Forensic Dentistry” OR “Pediatric Dentistry” OR “Orthodontics” OR “Dental Prothesis”) | 390 |
| SCIELO | (“Thermography” OR “Temperature Mapping” OR “Mapping, Temperature” OR “Mappings, Temperature” OR “Temperature Mappings” OR “Skin Temperature” OR “Skin Temperatures” OR “Temperature, Skin” OR “Temperatures, Skin” OR “Skin thermal” OR “Infrared imaging” OR “Infrared thermography” OR “Infrared Camera” OR “Thermographic pictures” OR “Thermographic images” OR “Thermographic imaging” OR “Thermal images” OR “Thermal image” OR “Thermal imagers” OR “Thermal imaging”) AND TÓPICO: (“General practice, dental” OR “Dental General Practices” OR “Dentistry” OR “Medicine, Oral” OR “Oral and Maxillofacial Pathology” OR “Neoplasms, Oral” OR “Fever Blister” OR "Temporomandibular joint dysfunction syndrome" OR "Temporomandibular joint disorders" OR “Facial Pain, Neuralgic” OR “Maxillofacial Surgery” OR “Paresthesias” OR “Endodontology” OR “Dental Pulp Necroses” OR “Odontalgia” OR “Odontalgias” OR “Periodontic” OR “Periodontal Disease” OR “Salivary Gland Diseases” OR “dental implant” OR “Geriatric Dentistry” OR “Forensic Dentistry” OR “Pediatric Dentistry” OR “Orthodontics” OR “Dental Prothesis”) | 2 |

| | | |
|---|---|---|
| EMBASE | ('thermography' OR 'temperature mapping' OR 'mapping, temperature' OR 'mappings, temperature' OR 'temperature mappings' OR 'skin temperature' OR 'skin temperatures' OR 'temperature, skin' OR 'temperatures, skin' OR 'skin thermal' OR 'infrared imaging' OR 'infrared thermography' OR 'infrared camera' OR 'thermographic pictures' OR 'thermographic images' OR 'thermographic imaging' OR 'thermal images' OR 'thermal image' OR 'thermal imagers' OR 'thermal imaging') AND ('dentistry' OR 'medicine, oral' OR 'oral and maxillofacial pathology' OR 'neoplasms, oral' OR 'fever blister' OR 'temporomandibular joint dysfunction syndrome' OR 'temporomandibular joint disorders' OR 'facial pain, neuralgic' OR 'maxillofacial surgery' OR 'paresthesias' OR 'endodontology' OR 'dental pulp necroses' OR 'odontalgia' OR 'odontalgias' OR 'periodontic' OR 'periodontal disease' OR 'salivary gland diseases' OR 'dental implant' OR 'geriatric dentistry' OR 'forensic dentistry' OR 'pediatric dentistry' OR 'orthodontics' OR 'dental prothesis') | 446 |
| WEB OF SCIENCE | (“Thermography” OR “Temperature Mapping” OR “Mapping, Temperature” OR “Mappings, Temperature” OR “Temperature Mappings” OR “Skin Temperature” OR “Skin Temperatures” OR “Temperature, Skin” OR “Temperatures, Skin” OR “Skin thermal” OR “Infrared imaging” OR “Infrared thermography” OR “Infrared Camera” OR “Thermographic pictures” OR “Thermographic images” OR “Thermographic imaging” OR “Thermal images” OR “Thermal image” OR “Thermal imagers” OR “Thermal imaging”) AND TÓPICO: (“General practice, dental” OR “Dental General Practices” OR “Dentistry” OR “Medicine, Oral” OR “Oral and Maxillofacial Pathology” OR “Neoplasms, Oral” OR “Fever Blister” OR "Temporomandibular joint dysfunction syndrome" OR "Temporomandibular joint disorders" OR “Facial Pain, Neuralgic” OR “Maxillofacial Surgery” OR “Paresthesias” OR “Endodontology” OR “Dental Pulp Necroses” OR “Odontalgia” OR “Odontalgias” OR “Periodontic” OR “Periodontal Disease” OR “Salivary Gland Diseases” OR “dental implant” OR “Geriatric Dentistry” OR “Forensic Dentistry” OR “Pediatric Dentistry” OR “Orthodontics” OR “Dental Prothesis”) | 75 |
| SCOPUS | ( TITLE-ABS-KEY ( "Thermography" OR "Temperature Mapping" OR "Mapping, Temperature" OR "Mappings, Temperature" OR "Temperature Mappings" OR "Skin Temperature" OR "Skin Temperatures" OR "Temperature, Skin" OR "Temperatures, Skin" OR "Skin thermal" OR "Infrared imaging" ) OR TITLE-ABS-KEY ( "Infrared thermography" OR "Infrared Camera" OR "Thermographic pictures" OR "Thermographic images" OR "Thermographic imaging" OR "Thermal images" OR "Thermal image" OR "Thermal imagers" OR "Thermal imaging" ) AND TITLE-ABS-KEY ( "General practice, dental" OR "Dental General Practices" OR "Dentistry" OR "Medicine, Oral" OR "Oral and Maxillofacial Pathology" OR "Neoplasms, Oral" OR "Fever Blister" OR "Temporomandibular joint dysfunction syndrome" ) OR TITLE-ABS-KEY ( "Temporomandibular joint disorders" OR "Facial Pain, Neuralgic" OR "Maxillofacial Surgery" OR "Paresthesias" OR "Endodontology" OR "Dental Pulp Necroses" OR "Odontalgia" OR "Odontalgias" OR "Periodontic" OR "Periodontal Disease" ) OR TITLE-ABS-KEY ( "Salivary Gland Diseases" OR "dental implant" OR "Geriatric Dentistry" OR "Forensic Dentistry" OR "Pediatric Dentistry" OR "Orthodontics" OR "Dental Prothesis" ) ) | 455 |

### 2.1.3 Study selection

The literature research identified 1368 articles, of which 493 were identified as potentially relevant after the duplicate exclusion. The eligibility phase evaluated 260 full-text articles. After the evaluation, 141 were excluded from the study based on exclusion criteria, and 119 were eligible for analysis, as shown in the flowchart of the study selection (Figure 1).

Figure 1. Flowchart of study selection.




The data extraction used the following indicators: Year of publication, journal, study title, the main area in Dentistry, the secondary area in Dentistry, type of study, sample size, camera model, camera manufacturer, camera resolution, the ambient temperature of data collection, reason (monitoring or diagnosis), keywords, authors, their institution and country. The data analysis used Excel spreadsheets, according to bibliometric laws. The Lotka law

consists of the study on authors productivity, Bradford law studies the journal productivity, and the Zipf law consists of counting the keywords in large samples [11].

## 3 RESULTS

### 3.1 BIBLIOMETRIC ANALYSIS

A bibliometric analysis was undertaken to present the publication trends relating thermographic imaging to dental specialties by year of publication, journals, country, type of study, camera manufacturer, camera resolution, and ambient temperature, totaling 119 publications in 83 journals.

The journals included in Table 2 met the prerequisite of having two or more publications (n=20). The TMD/OFP area had 27 publications, the endodontics area had 23 publications, 06 of them being in the International Endodontic Journal; and the Restorative Dentistry had 18 publications.

Table 2. Articles published in journals by specialties.

| **Journals with 2 or more publications** | **A** | **B** | **C** | **D** | **E** | **F** | **G** | **H** | **I** | **J** | **K** | **Total** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| American Association of Oral and Maxillofacial Surgeons | 2 | | | | | | | | | | | 2 |
| Clinical Oral Investigations | 1 | 1 | | | | | | | | | | 2 |
| Dentistry Journal | | | 2 | | | | 1 | | | | | 3 |
| Dentomaxillofacial Radiology | | | 3 | | | | | | | | 1 | 4 |
| International Association of Oral and Maxillofacial Surgeons | 1 | | | | | 1 | | | | | | 2 |
| International Endodontic Journal | | | | 6 | | | | | | | | 6 |
| Journal Oral Maxillofacial Surgery | 4 | | | | | | | | | | | 4 |
| Journal Orofacial Orthopedics | | | | 2 | | | | | | | | 2 |
| Journal of Clinical Medicine | | | | | | 2 | | | | | | 2 |
| Journal of Bodywork and Movement Therapies | | | 2 | | | | | | | | | 2 |
| Journal of Dentistry | | 4 | | | | 1 | | | | 1 | | 6 |
| Journal of Endodontics | | 1 | | 5 | | | | | | | | 6 |
| Journal of Oral Pathology and Medicine | | | | | 2 | | | | 1 | | | 3 |
| Lasers in Dentistry | | 1 | | | 1 | | | | | | | 2 |
| Lasers in Surgery and Medicine | | 2 | | | | | | | | | | 2 |
| Medical Problems of Performing Artists | | | 2 | | | | | | | | | 2 |
| Not mentioned | | | | | | 1 | | | | | 1 | 2 |
| Oral Surg, oral medic, oral pathol, oral radiology, and endodontology | 1 | | 3 | | | | | | | | 1 | 5 |
| **Total** | **17** | **18** | **27** | **23** | **5** | **16** | **1** | **3** | **3** | **1** | **5** | **119** |

**Legend:** A: Surgery. B: Restorative Dentistry. C: TMD/OFP. D: Endodontics. E: Stomatology. F: Dental Implantology G: Sports Dentistry. H: Orthodontics. I: Periodontics. J: Prosthodontics. K: Radiology.

Tables 3 and 4 show a period that there was an increased number of publications relating thermography to Dentistry in 2015, 2016, and 2018, when compared to previous years, like 2011. The Table shows that 2018 was the year with most publications (n=12), decreasing in the year after (n=6).

Table 3. Number of articles in each Dentistry specialization published from 1985 to 2000.

| **Specialty** | **1985** | **1989** | **1990** | **1991** | **1993** | **1995** | **1996** | **1997** | **1998** | **1999** | **2000** | **Total** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Surgery | | | | | | 1 | | | | | 1 | 2 |
| Restorative Dentistry | | | | | 2 | 1 | | | | | | 3 |
| TMD/OFP | | 1 | 1 | 1 | | | 1 | | | | | 4 |
| Endodontics | | | | | | | | 2 | | 1 | 1 | 4 |
| Stomatology | | | | | | | | 1 | 1 | | | 2 |
| Dental Implantology | | | | | | | 1 | | | | | 1 |
| Sports Dentistry | | | | | | | | | | | | 0 |
| Orthodontics | | | | | | | | | | | | 0 |
| Periodontics | 1 | | | | | | | | | | | 1 |
| Prosthodontics | | | | | | | 1 | | | | | 1 |
| Radiology | | 1 | | | | 1 | | | | | | 2 |
| **Total** | **1** | **2** | **1** | **1** | **2** | **3** | **3** | **3** | **1** | **1** | **2** | **20** |

Table 4. Number of articles in each Dentistry specialization published from 2001 to 2020.

| Specialty | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Surgery | 1 | | | | | | 1 | | | 2 | | 2 | 2 | 1 | | 2 | 1 | 3 | 17 |
| Restorative Dentistry | | 1 | | | | | 1 | 2 | | | 2 | | 2 | 2 | 1 | 4 | | | 18 |
| TMD/OFP | 1 | | | | | | | | | 1 | 3 | 4 | 5 | | 2 | 4 | 2 | 1 | 27 |
| Endodontics | 1 | | 1 | 2 | 3 | 1 | | 2 | | | 2 | 2 | 1 | | 3 | | 1 | | 23 |
| Stomatology | | | 1 | | | | | | | | 2 | | | | | | | | 5 |
| Dental Implantology | | 1 | | | | | | | 1 | 1 | | 1 | 1 | 5 | 2 | 1 | 1 | 1 | 16 |
| Sports Dentistry | | | | | | | | | | | | | | | | 1 | | | 1 |
| Orthodontics | | | | | | | | | | | | 1 | | | | | 1 | 1 | 3 |
| Periodontics | 1 | | | 1 | | | | | | | | | | | | | | | 3 |
| Prosthodontics | | | | | | | | | | | | | | | | | | | 1 |
| Radiology | | | | | | | | | | | | 1 | | 2 | | | | | 5 |
| **Total** | **4** | **2** | **2** | **3** | **3** | **1** | **2** | **4** | **1** | **4** | **9** | **11** | **11** | **10** | **8** | **12** | **6** | **6** | **119** |

The most frequent manufacturer present in the published studies was FLIR Systems, used in 58 of the analyzed articles, while the most frequent camera resolution was 320x240, as shown in Tables 5 and 6, respectively.

Table 5. Camera manufacturer that was most used in the studies included in the research.

| Thermal Camera Manufacturer | Count |
|---|---|
| FLIR systems | 58 |
| not mentioned | 20 |
| Agema | 18 |
| Infratec | 5 |
| Medicore Seongnam | 2 |
| Apiste | 1 |
| Bedford | 1 |
| Daiwa Co | 1 |
| DIAS Infrared GmbH | 1 |
| Dresden | 1 |
| Fluke Corp | 1 |
| Jenoptik | 1 |
| MicroEpsilon | 1 |
| Mikron Infrared | 1 |
| NEC Avio Infrared Technologies Co | 1 |
| Nippon Avionics | 1 |
| Optris | 1 |
| Testo SE | 1 |
| Trotec | 1 |
| UTI | 1 |
| Xenics | 1 |
| Total | 119 |

Table 6. Camera resolution most used in the included studies.

| Camera Resolution | A | B | C | D | E | F | G | H | I | J | K | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| not mentioned | 8 | 10 | 9 | 4 | 6 | 4 | | 1 | 3 | 1 | 2 | 48 |
| 320x240 | 10 | 14 | 2 | 7 | 7 | | 2 | | | | 4 | 46 |
| 640x480 | 2 | 1 | 1 | 2 | | | | | | | | 6 |
| 160x120 | | | | 1 | 3 | | | | | | | 4 |
| 640×512 | 1 | | 2 | | | | 1 | | | | | 4 |
| 176x220 | 1 | | 1 | | | | | | | | | 2 |
| 320x256 | | | 2 | | | | | | | | | 2 |
| 1024x768 | | | | | 1 | | | | | | | 1 |
| 320x320 | 1 | | | | | | | | | | | 1 |
| 360x200 | | | | 1 | | | | | | | | 1 |
| 384×288 | | | | 1 | | | | | | | | 1 |
| 480×360 | | | 1 | | | | | | | | | 1 |
| 50x50 | | | | | | 1 | | | | | | 1 |
| 60x60 | | 1 | | | | | | | | | | 1 |
| Total | 23 | 26 | 18 | 16 | 17 | 3 | 3 | 1 | 3 | 1 | 6 | 119 |

**Legend:** A: Surgery. B: Restorative Dentistry. C: TMD/OFP. D: Endodontics. E: Stomatology. F: Dental Implantology G: Sports Dentistry. H: Orthodontics. I: Periodontics. J: Prosthodontics. K: Radiology

The mean temperature of the ambient at the moment of the thermal imaging registration in most cases was from 22 to 23.9°C (n=26), as shown in Table 7.

Table 7. The ambient temperature (°C) at the moment of collecting the thermal images in studies.

| Ambient Temperature (°C) | below 22 | 22 to 23.9 | over 24 | Not mentioned | Total |
|---|---|---|---|---|---|
| TMD/OFP | 2 | 13 | | 11 | 26 |
| Endodontics | 1 | 3 | 3 | 16 | 23 |
| Restorative Dentistry | | 1 | | 17 | 18 |
| Surgery | 2 | 3 | 1 | 11 | 17 |
| Dental Implantology | | 1 | | 15 | 16 |
| Radiology | | 3 | | 3 | 6 |
| Stomatology | | | 1 | 4 | 5 |
| Orthodontics | | | | 3 | 3 |
| Periodontics | | 2 | | 1 | 3 |
| Sports Dentistry | | | 1 | | 1 |
| Prosthodontics | | | | 1 | 1 |
| Total | 5 | 26 | 6 | 82 | **119** |

Considering the sample size, most of the studies included less than 30 samples, as presented in Table 8.

Table 8. Sample size in each specialty.

| Sample Size | Sample < 30 | Sample >=30 | Total |
|---|---|---|---|
| TMD/OFP | 10 | 16 | 26 |
| Endodontics | 11 | 12 | 23 |
| Restorative Dentistry | 13 | 5 | 18 |
| Surgery | 8 | 9 | 17 |
| Dental Implantology | 12 | 4 | 16 |
| Radiology | 2 | 4 | 6 |
| Stomatology | 4 | 1 | 5 |
| Orthodontics | 1 | 2 | 3 |
| Periodontics | 2 | 1 | 3 |
| Sports Dentistry | 1 | | 1 |
| Prosthodontics | 1 | | 1 |
| Total | 65 | 54 | 119 |

As for the type of study, the longitudinal studies appeared in larger quantities in the analysis (n=69), followed by cross-sectional studies (n=46), as seen in Table 9.

Table 9. Type of study carried out in the articles searched.

| Type of Study | Longitudinal | Review | Cross-sectional | Total |
|---|---|---|---|---|
| TMD/OFP | 8 | 3 | 15 | 26 |
| Endodontics | 19 | | 4 | 23 |
| Restorative Dentistry | 11 | | 7 | 18 |
| Surgery | 6 | | 11 | 17 |
| Dental Implantology | 12 | 1 | 3 | 16 |
| Radiology | 5 | | 1 | 6 |
| Stomatology | 5 | | | 5 |
| Orthodontics | | | 3 | 3 |
| Periodontics | 2 | | 1 | 3 |
| Sports Dentistry | 1 | | | 1 |
| Prothesis | | | 1 | 1 |
| Total | 69 | 4 | 46 | 119 |

Regarding the number of authors in the studies, the majority included 4 authors in the articles (n = 32).

Table 10. Number of authors that published by dental specialty.

| Quantity de Authors | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 11 | 15 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|
| TMD/OFP | 1 | 2 | 3 | 8 | 5 | 5 | | 2 | | | 26 |
| Endodontics | 2 | 1 | 4 | 7 | 2 | 4 | 3 | | | | 23 |
| Restorative Dentistry | | 1 | 2 | 7 | 3 | 2 | 2 | 1 | | | 18 |
| Surgery | | 1 | | 3 | 4 | 5 | 1 | | 3 | | 17 |
| Dental Implantology | | | 1 | | 4 | 7 | 2 | 1 | 1 | | 16 |
| Radiology | | | 1 | 3 | 1 | 1 | | | | | 6 |
| Stomatology | | 1 | | 1 | 1 | 1 | | | | 1 | 5 |
| Orthodontics | | | | 2 | 1 | | | | | | 3 |
| Periodontics | | 1 | 1 | 1 | | | | | | | 3 |
| Sports Dentistry | | | | | | | 1 | | | | 1 |
| Prothesis | | | | | 1 | | | | | | 1 |
| Total | **3** | **7** | **12** | **32** | **22** | **25** | **8** | **4** | **4** | **1** | **119** |

The number of published articles where they were the first authors was also identified and it is presented in Table 11.

Table 11. First authors that were most frequently found in the articles.

| Authors | Number of published articles |
|---|---|
| Barton. M Gratt | 5 |
| Mariusz Lipski | 5 |
| Denise S Haddad | 4 |
| Almir Vieira Dibai-Filho | 3 |
| Antonio Scarano | 3 |
| Miguel Pais Clemente | 3 |
| Sc Mohlheinrich | 3 |
| Delaine Rodrigues-Bigaton | 2 |
| Dragana Gabric Panduric | 2 |
| Renata Maria Moreira Moraes Furlan | 2 |

The ten most frequent keywords that were identified in the studies were: Thermography (n=35), Infrared thermography (n=15), Temporomandibular joint disorders (n=12), Temperature (n=8), Heat generation (n=7), Dentistry (n=6), Skin temperature (n=5), Dental implant (n=5), Implant site preparation (n=5), and Dental caries (n=4).

Table 12. The most frequent keywords in the studies.

| Keywords | Count |
|---|---|
| Thermography | 35 |
| Infrared thermography | 15 |
| Temporomandibular joint disorders | 12 |
| Temperature | 8 |
| Heat generation | 7 |
| Dentistry | 6 |
| Skin temperature | 5 |
| Dental implant | 5 |
| Implant site preparation | 5 |
| Dental caries | 4 |

The institutions that published the majority of articles are presented in Table 13. The institutions with the same number of published articles are in alphabetic order in the table.

Table 13. Number of published articles by institution.

| Institution | Number of published articles |
|---|---|
| The Queen's University of Belfast | 43 |
| University of Porto | 32 |
| Aachen University, Aachen, Germany | 27 |
| Showa University School of Dentistry | 26 |
| Methodist University of Piracicaba | 25 |
| University of California | 23 |
| Bonn University | 19 |
| University of Zagreb | 19 |
| State University of Paraíba | 12 |
| University of Sao Paulo | 11 |

The institutions linked to the most published first authors were analyzed and are displayed in Table 14.

Table 14. Institutions of the first authors most cited in the articles included in this study.

| Institution | Count |
|---|---|
| The Queen's University of Belfast | 9 |
| Pomeranian Medical University | 5 |
| University of California | 5 |
| University hospital of Aachen University | 5 |
| University of Sao Paulo | 5 |
| Showa University School of Dentistry | 5 |
| Methodist University of Piracicaba | 4 |
| University of Porto | 4 |

| | |
|---|---|
| University of Chieti-Pescara | 3 |
| Aarhus University, Aarhus | 2 |

The country with the most publications relating thermography to Dentistry was Brazil, as presented in Table 15.

Table 15. Number of the citations by country included in the study.

| Country | Number of citations |
|---|---|
| Brazil | 72 |
| Japan | 71 |
| Germany | 67 |
| United Kingdom | 50 |
| Poland | 43 |
| Portugal | 41 |
| Turkey | 27 |
| United States of America | 21 |
| Croatia | 19 |
| Romania | 17 |

## 4 DISCUSSION

Infrared thermography is an imaging examination whose technique is recent in Dentistry. It is evident the progress of studies relating thermographic images to Dentistry. Scientific research results show that this examination is precise and reliable as a diagnostic, evolutive monitoring, and prognosis tool in the health area [4].

The search for articles included in this study was performed in databases considering keywords that relate thermography to Dentistry specialties recognized by the Federal Dentistry Council. The keywords found in most articles screened were thermography, infrared thermography, and temporomandibular joint disorders. The last one is justified once temporomandibular joint disorders (TMD) is the specialty of most publications connecting thermography to Dentistry (27 publications). Endodontics was the second specialty in the number of publications (23), and Restorative Dentistry was the third specialty with 18 published studies, followed by Surgery with 17. Larissa Rocha Presídio, Flávia Godinho Costa Wanderley and Alena Ribeiro Alves Peixoto Machado conducted a systematic review in 2016 named “O uso da termografia infravermelha na Odontologia e suas especialidades: uma revisão sistemática.”. According to it, infrared thermography is an auxiliary diagnostic method in TMD cases, taking into account that 7 of the 12 listed articles covered this specialty [15]. Another study published in 2019: “Is infrared thermography effective in the diagnosis of

temporomandibular disorders? A systematic review", concluded that literature still needs studies to make the use of infrared thermography reliable to diagnose TMD. The mentioned systematic review included 9 studies, in which 4 of them concluded that IT is not a precise instrument for TMD diagnostic whereas 5 considered the IT promising as a diagnostic aid of this condition [16], which corroborates with the results in this present work.

The journals included in this analysis comprise the areas of Dentistry. Journal of endodontics, International Endodontic Journal, Journal of Dentistry, were the journals with the largest number of publications, both with 06. The Oral surgery, oral medicine, oral pathology, oral radiology and endodontology journal comes next, with 5 publications.

In 1985 a single article was published relating thermography to periodontics, the specialty responsible for the studies of supporting structures around the teeth. In 2001, there was slight progress in the number of publications relating thermography to Dentistry, with 4 published articles. In 2013 this number increased to 9 publications, and the highest number occurred in 2018, totaling 12 published articles. That suggests a trend in studies that consider thermography as a diagnostic method in Dentistry. Posteriorly, there was another systematic review linking thermography to Dentistry. In this current study, the selected articles were from 1989, 1991, 1993, 1994, 1995, 1996, 2001, 2012, and the most current one from a study published in 2013. This information supports the fact that the number of studies relating thermography to Dentistry is growing [15]. A possible reason for this progression is the technological evolution of equipment. Another systematic review article with a bibliometric analysis that approaches public health concluded that from 2008 to 2013, there was an increased number of studies related to health in general. Besides that, diagnosis and treatment were the areas with the highest numbers of health studies, stated by that review [17].

Infrared thermography can be used as a screening method to assess pathological conditions in various dental specialties, comorbidities diagnosis, and treatment evolution. The samples evaluated in the studies comprised in this systematic review, in their majority, were composed of less than 30 volunteers and were longitudinal studies. These studies collect data in more than one time period, and they involve the comparison of data between the considered times. That is an efficient method for studies involving pathological condition evaluation since the surface skin temperature is directly associated with blood flow, regulated by the autonomic nervous system, and affects both sides of the body simultaneously and evenly, creating a thermal pattern in the face of normal conditions. Normality pattern alterations could be an indication of pathological conditions [7,10].

In patients with DTM, the myofascial trigger points cause regional sympathetic hyperactivity of the local temperature due to cutaneous vasoconstriction. To document this functional alteration objectively, thermography has been suggested as a diagnostic aid. Thermography alone identified trigger points in the masticatory muscle region with a sensibility of 62.5% and specificity of 71.1%. Gratt and Sickles (1993) studied the thermographic pattern of the temporomandibular joint (TMJ), concluding that $\Delta T=0.3^{o}C$ can be the cutoff point between the healthy articulation and the affected contralateral one to help the diagnoses of articular TMD [20].

Thermography is also a relevant instrument to monitor pulp alterations in the making process of the temporary prosthesis in prosthetic and restorative dentistry areas. In this procedure, an increase of the acrylic temperature up to 5.5ºC is observed during its polymerization. That could be responsible for pulp tissue damage. Thermographic monitoring during the procedure enables the oral surgeon to preventively act on the periodontal tissues and the dental organ, minimizing the detrimental effects caused by excessive heating [21].

In endodontics, the main symptom treated comes from pulp inflammation that causes pain to the patient. The absolute temperature limit for restoring procedures in the dental organ is 41.5ºC. Above this temperature, there could be pulp inflammation or even pulp necrosis [22].

That happens because the dentine lesion has a physiological connection (dentinal tubules) to the dental pulp. In other situations, monitoring the intrabuccal temperature can help to diagnose and differentiate the inflammatory conditions, such as acute pulpitis with apical periodontitis (endo-perio lesions) (36.07 ±0.45 ºC), acute periapical abscess (37.26 ±0.36 ºC), and chronic periapical abscess (35.03±0.63 ºC). Thermography is an efficient method, quantitative with a non-ionizing approach, that can be used to diagnose acute pulpitis with apical periodontitis, acute and chronic periapical abscess [22].

Thermography is also helpful in detecting inflammatory reactions during the pre-clinical stage, enabling early diagnosis, and has been used to detect lesions in dental caries in the early stages. A temperature of 49.66ºC suggests a progressive lesion in the tooth enamel. Thermography can help identify it in areas that are visually difficult to access clinically, complementing radiographic imaging to diagnose caries lesions [23].

The application of thermal imaging in orthodontics allows the monitoring of the variation in the tooth temperature increase during the electrothermal debonding of orthodontic brackets, avoiding the high risk of pulp lesion. It also makes it viable to analyze cross-sectioned teeth during the debonding process of ceramic brackets using a $CO_2$ laser [21].

Evidence from studies approaches about the impact of heat application to the teeth enamel, capable of increasing the temperature on more than 6.8°C above the physiological value of 35.3°C, producing a risk of 15% of irreversible damage in the pulp tissue [24].

Using the same experimental configuration (electrothermal debonding of orthodontic brackets), an iatrogenic increase in the pulp temperature higher than 8°C raises the risk of tissue damage by 50% [25, 27]. In the same way, thermography has shown that the temperature increase during orthodontic bonding is higher with longer exposure times. That happens because the shorter the distance between the tooth surface and the photopolymerization LED, the higher the temperature increase compared to halogen light [21].

In the surgery field, studies have confirmed that thermography is very useful to quantify the cutaneous response to inflammation after the surgical removal of impacted teeth. The skin surface temperature through infrared thermography shows an increase of 0.3ºC after the third molar removal surgery [24]. Some studies identified changes in facial circulatory patterns after the extraction of third molars, and have demonstrated that the regional blood flow can change after surgical trauma and increase local circulation. That happens mainly in lymphatic microcirculation. This biological process can cause a temporary local temperature increase [28]. In orthognathic surgery, thermography evaluates quantitatively facial temperature in patients submitted to maxilla and mandible osteotomy [29].

In implant surgery, osseointegration depends on bone quality, vascularization, and the correct use of operatory techniques. These discoveries suggest that applying heat through low-speed drilling can influence the osseointegration of dental implants. After the bone drilling and the dental implant placement, a sequence of cellular and molecular events starts [30]. The maximum safe temperature during drilling to place the implants is 56ºC. Above this temperature, the alkaline phosphatase denatures, and bone healing gets compromised, which could cause local necrosis due to high temperatures [31, 32]. Using thermal imaging can avoid the implant placements to reach alkaline phosphatase denaturation temperatures, preventing scarring complications in the operated area. During implant drilling, where it is necessary to use multiple drill bits, the surgeon can use thermography to avoid exceeding safe temperatures. That creates a procedure with more safety and control and decreases rates of implant loss after the surgical procedure.

Thermography as a supplementary method for evaluating the cutaneous inflammatory response can offer more safety to the dentist in the postoperative follow-up [33,34]. The main signs assessed in dental surgeries postoperatively are: the measurement of maximal mouth opening (trismus), extraoral edema measurement, visual analog scales, and pain intensity [24].

Recently, thermography has been included in multiple studies to support the follow-up of treatments. It is possible to analyze how the analgesic and anti-inflammatory usages preoperatively impact the course of scarring, reaching results that show a reduced difference in edema evolution, trismus, and pain [20, 30].

The ambient temperature where the thermal images are collected needs to follow a standard to ensure the results, and it can vary from 22 to 24ºC temperature [12, 19]. Regardless of the geographic location, the room must have an air-conditioning system with thermal capacity adequate for the room size to control the ambient temperature [12]. The present study suggests that this standard is being followed in the latest articles and clinical studies concerning thermography and Dentistry, of which from the 119 tracked studies, 26 mentioned that the room temperature at the moment of image collection was ranging from 22 to 23.9ºC. Eighty-two articles did not specify the temperature at the moment of image registration. Since it is relevant information for obtaining precise results, the importance of describing it in the studies is evident.

To obtain thermal images, the acquisition of portable infrared sensor cameras is necessary. There are several available camera models and brands. Specific lenses, spatial resolution, and adjustable emissivity settings are relevant features that must be taken into consideration before the acquisition of the equipment [12]. In this systematic review, FLIR Systems was the manufacturer that was most used in the studies analyzed, present in 58 of them. The most frequent equipment resolution used in the articles was 320x240. A possible hypothesis for the number of studies using FLIR Systems could be its time in the market since FLIR is responsible for the first generation of infrared devices for military purposes after the World War II [13]. The second most used manufacturer brand was Agema, mentioned in 18 studies. Both present a slight difference in market prices; hence it would not sustain the assumption of price preference.

In the health area, among the most recent technologies to aid diagnosis, monitoring evolution treatment, and longitudinal follow-up of disease/treatment, infrared thermography has shown to be a valuable ally because of its advantages. It is a method that is non-invasive, painless, and easy to perform, that does not rely on the use of ionizing radiation. In other words, it does not offer risk to the patients and allows a real-time physiological understanding of the region [10,11,15,16]. For being a functional exam, infrared thermography combined with the clinical condition brings valuable information about the metabolic, cutaneous microcirculatory, and immune response of the neurovegetative system to guide the therapeutic approach. These

advantages are not seen in the other anatomic diagnostic methods such as computerized tomography, radiography, magnetic resonance imaging, and ultrasonography.

Most articles included in this study involved four authors in their elaboration. The specialty of TMD and OFP presented the largest number of collaborators in the published studies. Since it is a specialty that shows a trend to increase the number of publications that relate the method reliability to temporomandibular alterations, this trend is also seen regarding the number of collaborators involved in the research. A published systematic review pointed that 7 of 12 considered articles discussed the TMD and OFP TMD [15]. Another systematic review evaluated the effectiveness of thermography in TMD diagnosis [16].

Regarding the authors that published the largest number of studies relating thermography to Dentistry, the principal first author was Barton. M Gratt and Mariusz Lipski, followed by Denise S Haddad, Miguel Pais Clemente, Almir Vieira Dibai-Filho, Antonio Scarano, and Sc Mohlheinrich, all ranking in the second position. In the third position came Delaine Rodrigues – Bigaton, Dragana Gabric Panduric, and Renata Moreira Moraes Furlan. However, Miguel Pais Clemente had a larger number of case reports publications, when compared to the other authors that published studies with larger N sample sizes.

Authors that participated more frequently in studies relating thermography to Dentistry were also screened. The authors that participated in 5 or more published studies relating thermography to Dentistry were: Almir Vieira Dibai Filho, P.A Biagioni, Amanda Carine Packer, Ana Claúdia de Souza Costa, Delaine Rodrigues-Bigaton, Barton M. Gratt, D.L Hussey, Koukochi Matsumoto, F Holzle, Mariusz Lipsk, and Miguel Pais Clemente.

Even though Barton M. Gratt is known as an author with significant importance in the publications relating thermography to Dentistry, participating as author or coauthor in many publications, some of them were not found in the search of this current study. For example, the following publications: A pilot study of nitric oxide blood levels in patients with chronic orofacial pain (2005), Variations in the radiographic interpretation of the periapical dental region (1988), Role of nitric oxide in the physiopathology of pain (1997), Computer comparison of bitemark patterns in identical twins (1992).

The Queen's University of Belfast was the institution with most citations in the studies relating thermography to Dentistry. The institution is not only on the top general position but also it is the first one when the first authors were evaluated. This fact suggests an interest in contributing to such research. That idea is supported by the Science and Engineering Indicators 2020, of the National Science Foundation (NSF, USA), which shows the number of scientific articles by country from 2000 to 2018. The United Kingdom, where The Queen's University of

Belfast is located, ranked in the third position of the world in number of publications. Moreover, this Institution is amongst the 200 best universities in the world (The World University Rankings 2021), and in eighth place in the United Kingdom for research intensity (Times Higher Education 2014).

The countries with the highest number of citations in studies of thermography in Dentistry were Brazil and Japan, showing a trend in interest by the authors in these countries for the advancement of studies on thermography examination and dental specialties. In another systematic review with a bibliometric analysis approaching the health area, Brazil ranked in 5$^{th}$ position, behind The Netherlands, United Kingdom, Canada, and the United States, which supports the development of studies in these countries on health [17]. Another systematic review has also ranked Brazil among the countries with the highest concentration of published studies in the health and environmental area. Brazil appeared with 80 studies, behind Russia and United States, both with 116 publications [18].

One study limitation that could be mentioned was the investigation of the author's country of origin because the affiliation does not always reflect the actual nationality of the author.

## 5 CONCLUSION

Through this study, it was possible to conclude that thermography is indicated as a diagnostic aid method in Dentistry specialties. The main recommendations of its use in Dentistry are in the scope of orofacial pain (TMD, muscular and articular, neuropathies), Endodontics (inflammatory odontalgias), Dental Implantology (osseointegration), and the evolution monitoring of postoperative stages and treatments.

Brazil is progressively producing research on thermography in the Dentistry area. Barton M. Gratt is the leading author of articles relating thermography to Dentistry. Regarding the equipment used for thermal imaging purposes, FLIR Systems 320x240 seems to be a reliable option. More studies are necessary about the several possibilities of using thermography to expand its use in Dentistry.

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