RESEARCH

Thermography as a quantitative imaging method for assessing postoperative inflammation

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Objective: To assess differences in skin temperature between the operated and control side of the face after mandibular third molar surgery using thermography.

Methods: 127 patients had 1 mandibular third molar removed. Before the surgery, standardized thermograms were taken of both sides of the patient's face using a Flir ThermaCamTM E320 (Precisions Teknik AB, Halmstad, Sweden). The imaging procedure was repeated 2 days and 7 days after surgery. A region of interest including the third molar region was marked on each image. The mean temperature within each region of interest was calculated. The difference between sides and over time were assessed using paired *t*-tests.

Results: No significant difference was found between the operated side and the control side either before or 7 days after surgery ($p > 0.3$). The temperature of the operated side (mean: 32.39 °C, range: 28.9–35.3 °C) was higher than that of the control side (mean: 32.06 °C, range: 28.5–35.0 °C) 2 days after surgery [0.33 °C, 95% confidence interval (CI): 0.22–0.44 °C, $p < 0.001$]. No significant difference was found between the pre-operative and the 7-day post-operative temperature ($p > 0.1$). After 2 days, the operated side was not significantly different from the temperature pre-operatively ($p = 0.12$), whereas the control side had a lower temperature (0.57 °C, 95% CI: 0.29–0.86 °C, $p < 0.001$).

Conclusions: Thermography seems useful for quantitative assessment of inflammation between the intervention side and the control side after surgical removal of mandibular third molars. However, thermography cannot be used to assess absolute temperature changes due to normal variations in skin temperature over time.

Dentomaxillofacial Radiology (2012) **41**, 494–499. doi: 10.1259/dmfr/98447974

Keywords: thermography; inflammation; third molar

Introduction

Thermography is an imaging method for assessing heat emission from a surface. The method has been used for multiple purposes within medicine^{1–3} and in the field of dentistry.^{4–19} An inflammatory process is characterized by heat production and emission as one of the cardinal symptoms, which is why thermography may be used to evaluate inflammation. Many studies have been performed on the use of thermography in the diagnosis of temporomandibular joint disorders^{5,6,9,11,12,15,16}

and diagnosis of nerve injuries after surgery or trauma,^{10,13,14,17} as well as within clinical research. Recent studies have used the method to assess bone heating during implant bed preparation.^{20,21} Moreover, the method has been used to evaluate temperature changes during internal bleaching and post preparation.^{22,23} Finally, it has been shown that interobserver variation in measuring absolute temperatures is large. However, the interobserver variation is small when measuring temperature differences between two sides, even among inexperienced users (Christensen et al, personal communication, abstract presented at the European Academy of DentoMaxilloFacial Radiology (EADMFR) meeting 2010, Istanbul, Turkey).

Thermography has been used only sparsely to assess inflammation. One study on inflammation of the lower

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The authors wish to thank the Calcin Fund Tandlaegeforeningen, Denmark for the financial support, making it possible to buy the thermographic camera.

Received 29 August 2011; revised 8 August 2011; accepted 8 August 2011

back (sacroiliac inflammation) showed that thermography was inadequate to display inflammation,²⁴ while a study on surgical removal of lower third molars found that thermography was useful to quantify temperature changes between images taken before and after the operation.¹⁹ By contrast, a study by Soffin *et al*¹⁸ concluded that thermography was inconsistent in detecting oral inflammatory conditions.

In conclusion, it is unclear whether thermography can be used to assess inflammation after oral surgery. Therefore, the objective of this study was to assess differences in skin temperature on the operated side and the control side of the face after surgical removal of a mandibular third molar using thermography to clarify whether thermograms can be used in clinical studies within the field of dentistry to evaluate inflammation.

Materials and methods

This study was part of a clinical trial performed at Aarhus University, Denmark, from December 2008 to November 2010, which was designed to compare the use of two types of local analgesics and the use of methylprednisolone relative to placebo for post-operative pain control. The primary endpoints were pain and swelling measured on a visual analogue scale and sample size was determined such that the study achieved a power of 80% for a specified difference of the mean pain scores.

A total of 127 patients (74 males, 53 females) with a mean age of 25.1 years (range: 18.1–44.2 years) were included in the study. The study design was approved by the local committee of ethics and by the Danish Medicines Agency, and was performed according to the guidelines of the Good Clinical Practice Unit at Aarhus University Hospital. Informed consent was obtained from all patients.

All patients underwent a clinical and radiographic examination before they received an offer to participate in the study. The inclusion criteria were 18 years old or over, semi-impacted mandibular third molars with indication for removal and a signed informed consent form. Exclusion criteria were use of medication (contraceptive pills were permitted), pregnancy, systemic disease and need of sedation. Indications for removal of the mandibular third molar were: recurring episodes of pericoronitis (more than two episodes), injury to adjacent tooth, unrestorable caries or other pathological conditions related to the third molar.

The thermography camera used was a Flir ThermoCam™ E320 (Precisions Teknik AB, Sweden) with a thermal sensitivity of 0.1 °C, an accuracy of $\pm 2\%$ and a reproducibility of $\pm 1\%$ according to the manufacturer. The detector was a focal plane array uncooled microbolometer. Images were taken with an emissivity (a surface's ability to emit heat at a given temperature) of 0.98.

Before surgery, standardized thermograms were taken of the patient's face in profile, one left- and one

right-side image, *i.e.* the side to be operated on and the control side. Images were taken by one of two trained operators. The operators were calibrated beforehand so that set-up and imaging technique were standardized. Before imaging, the patients rested in the department for a minimum of 10 min. The camera was placed on a tripod, and the distance from the patient's cheek to the lens of the camera was fixed at 25 cm. When the camera was correctly positioned, the lens was manipulated to bring the patient into focus and the image was taken with the patient's head in the Frankfort horizontal plane. The camera saved the images with a resolution of 320 × 240 pixels. The thermograms depict the patient and the surroundings in different colours according to temperature. Each colour represents a temperature, shown on a scale on the right side of the image (Figure 1). The typical temperature range for these images was 24–35 °C, but the temperature colour scale adapts according to the actual temperatures and therefore could vary between images.

Following pre-operative imaging, the patient had one mandibular third molar surgically removed. The patient received 600 mg of ibuprofen (Ibuprofen®; Nycomed Danmark, Roskilde, Denmark) pre-operatively and performed mouth-rinsing with a 0.12% chlorhexidine solution for 1 min. Local analgesics were applied using lidocaine with adrenaline (20 mg ml⁻¹ with 12.5 µg ml⁻¹ of Xyloplyin Dental Adrenalin; Dentsply, Addlestone, UK) or bupivacaine with adrenaline (5 mg ml⁻¹ with 5 µg ml⁻¹ of Marcain-Adrenalin®; AstraZeneca, Copenhagen, Denmark). A standard buccal flap approach was used. After raising a mucoperiosteal flap, buccal bone was removed with a bur under sterile saline irrigation. The tooth was removed in one piece, or a bur was used to split the tooth into two or more pieces before removal. After tooth removal, inflammatory tissue and sharp bone edges were removed before thorough irrigation of the extraction socket and the operation field and suturing. The patient was given standard post-operative information and a prescription for 600 mg of ibuprofen to be taken as needed, up to three times daily. None of the patients were treated with methylprednisolone or other steroids pre- or post-operatively.

The patients returned for post-operative controls 2 days and 7 days after surgery. During these visits the imaging procedure was repeated for both sides of the face. The sutures were removed during the 7 day visit.

The saved images were coded and randomly numbered, thereby blinding the observer to which images displayed the operated side and the control side as well as the time order of the images. A single observer assessed all the images. A rectangular region of interest (ROI) was marked on each image using the software provided by the manufacturer of the camera (FLIR Systems ThermoCAM™ QuickReport 1.1; Precisions Teknik AB). The ROI was defined as: the frontal border by the commissure of the lips, the posterior border by the frontal part of the earlobe, the superior border by the most caudal part of the nasal ala and the

Figure 1 Thermograms with regions of interest marked. The images are from a representative patient before (top), 2 days after (middle) and 7 days after (bottom) removal of the right lower third molar. Temperatures stated are before removal of low-temperature pixels

inferior border by the most caudal part of the chin (Figure 1). The temperature data for each pixel in the ROIs were then transferred to a spreadsheet file and the images decoded.

The resulting rectangular ROIs included background “air” outside the patient’s face with a lower temperature than the patient’s skin (Figure 1). To exclude this air, pixels with low temperatures (background) were

eliminated from the ROI to avoid misleading mean temperature values. As the temperature scale was not the same for all images owing to variations in the temperatures of the background and the patient's face, eliminating all pixels with a temperature lower than a given, absolute temperature, *e.g.* 28 °C, would have been incorrect. Therefore, a preliminary mean temperature within the full ROI was calculated, and pixels with a temperature greater than or equal to 4 °C lower than the mean of the preliminary rectangular ROI were excluded. After excluding these pixels, the mean temperature of the ROI was calculated again.

Data management was performed in Stata version 10 (StataCorp LP, College Station, TX). Paired *t*-tests were used to assess differences in temperature between the ROIs of the operated side and the control side within each patient and for the same side over time. The level of significance was set at 5%.

Results

Results are displayed graphically in Figure 2. No significant temperature difference between the operated side and the control side was found before surgery ($p = 0.5$). By contrast, the temperature of the operated side (mean: 32.39 °C, range: 28.9–35.3 °C) was significantly higher than that of the control side (mean: 32.06 °C, range: 28.5–35.0 °C) 2 days after surgery [temperature difference: 0.33 °C, 95% confidence interval (CI): 0.22–0.44 °C, $p < 0.001$]. 7 days after surgery, the operated side and the control side were not significantly different ($p = 0.3$).

For temperature change over time, the operated side was not significantly different from the temperature pre-operatively after 2 days ($p = 0.12$), whereas the control side was characterized by a significantly lower temperature after 2 days (temperature change: 0.57 °C, 95% CI: 0.29–0.86 °C, $p < 0.001$). Neither side showed

any significant difference between the pre-operative and the 7 day post-operative temperature ($p > 0.3$).

Discussion

This study was performed to assess the applicability of thermography as a method for imaging inflammation after removal of lower third molars. The thermographic method has evolved immensely during the past 20 years. For instance, the sensitivity of a thermography camera has improved from 0.5 °C 20 years ago⁸ to 0.1 °C today. Therefore, it is important to reassess its usefulness.

Thermography has many advantages. It is easy to use, non-invasive and relatively inexpensive to acquire and maintain. As inflamed tissue is characterised by liberation of heat, thermography has been used to detect inflammation after the surgical removal of mandibular third molars^{4,19} and to detect nerve injuries.^{10,13,14} Moreover, a higher skin temperature on the affected side has been shown in a patient with Frey's syndrome.²⁵

The main limitation of thermography is the method's inability to detect temperature changes far from the surface of the body. The method only measures heat emission from the skin, which means that pathological conditions located deep within the tissues or conditions close to the skin surface that only emit limited heat will not be detected. Furthermore, the results may be affected by the type of tissue being imaged. Fat tissue is an effective insulator causing low temperature readings; therefore, thermography of adipose subjects can be difficult or impossible.²⁶

Another limitation is difficulties in data assessment. A square ROI was marked initially and the mean temperature within the ROI calculated. To eliminate pixels outside the patient's skin, pixels with a temperature more than or equal to 4 °C lower than the

Figure 2 Mean temperatures for the operated side and the control side before surgery (0), and 2 days and 7 days following the removal of a third molar

preliminary mean of the ROI were excluded. This method is not without problems as the difference between skin temperature and background temperature may vary from patient to patient. Some patients will deviate more than 4°C and some will deviate less than 4°C from the background temperature. Therefore, some pixels from the background may be included in the ROI whereas other pixels related to the patient's skin may be excluded. The optimal solution would be to draw an ROI including only the patient's skin. However, the software at our disposal was unable to draw other shapes than squares. This software is dedicated to the camera and no software other can display temperature for a given pixel in an image.

The present study showed no significant differences in mean temperature between the two sides of the face in patients before the removal of a mandibular third molar. At the 2 days post-operative examination the mean temperature was significantly higher on the operated side than on the control side. This is in accordance with a previous study which showed a mean temperature difference of 0.9°C between the operated and non-operated side on the first post-operative day after third molar removal.¹⁹

It was expected that the operated side would display a significant temperature increase 2 days after the surgery and that the temperature on the control side would stay relatively constant. This was previously demonstrated in a pilot study reporting a temperature increase 3 days and 5 days post-operatively compared with the baseline temperature.⁴ However, the present study showed decreased temperature of the control side and no change of the operated side compared with the pre-operative examination. The background of this apparent discrepancy is unknown, but may be related to variations in skin temperature over time. An explanation could be that patients were more liable to be sedentary on the second post-operative day compared with the seventh post-operative day, given that

patients traditionally experience most discomfort, swelling and pain within the first few days after surgery.^{27,28} Also, patients were advised to avoid extensive physical activity for the first 2 days after surgery. Temperature is known to vary physiologically during the day, being lower in the morning than in the evening. The thermograms were not taken at specific times of the day, and this fact could contribute to the variation in temperature. A previous preliminary study has indicated that skin temperature varied over a long period of time, *i.e.* months (Christensen et al, personal communication, abstract presented at the EADMFR meeting 2010 Istanbul, Turkey). Moreover, the present study showed that the temperature may also vary over short periods of time, *i.e.* days. Consequently, thermography seems unsuitable to measure absolute temperatures or display absolute difference over time. However, if a control region within the individual (*e.g.* the contralateral side) can be included, thermography seems promising to image relative temperature differences. Therefore, the method may be useful to assess the effect of various anti-inflammatory drugs, including methylprednisolone after surgical removal of mandibular third molars in a randomized controlled clinical trial.

Conclusion

Thermography may be useful for a quantitative assessment of inflammation by displaying temperature differences between the intervention and the control side after the surgical removal of mandibular third molars, and may thus be useful in clinical studies to assess inflammation. However, the method cannot be used to assess absolute temperature changes at a specific site due to variations in skin temperature over time; therefore, the inclusion of a control region is mandatory.

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