

CRANIO®

The Journal of Craniomandibular & Sleep Practice

ISSN: 0886-9634 (Print) 2151-0903 (Online) Journal homepage: www.tandfonline.com/journals/ycra20

Thermographic findings related to facial pain – a survey of 40 subjects

Riina Rytivaara, Ritva Näpänkangas, Tiina Kainulainen, Annina Sipola, Soili Kallio-Pulkkinen, Aune Raustia & Jérôme Thevenot

To cite this article: Riina Rytivaara, Ritva Näpänkangas, Tiina Kainulainen, Annina Sipola, Soili Kallio-Pulkkinen, Aune Raustia & Jérôme Thevenot (2024) Thermographic findings related to facial pain – a survey of 40 subjects, CRANIO®, 42:1, 69-76, DOI: 10.1080/08869634.2021.1894859

To link to this article: https://doi.org/10.1080/08869634.2021.1894859

© 2021 The Author(s). Published with license by Taylor & Francis Group, LLC.

Published online: 09 Mar 2021.

Submit your article to this journal

Article views: 1769

View related articles

View Crossmark data

Citing articles: 2 View citing articles

Full Terms & Conditions of access and use can be found at https://www.tandfonline.com/action/journalInformation?journalCode=ycra20

CRANIO®: THE JOURNAL OF CRANIOMANDIBULAR & SLEEP PRACTICE
2024, VOL. 42, NO. 1, 69–76
https://doi.org/10.1080/08869634.2021.1894859

Taylor & Francis
Taylor & Francis Group

CRANIOFACIAL PAIN

OPEN ACCESS Check for updates

Thermographic findings related to facial pain – a survey of 40 subjects

Riina Rytivaara DDS[a,b], Ritva Näpänkangas DDS, PhD[b,c], Tiina Kainulainen DDS, PhD[c], Annina Sipola DDS, PhD[a,b,c], Soili Kallio-Pulkkinen DDS, PhD[a,b], Aune Raustia DDS, PhD[b,c] and Jérôme Thevenot PhD[d]

[a]Department of Dental Imaging, Oulu University Hospital, Oulu, Finland; [b]Medical Research Center, Oulu University Hospital and University of Oulu, Oulu, Finland; [c]Research Unit of Oral Health Sciences, Faculty of Medicine, University of Oulu, Oulu, Finland; [d]Medical Imaging, Physics and Technology Research Unit, University of Oulu, Oulu, Finland

ABSTRACT

Objective: The purpose of this study was to assess how thermography findings relate painful symptoms and signs of temporomandibular disorders (TMD).
Methods: Thermography, combined with chewing of paraffin wax, was performed on 40 subjects. The results were analyzed according to gender and pain-related TMD symptoms and clinical signs.
Results: The overall temperatures after chewing were higher in TMD patients than in controls. For females, the most significant findings were the thermal increase between the relaxed state and subjects' state after chewing in temporal and temporomandibular joint (TMJ) regions. For males, all calculated parameters demonstrated a poor ability to discriminate TMD from controls.
Conclusion: Thermography could be a potential tool in diagnostics of female TMD patients. The results suggest that the thermal information assessed in specific facial areas could help to discriminate TMD patients from non-TMD patients and could be used to quantify the pain associated with TMD.

KEYWORDS
Thermography; temporomandibular disorders; pain; temporomandibular joint; diagnostic imaging

Introduction

Temporomandibular disorders (TMD) are a complex group of dysfunctions and pain around the temporomandibular joint (TMJ) and the masticatory muscles [1]. TMD can roughly be divided into joint-derived, muscle-derived, and combinations of the two [2]. TMD symptoms and signs are common among the population, varying in different studies from 25% to 56% [1,3–5], although the number of individuals needing treatment is remarkably lower, at less than 10% of the population [1,6,7]. Clinical TMD signs are more common than subjective symptoms, and TMD is more prevalent among females than males, especially in the age range of 35 to 50 years. Predisposing factors include tooth loss, emotional stress, bruxism, trauma, occlusal factors, and systemic diseases like rheumatoid arthritis [1,8–14]. Additionally, genetic and hormonal factors, as well as psychosocial elements, contribute to both the prevalence of TMD and the degree of pain experienced [15–19]. The patient's anamnesis and a systematically-performed clinical stomatognathic examination are the most important parts of the diagnosis of TMD [1]. Imaging is a diagnostic method to support the TMD diagnosis, as well as in differential diagnosis concerning other diseases of the teeth, jaw, and surrounding structures [20].

The development of alternative low-cost imaging solutions as supporting tools to conventional diagnostic medical imaging modalities is an emerging area of interest [21]. One such solution is thermography, a modality that allows one to capture the mid-infrared range spectrum of the skin or another surface non-invasively and without ionizing radiation [21,22]. Thermography has already shown its usefulness in multiple applications related to medical diagnostics, as the thermal print can provide information on the thermal changes occurring at the superficial layer of the skin. As an example, higher skin temperature and faster temperature variations were detected around the joints of patients with psoriatic arthritis compared to healthy controls [22,23], suggesting that inflammation of the joint can be detected as infrared radiation from the skin.

Thermography has also been suggested as an objective tool in the diagnosis of TMD [24–26]. Nonetheless, both the imaging procedures and the thermal patterns analysis methods related to thermography need to be improved [27–29]. The lack of standardized protocols makes comparative studies challenging to complete, as

CONTACT Ritva Näpänkanga ritva.napankangas@oulu.fi Research Unit of Oral Health Sciences Faculty of Medicine, FI – 90014 University of Oulu Finland, 5281.

© 2021 The Author(s). Published with license by Taylor & Francis Group, LLC.
This is an Open Access article distributed under the terms of the Creative Commons Attribution-NonCommercial-NoDerivatives License (http://creativecommons.org/licenses/by-nc-nd/4.0/), which permits non-commercial re-use, distribution, and reproduction in any medium, provided the original work is properly cited, and is not altered, transformed, or built upon in any way. The terms on which this article has been published allow the posting of the Accepted Manuscript in a repository by the author(s) or with their consent.

previous literature has reported different methodologies to assess the TMJ and the masticatory system [30–32].

In this study, the hypothesis was that higher skin temperatures around the TMJs and the temporal and masseter muscles are associated with painful TMD and could be detectable by thermography. The aim was to study whether thermography could be a diagnostic assessment tool in the diagnosis of TMD. An additional goal was to assess how thermal changes are associated with subjective pain-related symptoms or clinically recorded pain on palpation around temporal and masseter muscles and TMJs.

Materials and methods

Subjects

The present study was approved by the Ethical Committee of Northern Ostrobothnia Hospital District, Oulu, Finland (27/2016). All participants were informed about the course of the study and signed a written consent form.

Subjects (n = 40) consisted of 19 patients with diagnosed TMD and 21 volunteers. The patients were referred for specialist care at Oulu University Hospital for their TMD signs and symptoms. The volunteers were recruited by e-mail from the Oulu University Unit of Oral Health Sciences' staff, dental students at the Oulu University, and Oulu University Hospital staff. The mean age of the subjects was 40.0 ± 14.0 years, and there were 22 females (44.0 ± 15.1 years) and 18 males (35.2 ± 10.7 years).

Clinical examination

The same clinical examination protocol was used for all subjects and included gathering the anamnestic information focusing on pain-related TMD symptoms (facial pain, pain in the TMJs, or pain during jaw movements), clinically examined pain on palpation in the TMJs and in masseter and temporal muscles, registration of pain in mandibular movements, and pain related to restrictions in mandibular movements [1]. The TMD patients were examined and diagnosed by an experienced specialist in stomatognathic physiology (TK) during their treatment, and their anamnestic and clinical information was collected from the patient database of Oulu University Hospital. The radiographic examination, cone beam computed tomography (CBCT), and/or magnetic resonance imaging (MRI) was included, if needed. The volunteers underwent stomatognathic examination by the same experienced specialist in stomatognathic physiology (TK).

The subjects (n = 40) were analyzed by pain/no pain based on pain-related symptoms in anamnesis, pain on palpation in the TMJs or in masseter and temporal muscles, pain during jaw movements, and pain related to restriction of jaw movements (Table 1). For each subject, the presence or absence of pain was evaluated per side (right or left side), and one subject could have both sides painful, only one side painful, or both sides non-painful.

The TMD diagnosis was based on subjective symptoms and clinical examination. The TMD was analyzed separately by right and left sides. In females, the TMD group consisted of 27 painful sides (within 17 females, mean age 43.8 ± 16.3) and the control group of 17 non-painful sides (within 12 females, mean age 44.2 ± 13.6. In males, the TMD group consisted of 15 painful sides (within 10 males, mean age 38.2 ± 11.9) and the control group of 21 non-painful sides (within 13 males, mean age 33.1 ± 9.4).

Thermal imaging protocol

Before thermography, the subjects were instructed to avoid exercise, hot/cold drinks, and meals for two hours. This was done to avoid any additional thermal changes on the face before the study. To avoid thermal imaging artifacts, all facial hair was shaved, use of makeup on the face was forbidden, hair was pulled aside from the TMJ area with hairpins if necessary, and earrings and necklaces were removed. The subjects stayed still for 30 minutes in the waiting room to stabilize their temperatures.

A room without windows was dedicated to thermal imaging acquisition, with the air conditioner turned off

Table 1. Distribution of the measured parameters in painful / non-painful left and right sides within the subjects, separated by gender.

	Females			Males		
	left	right	total	left	right	total
Parameters	n(pain/no pain)	n(pain/no pain)	n(pain/no pain)	n(pain/no pain)	n(pain/no pain)	n(pain/no pain)
Pain-related symptoms	9 / 13	6 / 16	15 / 29	4 / 14	4 / 14	8 / 28
Pain on palpation	6 / 16	5 / 17	11 / 33	6 / 12	3 / 15	9 / 27
Pain during jaw movements	5 / 17	3 / 19	8 / 36	3 / 15	2 / 16	5 / 31
Pain related to restriction of jaw movements	5 / 17	4 / 18	9 / 35	3 / 15	3 /15	6 / 30

to minimize airflow, and the background temperature was stabilized to 22°C. The height and weight of the subjects were measured to calculate their body mass index (BMI). Female participants were questioned as to the stage of the menstrual cycle to estimate their ovulation periods.

Three thermographic images were taken three times during the study session: one from each side of the face and one from the front. Paraffin wax was chewed between the first and second session of imaging and again between the second and third session of imaging, for four minutes each time. A FLIR T420 thermal camera (FLIR SYSTEMS; USA) with a resolution of 320 x 240 pixels, a sensitivity of 0.02°C, and calibrated to factory specifications, was used along with the software provided by the manufacturer to obtain thermal images in comma-separated values (CSV) format. The camera was stabilized at a 1-m distance from the subject (Figure 1). To improve the repeatability of the data acquisition, a custom-made, 3D-printed chin cup in polylactide (PLA) was used to stabilize the head during the imaging, and a black foam background was placed behind the subject to avoid disturbing reflections (Figure 1).

Processing of thermal data

A custom-made algorithm was developed in MATLAB (v. 2017b, Mathworks, Natick, MA, USA) to segment and analyze the thermal data. Three regions of interest (ROIs) were identified as relevant in this study: the TMJ area, the temporal area (anterior part of temporal muscle), and masseter area. Figure 2 shows an example of the locations of the different ROIs. The algorithm allowed a semi-automatic segmentation of these ROIs to be performed as follows: The thermal data was converted into a full dynamic range 8-bit matrix, and the thermal image was visualized with the help of an RGB color map to improve the visibility of anatomical landmarks. Then, ellipses were manually applied for each ROI and oriented based on the anatomical landmarks to

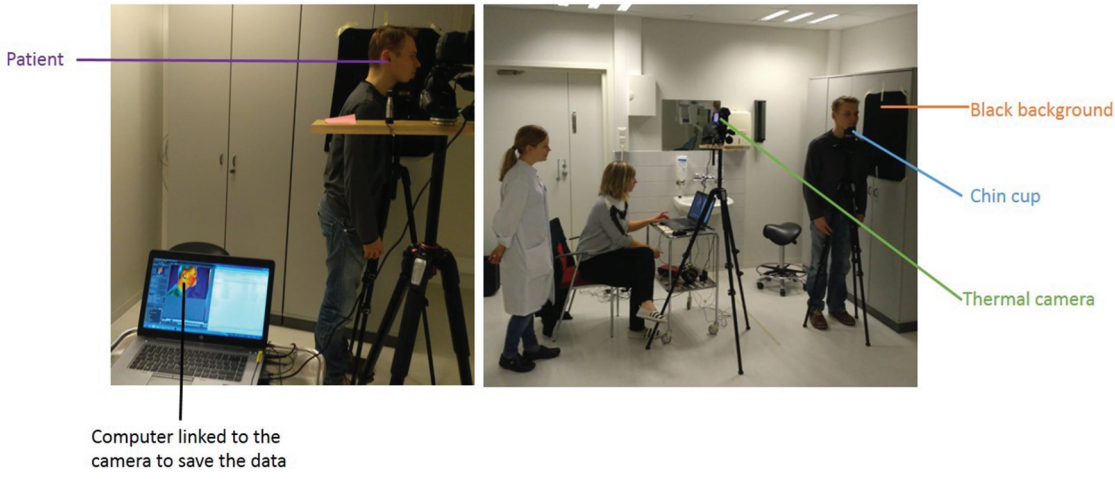


Figure 1. Thermal imaging acquisition.

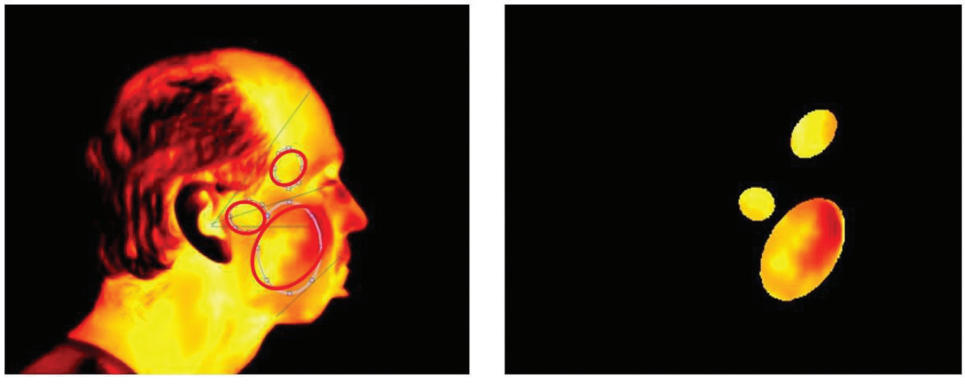


Figure 2. Example of thermal data visualization and segmentation of the ROIs (the TMJ area, temporalis area, and masseter area). (ROI: region of interest; TMJ: temporomandibular joint).

fit the identified areas of interest with the best accuracy. Finally, the integrity of each ROI was inspected, and any artifact (such as remaining hair) was manually removed from the segmented ROIs.

Each ROI's average temperature value was then calculated, and the differences before and after chewing were calculated as a measure of temperature changes induced by muscle activation. Furthermore, the standard deviation and homogeneity of thermal values (H_{temp}) from the raw values of the masseter area were calculated, as this ROI was large and not affected by hair artifacts. This parameter described the spatial distribution of the temperature values and provided an indication of their continuity and the overall "smoothness" of the thermal distribution within the ROI. To assess the spatial distribution of the thermal value, a thermal-level co-occurrence matrix (TLCM) was first calculated with rotational invariance. The homogeneity of the temperatures was then calculated from the TLCM, as follows:

$$H_{temp} = \sum_{i,j} \frac{TLCM(i,j)}{1+|i-j|} \quad (1)$$

where each element (i,j) in the TLCM is the sum of the occurrences in which a pixel with thermal value i has a pixel with thermal value j in its vicinity (1-pixel size radius). A high H_{temp} value corresponds to an ROI with a very smooth distribution of temperatures, meaning that the pixels within the ROI have similar temperature values to their surroundings.

Statistical analysis

Statistical analysis was performed using the SPSS statistical software (version 25, USA). An independent *t*-test was used to assess the difference in BMI and age between each group. Receiving operating characteristic (ROC) analysis was used to assess the ability of parameters calculated from the thermal images to discriminate the TMD group from controls. The statistical power was calculated using an alpha error of 5%; a power > 80% was considered significant. The linear mixed model was employed to evaluate the difference between the presence of pain related to TMD and the parameters calculated from the thermal images. This model was chosen so the side effects in each subject could be adjusted. A result of $p < 0.05$ was considered to have statistical significance.

Results

BMIs were similar in male and female subjects, but males were younger than females, especially in the control group.

The evolution of the mean temperatures per region while chewing is shown in Figure 3. The overall temperatures were higher in males than in females and higher after chewing for the TMD group compared to the control group. Overall, there was a significant rise in all the parameters after the first four minutes of chewing, but they did not rise significantly after the second chewing, at the eight-minute chewing point (Figure 3).

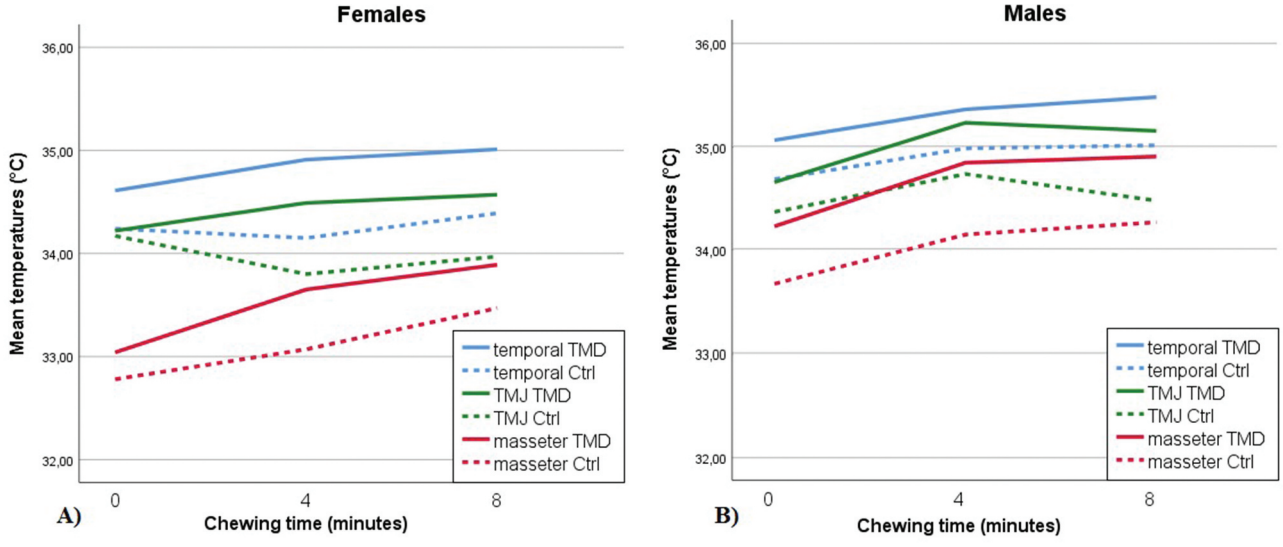


Figure 3. Changes of the mean temperature per region of interest during chewing for sides affected by TMD and controls. A) female group (TMD N = 27, ctrl N = 17), and B) male group (TMD N = 15, ctrl N = 21). (TMD: temporomandibular disorder).

Table 2. Distribution of mean (SD) thermal values and changes in temperature per regions of interest after chewing for 4 minutes. The homogeneity in the masseter was assessed after 4 minutes of chewing. The performance to discriminate TMD from controls is reported as AUC from the ROC (Receiving Operator Characteristic) analysis.

	Females			Males		
Parameters	TMD (N = 27)	Control (N = 17)	AUC	TMD (N = 15)	Control (N = 21)	AUC
	mean (SD)	mean (SD)		mean (SD)	mean (SD)	
T°C temporal	34.91 (0.73)	34.15 (1.34)	0.66	35.36 (0.68)	34.98 (0.77)	0.63
Temporal change	0.297 (0.53)	−0.094 (0.39)	0.72*	0.299 (0.53)	0.301 (0.29)	0.46
T°C TMJ	34.49 (0.81)	33.80 (0.81)	0.73*	35.23 (1.08)	34.73 (1.03)	0.61
TMJ change	0.268 (0.66)	−0.368 (0.68)	0.76*	0.579 (0.68)	0.367(0.41)	0.58
T°C masseter	33.65 (1.34)	33.07(0.74)	0.65	34.84 (1.06)	34.14 (1.18)	0.70
Masseter change	0.617 (0.35)	0.289 (0.62)	0.66	0.622 (0.45)	0.490 (0.39)	0.59
Hom. masseter	0.82 (0.05)	0.78 (0.03)	0.76*	0.84 (0.04)	0.84 (0.04)	0.53

SD: standard deviation; T°C: temperature; TMJ: temporomandibular joint; Hom.: homogeneity of thermal values; TMD: temporomandibular disorder; AUC: area under the curve.
*Statistical power >80%.

Table 2 shows the potential, as the area under the curve (AUC) derived from ROC analysis, of each thermal feature to discriminate TMD joints from control joints. For females, the most statistically significant features were the thermal increase between the relaxed state and subjects' state after chewing for four minutes for the temporal (AUC: 0.72) and TMJ (AUC: 0.76) regions. For males, all the calculated parameters showed a poor ability to discriminate TMD joints from controls. In the masseter area, the most significant feature was the homogeneity of thermal values for the females (AUC: 0.76), whereas it was the mean temperature for the males (AUC: 0.70). These results were also obtained after subjects chewed for four minutes.

For the assessment of pain associated with TMD, none of the calculated thermal parameters demonstrated any statistically significant association in males and, therefore, males were not included in further analysis. Table 3 reports the differences among females in thermal parameters between the presence and absence of pain associated with TMD in the different ROIs. Among females, a statistically significant temperature increase in the temporal and TMJ areas was observed during four minutes of chewing when subjective pain symptoms had been reported or pain on palpation was observed clinically in TMJs or in temporal muscle. If the pain was associated with mandibular movements or restriction in jaw movements, the increase in thermal values was statistically significant solely in the temporal area. The homogeneity of thermal values was statistically higher in the masseter area after chewing for four minutes when pain was related to mandibular movements or restriction in movements.

Discussion

In the present study, significantly higher skin temperatures were observed by thermography among female

Table 3. Estimated mean difference in thermal values in females by regions of interest (adjusted for side effect from the linear mixed model) related to pain-related symptoms of TMD before and after chewing for 4 minutes. The homogeneity in the masseter was assessed after 4 minutes of chewing.

Pain	ROIs	Positive mean (SD)	Negative mean (SD)	*p*-value
Pain-related symptoms N: 15 / 29	Temporal	0.49 (± 0.12)	−0.03 (± 0.09)	0.0013*
	TMJ	0.44 (± 0.18)	−0.19 (± 0.13)	0.006*
Pain on palpation N: 11 / 33	Temporal	0.42 (± 0.15)	0.05 (± 0.09)	0.027*
	TMJ	0.53 (± 0.20)	−0.15 (± 0.12)	0.004*
Pain during jaw movements N: 8 / 36	Temporal	0.82 (± 0.17)	0.00 (± 0.08)	<0.001*
	TMJ	0.45 (± 0.27)	−0.07 (± 0.13)	0.088
	Masseter	0.53 (± 0.18)	0.48 (± 0.11)	0.787
	Hom. masseter	0.84 (± 0.02)	0.80 (± 0.01)	0.026*
Pain related to restriction of jaw movements N: 9 / 35	Temporal	0.56 (± 0.17)	0.04 (± 0.09)	0.012*
	Masseter	0.15 (± 0.27)	−0.01 (± 0.14)	0.427
	Hom. masseter	0.83 (± 0.02)	0.80 (± 0.01)	0.071

SD: standard deviation; ROI: region of interest; TMJ: temporomandibular joint; Hom.: homogeneity of thermal values.
*Statistically significant difference.

subjects experiencing pain related to TMD compared to those without pain when measuring on the TMJ, masseter, and temporal areas (anterior part of temporal muscle). In males, the results were not statistically significant, suggesting that thermography might not be an effective tool in the male TMD population. The results align with the previous study conducted in females by Rodrigues-Bigaton et al. [28]. Here, the chewing emphasized the temperature differences between subjects with or without pain-related TMD and, thus, added to the diagnostic efficacy of thermography, in agreement with the study by Wozniak et al. [26], although in the present study, the chewing time was shorter, and the thermography was taken at different time points. Additionally, the first chewing (lasting four minutes) displayed a relevant rise of temperature differences, whereas the second four-minute chewing yielded no additional temperature increase. Thus, it can be assumed that the relevant differences in the temperatures can be seen before eight minutes of chewing. In future studies, more information about chewing's effect on temperature changes could be obtained if the temperatures were to be measured after two, four, and six minutes of chewing. However, skin temperatures might rise much faster in cases of severe inflammation.

The homogeneity of thermal values in the masseter area in females was higher after chewing for four minutes, suggesting that the overall masseter muscle area temperature stabilizes after chewing. One explanation for this phenomenon may be that this region was the largest considered and that it covers regions affected by adipose tissue, especially in females. While at rest, this region can have both cold and hot spots due to the local biological variations, i.e., fat tissues or veins. After chewing, it harmonizes, and the discrete variations in local temperatures are diminished. For males, it can be hypothesized that the lower amount of adipose tissue in this area means the homogeneity of the thermal values is unaffected and that the absolute temperature after chewing is a good discriminant.

Estrogen hormone-related factors, however, influence pathological changes in the TMJ and surrounding structures in females and, furthermore, have an effect in pain sensitivity [33,34]. These factors can be expected to play a role in a better response to thermography in female TMD subjects beyond just having more adipose tissue over the "region of interest," as compared to male subjects [16,35].

In previous studies, temperature was often measured from the center point of the muscle, or the TMJ was marked as a single point [26,28,30]. In the present study, three regions of interest (ROIs) were chosen. These encompassed wider areas, and the temperature change could then be evaluated in the whole muscle or facial area two-dimensionally. Furthermore, this study introduces a textural parameter, which has not been previously evaluated. The homogeneity of temperatures provides some information on distribution of temperatures within the ROIs. This parameter can quantify any discrete rise in temperature, which suggests that only sufficiently large regions can be studied with it. There is a potential of textural analysis for use in future studies about thermal imaging of TMD, as the anatomical structures are connected to each other, and pain in the TMJ, for example, affects the function of the whole masticatory system, and it can affect the thermal changes within the muscles unevenly. Thus, it makes sense to study thermal changes in the wider areas of the face, and it also decreases the effects of random thermal variations that could be detected in a single point ROI.

One of the issues with the thermal imaging modality is the lack of standardized protocol, not only for the data acquisition but also for the analysis of thermal prints. In the present study, thermal distribution was compared side by side both for each subject and also between groups (TMD group and controls). When considering TMD, it might be expected that the symptomatic side would present higher temperatures as a result of local inflammation. However, as an example, the study by Haddad et al. [31] yielded the opposite results, showing that the painful side was significantly colder than the healthy side. In this specific case, it can be hypothesized that the patient has a diminished use of the affected side or that the other side's function is being altered in compensation for the limited muscular activity on the affected side. Structural changes have been found in masticatory muscles in patients with intra-articular TMJ disorders, and joint pathology, even in the absence of pain, has been noted to inhibit muscle activity associated with the joint [36,37]. This finding accurately reflects the issue inherent in the lack of standardization of the protocol of data acquisition, which this study endeavored to address. In this paper, the authors suggest the assessment of thermal changes occurring between a relaxed state and subjects' state after chewing. By assessing the difference instead of using the actual thermal data, the impact of biological artifacts can be reduced, specifically, how the pain associated with TMD relates to the thermal changes occurring after muscle activation can be quantified.

The limitation in comparative studies of thermal data from patients has been the discrepancy of biological characteristics, which can affect the results. Although the environmental parameters (room temperature, wall reflection etc.) can be stabilized, only a few thermal artifacts from the patients can be diminished (e.g.,

hair, make-up, and muscular activity). The most specific thermal artifacts of distribution of adipose tissue and venous circulation of the subject cannot be altered. Ultimately, the main challenge related to facial thermography is the lack of standardized acquisition and analysis protocols addressing the issue of fat content distribution varying among subjects, as well as the definition of relevant regions of interest to evaluate.

The limitation of this study was the small number of subjects. That may at least partly explain the difference in the results between the females and the males. The males who were studied were younger than the females and, among females, there were more joints with TMD than among the males. The results here suggest that further studies are needed to assess, especially, the observed gender specific differences. In the present study, ear temperatures were collected for use as a reference for internal body temperature; however, this reference parameter did not prove useful, as the superficial skin temperature is also affected by the thickness of adipose tissues. While a subjects' BMI is associated with the amount of adipose tissues, the facial distribution of these tissues varies between participants, suggesting that other reference variables should be explored. Frontal pictures were taken so that the thermal information of the forehead could be used as a reference; however, this area often shows the presence of superficial veins and, thus, does not offer robust data for normalization. Considering these facts, it is recommended that, in future studies, temperatures of other body parts (such as the arm) should be taken as reference points.

Thermography does not use any ionizing radiation, and it is non-invasive, quick, and relatively inexpensive and easy to use in the dental office environment. It can be regarded as a supporting method in TMD diagnostics and in determination of response to treatment interventions, especially in female TMD patients. The results do not support the effective use in male TMD patients. In general, there are more female than male TMD patients, and a recent longitudinal study conducted in Sweden showed that the gender differences for persistent orofacial pain is increasing over time [5]. The authors' hypothesis was that higher skin temperatures around the TMJs and temporal and masseter muscles are associated with painful TMD and could be detectable by thermography, i.e., the painful areas will become inflamed faster than the non-painful areas, and that changes in thermography could be used to quantify inflammation. The outcomes of this study show the potential of this modality to provide further insights regarding pain associated with TMD, especially in females, and to quantify the inflammation of the specific areas involved. The authors propose a new protocol of imaging acquisition with wider regions of interest, which reduces the impact of thermal artifacts. Furthermore, the results obtained here demonstrate the potential of textural analysis in thermal imaging analysis and suggest alternative options for the normalization of data for comparative studies.

Conclusion

It can be concluded that thermography could be a potential diagnostic tool in the diagnosis of TMD in female patients. The results suggest that the thermal information assessed in specific facial areas could help to discriminate TMD patients from non-TMD patients and could be used to quantify the pain associated with TMD.

Conflict of interest

No potential conflict of interest was reported by the authors.

Acknowledgments

We thank Ms. Camille Moisset for helping in the acquisition of thermal images and Dr. Marianne Haapea for her advice with the statistical analysis.

Funding

This study has been financially supported by VTR research grants from Oulu University and Medical Imaging, Oulu University Hospital.

ORCID

Aune Raustia DDS, PhD http://orcid.org/0000-0001-9644-4148

References

1. Okeson JP. Management of temporomandibular disorders and occlusion. Vol. 7. ed. St. Louis (Mo): Elsevier. 2013.
2. Manfredini D, Guarda-Nardini L, Winocur E, et al. Research Diagnostic Criteria for Temporomandibular Disorders: a systematic review of axis I epidemiologic findings. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2011 Oct;112(4):453–462.
3. Jussila P, Kiviahde H, Napankangas R, et al. Prevalence of temporomandibular disorders in the Northern Finland Birth Cohort 1966. J Oral Facial Pain Headache. 2017;31(2):159–164.
4. Rutkiewicz T, Kononen M, Suominen-Taipale L, et al. Occurrence of clinical signs of temporomandibular disorders in adult Finns. J Orofac Pain. 2006;20(3):208–217.
5. Häggman-Henrikson B, Liv P, Ilgunas A, et al. Increasing gender differences in the prevalence and

chronification of orofacial pain in the population. Pain. 2020 Aug;161(8):1768–1775.
6. Carlsson GE. Epidemiology and treatment need for temporomandibular disorders. J Orofac Pain. 1999;13 (4):232–237.
7. Al-Jundi MA, John MT, Setz JM, et al. Meta-analysis of treatment need for temporomandibular disorders in adult nonpatients. J Orofac Pain. 2008;22(2):97–107.
8. Kuttila M, Niemi PM, Kuttila S, et al. TMD treatment need in relation to age, gender, stress, and diagnostic subgroup. J Orofac Pain. 1998;12(1):67–74.
9. Johansson A, Unell L, Carlsson GE, et al. Gender difference in symptoms related to temporomandibular disorders in a population of 50-year-old subjects. J Orofac Pain. 2003;17(1):29–35. Winter.
10. Bardel A, Wallander M-A, Wedel H, et al. Age-specific symptom prevalence in women 35–64 years old: A population-based study. BMC Public Health. 2009 Jan 26;9(1):37.
11. Sipila K, Ensio K, Hanhela H, et al. Occlusal characteristics in subjects with facial pain compared to a pain-free control group. CRANIO®. 2006 Oct;24 (4):245–251. DOI:10.1179/crn.2006.039.
12. Wang MQ, Xue F, He JJ, et al. Missing posterior teeth and risk of temporomandibular disorders. J Dent Res. 2009 Oct;88(10):942–945. DOI:10.1177/0022034509344387.
13. Jussila P, Knuutila J, Salmela S, et al. Association of risk factors with temporomandibular disorders in the Northern Finland Birth Cohort 1966. Acta Odontol Scand. 2018 Oct;76(7):525–529.
14. Jussila P, Krooks L, Napankangas R, et al. The role of occlusion in temporomandibular disorders (TMD) in the Northern Finland Birth Cohort (NFBC) 1966. CRANIO® 2019 Jul. 37(4):231–237.
15. Rantala MA, Ahlberg J, Suvinen TI, et al. Temporomandibular joint related painless symptoms, orofacial pain, neck pain, headache, and psychosocial factors among non-patients. Acta Odontol Scand. 2003 Aug;61(4):217–222.
16. Lee DG, Kim TW, Kang SC, et al. Estrogen receptor gene polymorphism and craniofacial morphology in female TMJ osteoarthritis patients. Int J Oral Maxillofac Surg. 2006 Feb;35(2):165–169.
17. Manfredini D, Winocur E, Ahlberg J, et al. Psychosocial impairment in temporomandibular disorders patients. RDC/TMD axis II findings from a multicentre study. J Dent. 2010 Oct;38(10):765–772.
18. Bi RY, Ding Y, Gan YH. A new hypothesis of sex-differences in temporomandibular disorders: estrogen enhances hyperalgesia of inflamed TMJ through modulating voltage-gated sodium channel 1.7 in trigeminal ganglion? Med Hypotheses. 2015 Feb;84(2):100–103.
19. Horst OV, Cunha-Cruz J, Zhou L, et al. Prevalence of pain in the orofacial regions in patients visiting general dentists in the Northwest Practice-based REsearch Collaborative in Evidence-based DENTistry research network. J Am Dent Assoc. 2015 Oct;146(10):721–728.e3. Erratum in: J Am Dent Assoc. 2015 Dec;146(12):874.
20. Mallya SM, Lam EWN, White SC, et al. White and Pharoah's oral radiology. 8th edition ed. St. Louis (MO): Elsevier; 2019.
21. Thevenot J, Lopez MB, Hadid AA. Survey on computer vision for assistive medical diagnosis from faces. IEEE J Biomed Health Inform. 2018 Sep;22(5):1497–1511.
22. Mountz JM, Alavi A, Mountz JD. Emerging optical and nuclear medicine imaging methods in rheumatoid arthritis. Nat Rev Rheumatol. 2012 Dec;8(12):719–728.
23. Capo A, Ismail E, Cardone D, et al. Joint functional impairment and thermal alterations in patients with psoriatic arthritis: A thermal imaging study. Microvasc Res. 2015;102:86–91.
24. Dibai-Filho AV, Costa AC, Packer AC, et al. Women with more severe degrees of temporomandibular disorder exhibit an increase in temperature over the temporomandibular joint. Saudi Dent J. 2015 Jan;27(1):44–49.
25. McBeth SB, Gratt BM. Thermographic assessment of temporomandibular disorders symptomology during orthodontic treatment. Am J Orthod Dentofacial Orthop. 1996 May;109(5):481–488.
26. Wozniak K, Szyszka-Sommerfeld L, Trybek G, et al. Assessment of the sensitivity, specificity and accuracy of thermography in identifying patients with TMD. Med Sci Monit. 2015 May;23(21):1485–1493.
27. De Melo DP, Bento PM, Peixoto LR, et al. Is infrared thermography effective in the diagnosis of temporomandibular disorders? A systematic review. Oral Surg Oral Med Oral Pathol Oral Radiol. 2019 Feb;127(2):185–192.
28. Rodrigues-Bigaton D, Dibai Filho AV, Costa AC, et al. Accuracy and reliability of infrared thermography in the diagnosis of arthralgia in women with temporomandibular disorder. J Manipulative Physiol Ther. 2013 May;36(4):253–258.
29. Fikackova H, Ekberg E. Can infrared thermography be a diagnostic tool for arthralgia of the temporomandibular joint? Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2004 Dec;98(6):643–650.
30. Dibai Filho AV, Packer AC, Costa AC, et al. Accuracy of infrared thermography of the masticatory muscles for the diagnosis of myogenous temporomandibular disorder. J Manipulative Physiol Ther. 2013 May;36(4):245–252.
31. Haddad DS, Brioschi ML, Vardasca R, et al. Thermographic characterization of masticatory muscle regions in volunteers with and without myogenous temporomandibular disorder: preliminary results. Dentomaxillofac Radiol. 2014;43(8):20130440.
32. Singh J, Arora AS. An automated approach to enhance the thermographic evaluation on orofacial regions in lateral facial thermograms. J Therm Biol. 2018 Jan;71:91–98.
33. Tashiro A, Bereiter DA. The effects of estrogen on temporomandibular joint pain as influenced by trigeminal caudalis neurons. J Oral Sci. 2020 Mar 28;62(2):150–155.
34. Da Silva R 2017<AQ>This reference is incomplete</AQ>.
35. Iwasaki LR, Gonzalez YM, Liu Y, et al. TMJ energy densities in healthy men and women. Osteoarthritis Cartilage. 2017 Jun;25(6):846–849.
36. Raustia AM, Oikarinen KS, Pyhtinen J. Densities and sizes of main masticatory muscle in patients with internal derangements of temporomandibular joint obtained by computed tomography. J Oral Rehabil. 1998;25(1):59–63.
37. Stokes M, Yong A. The contribution of reflex inhibition to arthrogenous muscle weakness. Clin Sci (Lond). 1984 Jul;67(1):7–14.