

Infrared thermographic investigation of PMMA material effects on oral tissues

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This work aims to investigate the effect of poly(methyl methacrylate) (PMMA) – fabricated prostheses on oral tissues. The novelty of this study was the comparative investigation of thermal signatures of the denture bearing maxillary and mandibular mucosa using passive infrared (IR) thermography. IR thermography is an optoelectronic method of investigation that has only recently begun to be used in dentistry. In this study, it was investigated the influence of age on the mucosal response at the contact with PMMA, and also the increased incidence of denture stomatitis at the level of maxillary mucosal prosthetic support.

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1. Introduction

Removable partial and complete dentures, respectively implant-supported overdentures constitute in many clinical edentulous situations the only prosthetic treatment option, having a series of advantages, but also disadvantages. One of the disadvantages is directly related to the shortcomings of the material from which the removable dentures bases are made, respectively poly(methyl methacrylate) (PMMA). It still remains actually the main material used in dentures fabrication with a consumption of approximate 400 t/year at the European level, corresponding to about 10 million manufactured dentures. This material is frequently used for dental restorative materials [1], but especially in prosthetic treatment for geriatric patients, an increasing population segment, having a direct impact on their quality of life, also affected through facial physiognomic, masticatory, phonetic and psycho-social changes. Moreover, due to its interesting properties (low-cost, high flexibility, good solubility in organic solvents, good optical clarity, and high optical transmission in Vis range), the polymer PMMA is also used to develop materials with enhanced optoelectronic properties [2-4].

From a chemical point of view, PMMA belongs to an important class of thermoplastic materials, being a long-chain polymeric branched compound (Fig. 1).

The biggest shortcomings of polymeric denture bases are related to their poor mechanical strength, roughness surface, high wettability [5], and weak thermal features, with a negative impact on oral structures by creating surface microbial loading conditions and inducing infectious-inflammatory lesions in the denture bearing oral mucosa (denture stomatitis type). The microbial load of

the prosthesis and the oral mucosa, especially with *Candida*-type yeasts is responsible for the appearance of denture stomatitis (DS), a less investigated aspect, which seems to be favoured by the alleged increase in temperature under the acrylic prosthesis [6], heat flux that would allow the pathogenesis of saprophytic microbial flora and its toxic action [7], [8].

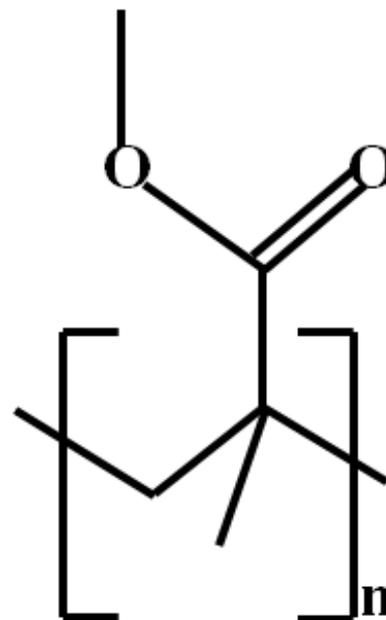


Fig. 1. Chemical formula of poly(methyl methacrylate) (PMMA)

In fact, PMMA is not thermally stable, its thermal properties including low thermal conductivity (0.2 W/mK)

and low thermal resistance [9]. The average transmission factor is in the spectral domains usually used in thermography, and the material has an emissivity equal to 1 (specific to all polymer matrices), similarly to that of the human skin and mucosa, a value considered high, which is why both are well suited for thermographic examination [10]. Infrared thermography is commonly used in medicine as an effective non-destructive tool by measuring the surface temperature distribution [11], and the heat flux can be instrumented without direct thermal contact. This non-invasive method known as passive infrared thermography constitutes the method of investigation of the present study. The precise evaluation of the biological surfaces by using passive infrared thermography method, has crucial importance in predicting thermal changes at the interface between the biological tissue and polymeric environment, and contributes to monitor the evolution of any pathologic process, and thus adopting prophylactic measures and individualizing treatment behaviour in completely edentulous subjects.

The main purpose of this study was to evaluate the thermal changes induced by complete prostheses made of PMMA on the oral mucosa in edentulous subjects belonging to different age categories, by comparative reports with edentulous subjects without prostheses and with denture wearers affected by DS, respectively. Last but not least, by analysing the thermal profile generated by the denture bearing mucosa from the mandible and from the maxillary, the aim was to argue the clearly higher frequency of DS in the latter.

2. Materials and methods

An experimental study was performed by the method of passive infrared thermography on a series of bimaxillary completely edentulous cases ($n = 35$), aged between 56 and 85 years, of which 27 bimaxillary completely denture wearers, made of PMMA. Patients were enrolled following the presentation of prosthodontic treatment and distributed by age groups, as follows: Group I with 13 cases, aged between 56 and 65 years; Group II with 11 cases and ages between 66 and 75 years and Group III, with 11 cases with ages ranging from 76 to 85 years. Criteria for inclusion in these groups were the status of bimaxillary completely edentulous subjects, and among the situations with prosthesis, subjects with complete dentures at both jaws, with a healthy clinically supportive mucosa, or presenting the specific pathological clinical signs of DS. The number of cases with DS in the upper jaw was 12, and of these only 3 presented the specific pathological aspect at the mandibular level (there are no situations in which the disease is diagnosed only in the mandible). The exclusion criteria referred to the presence of other pathologies than DS at the level of the supporting mucosa, major cognitive/ mental/ locomotor deficiencies, physiological/pathological conditions with implications on thermal homeostasis, respectively refusal to participate in the study.

The study was conducted in accordance with the ethical principles of the "Declaration of Human Rights" in Helsinki, and with the Rules of Good Practice in Clinical Trials. Patients received information on the thermography method, and expressed their written agreement to participate. The thermographic study was carried out within the Department of Total Prosthesis of the Faculty of Dentistry within the University of Medicine and Pharmacy "Carol Davila" in Bucharest, with logistical support and specialized assistance from the Department of Materials Technology and Welding, Faculty of Engineering and Management of Technological Systems, within the "Politehnica" University of Bucharest.

In this sense, an IR detector (ThermaCAM PM350 thermographic camera from the Inframetrics/ FLIR system range, USA) with applicability in the medical field was used. The optimal temperature range of the IR thermography chamber is adjusted automatically, but it can be also adjusted manually by the operator. In general, a wide temperature range is chosen for the thermography of large body surfaces. Thus, IR camera is the one that detects the thermal difference between the "hottest" and the "coldest" point of the scanned surface, and depending on this difference (of the order of degrees, tenths or hundreds of degrees, etc.), the scale is automatically calibrated. Likewise, the colour palette assigned to the numerical scale differs from thermogram to thermogram, the IR camera automatically setting the colours to obtain the best possible visual contrast.

Therefore, the reference scale visible on the left side of digital thermal images has an influence on the quality of the detailed information provided by IR images [12]. For example, if the reference scale starts at 15°C and ends at 35°C, with a temperature range of 20°C, each colour level in the colour palette is 1°C. At a reference scale between 25°C and 27°C, with a low thermal range of only 2°C, each colour level is 0.1°C. Depending on the thermography investigated surface, which in our study was represented by the denture bearing oral mucosa, the temperature range was set so that both detailed elements and the overall image can be viewed on the images. The colour palettes visible at the level of the thermograms were selected differently by the thermography camera, which has the possibility to automatically "notice" the minimum and maximum values on the thermal scene. In other words, the analysis of the thermograms consisted in monitoring and interpreting the thermal values, not the colours themselves, these representing a quantitative coding of the temperature, not a qualitative one. For an easier analysis of the thermograms in our study, it should be noted that the colour scale was set so that the "cold" colours (purple, blue, green) correspond to the lowest temperatures, while "warm" colours (red, orange, yellow) were associated with high temperatures.

The investigation itself complied with a certain procedure (Table 1), in accordance with the Glamorgan Protocol of 2001 [13], [14]. It is important to mention that various factors (see Table 1) may influence the results of the thermographic investigation, by compromising real thermal values.

After thermal accommodation period, sterile plastic spacers were applied in the oral cavity of the patients, the investigation being carried out in supine position, with support for the cephalic extremity. Thermo scanning was performed at a distance of (25-30) cm between the front lenses of the thermal imaging chamber and the oral mucosa, and in the case of denture wearers, this was possible in the first 10 s from the prostheses removal from the oral cavity, given the special sensitivity of the thermal detector used in the study and the high thermal inertia of the polymeric material [10]. The thermal images were stored on the PCMCIA card in TIFF format, specific to the ThermoGram Pro 95 software, with the optimization of the used temperature range, adapted to the colour palette, and then transferred to the computer for processing, analysis, and storage. Thus, the records were comparatively analysed for the maxilla and mandible, for edentulous subjects with and without prostheses, with and without affecting the mucosa by DS. Data interpretation was performed by comparative evaluation of thermograms (thermal images obtained in real time), starting from the deviation of 1°C from the clinically healthy supporting mucosa, which is considered significant from a pathological point of view [15-17].

Table 1. Examination protocol by infrared thermography

Environment	Patient
Uniform, constant temperature, in the range (20-24)°C	Avoiding special thermal conditions: sun exposure/cold/physical effort
Maintaining air humidity in a range (45-60)%	Exclusion of treatments for 24 hours before the investigation: acupuncture/ electrostimulation/ ultrasound/anti-inflammatory medication
Avoiding air drafts in the room	Exclusion of consumption of alcohol/nicotine/coffee/tea
Removal of the computer equipment from the place of investigation	Maintaining a rest period of 30 minutes to accommodate to the ambient temperature
Exclusion of interference with other infrared sources (closing and covering windows with opaque textiles, closing of artificial lighting sources)	Avoiding orally expiration of the air column during the procedure

The microbiological studies were carried out for *Candida spp.* presence. Biological samples were collected from the palatal vault and the mandibular denture bearing mucosa, using a sterile swab, followed by its introduction into a sterile test tube and stored in a refrigerator at 4°C. The samples were inoculated in Petri dishes containing growth media, and then incubated for (24-72) hours at 37°C, on Sabouraud-Dextrose-Agar (SDA) medium, supplemented with chloramphenicol as an inhibitor of bacterial growth.

3. Results

As known, the temperature has been proved to be a very good sensor of health [18]. For this reason, in this study the IR thermography has been used as an alternative diagnosis tool, in fast monitoring the health status of oral cavity in order to detect, in a non-invasive manner, the appearance of *Candida*-associated DS.

Fig. 2 displays a comparison between healthy maxillary mucosa (left) vs. maxillary with denture stomatitis (right).

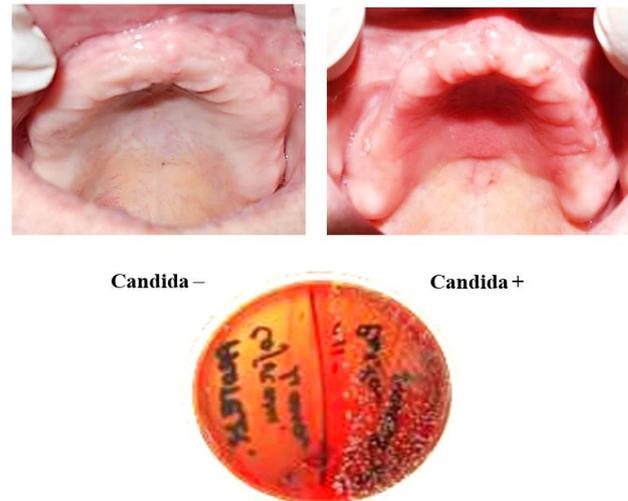


Fig. 2. Healthy maxillary mucosa (left) vs. maxillary with denture stomatitis (right) with a negative and positive *Candida* test, respectively (color online)

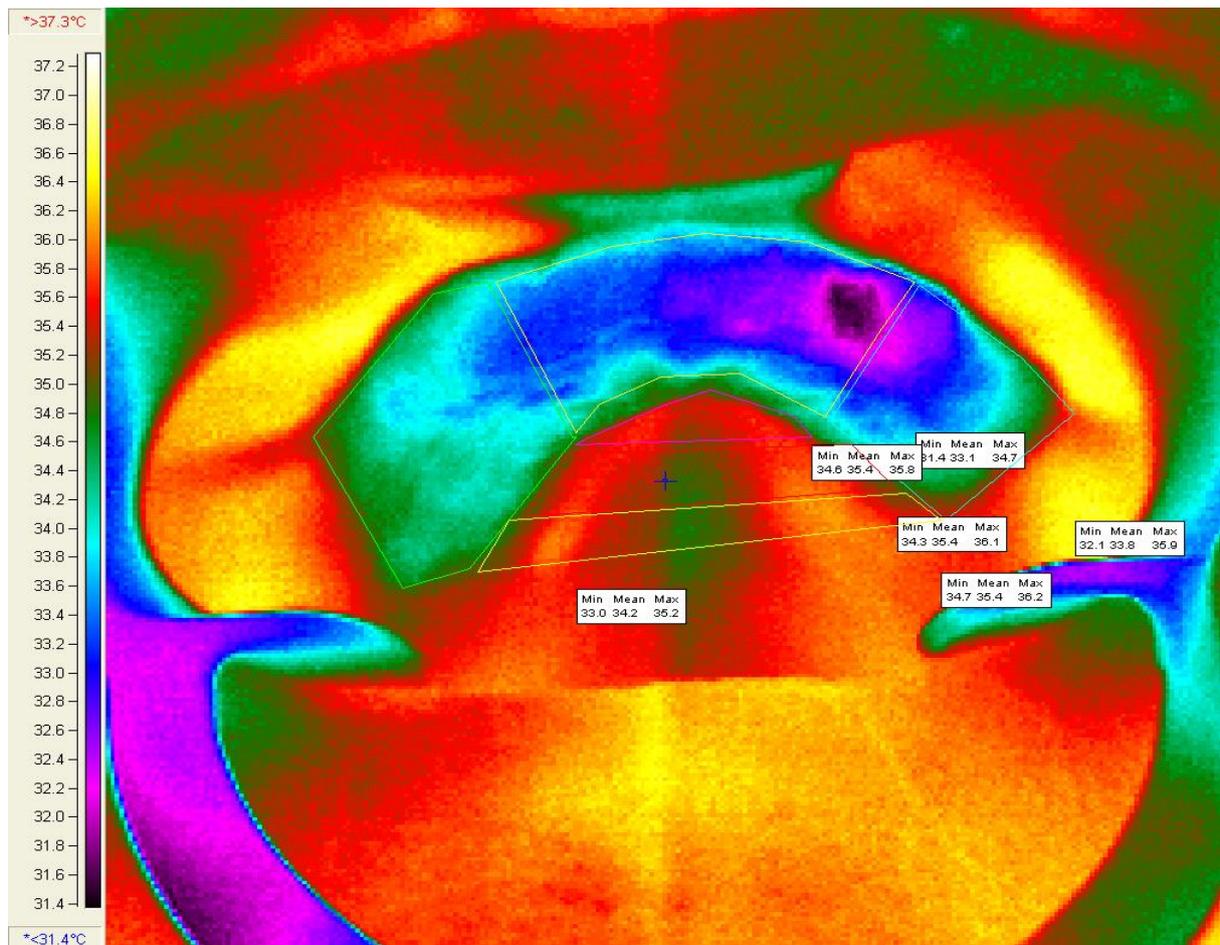
Given that this type of comparative evaluation of the temperatures of the supporting mucosa of the jaw and mandible has not been investigated, the first step was to test random areas of the oral cavity. These included both prosthetic support areas (Figs. 3, 5 and 7), and paraprosthetic ones (Figs. 4, 6, and 8), in order to see the hottest area. In the next stage of thermal analysis, with the help of the software, we delimited as strictly as possible, the surfaces on which the PMMA prostheses are placed. The notations on the thermograms reflect some random test values made before the strictest delimitation with the help of the software, of the support mucosa for prostheses.

In a first stage, the thermal recordings for the maxilla and mandible mucosa were comparatively analysed, for edentulous subjects without acrylic prostheses, belonging to all age categories. Thus, the average thermal values for all three age categories (see Table 2) were calculated, resulting in similar mean temperatures for the maxillary and mandibular support mucosa, for all completely edentulous subjects without prostheses of 35.66°C and 35.40°C, respectively. The thermal scene in this clinical situation is exemplified in Figs. 3 and 4, the thermograms belonging to the same bimaxillary completely edentulous subject without dentures.

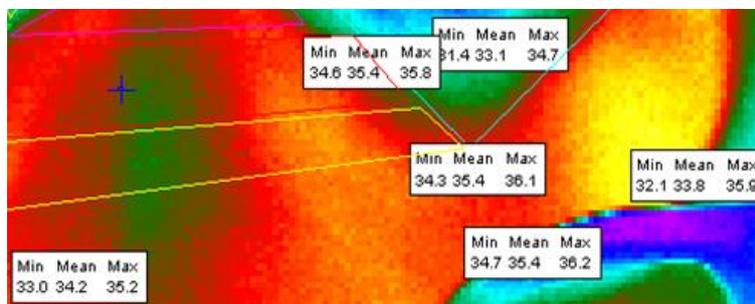
In the second stage, the thermograms of the denture wearers' mucosa without local pathological phenomena such as DS were evaluated comparatively with those of the

edentulous subjects without prosthesis. In the case of denture wearers with healthy mucosa, the thermal scene was slightly lower compared to edentulous ones not wearing prostheses, but below the difference of 1°C, which could be associated, as previously mentioned, with pathological changes.

Thus, the thermal average of the thermograms of the denture wearers from PMMA (Table 2), regardless of their age category, was located at the maxillary at 35.49°C, and for the mandibular support mucosa at 35.52°C, the values being quite close including each other. Figs. 5 and 6 illustrate the thermal images in the case of a patient in this category (PMMA denture wearers with healthy supporting mucosa).



(a)



(b)

Fig. 3. Maxillary mucosa thermogram of an edentulous subject non-denture wearer, $T = 35.20^{\circ}\text{C}$ (a); Magnification of preliminary random areas of the oral cavity (b) (color online)

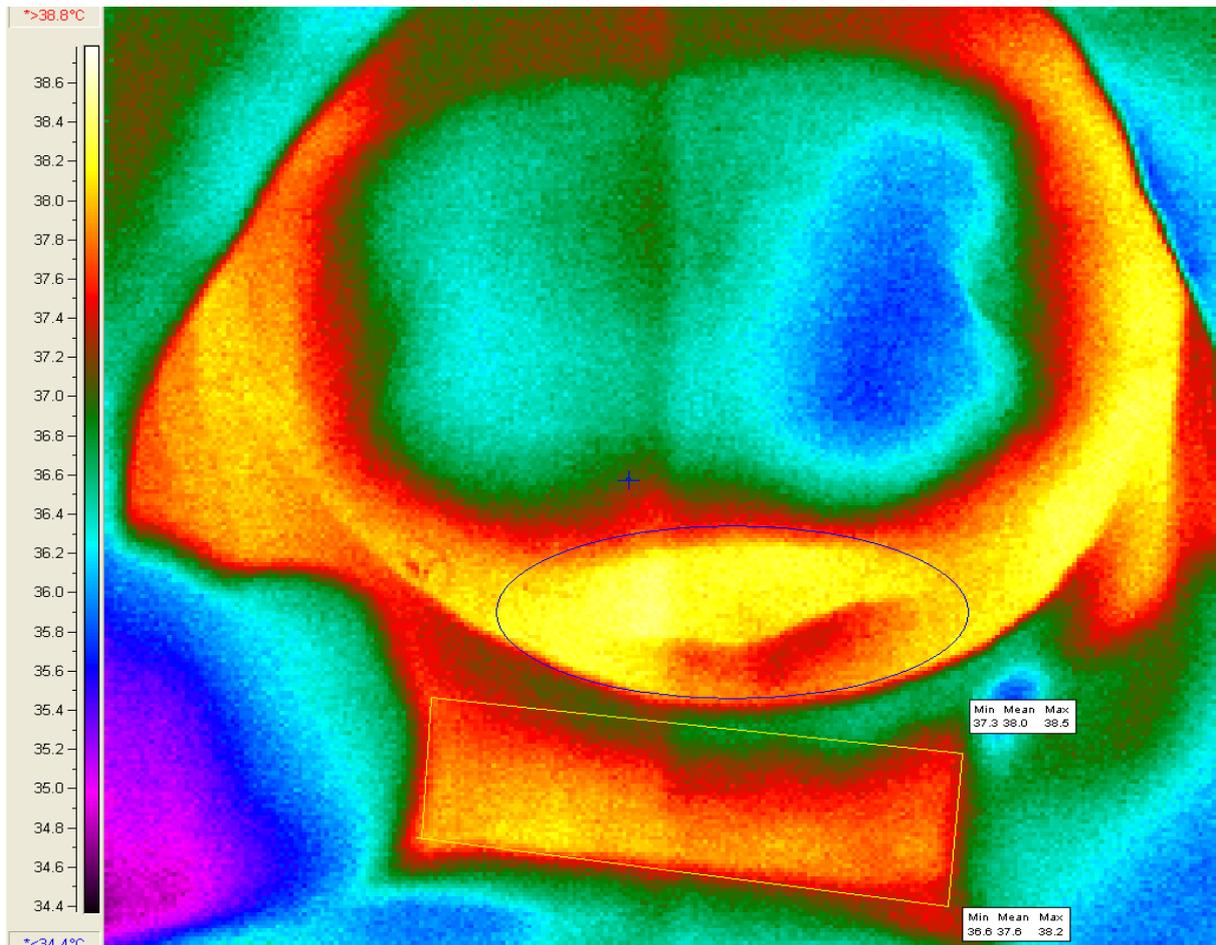
In the third stage, the situation of denture wearers with clinical diagnosis of DS was evaluated, exemplified in Figs. 7 and 8 that give the thermal scene to an edentulous subject with both maxillary mini-implants

supported overdentures. Thus, regarding the average temperature of the supporting mucosa for all age categories (Table 2), the thermograms indicated mean values for the upper and the lower mucosa of 36.57°C and

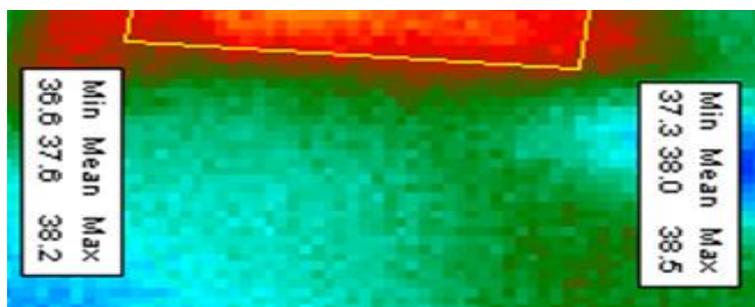
36.61°C, respectively. Once again, the values from the maxillary and the mandibular *In the third stage*, the situation of denture wearers with clinical diagnosis of DS was evaluated, exemplified in Figs. 7 and 8 that give the thermal scene to an edentulous subject with both maxillary mini-implants supported overdentures. Thus, regarding the average temperature of the supporting mucosa for all age categories (Table 2), the thermograms indicated mean

values for the upper and the lower mucosa of 36.57°C and 36.61°C, respectively.

Once again, the values from the maxillary and the mandibular denture bearing mucosa are close to each other. In exchange, there are thermal differences of over 1°C compared to edentulous subjects without pathological phenomena such as DS, regardless of their prosthetic status or age.



(a)



(b)

Fig. 4. Mandibular mucosa thermogram of an edentulous non-denture wearer $T = 35.00^{\circ}\text{C}$ (a); Magnification of preliminary random areas of the oral cavity (b) (color online)

In the last stage, the age groups were analysed (see Table 2), so that, for the interval (56-65) years, the IR thermography determined a similar average maxillary

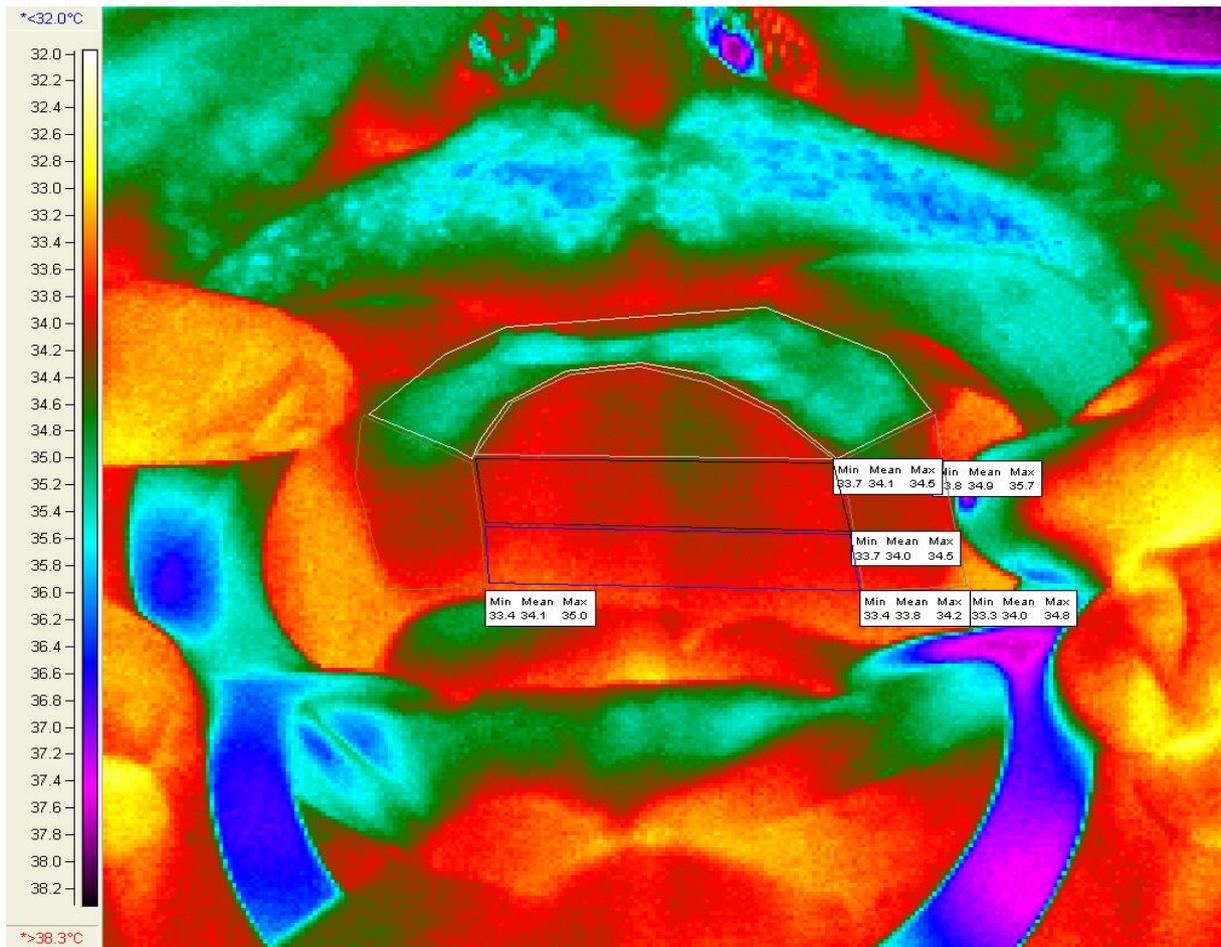
temperature of 35.70°C for non-denture wearers and 35.76°C for wearers of PMMA prostheses, respectively, while in denture wearer with DS, the temperature

increases on average by 1.12°C in the same age group. In the case of the mandibular mucosa, the results are similar, with an average temperature of 35.40°C in non-wearers and 35.48°C in wearers and an additional thermal difference of about 1.36°C in mandibular denture wearers with DS.

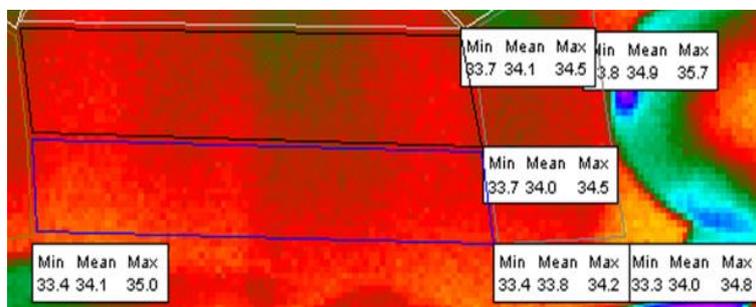
The second age group (66-75) years presented similar thermal distributions, namely thermal averages at the maxillary of 35.33°C and 35.31°C, respectively at non-wearers vs. denture wearers with healthy mucosa, and an

increase in the range of the same group, of 1.14°C, in those affected by DS.

Regarding the thermal scene for the mandibular mucosa for patients of age group between 66 and 75 years, the thermal differences between non-wearers and denture wearers without DS are minor (35.00°C vs. 35.50°C), values that change with the damage of the supporting mucosa through the infectious disease, where an average thermal increase over 1.15°C is registered.



(a)

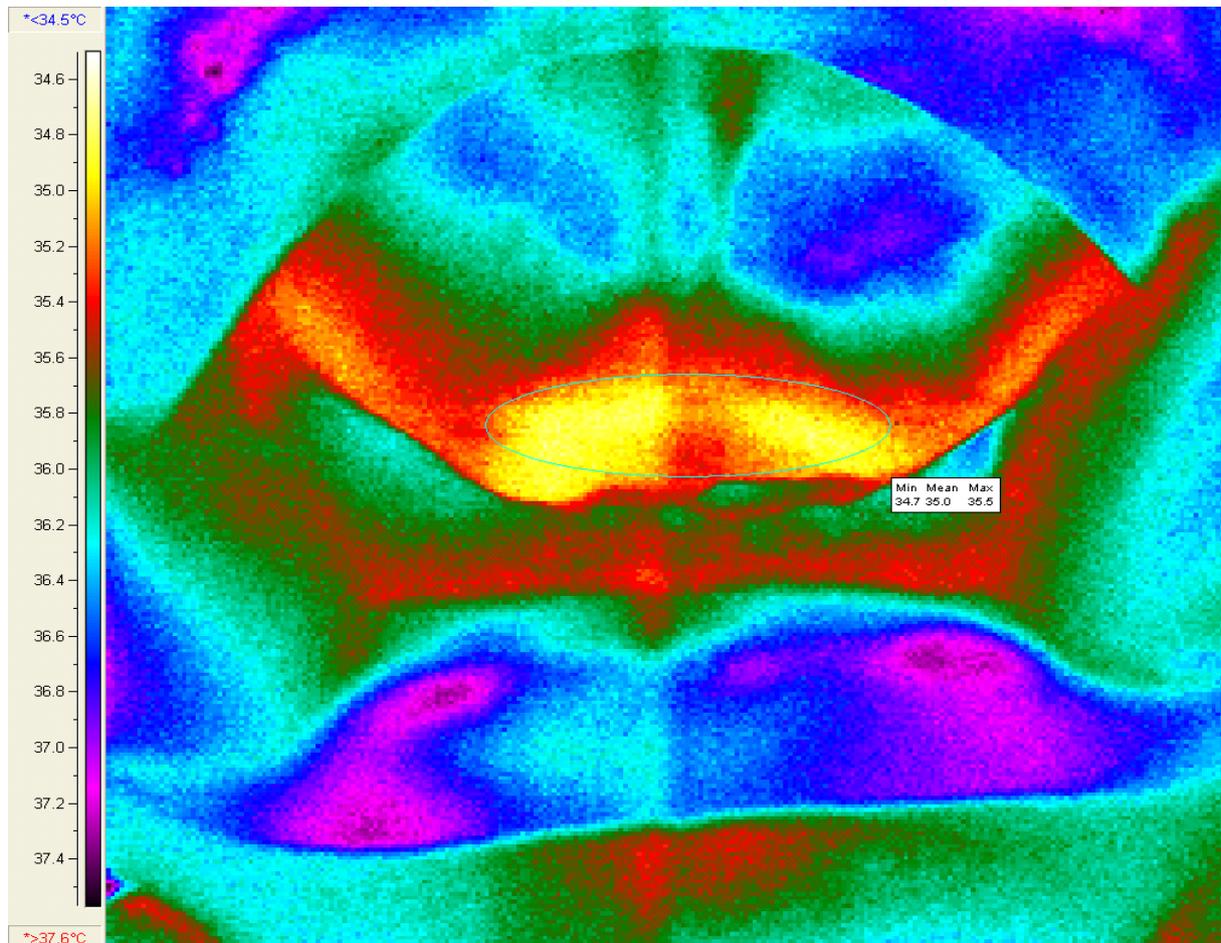


(b)

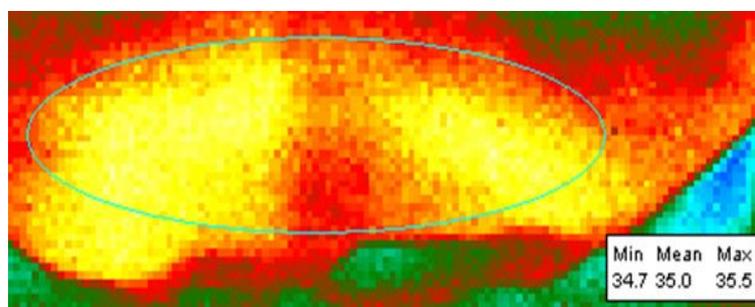
Fig. 5. Maxillary mucosa thermogram of a denture wearer with healthy mucosa $T = 34.96^{\circ}\text{C}$ (a); Magnification of preliminary random areas of the oral cavity (b) (color online)

The last age range (76-85) years reproduces the same thermal behaviour of the mandibular mucosa; as in the case of the previous groups. Similar mean thermal values of the mandibular mucosa were established in edentulous without and with dentures, but healthy mucosa (35.80°C vs. 35.60°C); the thermal threshold of over 1°C in the case of the mandibular supporting mucosa with DS was not

exceeded (although at the limit), the difference compared to previous groups stopping at an increase of 0.93°C. In the case of the maxillary mucosa, edentulous subjects without prostheses and wearers whose mucosa is not affected by DS, have close temperature values (35.96°C and 35.41°C), and an increase in the range of the same group of 0.80°C in patients with DS therefore also below the limit of 1°C.

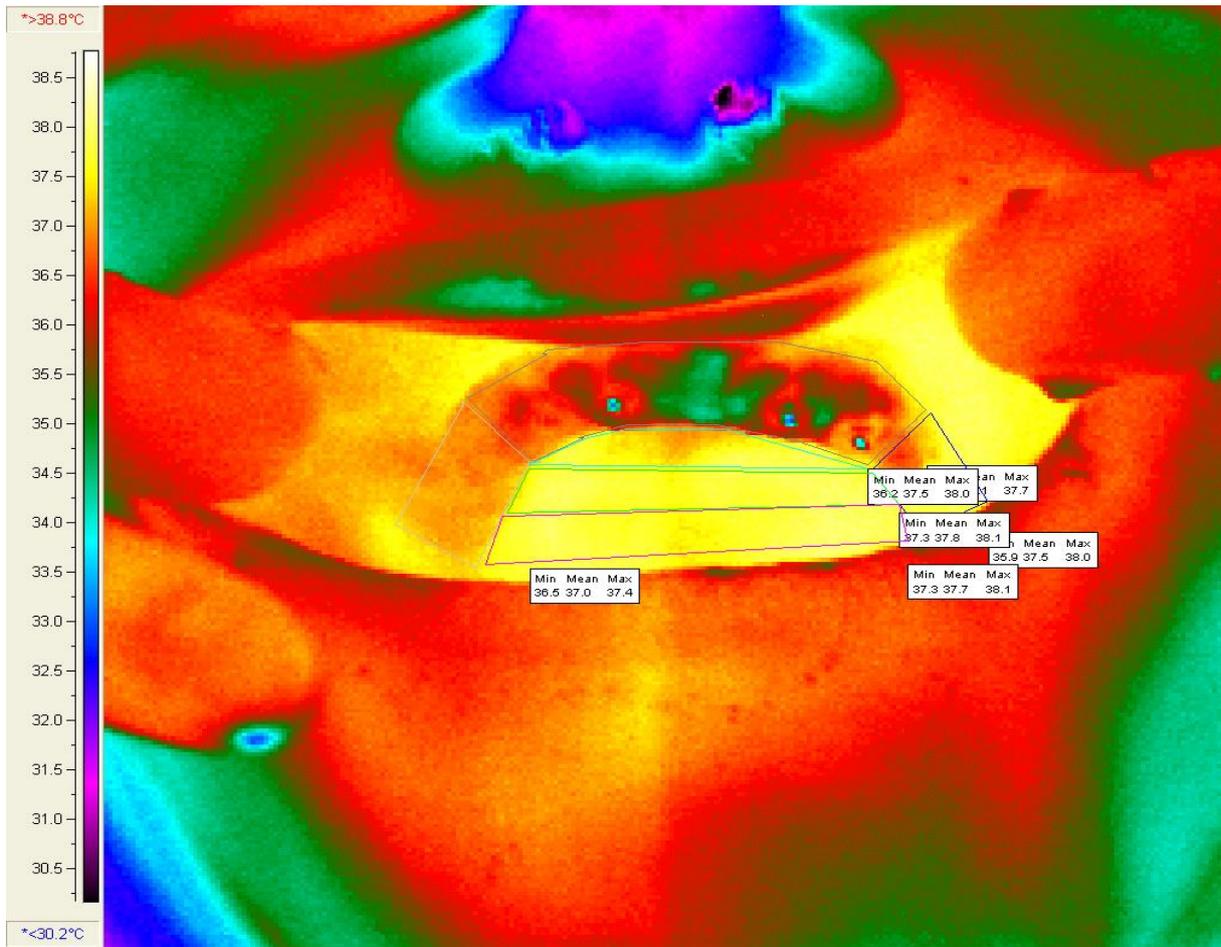


(a)

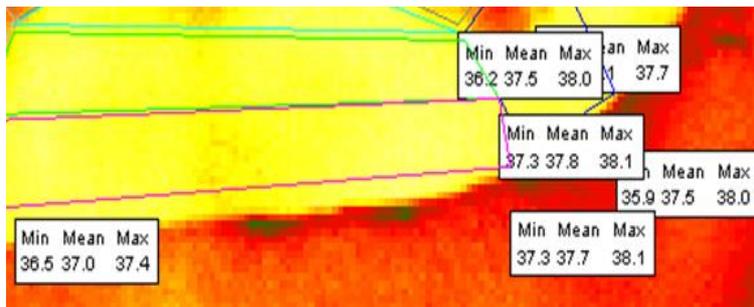


(b)

Fig. 6. Mandibular mucosa thermogram of a denture wearer with healthy mucosa $T = 35.20^{\circ}\text{C}$ (a); Magnification of preliminary random areas of the oral cavity (b) (color online)

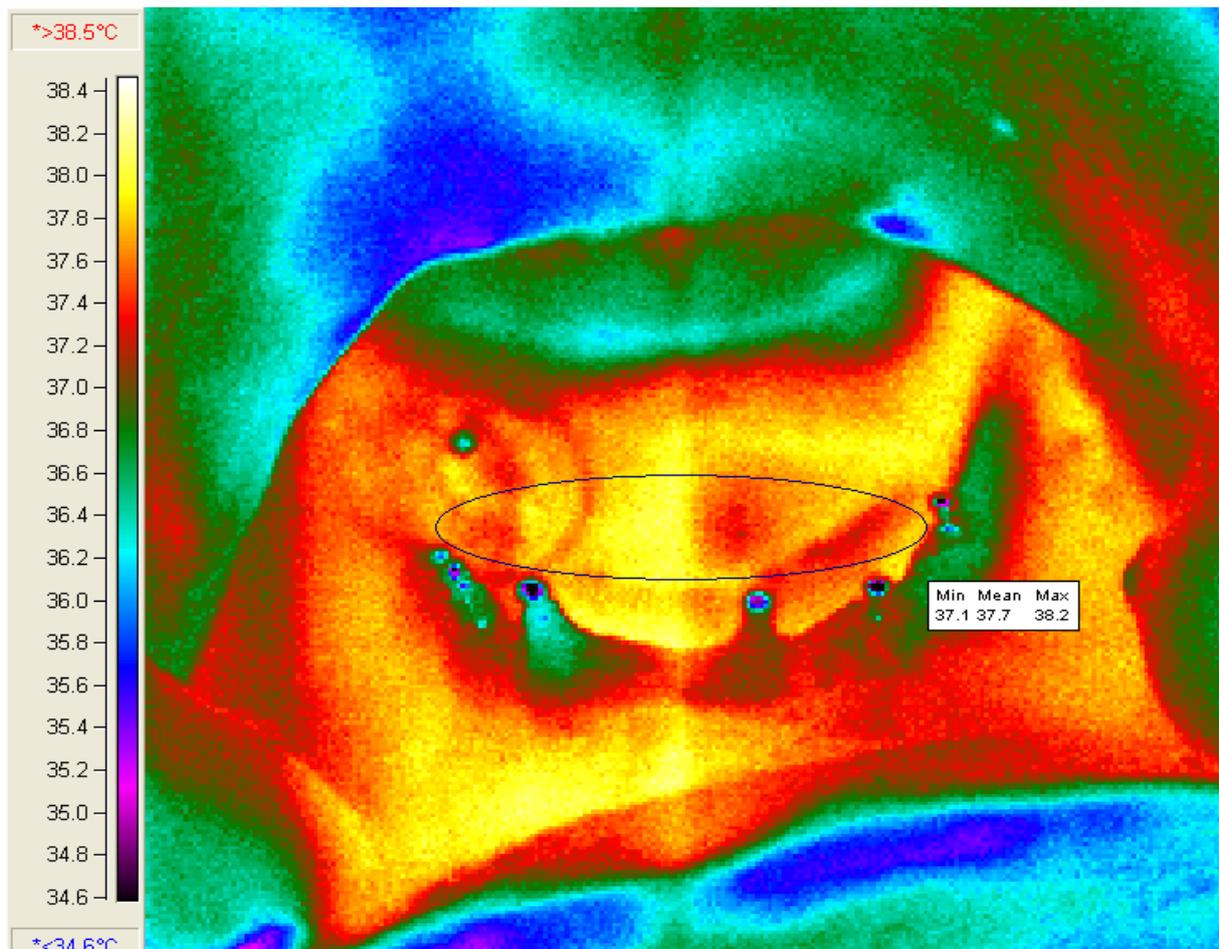


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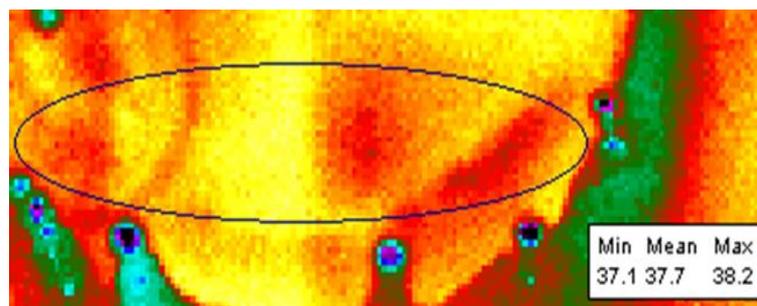


(b)

Fig. 7. Maxillary mucosa thermogram of an overdenture wearer with $DS T = 36.53^{\circ}C$ (a); Magnification of preliminary random areas of the oral cavity (b) (color online)



(a)



(b)

Fig. 8. Mandibular mucosa thermogram of an overdenture wearer with DS $T = 36.90^{\circ}\text{C}$ (a); Magnification of preliminary random areas of the oral cavity (b) (color online)

4. Discussion

This study was carried out to assess the PMMA effect both on the maxillary and mandibular denture bearing mucosa temperature due to the comparison between denture wearing and non-denture wearing edentulous patients according to different age groups, using IR thermographic method.

It was also wanted to identify possible thermal differences between the supporting tissues of the maxillary

and the mandible, which could explain the lower frequency of DS in the mandibular mucosa, as shown by the reports of Budtz-Jørgensen [19], [20] and Wilson [21].

Thermography as a diagnostic method has been experimented in prosthodontics relatively recently, in 2010 [15] and 2011 [22]. These first studies demonstrated not only the change of the mucosal thermal scene depending on the pathological context, but also the phenomenon of heat transfer by conduction (specific to solid bodies) between the maxillary oral mucosa and the inner face of

the maxillary prosthesis made of PMMA. The acrylates - the main material from which the removable prostheses are made - have a long-lasting thermal memory after removing the prostheses from the oral cavity, wearing a true negative copy of the temperatures of the oral mucosa they cover, the temperatures recorded in the mucosa exceeding those recorded on acrylic surfaces [22].

It is recognized that in certain situations, patients wearing PMMA removable dentures experience an unpleasant sensation of heat in the bearing mucosa, which can be exacerbated until they feel a burning sensation, especially in the palatal vault mucosa. Clinical examination revealed in most of these cases, both edema and associated erythema, with varying degrees of severity. At the base of this phenomenon, the literature cites a thermal block under the acrylic prosthesis [23], at which temperatures of 40°C was been recorded. In 2008, Arnetzl *et al.* [24] considered that the thermal blockage under the base of partial or total dentures would come due to the poor thermal conductivity of acrylates, resulting in the imbalance of the oral microbial flora. Although the total number of germs decreases drastically with the loss of teeth, it increases considerably by inserting removable prosthodontic appliances, due to the appearance of retentive areas, favourable for microbial growth and development. Different species of flora present in the dentate subjects can return, both to the upper and to the lower jaw of edentulous patients. Of these, the most strongly represented is *Candida albicans* [25], the major fungal pathogen of humans, responsible for the appearance of DS, together with several other subspecies.

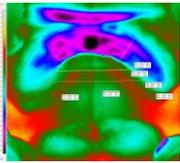
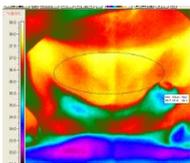
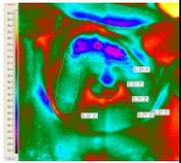
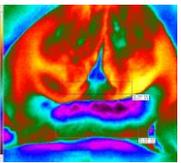
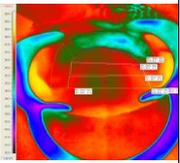
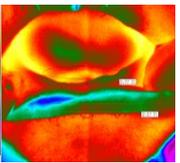
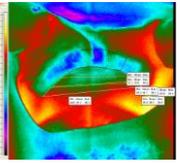
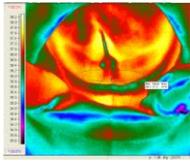
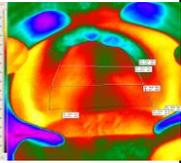
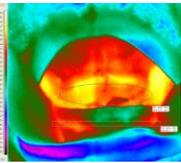
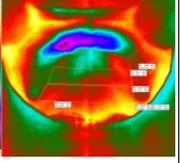
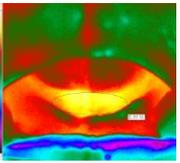
These fungi occur in denture wearers in large numbers compared to the period of natural dentition, or even in patients who have not reported *Candida* colonies prior to

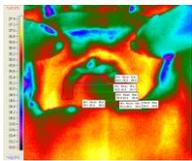
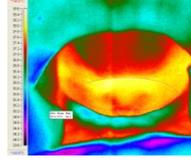
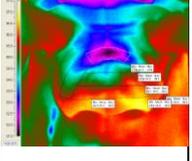
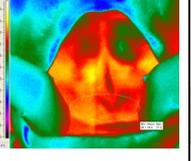
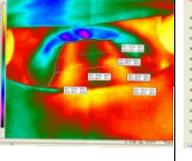
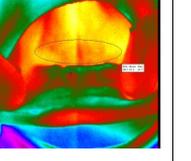
PMMA dentures, and can even instigate life-threatening systemic infections in immunocompromised elderly subjects *via* haematogenous dissemination [25]. Moreover, the temperature up-shifts under the PMMA prosthesis may contribute to the filamentation of *Candida* spores (switching phenomena) and morphological transition from the commensal yeast to hyphal pathogenic growth forms [26], [27], which act with major virulence.

The present study aimed to make some comparative observations on the temperature of the supporting mucosa in edentulous patients, the role of wearing PMMA prostheses on it, and to identify the existence of thermal differences depending on the prosthetic status, supporting mucosa (maxilla/ mandible), age and inflammatory status.

In terms of prosthetic status, the results of this study show that the edentulous patients without dentures (Group I) have average temperature values of 35.66°C in the maxilla and 35.40°C in the mandible, respectively, which are very close to the denture wearers (Group II) with healthy mucosa, such as 35.49°C for the maxillary and 35.52°C for the mandibular support mucosa, respectively. In terms of mucosal type, the average thermal values of the maxilla and mandible are similar in all situations analysed, our result being divergent from the observations of Maeda *et al.* [28], which determined that in the denture wearers, temperatures were significantly increased in the upper jaw, but not in the lower jaw, and convergent with that reported by Nayar *et al.* [29], where the values were similar. Even so, the latter authors had obtained significantly increased bimaxillary values compared to our study, but they strictly scanned the frontal areas and not the entire supporting mucosa, as was done in the present study.

Table 2. Thermal images of the oral supporting mucosa in edentulous subjects with and without PMMA dentures. The mean temperature values (T_m) have been recorded

	Group I (56-65) years		Group II (66-75) years		Group III (76-85) years	
	Maxilla	Mandible	Maxilla	Mandible	Maxilla	Mandible
Without dentures	$T_m = 35.70^\circ\text{C}$ 	$T_m = 35.40^\circ\text{C}$ 	$T_m = 35.33^\circ\text{C}$ 	$T_m = 35.00^\circ\text{C}$ 	$T_m = 35.96^\circ\text{C}$ 	$T_m = 35.80^\circ\text{C}$ 
Denture-wearer a. Without DS	$T_m = 35.76^\circ\text{C}$ 	$T_m = 35.48^\circ\text{C}$ 	$T_m = 35.31^\circ\text{C}$ 	$T_m = 35.50^\circ\text{C}$ 	$T_m = 35.41^\circ\text{C}$ 	$T_m = 35.60^\circ\text{C}$ 

	Group I (56-65) years		Group II (66-75) years		Group III (76-85) years	
	Maxilla	Mandible	Maxilla	Mandible	Maxilla	Mandible
	$T_m = 36.85^\circ\text{C}$	$T_m = 36.80^\circ\text{C}$	$T_m = 36.36^\circ\text{C}$	$T_m = 36.40^\circ\text{C}$	$T_m = 36.50^\circ\text{C}$	$T_m = 36.63^\circ\text{C}$
b. With DS						

In terms of age, the analysis of patients without DS distributed in the 3 different decades of age indicates a similar thermal profile, namely at the maxilla of $35.70^\circ\text{C}/35.33^\circ\text{C}/35.96^\circ\text{C}$ for edentulous without prosthesis and $35.76^\circ\text{C}/35.31^\circ\text{C}/35.41^\circ\text{C}$ for PMMA denture wearers, respectively, and in the case of the mandibular mucosa of $35.40^\circ\text{C}/35.00^\circ\text{C}/35.8^\circ\text{C}$ for non-wearers, and $35.48^\circ\text{C}/35.5^\circ\text{C}/35.60^\circ\text{C}$ to wearers, respectively (Groups I, II and III). These results indicate constant thermal values for edentulous subjects from the three decades of advanced age, although we would have expected the thermal gradient to decrease with age. In this respect, there are no reports in the literature.

Instead, in the first two of the three age groups, DS as an inflammatory status brings a thermal increase of over 1°C both in the maxilla and mandibular mucosa, this jump with pathological significance being confirmed by previous studies [15], [22], [30]. In the third group, the slightly reduced difference below this value cannot be explained otherwise than by the small size of the investigated group, this being one of the limits of our study. Last but not least, the much lower frequency of DS in the supporting mucosa of the mandible compared to that of the upper jaw reported in the present study and correlated with evidence based reports [19-21], could be attributed to a density of much lower heat flux in the case of mandibular denture made of PMMA, along with other biological arguments such as access to salivary antibodies much facilitated in the case of mandibular supporting tissue, blood flow differences, or those related to the construction of prostheses such as lower suction in the case of complete mandibular dentures. Generally, the heat flow transferred by thermal radiation is directly proportional to the area of the heat exchange surface, according to Stefan-Boltzmann law [10]. Thus, in the case of the complete mandibular prosthesis that has an area which is half that of the upper jaw, such as the corresponding supporting mucosa, the heat flow becomes lower on unit area. This may suggest lower conditions for the pathogenesis of fungal agents.

The thermal behaviour of dentures made of PMMA, as brought to light by a previous study [30], suggests that the direction of heat propagation, respecting the second principle of thermodynamics, is from the mucosa to the acrylic prosthesis, which functions as an insulating material, and at the same time the larger the covered surface, the more frequent the infectious process.

5. Conclusions

The findings of our study indicated that on an average, temperature values obtained for PMMA denture wearers were similar to the average temperature values obtained for non-denture wearers. Thermograms of the maxillary and mandibular mucosa also indicated a similar thermal profile, regardless of the age category of the patients, or their prosthetic status, so we can conclude that, in our study, the mere wearing of prostheses does not cause increase in temperature under the PMMA prosthesis. In contrast, the cases with significantly elevated temperatures of the maxillary and mandibular mucosa were observed, the increase being around 1°C , in which the supporting tissue had clinical aspects of DS. This could lead to the presumption that the wearing of PMMA prostheses could have the role of maintaining a thermal block between the biological and polymeric environment in the condition of the infectious phenomenon, but mainly only in the upper jaw. Surface support almost halved of the completely mandibular prostheses made of PMMA, together with other stated factors, can be correlated with a much lower heat flux density than that of the maxilla, significantly reducing the frequency of DS.

Due to the small sample size of the study, the age of the worn dentures was not taken into account as a variable, but this will be the subject of future research studies.

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