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Original Research Article

Thermographic analysis during rapid maxillary expansion

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Abstract

Objective: The aim of this study was to evaluate the temperature of the palate during rapid maxillary expansion through thermal imaging. **Material and methods:** Modified Hyrax palatal expander was installed in 11 patients. Thermal images of the palate were obtained using the FLIR A325 infrared camera. The evaluation was carried out 6 times: T0 – without activation; T1 – 4; T2 – 8; T3 – 12; T4 – 16; T5 – 30 screw activations. The thermographic images were analyzed qualitatively by visualizing the colors and quantitatively, by measuring the temperature of the palate at points Sp1, Sp2, Sp3 and Line 1 (Li1), in the midpalatal suture and Sp4 and Line 2 (Li2) in the lateral region of the hard palate. ANOVA and Games-Howell statistical tests were used. **Results:** When evaluating each region over time, in Sp4 and Li2, it was observed a lower temperature in T5 than in T1 and in Li1 a lower temperature in T5 than in T4 ($p<0.05$). **Conclusion:** Similar temperatures were observed in the central and lateral regions of the palate. Higher temperatures were recorded at the time of the first activations and lower temperatures were recorded on the 14th day.

Introduction

Rapid maxillary expansion (RME) is routinely used in cases of maxillary growth deficiency, to correct transverse skeletal and dental discrepancies or to increase the perimeter of the upper arch [17]. The effects RME include opening of the median palatine suture, increase in the width of the upper arch followed by enlargement of the lower arch, and increase in the intranasal capacity [11]. Furthermore, after opening of the suture, the sutural tissue shows signs of inflammation with marked osteoblastic activity [18].

Skeletal and dental changes from short- and long-term RME are usually evaluated using orthodontic models or two-dimensional cephalometric tracings of lateral and postero-anterior teleradiographs [10, 11]. Owing to its ability to produce images of anatomical structures in all three planes, cone beam computed tomography has been used for measuring the dimensions of the maxillary complex in any plane as well as the changes in the axial inclination of the posterior and anterior teeth [9].

Histological examination is the most accurate method to evaluate vascular and inflamed areas. Studies conducted on animals [5, 13]and in humans [14, 18] have verified the presence of increased vascularization and an inflammatory response in the median palatine suture after RME. However, because it is an invasive method, biopsy is rarely used in humans for this purpose.

Infrared thermography (IRT) is a safe, non-invasive, low-cost technique that allows rapid recording of the thermal radiation that is released by the body [20]. For IRT evaluation, infrared cameras that use a sensor with infrared response to convert the thermal radiation emitted by the surface of the skin into electrical signals are used. These signals are quantized and presented in the form of grayscale images, facilitating interpretation of the temperature; pseudo-colors are attributed to the gray scale [21].

IRT has been used widely since the early 1960s in different areas of knowledge; however, its use as a diagnostic tool has remained the main focus. Recent technical advances in infrared cameras have allowed new applications of IRT in humans [8], it is also an alternative to evaluate the significant increase in local temperature, related to the increase in blood flow and the tissue catabolism that accompanies the inflammatory reaction [3].

In Orthodontics, the number of patients with RME is expressive, which induces an inflammatory response in the tissues of the medial palatine suture due to the use of high magnitude forces. It is thus important to understand the vascular changes in the median palatine suture after this procedure, as blood supply and circulation are fundamental for osteogenesis and bone remodeling after expansion [13]. IRT has been used to evaluate the temperature distribution at different anatomical locations [1, 14, 15], however, its use in measurement of the temperature of the palate during RME has not been reported.

It is therefore proposed that infrared image thermography can be used as an alternative to evaluate the temperature of the palate during rapid maxillary expansion.

Material and methods

The research was approved by the Research Ethics Committee with the opinion (n.1.709.514).

Sample

In the Dental Clinic of university, 11 patients of both sexes, aged between 7.1 and 9.1 years, were selected for the study according to the following inclusion criteria: age between 7 and 10 years, adequate oral health (absence of extensive dental caries, premature tooth loss, and periodontal disease), maxillary atresia, uni- or bi-lateral posterior crossbite, and no history of orthodontic treatment. In addition to cross-bite, dental crowding and increased buccal corridor were considered clinical manifestations of a narrow and sharp jaw [17].

Expansion appliance

Modified Hyrax palatal expander, made with an 11-mm expansion screw (600-010, Hyrax®, Dentaurum, Ispringen, Germany) was used for the study. In the posterior region, the screw arms were welded onto the orthodontic bands of the first and/or second primary molars in a semi-circumferential clamp extending to the vestibular face of the deciduous upper canines.

The activation protocol comprised of a full turn of the screw at five minutes intervals, after each ¼ turn on the day of installation. On the subsequent days, those responsible were instructed to perform activations twice daily, one in the morning and one in the evening [11], the activations were of ¼ turn each with a twelve-hour interval. The first activation of the device was performed by the researchers and the following 3 activations by the person responsible for the patient, after detailed explanation and monitoring by the researchers. The other activations were performed by the person in-

charge at home, for a total of 14 days and 7.5-mm expansion for all patients. A table was delivered to the persons responsible, so that the activations could be carried out on the indicated days and the times could be recorded.

Infrared thermography (IRT)

For obtaining thermographic images of the palate, an FLIR model A325 infrared camera (FLIR Systems, Wilsonville, OR) was used. It had a wavelength sensitivity quality of 7.5 to 13 μm and could record temperatures from -20°C to 120°C, with a thermal resolution of 0.05º. It could record movies at a rate of 30 frames per second, generating images with a resolution of 320 x 240 pixels. The lens had a nominal focal length of 18 mm.

In a thermographic image, each pixel is associated with a temperature value. Regions of abnormal vascularization are detected in thermography as hot spots, which indicate areas of increased local blood flow resulting from inflammatory processes. In contrast, cold spots indicate regions of affected vascularization or necrosis [19].

All images were collected in an air-conditioned room, with controlled temperature, humidity, and air circulation. The persons responsible for the patients were instructed to ensure that the patients do not eat thermogenic foods and do not use any type of medication.

The following protocol was followed: the patient was made to lie in the dental chair in the dorsal decubitus position, the camera was positioned perpendicular to the mirror at a distance of 19 cm, cheek retractors and an intraoral mirror were then used to obtain the image of the palate (figure 1).

The images were obtained by a single operator (MAS), who had previous experience of handling the camera and using the software. Five shots were taken for each patient; to achieve good dental arch framing in the mirror, to adjust parallelism of the mirror with the camera lens, and to balance the internal and external temperatures of the mouth. The first two shots were discarded and the image with the best framing and sharpness was analyzed with the help of FLIR Tools Software (FLIR Systems, Wilsonville, OR).

The evaluation was performed at the following times: T0 – immediately after installation (without activation); T1 – immediately after installation (4 activations – 1 mm); T2 – two days after installation (8 activations – 2 mm); T3 – five days after installation (12 activations – 3 mm); T4 – seven days after installation (16 activations – 4 mm); T5 – fourteen days after installation (30 activations – 7.5 mm).

Figure 1 – Thermographic image collection

Analysis of the images

Qualitative and quantitative evaluation of the temperature of the palate during RME could be performed using the thermographic images. The analyses were performed by a single operator (MGR), who was unaware of the names of the patients to whom the images belonged (blinding). The different image colors, which represented the temperature differences were visualized. The color palette used was Rainbow HC, the minimum scale temperature was 25.0ºC and the maximum temperature was 39.0ºC (figure 2). In the quantitative analysis, points and lines were evaluated.

For determining the points, reference lines were drawn for standardization of the four points, which were evaluated in all patients at all times of the study (figure 2):

Li1 – Median vertical line passing through the center of the expander screw;

Li2 and Li3 – Vertical, lateral, and parallel lines, at distances of 17 pixels from Li1;

Li4 – Horizontal line, delimiting the front face of the expander screw;

Li5 – Horizontal line, parallel to and 20 pixels anterior of Li4;

Li6 – Horizontal line, parallel to and 40 pixels anterior of Li4;

Li7 – Lateral line on the left side, connecting the fold of the anterior shank of the screw to the union of the posterior shank with the orthodontic band;

Sp1 – Point on the median line, 30 pixels distant from Li4;

Sp2 – Point on the median line, at the intersection of Li1 with Li5;

Sp3 – Point on the median line, at the intersection of Li1 and Li4;

Sp4 – Side point, in the middle of the Li7 line.

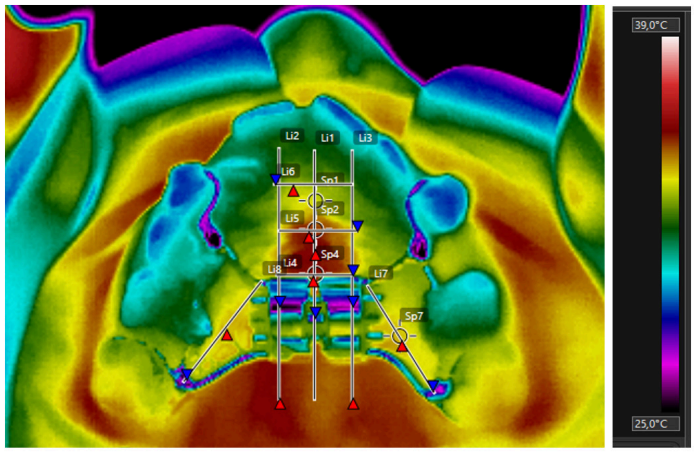

Figure 2 – Thermographic image (thermogram) of the sample patient in T1, with the lines and reference points used. The color scale used is shown on the right side

Four horizontal lines were drawn for standardization; two lines were drawn for reference lines i.e., one central (Li1) line and one lateral (Li2) line, which were evaluated in all patients at all times of the study (figure 3):
Li3 – Horizontal line, delimiting the front face of the expander screw;
Li4 – Horizontal line, parallel to and 20 pixels anterior of Li4;
Li5 – Horizontal line, parallel to Li3 and coincident with the first screw bar;
Li6 – Horizontal line, parallel to Li3 and coincident with the last screw bar;
Li1 – Vertical median line at the center of the expander screw, delimited by Li3 and Li4;
Li2 – Vertical line based on the palatine surface of the canine clamp, delimited by Li5 and Li6.

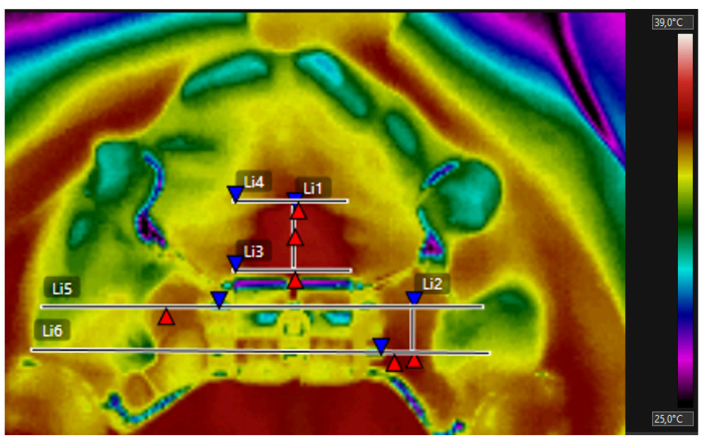

Figure 3 – Thermographic image of a patient at time T1, with the reference lines (Li3, Li4, Li5 and Li6) and the evaluated lines (Li1 and Li2). The color scale used is shown in the right side

Statistical analysis

Statistical analysis was performed using the SPSS program (version 22.0; IBM SPSS, Armonk, NY). The level of significance adopted in all statistical tests was 0.05.

For the temperature-dependent variables, when the tests accounted for normal distribution or symmetric distribution and heterogeneity of variances of variables according to the group and time, analysis of variance (Anova) was used at two criteria (point / line and time), with repeated measures in time. Then, the two-way comparison between point / line and time was made using Games-Howell's multiple parametric comparison test for heterogeneous variances, since the Levene variance homogeneity test accounted for heterogeneous variances for the temperature-variable second point / line and time.

The observed power was used to calculate the power of the tests based on the sample size to accept the hypothesis of the difference between the mean values of the dependent variables according to the region and time.

Results

Qualitative analysis

In the visual analysis of the images over time (figure 4), the region of the medial palatine suture adjacent to the expander screw appeared reddish at T4, representing a higher temperature.

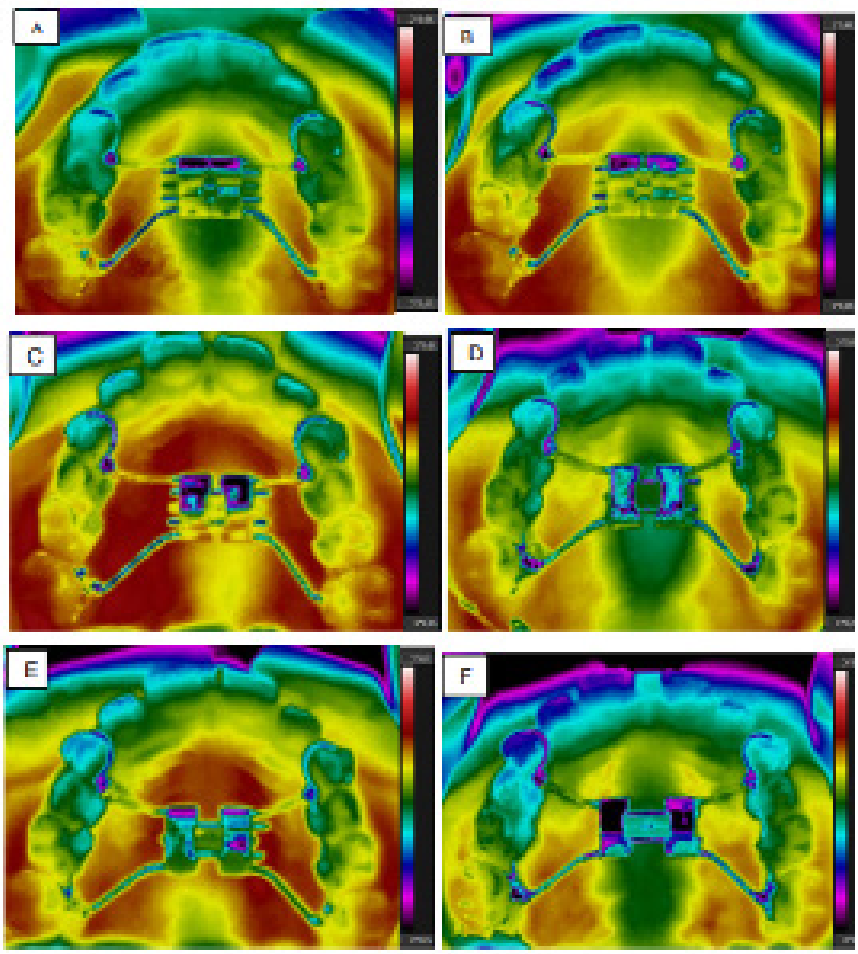

Figure 4 - Thermographic images of a patient at different times. A) TO - no activation; B) T1 - four activations; C) T2 - two days after appliance installation; D) T3 - five days after installation; E) T4 - seven days after installation; F) T5 - 14 days after installation

Quantitative analysis of the points (Sp1, Sp2, Sp3, and Sp4)

In the comparison between the points at each time, no statistically significant difference was observed ($p > 0.05$).

When comparing each point over time, we observed a statistically significant difference in Sp4, between T1 and T5 ($p < 0.05$), with the lowest temperature at T5. In the other comparisons, no difference was observed ($p > 0.05$) (table I).

Table I – Comparison of the temperature (degrees Celsius), at the analyzed points, at each evaluation time

Point / Time	N	Sp1 (average ± SD)	Sp2 (average ± SD)	Sp3 (average ± SD)	Sp4 (average ± SD)	Power test
T0 without activ	11	33.61 ± 1.57	34.50 ± 1.40	33.38 ± 1.32	35.04 ± 1.01	
T1 4 activ	11	34.07± 1.01	34.79 ± 1.01	34.61 ± 1.11	*34.96 ± 0.61	
T2 2 days	11	33.34 ±1.69	34.19 ± 1.66	34.22 ± 1.55	33.95 ± 1.44	0.9999
T3 5 days	11	33.18±1.78	33.97 ± 1.61	33.95 ± 1.55	34.10 ± 1.10	
T4 7 days	11	34.45±0.96	35.04 ± 0.81	35.05 ± 0.65	34.78 ± 0.73	
T5 14 days	11	33.13±1.24	33.92 ± 1.08	33.90 ± 1.21	*33.85 ± 0.92	

*Significance level for the Games-Howell test: p<0,05.

Quantitative analysis of the lines (Li1 and Li2)

In the comparison between the lines at each time, no statistically significant difference was observed (p> 0.05).

When comparing each line over time, we observed a statistically significant difference in Li1 between T4 and T5, and Li2 at T1 and T5 (p <0.05), with the lowest temperature at T5 (table II).

Table II – Comparison of the temperature (degrees Celsius), in the analyzed lines in the evaluated times

Table 2. Comparison of the temperature (degrees celsius), in the analyzed lines in the evaluated times.

Time / Line	N	T0 (average ± SD)	T1 (average ± SD)	T2 (average ± SD)	T3 (average ± SD)	T4 (average ± SD)	T5 (average ± SD)	Power test
L1	11	34.74 ± 1.54	34.92± 1.08	34.20 ±1.58	33.39±1.48	*35.14±0.75	*33.83±1.12	0.9749
L2	11	34.45 ± 1.01	*34.83 ± 0.53	33.90 ±1.25	33.84 ± 1.16	34.47 ± 0.63	*33.68 ± 1.06	

*Significance level for the Games-Howell test: p<0,05.

Discussion

The thermography (IRT) method was used in the present study because it has several advantages over other imaging techniques. It is painless, noninvasive, fast, does not cause exposure to radiation, does not require contrast, and the result is generated immediately [21]. This method has already been used in dentistry for the diagnosis of alterations such as inflammatory lesions leading to periodontitis, lingual abscess, mixed tumors of the salivary glands, and chronic maxillary sinusitis [6, 7, 15]. IRT was also used to assess pain in children by assessing changes in temperature after dental extractions [15], and to evaluate periapical inflammatory lesions [1].

Initially, the technique was performed without a mirror; however, due to difficulty in obtaining mouth opening sufficient to analyze the whole palate, the images were obtained with the aid of an intraoral mirror. This accessory was also used by Komoriyama *et al.*

In the first evaluated period (T0), the device was already cemented, which may have caused some change in the temperature of the palate. It was not possible to perform thermography without the device in the mouth, because it was not possible to focus on the images and the references used to standardize the regions to be studied were in the device itself.

Four points and two lines were evaluated to verify if RME causes a greater inflammatory reaction at a specific site on the palate, because the literature reports that the median palatine suture opens in the form of a 'V' [12], and that inflammation occurs at the same time [21]. However, in the comparisons between the points and between the lines, no difference was found, and all regions of the palate were verified to have the same behavior.

We have not come across human studies that have demonstrated the temperature changes generated by RME, as performed in the present study. According to our results, the highest temperature in the evaluated points as well as in the median line (Li1) occurred 7 days after the installation of the device, suggesting the presence of inflammation probably related to rupture of the median palatine suture. This rupture occurs between the 7th and 10th days of screw activation [2]. However, Caprioglio *et al.* [4] observed in a study of children with a mean age of 8.3 years that on

the 7th day after the activation of the device, few areas of blood clots with several red blood cells were present in the suture, probably caused by the trauma of the expansion; however, inflammatory cells were found to be absent. This divergence in the results is probably due to the difference in the protocol of activation of the expander screw. While in the present study the screw was initially activated by 1 mm and then by 0.5 mm in a day, Caprioglio *et al*. [4] initially activated the screws by 0.45 mm and then by 0.225 mm per day, delaying the inflammatory process related to the opening of the median palatine suture.

In the present study, a protocol of activation of the expander screw similar to that adopted by Hirose (0.4 mm per day) was used. The author observed the opening of the median palatine suture, hyperemia and enlargement of the blood vessels on the 3rd day, and a more significant increase in blood vessels on the 7th and 14th days after expansion in dogs [13]. Cleall *et al*. [5] expanded the maxilla of the monkeys by 6 mm and found that on the 14th day, the median palatine suture ruptured, and the area of the bone defect was filled with disorganized fibrous connective tissue that was well vascularized, suggesting a mild chronic inflammatory response. Despite the amount of expansion of the screw performed in these studies being close to that obtained in the present study, the comparison becomes difficult because they are animal studies while ours was performed in humans.

Komoriyama *et al*. [16] obtained thermographs of the buccal mucosa of the anterior region of the mouth directly, and the posterior region of the buccal mucosa indirectly, using a dental mirror, in 20 adult individuals. They demonstrated that the mean temperature of the alveolar mucosa (32.0ºC) was lower than the mean body temperature (36.1ºC) [16]. In our sample, the mean temperature of the palate at T0 (with device, without activation) was 34.0ºC, higher than that verified by these authors; this was perhaps because we evaluated the mucosa of an inner region, which would be affected less by the ambient temperature or by the manipulation of the patients in the installation of the apparatus, just before thermography. We did not find any studies that evaluated the average temperature of the palate.

In the present study, the lowest temperature, both in the point and in the linear analysis, was observed at T5, which corresponds to 14 days after the appliance installation; this suggests a decrease in the inflammatory process and tissue reorganization. Hirose observed that at 21 days after the expansion in dogs, the sutural area was filled by new bone, new blood vessels were incorporated into the bone, and the number of vessels had decreased [13]. In this way, it can be inferred that in animals as well as in humans, using the activation protocol suggested by Haas (2/4 of a day) [11], after 14 days initiates formation of new bone, decreases the number of vessels and the inflammatory process, and as a consequence, decreases the temperature of the palate. However, Melsen [18] studied palatal biopsies of children aged 8 to 13 years, in whom she used 3/4 turn of a day on the expander screw during RME. She found that in the third and fourth weeks after expansion, the sutural tissue showed signs of inflammation, with marked osteoblastic activity, concomitantly with the enlargement of the suture [18]. These findings suggested that the areas of inflammation persist during the reorganization phase of the sutural tissues.

As in the quantitative analysis, in the qualitative analysis one could observe the differences in the temperatures over time by means of the alteration of the colors in the thermal images, mainly in the region of higher temperature in the median palatine suture (table II and figure 3). Perhaps most of the comparisons in the quantitative analysis did not present a significant difference, since the quantitative analyses were based on point and linear measures of the temperatures, while the area as a whole was visualized in the qualitative evaluation. It is suggested that new studies evaluating larger areas or the entire palate be conducted to evaluate the temperature changes related to palatal disjunction, in a more generalized way. This method may also be used as an adjunct to cases of RME in patients in their late adolescence, and in borderline cases where the median palatine suture may not open.

IRT as a tool has not yet been explored in dentistry, due to some limitations in the use of the technique. However, this research suggested the possibility of the clinical application of IRT in the diagnosis of temperature changes in oral lesions associated with inflammatory reactions.

Conclusion

Thermography was shown to be a viable technique for evaluating inflammation-related temperature changes during rapid maxillary expansion.

Similar temperatures were observed in the central and lateral regions of the palate. Higher temperatures were observed after the first activations and lower temperatures were observed on the 14th day of activation of the expander screw.

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