Thermographic evaluation of gingival phenotypes: correlation between morphological and thermodynamic parameters

Niebla Bezerra de Melo (✉ niebla.melo@gmail.com)  
State University of Paraiba

Lígia Natália Sobreira Duarte  
State University of Paraiba

Camila Maia Vieira Pereira  
State University of Paraiba

Jussara Silva Barbosa  
State University of Paraiba

Ariane Matos Gonçalves da Silva  
State University of Paraiba

Renata de Souza Coelho Soares  
State University of Paraiba

Patrícia Meira Bento  
State University of Paraiba

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Abstract

Objectives

to evaluate the clinical and thermographic aspects of the gingival phenotype (GP) in healthy subjects.

Materials and methods

the study sample examined 264 upper and lower incisors, comprising 132 central incisors (CI) and 132 lateral incisors (LI). Four periodontal parameters were recorded systematically: ratio of width to length of the dental crown (CW/CL), height of the gingival attachment (GH), probing depth (PD) and gingival transparency (GT). The temperatures of the attached gingiva (GH Temp) and the free gingival margin (FGM Temp) were also recorded by way of infrared thermography (IRT).

Results

the average age of the sample was 30.70 ± 7.65 years. Of the 264 teeth evaluated, 76.1% had a thin GP. There was a significant association between CW/CL (p < 0.001), GH (p < 0.001), PD (p < 0.007) and FGM Temp (p < 0.006) with the tooth groups. The results show a significant and inversely proportional correlation between clinical parameters and gingival temperature (p < 0.05). A significant association was found between CW/CL (p < 0.026); GH (p < 0.001), and GP.

Conclusion

CW/CL and GH are determining parameters for GP. Moreover, an inversely proportional correlation can be observed between gingival temperature and the clinical morphological parameters that determine the GP.

Clinical Relevance:

The relationship between the clinical characteristics of the GPs and temperature could serve as one more parameter to help with the classification of gingival tissue. Moreover, our findings will help future studies evaluate the use of IR as an auxiliary diagnostic method in dentistry.

1. INTRODUCTION

In 2017, the World Workshop on the Classification of Periodontal and Peri-Implant Diseases and Conditions recommended the use of the term “periodontal phenotype” (PP) to describe the combination of the gingival phenotype (GP), i.e., the morphological characteristics of the gums and crowns, with the underlying alveolar bone morphotype (Jepsen et al., 2018; Steffens & Marcantonio, 2018).
The correct classification of the GP is extremely important for the planning of dental treatment (Yin et al., 2020; Araújo et al., 2018; Zweers et al., 2014). There are a variety of GP classification methods, such as direct or indirect visual inspection, probe transparency, transgingival probing, ultrasound transducer, periapical radiography using the parallel technique, and cone-beam computed tomography (CBCT) (De Rouck et al., 2009; Yin et al., 2020; Januário, Barriviera, Duarte et al., 2008; Gkogkos et al., 2020; Muller & Eger, 1997). However, these methods may entail a number of shortcomings, for example the lack of inter-examiner reproducibility (Aguilar Duran et al., 2020).

Infrared thermography (IRT) is a non-invasive technique that identifies the distribution of heat radiated by a body (Rytivaara et al., 2021; Brioschi et al., 2010; Nicandro et al., 2013), enabling the quantification of temperature variations in any region (Anbar, 1995; Brioschi et al. 2010; Iosif et al., 2021). IRT is a promising, auxiliary method for a variety of dental specialties, possessing diverse advantages such as functionality, speed and safety (Haddad et al, 2016; Rytivaara et al., 2021; Magalhães, Mendes & Vardasca, 2021).

The thermal properties of periodontal tissue may furnish a wide range of information and have been the subject of studies for many years (Mukherje et al., 1978; Brill et al., 1978; Molnár et al., 2015). Studies show that thermodynamic behavior is different between the various gingival regions, as well as between individuals, with or without gingivitis (Haffajee et al. 1992; Niederman et al., 1995; Holthuis et al., 1983; Komoriyama et al. 2003).

Accordingly, the aim of this study was to perform a quantitative analysis of the clinical parameters of the gingival and coronal morphology in clinically healthy volunteers and to ascertain if there is a correlation of these parameters with the temperature of the gingival tissue, using IRT, in order to help improve the criteria for the diagnosis of GPs.

2. MATERIALS AND METHODS

2.1 Study design and sample characteristics

This was a cross-sectional study. The sample was obtained spontaneously, at random, comprising 33 healthy volunteers selected at the Paraíba State University (UEPB), Campina Grande, Brazil. A total of 264 incisors were evaluated, comprising 132 central incisors (CIs) and 132 lateral incisors (LIs), in both the upper and lower arches.

2.2 Eligibility criteria

The inclusion criteria were as follows: having all anterior teeth; being aged 18 or over; having good periodontal health (with no loss of attachment and a probing depth of up to 3 mm).

The following parameters were employed as the criteria for exclusion: prosthetic users, dental implants, orthodontic appliances or other factors that could obstruct the view of the region of interest (ROI) and/or might behave as a conductor of heat; presence of anodontia, diastemas, caries, fillings or unsatisfactory
dental restorations; bruxism; performance of tooth whitening (in the previous 3 months); individuals with clinical signs or symptoms of gingivitis or periodontitis (gingival bleeding; loss of clinical attachment; probing depth > 3 mm); having been submitted to drug therapy that has known effects on periodontal tissue (within the previous 3 months); smokers; women going through the menopause or with irregular menstrual cycles, or menstruating on the day of the examination; individuals with odontalgia, fever and/or systemic changes, or undergoing treatment with drugs.

2.3 Interventions prior to collecting the data

All the selected volunteers received instruction about oral hygiene and an information leaflet containing procedures to be followed prior to the IRT. A pilot study involving 10 volunteers was conducted for the purpose of researcher calibration.

2.4 Collection of clinical data

Data collection was divided into three stages: acquisition of sociodemographic data and collection of anthropometric data; thermographic examinations; and clinical periodontal examinations. All of these stages took place on the same day, in the order described.

2.5 Thermographic examinations

Thermographic images were acquired using a portable camera equipped with an FLIR T650 Infrared sensor with a spatial resolution of 640 x 480 pixels, a spectrum of 7.5–14 µm, thermal sensitivity of 0.05 to 30ºC and a precision of ± 1°C. The thermographic examinations observed the guidelines advocated by the American Academy of Thermology (AAT) (PANJMT, 2019), were carried out by a single examiner and took place in the standardized environment of the UEPB’s IRT Laboratory (LTI-UEPB). The LTI-UEPB consists of a thermally insulated room, i.e., without any energy-generating equipment, without sources of air or sunlight (no windows), with cold lighting (fluorescent lamps) and carpeted flooring (IACT, 2020; Fernández-Cuevas et al., 2015). In addition, the back walls where the volunteer’s chair is located are lined with 25 mm thick Expanded Polystyrene Sheets (EPS), aluminum foil and black EVA adhesive (Aires et al., 2018, Barbosa et al., 2019; Rytivaara et al., 2021; Woźniak et al., 2015), forming a heat insulation barrier. Air-conditioning and a digital thermos-hygrometer were employed to ensure the thermal stability of the room.

Prior to commencing the IRT examinations, each volunteer was asked to remove any accessories that might interfere with the image and to sit in a relaxed position for around 10 to 15 minutes at an ambient temperature (AT) of between 20º and 25ºC (± 1ºC) and a relative humidity (RH) between 40 and 60%. In addition, the thermographic sensor was affixed to a tripod with angle and height adjustment, and which had been in this environment for 10 minutes. The sensor was then duly calibrated using the following parameters: manual focus, distance from the object (0.30 cm), AT (20ºC to 25ºC), RH (between 40% and 60%), skin emissivity (0.98%) and the reflected temperature (RT) value (Brioschi et al., 2010; Dibai-Filho et al., 2014; Rodrigues-Bigaton et al., 2014; Woźniak et al., 2015).
The RT was obtained using the reflector method (Usamentiaga et al., 2014; Fernández-Cuevas et al., 2015), consisting of positioning a polystyrene sheet lined with crumpled aluminum foil on the examination chair facing the IRT camera. The camera was then configured with a distance from the object of 0 and emissivity of 1, and the temperature recorded by the sensor was converted into reflected temperature. The measurement of RT and the calibration of the thermographic camera took place prior to the examination of each volunteer.

For the acquisition of the IRT images, the volunteers were seated in a height-adjustable, revolving chair, maintaining an erect posture and with the sagittal plane perpendicular to the ground, feet on the floor and hands resting on the thighs. During the examinations, a maximum of three people were allowed to remain in the LTI-UEPB. The tripod with the thermographic camera was positioned at a distance of 30 cm from the volunteer and the height was adjusted such that the ROIs were centralized in the thermal imager. To help with the viewing of the ROIs, the images were captured with the aid of an Expander-type lip separator. Each individual was subjected to three examinations, in the following sequence: 1st : frontal intraoral (90º); 2nd : right intraoral (45º); 3rd : left intraoral (45º). Prior to each image capture, the volunteers were instructed not to occlude the teeth, to hold their breath and remain still for 10 seconds.

2.6 Clinical periodontal examinations

The periodontal examinations were carried out in a dentist’s office by an examiner blinded to the thermographic examinations. The volunteers’ incisors and adjacent mucogingival regions were analyzed with the aid of an Expandex-type lip separator (the same as used for the thermographic examination). The following periodontal indices were recorded:

1. **Ratio of crown width to crown length (CW/CL)**: determined as per Olsson & Lindhe (1991) and De Rouck et al. (2009). The measurements were taken with the aid of a dry-tip pachymeter and a millimeter ruler. The length of the dental crown was measured between the incisal edge of the dental crown and the free gingival margin or, when discernable, the cemento-enamel junction. The crown width was recorded based on the ridge between the mid- and cervical portion of the vestibular surface of the dental crown.

2. **Gingival height (GH)**: was defined as the distance between the free gingival margin and the mucogingival junction. To this end, a North Carolina periodontal probe (CPU 15 UNC, Hu-Friedys, Chicago, IL, USA) was positioned parallel to the long axis of the tooth, above the mid-buccal point of the incisors (De Rouck et al., 2009).

3. **Probing depth (PD)**: defined as the distance in millimeters (mm) between the gingival margin and the bottom of the incisal groove. This measurement was obtained by delicately inserting the North Carolina periodontal probe (CPU 15 UNC, Hu-Friedys, Chicago, IL, USA) into the gingival sulcus on the disto-buccal, mid-buccal and mesio-buccal surfaces of each tooth. For the statistical analysis, the mid-buccal PD (medial PD) and the sum of all the distal, mid and mesial surfaces (total PD) were used.

4. **Probe transparency (GT)**: was based on the transparency of the periodontal probe (CPU 15 UNC, Hu-Friedys, Chicago, IL, USA), using the gingival margin. To this end, probing was carried out about 1...
mm from the gingival sulcus on the mid-buccal surface of the incisors. If the contour of the periodontal probe could be seen through the gingiva, the GP was classified as thin, otherwise it was classified as thick (De Rouck et al., 2009; Kan et al. 2003).

2.7 Analysis of thermographic images

A total of 99 thermograms were obtained, representing three images per volunteer. The thermograms were analyzed by a single, blinded examiner with the aid of version 6.4 of the FLIR Tools+™ software package (2015). To measure the thermal gradient, a rainbow-type scale was employed using the “circle” (2 mm diameter) and “line” measurement tools. Each point analyzed was defined observing the measurements obtained in the periodontal clinical examinations. For this, guidelines were drawn on the thermograms. The following thermographic variables were established: temperature of the free gingival margin: disto-buccal (distal FGM Temp), mid-buccal (medial FGM Temp) and mesio-buccal (mesial FGM Temp), obtained using the “circle” tool; total margin temperature (total FGM Temp total), relating to the sum of the temperature of the three regions of the free gingival margin; and the temperature of the attached gingiva band (GH Temp), relating to the GH region, evaluated using the “line” tool. The mid FGM Temp, mesial FGM Temp and GH Temp temperatures of the LIs were analyzed in side-view thermograms. The maximum, minimum and mean temperatures were obtained for each point (Fig. 1).

2.8 Statistical analysis

Absolute and percentage frequencies were calculated for the categorical variables, as well as measures of central tendency and variability for the quantitative variables. Next, Pearson's chi-squared test (or Fisher's exact test, if appropriate) was used to test the association between the studied variables. The Mann-Whitney and Kruskal-Wallis nonparametric tests, with Dunn's multiple comparison, were used to compare the clinical and thermographic parameters to the tooth groups, as the data normality assumptions were not ratified through the Kolmogorov-Smirnov tests. In addition, Spearman's Coefficient of Correlation was used to correlate the variables CW/CL, GH and PD with GH Temp. For the comparison of clinical parameters with the parametric variables mid FGM Temp and total FGM Temp, the ANOVA test with Tukey's Post-Hoc were employed. Comparisons of the GP with the clinical parameters and with the temperature variables were made using the Student's t-test and the Mann-Whitney test, respectively. The level of significance was set at $p \leq 0.05$. All analyses were conducted using version 20.0 for Windows of the Statistical Package for the Social Sciences (IBM Corporation, Armonk, NY).

3. RESULTS

The definitive study sample comprised 33 healthy volunteers, 11 of them female and 22 male, predominantly brown (48.48%) or white (45.45%), with an average age of 30.70 ± 7.65 years, mean weight of 71.91 ± 11.37 kilograms (Kg), and mean BMI of 25.25 ± Kg/m². The coronal and mucogingival, morphological characteristics of 264 incisors were evaluated (Table 1).
Table 1 – Characterization of sample according to anthropometric data and tooth group.
<table>
<thead>
<tr>
<th>Variables</th>
<th>n</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Age [33]</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean: 30.70</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SD: 7.65</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Median: 29.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IQR: 25.00 - 29.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Min - Max: 20.0 – 53.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Weight [33]</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean: 71.91</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SD: 11.37</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Median: 70.80</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IQR: 64.50 - 77.10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Min - Max: 55.3 – 108.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>BMI [33]</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean: 25.25</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SD: 3.79</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Median: 24.58</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IQR: 23.35 - 26.25</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Min - Max: 19.50 – 34.95</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Sex [33]</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>11</td>
<td>33.3</td>
</tr>
<tr>
<td>Male</td>
<td>22</td>
<td>67.7</td>
</tr>
<tr>
<td><strong>Race [33]</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>White</td>
<td>15</td>
<td>45.45</td>
</tr>
<tr>
<td>Brown</td>
<td>16</td>
<td>48.48</td>
</tr>
<tr>
<td>Black</td>
<td>2</td>
<td>6.07</td>
</tr>
<tr>
<td><strong>Tooth [264]</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Upper central incisors (11 and 21)</td>
<td>66</td>
<td>25.0</td>
</tr>
<tr>
<td>Lower central incisors (31 and 41)</td>
<td>66</td>
<td>25.0</td>
</tr>
</tbody>
</table>
Table 2 shows the clinical and thermographic characteristics of the coronal and gingival morphology, by evaluated tooth group. It should be noted that, in respect of the incisors, only the association between GH Temp and medial PD was not found to be significant.

Table 2 – Clinical and thermographic characteristics of the coronal and gingival morphology, by tooth group.

<table>
<thead>
<tr>
<th>Tooth group</th>
<th>Variables</th>
<th>Upper CI</th>
<th>Lower CI</th>
<th>Upper LI</th>
<th>Lower LI</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mean ± SD</td>
<td>Mean ± SD</td>
<td>Mean ± SD</td>
<td>Mean ± SD</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Clinical parameters (mm)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>CW/CL</td>
<td>0.72 ± 0.12</td>
<td>0.53 ± 0.09&lt;sup&gt;A&lt;/sup&gt;</td>
<td>0.64 ± 0.12&lt;sup&gt;AB&lt;/sup&gt;</td>
<td>0.56 ± 0.11&lt;sup&gt;ABC&lt;/sup&gt;</td>
<td>&lt;0.001&lt;sup&gt;(a)*&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>GH</td>
<td>5.91 ± 1.77</td>
<td>4.79 ± 1.37&lt;sup&gt;A&lt;/sup&gt;</td>
<td>6.76 ± 1.63&lt;sup&gt;AB&lt;/sup&gt;</td>
<td>5.31 ± 1.33&lt;sup&gt;ABC&lt;/sup&gt;</td>
<td>&lt;0.001&lt;sup&gt;(a)*&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>Medial PD</td>
<td>0.58 ± 0.24</td>
<td>0.56 ± 0.21</td>
<td>0.59 ± 0.23</td>
<td>0.61 ± 0.31</td>
<td>0.781&lt;sup&gt;(a)&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>Total PD</td>
<td>0.67 ± 0.26</td>
<td>0.68 ± 0.24</td>
<td>0.69 ± 0.24</td>
<td>0.77 ± 0.27</td>
<td>0.007&lt;sup&gt;(a)*&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>Thermographic parameters (°C)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>GH Temp</td>
<td>31.93 ± 1.09</td>
<td>32.33 ± 0.96&lt;sup&gt;A&lt;/sup&gt;</td>
<td>32.03 ± 1.04</td>
<td>32.29 ± 1.00&lt;sup&gt;A&lt;/sup&gt;</td>
<td>0.094&lt;sup&gt;(a)&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>Medial FGM Temp</td>
<td>31.36 ± 1.18</td>
<td>32.03 ± 1.10&lt;sup&gt;A&lt;/sup&gt;</td>
<td>31.50 ± 1.15&lt;sup&gt;B&lt;/sup&gt;</td>
<td>32.04 ± 1.12&lt;sup&gt;AC&lt;/sup&gt;</td>
<td>&lt;0.001&lt;sup&gt;(b)*&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>Total FGM Temp</td>
<td>31.32 ± 1.03</td>
<td>31.77 ± 1.01</td>
<td>31.56 ± 1.04&lt;sup&gt;A&lt;/sup&gt;</td>
<td>31.92 ± 1.04</td>
<td>0.006&lt;sup&gt;(b)*&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

Notes: <sup>(a)</sup>Kruskal-Wallis; <sup>(b)</sup>ANOVA; *p ≤ 0.05;
(A) Statistically significant difference in relation to Upper CIs;
(B) Statistically significant difference in relation to Lower CIs;
(C) Statistically significant difference in relation to Upper LIs.
Abbreviations:
CI- central incisor; LI- lower incisor; CW/CL- ratio of crown width to crown length; GH- gingival height;
Medial PD- mean probing depth; Total PD- total probing depth; GH Temp- temperature of gingival attachment band; Medial FGM Temp- temperature of medial site of free gingival margin; Total FGM Temp- total temperature of free gingival margin; mm- millimeter; °C- Celsius scale; SD- standard deviation.
The majority of the sample's GPs were classified as thin (76.1%), as shown in Table 3. A significant difference can be seen between GP and tooth groups and the lower LIs and Cls, with thin GP being most prevalent, (86.4%) and (83.3%), respectively.

**Table 3** – Frequency and distribution of the gingival thickness, by tooth group.

<table>
<thead>
<tr>
<th>Tooth group</th>
<th>Variables</th>
<th>Upper</th>
<th>Lower</th>
<th>Upper</th>
<th>Lower</th>
<th>Total</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CI</td>
<td>Cl (%)</td>
<td>Cl (%)</td>
<td>LI (%)</td>
<td>LI (%)</td>
<td>n (%)</td>
<td></td>
</tr>
<tr>
<td>GP</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.009(a)</td>
</tr>
<tr>
<td>Thin</td>
<td></td>
<td>43 (65.2)</td>
<td>55 (83.3)</td>
<td>46 (69.7)</td>
<td>57 (86.4)</td>
<td>201 (76.1)</td>
<td></td>
</tr>
<tr>
<td>Thick</td>
<td></td>
<td>23 (34.8)</td>
<td>11 (16.7)</td>
<td>20 (30.3)</td>
<td>9 (13.6)</td>
<td>63 (23.9)</td>
<td></td>
</tr>
</tbody>
</table>

**Notes.** (a)Pearson’s chi-squared test; *p 0.05.

**Abbreviations:** CI- Central incisor; LI- Lateral incisor; GP- gingival phenotype.

Table 4 shows there was a significant, inversely proportional correlation between the coronal and gingival morphological, clinical parameters and the thermographic characteristics (p < 0.005).

**Table 4** – Correlation between clinical parameters and thermographic characteristics of the coronal and gingival morphology of the evaluated teeth.
<table>
<thead>
<tr>
<th>Variables</th>
<th>GH Temp (ºC)</th>
<th>Medial FGM Temp (ºC)</th>
<th>Total FGM Temp (ºC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CW/CL (mm)</td>
<td>-0.315</td>
<td>-0.372</td>
<td>-0.357</td>
</tr>
<tr>
<td>p-value</td>
<td>&lt;0.001*</td>
<td>&lt;0.001*</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td>GH (mm)</td>
<td>-0.135</td>
<td>-0.218</td>
<td>-0.146</td>
</tr>
<tr>
<td>p-value</td>
<td>0.028*</td>
<td>&lt;0.001*</td>
<td>0.018*</td>
</tr>
<tr>
<td>Medial PD (mm)</td>
<td>-0.272</td>
<td>-0.235</td>
<td>-0.234</td>
</tr>
<tr>
<td>p-value</td>
<td>&lt;0.001*</td>
<td>&lt;0.001*</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td>Total PD (mm)</td>
<td>-0.213</td>
<td>-0.161</td>
<td>-0.166</td>
</tr>
<tr>
<td>p-value</td>
<td>0.001*</td>
<td>0.009*</td>
<td>0.007*</td>
</tr>
</tbody>
</table>

Notes. Spearman’s Correlation\(^{(a)}\); *p ≤ 0.05.  
Abbreviations:  
CW/CL- ratio of crown width to crown length; GH- gingival height; Medial PD- medial probing depth; Total PD- total probing depth; GH Temp- temperature of gingival attachment band; Medial FGM Temp- temperature of medial location of free gingival margin; Total FGM Temp- total temperature of free gingival margin; mm- millimeter; ºC- Celsius scale.  
A significant association can be seen between CW/CL and GH and the type of GP. However, it was not possible to establish a significant association between the GP and the thermographic characteristics (Table 5).  

Table 5 – Comparative analysis between the clinical morphological coronal and thermographic parameters, by GP type.
### Gingival Phenotype

<table>
<thead>
<tr>
<th>Variables</th>
<th>Thin</th>
<th>Thick</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean ± SD</td>
<td>Mean ± SD</td>
<td></td>
</tr>
<tr>
<td><strong>Clinical parameters (mm)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CW/CL</td>
<td>0.60 ± 0.13</td>
<td>0.65 ± 0.14</td>
<td>0.026^(b)*</td>
</tr>
<tr>
<td>GH</td>
<td>5.38 ± 1.55</td>
<td>6.68 ± 1.76</td>
<td>&lt; 0.001^(b)*</td>
</tr>
<tr>
<td>Medial PD</td>
<td>0.58 ± 0.26</td>
<td>0.58 ± 0.23</td>
<td>0.945^(b)</td>
</tr>
<tr>
<td>Total PD</td>
<td>0.70 ± 0.26</td>
<td>0.72 ± 0.24</td>
<td>0.342^(b)</td>
</tr>
<tr>
<td><strong>Thermographic parameters (°C)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medial FGM Temp</td>
<td>31.72 ± 1.23</td>
<td>31.79 ± 0.99</td>
<td>0.696^(a)</td>
</tr>
<tr>
<td>Total FGM Temp</td>
<td>31.62 ± 1.09</td>
<td>31.73 ± 0.92</td>
<td>0.456^(a)</td>
</tr>
<tr>
<td>GH Temp</td>
<td>32.11 ± 1.06</td>
<td>32.27 ± 0.93</td>
<td>0.267^(a)</td>
</tr>
</tbody>
</table>

*Notes.* (a)Student’s t-test; (b)Mann-Whitney test; *p ≤ 0.05.*

*Abbreviations:*

- CW/CL - ratio of crown width to crown length
- GH - gingival height
- Mid PD - mean probing depth
- Total PD - total probing depth
- GH Temp - temperature of gingival attachment band
- Medial FGM Temp - temperature of medial location of free gingival margin
- Total FGM Temp - total temperature of free gingival margin
- mm - millimeter
- ºC - Celsius scale
- SD - standard deviation

### 4. DISCUSSION

An understanding of the morphological concepts relating to the GP is essential for guaranteeing better results in esthetic dental treatment (Araújo et al., 2018; Zweers et al., 2014). The clinical morphological characteristics of dental crowns, such as the format, as determined by the CW/CL ratio, may have an influence on the characterization of GPs (Olsson & Lindhe, 1991; Muller & Eger, 1997; Muller et al., 2000; De Rouck et al., 2009; Yin et al., 2020; Stellini et al., 2013). The results of our study revealed low mean values for the CW/CL ratio, with a significant difference between the tooth groups (*p < 0.001*) (Table 2). Thus, our sample included teeth with long, narrow coronal formats, with the crowns of the upper incisors being wider and shorter than those of the lower incisors. Our findings are relatively akin to those found by Yin et al. (2020), whose study reported mean CW/CL values of 0.79 mm and 0.71 mm, respectively, for the upper CIs and LIs. By contrast, the study conducted by De Rouck et al. (2009) observed mean CW/CL values of 0.81 mm for the upper CIs. These morphological differences may be attributable to...
characteristics of gender, race or ethnicity (Joshi et al., 2016; Kim, Bassir & Nguyen, 2020; Chou et al., 2008).

GH, PD and GT are important morphological parameters in the classification of GPs (Kim et al., 2020; De Rouck et al., 2009). As far as GH is concerned, the values found in our sample ranged from 4.79 mm (lower CIs) to 6.76 mm (upper LIs) (Table 2). Additionally, our results revealed higher mean GH values in the upper LIs, followed by the upper CIs, corroborating the results of Alhajj (2020), Kim, Bassir and Nguyen (2020), Shah et al. (2015) and Müller and Eger (1997).

For the evaluation of gingival thickness, we used the GT method since it is a widely used technique (De Rouck et al., 2009; Kan et al., 2010). Our results showed a greater prevalence of the thin GP (Table 3), corroborating the findings of Lee et al. (2013) though in disagreement with De Rouck et al. (2009), Shah et al., (2015) and Alhajj (2020). These divergences may be explained by the use of different methods and classifications from one study to another. We also noted in this study a significant difference when analyzing the association between GP and tooth groups (p=0.009), and the lower LIs and CIs, with a higher prevalence of the thin form of the GP. These results are similar to those of Fischer et al. (2021), who report a moderate propensity for thin GPs in the area of the incisors (p = 0.046) and a tendency for a thick GP in the upper jaw.

Studies have demonstrated that teeth with a long, narrow crown format and with low GH values are more likely to have a thin GP (Joshi et al., 2016; Stein et al., 2013; Stellini et al., 2013; Vlachodimou, Fragkioudakis, & Vouros, 2021). These results corroborate the findings in our study (Table 5), which found a significant association between CW/CL and GH and the type of GP (p < 0.05). It was also found that the mean value for total PD was discreetly higher in the tooth group with a thick GP, corroborating De Rouck et al. (2009), Olsson et al. (1993) and Müller et al. (2005), although there was no significant statistical difference (p = 0.342) (Table 5).

Various different methods have been described in the literature for evaluating and classifying GPs (De Rouck et al., 2009; Aguilar-Duran et al., 2020; Joshi et al., 2016). The visual assessment and GT methods are the ones most frequently quoted (De Rouck et al., 2009; Kan et al., 2010; Muller & Eger, 1997; Müller et al., 2000). Other studies refer to evaluation of the GP using a transgingival probe (Pascual et al., 2017), ultrasound (Müller et al. 2000; Eger et al., 1996) or CBCT (Stein et al., 2013). However, despite these methods having some promise, errors in precision, reproducibility, exposure to radiation and the high cost are regarded as disadvantages of the techniques, the last two being specifically related to CBCT (Aguilar-Duran et al., 2020).

Realizing that the thermal properties of periodontal tissue could furnish a wide array of information (Mukherje et al., 1978; Brill et al., 1978; Molnár et al., 2015), our study evaluated the temperature in different gingival regions through the use of IRT. Using IRT requires numerous factors to be taken into consideration: environmental, technical and biological. All of these could have an impact on the recording and interpretation of the images (Fernández-Cuevas et al., 2015). Identifying them and minimizing them...
is important for assuring greater precision in the thermographic evaluation (Fernández-Cuevas et al., 2015; Zaproudina et al., 2008; Harrap et al., 2018).

This study recorded the RT prior to the turn of each volunteer, bearing in mind that, when analyzing a body through IRT, the total radianc of the environment has to be taken into account, in other words, the infrared radiation emitted by the object of study added to the radiation reflected by the environment. This summation of radiation values overestimates the actual temperature of the object and can be eliminated through the measurement of the RT (International Organization for Standardization, 2011; Usamentiaga et al., 2014; Harrap et al., 2018). However, most of the studies that use IRT in the area of health fail to consider this parameter in their evaluations (Fernández-Cuevas et al., 2015).

On evaluating the temperature of the gingival tissue, we observed that the maxillary GH Temp values found in this study are similar to those recorded by Nakamoto et al. (2012) (GH Temp = 34.4°C ± 1.1°C). However, the mean GH Temp values for both dental arches were higher in our study than in the studies of Komoriyama et al. (2003) (maxillary GH Temp = 29.7°C; mandibular GH = 29.8°C) and of Barnett et al., (1989) (maxillary GH Temp = 24.3°C) (Table 2). Differences in methodology, such as the previous cooling of the mucosa, the distance between the equipment and the volunteer, ROIs and the configuration of the thermographic cameras, might explain these discrepancies. As far as total FGM Temp is concerned, it was possible to identify a higher mean temperature in the lower LIs and lower in the upper CIs (Table 2). There was a significant difference between total FGM Temp in relation to the tooth groups, more precisely between the upper LIs and the upper CIs (p=0.006).

On correlating the coronal and gingival, clinical morphological parameters with tissue temperature, our results show a significant and inversely proportional correlation among all parameters evaluated (Table 4). It can be observed that teeth with wide, short crowns, greater GH and greater PD (total or medial) tend to present lower gingival temperatures (GH Temp and FGM Temp). As previously noted, these clinical morphological characteristics are associated more with thick GPs (Cortellini & Bissada, 2018; Vlachodimou, Fragkioudakis & Vouros, 2021). The opposite was also true, in other words, teeth with long, narrow crowns, smaller GH and smaller PD, characteristics more typical of thin GPs (Joshi et al., 2016; Stein et al., 2013; Stellini et al., 2013; Shao et al., 2018), tend to exhibit higher temperatures in the gingival tissue. In spite of this, it was not possible to observe a significant difference between gingival temperatures and the GP (Table 5). This may be explained by the small sample size in the study.

Histologically, the thin GP is characterized by having less conjunctive tissue than the thick GP, there being no significant differences for the epithelial components (Motta et al., 2017) and blood flow (Mikecs et al., 2021). Moreover, the relationship between blood flow and temperature is limited (Komoriyama et al., 2003). Accordingly, the correlations between temperature and morphological characteristics found in our study are likely attributable to the physical mechanisms of heat dissipation inherent to each type of tissue (Davanzo et al., 2015; Komoriyama et al., 2003; Baab et al., 1990; Nilsson et al., 1987).)

Lastly, the diagnostic evaluation of the morphology of the gingival tissue may have a substantial, multidisciplinary impact on the treatment decision-making process (Malpartida-Carrillo et al., 2021).
However, the lack of a gold-standard procedure for classifying GPs could result in imprecision (Kloukos et al., 2021). Thus, the development of new economical, non-traumatic methods for precisely identifying the GP should be evaluated (Aguilar-Duran et al., 2020).

IRT has great potential as an auxiliary diagnostic method in the area of health, however there are challenges that need to be taken into consideration when used in the intraoral region. The absence of a standardized image acquisition protocol and the difficulty of use in the more posterior regions of the dental arch constitute methodological limitations, which needs to be better studied. Moreover, the natural humidity of the mucosa represents an object of confusion which could interact through radiation with the measurements of local temperature. Accordingly, it is recommended that future studies use methods involving the drying or cooling of the mucosa prior to commencing the thermographic examinations (Nilsson, 1987). As for the association between gingival temperature and the GP type, it is recommended that studies be conducted with a larger sample size and with a proportional distribution of GPs, sex and race, and that variables related to the bone morphotype be taken into consideration.

5. CONCLUSION

The results show that CW/CL, GH, PD and FGM Temp vary according to tooth group. The majority of the sample presented with the thin GP, which was more prevalent in the lower LIs and CIs. There was a significant and inversely proportional correlation between clinical morphological parameters that determine the GP and the temperature of the gingival tissue.

Declarations

Conflicts of interest

The authors explicitly state that there are no conflicts of interest directly connected with this article.

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Ethical statement

All the ethical precepts of research in Brazil have been complied with in accordance with article 14, chapter II of Resolution 466/12, having been submitted for the evaluation of the research ethics committee.

Informed Consent Statements

The prior signing of consent forms was required from all participants in the study.

Ethics Approval and Consent to Participate
The present study was approved by the local committee of ethics in research under the protocol number: CAAE 40371920.1.0000.5187. A signed written informed consent form was obtained from each patient sampled in this study.

Author Contribution

N.B.M., R.S.C.S. and P.M.B conceived and designed of study; N.B.M., L.N.S.D. and C.M.V.P. acquired of clinical data; N.B.M., J.S.B. and A.M.G.S. analyzed and interpreted of data collected; N.B.M., R.S.C.S and P.M.B. drew of article and critical revision; N.B.M. and P.M.B. All authors reviewed the manuscript.

References


Figures
Figure 1

Reference points traced on the photo clinical and thermograms.