RESEARCH ARTICLE

The employment of thermographic examinations in the diagnostics of diseases of the paranasal sinuses

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Objectives: The article was aimed at assessing the diagnostic value of a thermographic examination of the pathology of the paranasal sinuses.

Methods: 39 patients met the inclusion criteria for the study. The cases of unilateral inflammations of the maxillary sinuses (odontogenic and non-odontogenic, acute and chronic) were chosen on the basis of a comprehensive panel of diagnostic tests including among other things: a radiological examination, endoscopy, the histopathological assessment of the state of the collected mucous membrane. The thermographic examination was carried out on the day preceding the surgery in the ward after finishing full clinical and radiological diagnostics. The measurements were conducted in accordance with the recommendations of the European Society of Thermology with the use of a FLIR E50 thermal imaging camera. The differences of the maximum temperatures ($\Delta T_{\max}$) between the affected side and the healthy side were characterized. The recorded thermal parameters were related to the totality of cases, the patients' age and gender, the category of clinical diagnoses in respect of aetiology, the presence of communication of the oral cavity with the maxillary sinus, changes in the radiological image and the degree of their intensity, a histopathological diagnosis, the presence of acute symptoms in the past as well as the time which elapsed between the occurrence of the first clinical symptoms of sinusitis noticed by the patients and the moment of surgical treatment implementation.

Results: When the oroantral fistulas were present, a highly significant relationship between $T_{\max}$ of the affected and healthy sides was found ($p = 0.0095$). Odontogenic vs non-odontogenic aetiology seemed to have a significant influence on these temperature differences ($p = 0.0133$). $\Delta T_{\max}$ links also with the state of the mucous membrane assessed during endoscopy ($p = 0.038$).

Conclusions: A thermographic examination can be only an auxiliary examination in the diagnostics of the diseases of the maxillary sinuses and may be helpful in the initial assessment of a chronic unilateral pathology.

Dentomaxillofacial Radiology (2017) 46, 20160367. doi: 10.1259/dmfr.20160367

Cite this article as: Niedzielska I, Pawelec S, Puszczewicz Z. The employment of thermographic examinations in the diagnostics of diseases of the paranasal sinuses. *Dentomaxillofac Radiol* 2017; 46: 20160367.

Keywords: thermography; diagnostic imaging; sinusitis; radiography

Introduction

The term sinusitis refers to an inflammation of the mucous membrane lining the paranasal sinuses. At present, the use of the term rhinosinusitis is recommended on account of the fact that sinusitis is usually accompanied by rhinitis. Rhinosinusitis can be

distinguished into acute and chronic forms.^{1–3} Moreover, in terms of aetiology, the inflammation of the mucous membrane of the nose and paranasal sinuses can be divided into viral, bacterial and mycotic. The division into odontogenic and non-odontogenic inflammations is another particularly significant aetiological division conditioning the manner of treatment and its effectiveness.^{4–8}

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Received 13 September 2016; revised 31 May 2017; accepted 5 June 2017

An acute inflammation of the mucous membrane of the nose and paranasal sinuses (ARS) involves the sudden occurrence of symptoms which lasts shorter than 12 weeks and totally retreat.¹ The definition by the American Academy of Otolaryngology and the Canadian Society of Otolaryngology–Head and Neck Surgery describes ARS as ailments lasting up to 4 weeks.^{2,3} Acute rhinosinusitis is widely spread and affects 6–15% of the population.^{1–3} According to the guidelines of the European Position Paper on Rhinosinusitis and Nasal Polyps of 2012 (EPOS 2012), a clinical examination with anterior rhinoscopy and determining body temperature is sufficient for the diagnostics of ARS within primary healthcare. Imaging examinations such as standard radiography of the sinuses should not be used on account of their limited diagnostic value,¹ also CT of the sinuses, in the case of ARS, is not routinely recommended.^{1–3}

Chronic rhinosinusitis (CRS) involves symptoms lasting for more than 12 weeks.^{1–3} The lack of epidemiological research, particularly in European countries, hinders the assessment of the occurrence of CRS. Recent research proves that CRS affects 5–15% of the population both in European countries and the USA.^{1–3} A diagnosis is based on a clinical examination, also including a full otorhinolaryngological examination, endoscopy of the nasal cavity and CT of the paranasal sinuses, constituting additionally the gold standard in the diagnostics of CRS.^{1–3} The diagnostic guidelines of the American Academy of Otolaryngology and the Canadian Society of Otolaryngology–Head and Neck Surgery include additionally performing allergy and immunology tests, particularly in the cases of recurring acute states.^{2,3}

Odontogenic sinusitis constitutes a special form of bacterial sinusitis in which the inflammation of the mucous membrane of the paranasal sinuses is caused by dentition pathology in a patient, confirmed clinically and radiologically.^{4,6–8} The frequency of occurrence of odontogenic inflammations of the sinuses is traditionally estimated at 10–12% of inflammations of the sinuses, whereas more recent sources reveal that the percentage is higher and amounts to 30–40%^{5–8} and even to 72.6%.⁴ Basic examinations in the diagnostics of odontogenic sinusitis encompass CT, orthopantomogram, a full clinical examination including a dental examination and teeth vitality tests.^{4,6,7} At present, it is considered that CBCT is the best and sufficient method of imaging odontogenic inflammations of the sinuses.^{6–13}

Attempts are constantly being made to promote employing other examinations in the diagnostics of diseases of the paranasal sinuses which may reveal an existing inflammatory process. Thermography is one of them.

Thermography is a totally non-invasive, painless and touchless diagnostic method, safe for the person being examined and the person who is examining. Changes in the metabolism of tissues and organs can be imaged thanks to the recording of emitted infrared radiation,

which allows the determination of their physiological state. A thermogram produced in this manner describes the distribution of temperatures on the surface of a given object and, subjected to analysis, allows showing hyper- and hypothermal foci which can be related to possible pathologies.^{14–16,18}

The increased emission of infrared radiation is recorded in cases of inflammations and neoplastic lesions. The skin over the organs and the richly vascularized body areas is also warmer.^{14–19} A decrease in the intensity of infrared radiation occurs over ischaemic areas in the course of peripheral circulation disorders. Thermal emission is also smaller over poorly vascularized areas, directly in the neighbourhood of osseous and adipose tissue, in the vicinity of cicatricial lesions and cysts.^{14–19} On the basis of the experiments performed and the observation, it was determined that temperatures $\geq 0.5^\circ\text{C}$ in comparison with the temperature of the surrounding tissues or the symmetrical body area may indicate the occurrence of a pathological state.^{15,19,21,25,27,28,30,32,35}

So far many articles assessing the usefulness of thermographic diagnostics in different areas of medicine: allergology,^{15,16,27} angiology,^{15,16} cardiology^{15,16} and cardiac surgery,^{15,16} dermatology,^{15,16} orthopaedics,^{15,16} oncology,^{15,16} rheumatology^{15,16} and rehabilitation^{15–18} have been published. The use of thermography in the diagnostics of pathologies in the areas of the head and neck including the paranasal sinuses has also been described in publications in laryngology, maxillofacial surgery and dentistry.^{28–32} In the presented article, the results of thermographic examinations of the paranasal sinuses were related to clinical diagnoses with respect to aetiology, changes in the radiological image as well as the degree of their intensity, a histopathological diagnosis, the presence of acute symptoms in the past and the time which elapsed between the occurrence of the first clinical symptoms of sinusitis noticed by the patient and the moment of surgical treatment implementation.

The article was aimed at assessing the diagnostic value of a thermographic examination of inflammatory pathology of the paranasal sinuses.

Methods and materials

From January to December 2014 in the Department of Craniomaxillofacial Surgery in Katowice, Poland, 83 patients were operated due to inflammations of the maxillary sinuses including 77 unilateral and 69 odontogenic ones.

39 patients meeting the inclusion criteria for the study and diagnosis with the use of a thermographic camera were selected from this group. The cases of unilateral inflammations of the maxillary sinuses (odontogenic and non-odontogenic, acute and chronic) were chosen on the basis of a comprehensive panel of diagnostic tests including, among other things, a radiological examination (radiographic examination, CT and CBCT), endoscopy

and the histopathological assessment of the state of the collected mucous membrane.

The cases of bilateral inflammations, systemic diseases and injuries sustained in the area of the facial part of the cranium, treatments and other diseases which can have an influence on a recorded image were excluded.

The thermographic examination was performed with the use of a infrared-based FLIR E50 thermal imaging camera (FLIR Systems, Wilsonville, OR) with the basic technical parameters: image resolution 240×180 pixels, thermal resolution $<0.05^\circ\text{C}$, measuring range -20 to $+650^\circ\text{C}$, accuracy $\pm 2^\circ\text{C}$. The examination was carried out on the day preceding the surgery in the ward after finishing full clinical and radiological diagnostics. The measurements were conducted in accordance with the recommendations of the European Society of Thermology,^{18,20} in the same room with a fixed temperature (about $22\text{--}23^\circ\text{C}$) and humidity ($50\text{--}55\%$) with the use of a thermohygrometer. The examination was performed after about a 15-min adaptation of the patient in the sitting position from a distance between 1 and 0.4 m in an *en face* projection and in profile. Then, the recorded image was archived and processed by means of the FLIR Tools software (FLIR Systems, Wilsonville, OR). The comparative analysis of symmetry of temperature distribution was carried out. The area of the facial skin was marked by using a tool for marking an area of the photo in the shape of an ellipse in the FLIR Tools software. The outline of the ellipse ran from above tangentially to the inferior orbital rim, medially to the nasal pyramid, laterally to the line, being a continuation of the lateral orbital rim (Figure 1).

The above-described parameters were recorded and marked automatically by the software. The thermograms obtained were analysed by recording the maximum temperature (T_{max}) in the skin areas corresponding to the maxillary sinuses both on the healthy side ($T_{2\text{max}}$) and on the side affected by pathological lesions ($T_{1\text{max}}$). Next, the difference between the recorded maximum temperature ($\Delta T_{\text{max}} = T_{1\text{max}} - T_{2\text{max}}$) in the given facial skin areas was determined. This recorded maximum temperature difference (ΔT_{max}) is the major outcome and is used for all the assessments. The norm amounts to up to 0.5°C .^{15,19,25,27,28,30,32,35} On the basis of the experiments performed and the observation, it was determined that temperatures $>0.5^\circ\text{C}$ in comparison with the temperature of the symmetrical body area may indicate the occurrence of a pathological state.^{15,19,25,27,28,30,32,35}

In the course of the diagnostic proceeding, radiological examinations were performed in the patients, which allowed the determination of the severity of inflammatory lesions/cystic lesions in the maxillary sinuses. The analysis of available radiological examinations (a radiograph of the sinuses in Water's projection, CT of the sinuses and CBCT of the sinuses) with respect to the degree of pneumatization loss of the maxillary sinuses involved describing changes in the radiological image by means of one's own three-graded scale, where 0 is for radiologically healthy sinus(es), 1 is

for a partial loss of sinus pneumatization and 2 is for a total loss of maxillary sinus pneumatization.

The patients were classified into groups based on the clinical diagnoses, including the odontogenic and non-odontogenic aetiology of inflammations with the additional determination of the presence of oroantral fistulas. A full description of the study group was provided. An analysis was carried out for each group of diagnoses and the intensity of changes in the radiological image was determined. The conformity of the radiological image with the intrasurgical endoscopic image was assessed, the results of the histopathological examination were compared with the clinical diagnosis, the differences of the maximum temperatures between the affected side and the healthy side were characterized and the time which elapsed from the occurrence of the first symptoms to the implementation of surgical treatment was determined. The recorded parameter ΔT_{max} was related to the totality of the cases, the patients' age and gender, the category of clinical diagnoses with respect to aetiology, the presence of the communication of the oral cavity with the maxillary sinus in the form of an oroantral fistula, the category of separate clinical diagnoses in terms of aetiology with an additional division of these groups with respect to the presence of an oroantral fistula or its absence, changes in the radiological image and the degree of their intensity, a histopathological diagnosis, the presence of acute symptoms in the past as well as the time which elapsed between the occurrence of the first clinical symptoms of sinusitis noticed by the patients and the moment of surgical treatment implementation.

Figure 1 Measurement scheme with reference lines. Reference lines are marked on the thermogram of the patient. (a) Tangential line to the lateral orbital rims. (b) Lines parallel to (a) through the medial edges of the nasal pyramid. (c) Line perpendicular to (a) and (b); tangential line to the infraorbital rims. (d) Line parallel to (c) tangential to the base of the nasal pyramid. This construction divides the face into measurement areas: affected (here EI1) and healthy (here EI2). In the two infraorbital squares of the grid ellipses were fitted by the program in which the maximum temperature was automatically recorded.

Statistical analyses of the results were performed by means of the statistical package PQStat v. 1.6. The results— $\Delta T_{\max}$ —(categorized into: <0.5 and ≥ 0.5 °C) depending on the remaining scales were analysed using Fisher's exact test. For significant results, test probability was adopted at the level of $p < 0.05$, and for highly significant results, test probability was adopted at the level of $p < 0.01$.

Results

39 patients aged 9–73 years including 19 females and 20 males were qualified for the study (Table 1—the description of the study group).

The average maximum temperature on the affected side was 35.6 °C ($T_{1\max}$) and on the healthy side was 35.3 °C ($T_{2\max}$). The average amount of $\Delta T_{\max}$ was 0.3 °C (Table 2).

In only 48.7% of the cases, $\Delta T_{\max}$ exceeded the level of 0.5 °C.

$\Delta T_{\max}$ did not correlate to age ($p = 0.7524$), gender ($p = 0.7524$) or aetiology (odontogenic and non-odontogenic inflammatory) of the inflammation ($p = 1.0000$).

In the presence of an oroantral fistula, however, we observed a significant difference in $\Delta T_{\max}$ between the affected and healthy sides. In the case of the presence of

oroantral fistulas, a highly significant relationship of $\Delta T_{\max}$ ($p = 0.0095$) was found. In the group with the presence of an oroantral fistula, the $\Delta T_{\max}$ results were found ≥ 0.5 °C (Table 3). Therefore, it is easier to record the difference of temperatures between the healthy and affected sides (Table 4).

$\Delta T_{\max}$ was also significantly correlated ($p = 0.0038$) to the state of the sinus mucosa as evaluated by endoscopy. If the mucosa was affected, $\Delta T_{\max}$ more often was found to be ≥ 0.5 °C (Table 3).

We observed no significant relation ($p = 0.1609$) between radiological image and thermographical evaluation ($\Delta T_{\max}$). Yet, if no pathological radiological signs were present, thermographic assessment was also insignificant.

We neither observed a correlation between $\Delta T_{\max}$ and symptoms of acute inflammation in the course of the disease ($p = 1.0000$) nor with histopathological diagnosis ($p = 0.7142$). The same applies to the relation with the time elapsed between the first symptoms and surgical intervention ($p = 1.0000$).

Discussion

Regarding the above results, the presence of the communication of the oral cavity with the maxillary sinus in the form of a fistula in the considerable majority of the

Table 1 Description of the study group

Evaluated factors	Odontogenic inflammatory processes		Non-odontogenic inflammatory processes	
	Without oroantral fistula	Presence of an oroantral fistula	Without oroantral fistula	Presence of an oroantral fistula
Frequency of pathology (%)	12 (44.4%)	15 (55.7%)	11 (91.7%)	1 (8.3%)
Age (years)	9–73 (average 37.5)	18–72 (average 45.9)	12–73 (average 37.09)	55
Sex (W/M)	7W (58.3%) 5M (41.7%)	5W (33.3%) 10M (66.7%)	6W (54.6%) 5M (45.4%)	1W
Acute inflammation	0	0	0	0
Chronic inflammation	12	15	11	1
Radiological status 0°	2 (16.7%)	0	1 (9.1%)	0
1°	4 (33.3%)	9 (60%)	10 (90.9%)	0
2°	6 (50%)	6 (40%)	0	1
Endoscopic image Corresponding to RTG	10 (83.3%)	13 (86.7%)	7 (63.6%)	0
Non-corresponding to RTG	2 (16.7%)	2 (13.3%)	4 (36.4%)	1
Histopathological examination Chronic inflammatory lesions	6 (50%)	13 (86.7%)	4 (36.4%)	0
Cystic lesions	4 (33.3%)	2 (13.3%)	4 (36.4%)	0
Unchanged mucous membrane	2 (16.7%)	0	1 (9%)	1 (100%)
Not collected	0	0	2 (18.2%)	0
Difference between the maximum temperature on the healthy and affected sides (°C)	Range: −0.3 to +0.6 (average +0.1)	Range: −0.6 to +0.9 (average +0.4)	Range: −0.2 to +0.8 (average +0.4)	0.5
Time to the moment of surgical treatment (months)	Range: 1–10 (average 4.1); 1 patient did not define the beginning of the disease	Range: 1–120 (average 16.3)	Range: 1–60 (average 11); 2 patients did not define the beginning of the disease	7

W, females; M, males; RTG, Results of radiological examinations.

The radiological status degrees are given as follows: 0, radiologically healthy sinus/sinuses; 1, partial loss of maxillary sinus pneumatization; 2, total loss of maxillary sinus pneumatization.

Table 2 Minimum, maximum and average values with standard deviation of $T_{1\max}$ (°C), $T_{2\max}$ (°C) and $\Delta T_{\max}$ (°C)

Scale	Average	Standard deviation	Minimum	Maximum
$T_{1\max}$ (°C)	35.6	0.9	33.9	37.4
$T_{2\max}$ (°C)	35.3	1.0	33.3	37.7
$\Delta T_{\max}$ (°C)	0.3	0.4	−0.6	0.9

patients allows recording of the threshold values of the $\Delta T_{\max}$ parameter. On the basis of the collected data, it can be seen that in the situation when the existence of an oroantral fistula was found, regardless of the aetiological division into odontogenic and non-odontogenic processes, the threshold of 0.5 °C was exceeded. The permanent presence of an oroantral fistula causes the sustaining of inflammation of the mucous membrane of the maxillary sinuses. This is reflected in a thermographic examination as well. In cases when the presence of a fistula was not found, the relationship in the case of non-odontogenic processes is not clear because the results are distributed almost equally, whereas in the case of odontogenic processes, the considerable predominance of the value below the threshold of 0.5 °C can be observed. The communication of the sinus with the oral cavity probably causes the formation of inflammatory lesions of the mucous membrane of the maxillary sinus characterized by higher severity and a higher degree of metabolism than in the case when such communication does not exist.

The comparison of the recorded differences of the maximum temperatures $\Delta T_{\max}$ with the intrasurgical endoscopic image of the mucous membrane of the maxillary sinuses establishes that in a situation when the mucous membrane was inflamed, in the majority of the cases (73%), the $\Delta T_{\max}$ parameter exceeded the threshold value. The tendency was the most noticeable in the group of odontogenic processes with an oroantral fistula. This fact can confirm the higher degree of severity of inflammatory lesions in this group of diagnoses and, consequently, the easier recording of threshold values in the thermographic image.

Within the past few years, several articles in otolaryngology, maxillofacial surgery, allergology and paediatrics concerning the employment of thermography in the diagnostics and monitoring of treatment progress of inflammations of the maxillary sinuses have been published.^{21–30}

Bihl *et al*²² assessed the thermograms of patients entitled to surgeries of the maxillary sinuses relating them to a clinical and histopathological diagnosis and a radiological image. They state that there is a possibility of differentiating between cystic lesions and acute and chronic inflammations, although the presented data are not fully unambiguous. On the basis of the results obtained in our research, inflammatory lesions of the sinuses caused, in a considerable part of the cases, an increase in temperature in the image of the sinus affected by pathology, which coincides with the reports of Bihl *et al*.²² Cystic lesions did not give an unambiguous thermal image and did not cause any temperature differences in a considerable part of the cases.²² This could be interpreted as lack of sensitivity if the diagnosis only relies on thermography.

Pogrel *et al*,²³ Murlewska *et al*,²⁴ Fita *et al*,^{21,25} Gratt and Anbar²⁶ and Gratt *et al*²⁷ used thermovision for the assessment of various pathologies in the area of the head and neck, including sinusitis. Jung *et al*^{28,29} and Gauthier *et al*³⁰ focused only on thermal imaging of lesions of the paranasal sinuses.^{28–30} All the mentioned authors were of the opinion that existing pathology influences the recorded thermographic image.^{23–30} They recorded asymmetry in the temperature distribution in the area of the maxillary sinuses and confirmed sinusitis on clinical examination.^{23–30} Jung *et al*^{28,29} postulate the possibility of differentiation of inflammatory and allergic diseases of the paranasal sinuses. They also recommend the use of the hyperventilation test to increase the gradient of temperatures between both sinuses as a result of enhancing the air flow through the nasal cavity and the paranasal sinuses and, consequently, better revealing of the lesions in the thermographic image.^{28,29} Some authors pointed out the lack of difference between inflammatory and proliferative lesions in thermal images, what implies deficiency of examination specificity.²⁴ Taking into consideration the metabolic nature of proliferative and inflammatory lesions, they always involve an increase in temperature in their image, which means the lack of the possibility of differentiating these lesions only on the basis of the thermographic image. Other authors pay attention to the importance of the reference point in examination based on thermal imaging.^{28–30} The authors' results^{28–30} coincide with the results presented in our study. A

Table 3 Correlation between $\Delta T_{\max}$ (°C) and the presence of oroantral fistula and endoscopic state of the mucosal membrane

Evaluated factors	$\Delta T_{\max}$ (°C)	Absolute frequency	Relative frequency (%)
Presence of an oroantral fistula			
No	<0.5	16	69.6
	≥0.5	7	30.4
Yes	<0.5	4	25.0
	≥0.5	12	75.0
State of mucous membrane of maxillary sinus			
Unaffected	<0.5	15	75.0
	≥0.5	5	25.0
Affected	<0.5	5	26.3
	≥0.5	14	73.7

Table 4 Correlations between ΔT_{max} (°C) and the odontogenic and non-odontogenic aetiology of an inflammatory process additionally with regard to the presence of an oroantral fistula

Pathology	Presence of oroantral fistula	ΔT_{max} (°C)	Absolute frequency	Relative frequency (%)
Non-odontogenic inflammatory processes	No	<0.5	6	54.5
		≥ 0.5	5	45.5
Non-odontogenic inflammatory processes	Yes	<0.5	0	0
		≥ 0.5	1	100
Odontogenic inflammatory processes	No	<0.5	10	83.3
		≥ 0.5	2	16.7
Odontogenic inflammatory processes	Yes	<0.5	4	26.7
		≥ 0.5	11	73.3

unilateral disease process in the maxillary sinuses creates a possibility of comparing the recorded change in temperature. In cases of bilateral lesions such a comparison is not possible.

Marszał *et al*³¹ and Wojaczyńska-Stanek *et al*³² describe the employment of thermography in diagnosing and also in monitoring the treatment of sinus diseases in children, comparing its results to a laryngological and radiological examination.^{31,32} They confirm the possibility of using thermographic examinations for screening examinations in children, simultaneously mentioning the possibility of resigning from radiological examinations.³¹ Complete resignation from performing radiological examinations in favour of a clinical and thermographic examination is impossible on the account of the nature of the data provided by a thermographic examination showing only an increase and decrease in temperature but without other data on the nature of pathology and its scope.

Ring *et al*³³ mention the possibility of employing thermographic examinations as screening examinations in the diagnostics of sinus diseases. They emphasize that thermographic examinations must be performed in a correct manner and that they constitute only a supplement to a clinical examination and do not form the

basis for a diagnosis. At present, work also on defining automatic algorithms for analysing recorded thermograms based on recognizing characteristics in the physiological areas of the face in thermograms is in progress.^{34,35} An elaborated algorithm could be a part of a software for analysing photographs or even could be implemented in every device, which would make quick interpretation of results possible.^{34,35} After the introduction of the described changes in devices and their software, conducting screening examinations would proceed in a quick and maximally repeatable manner, which would popularise this method of examination as a screening examination of lesions in the paranasal sinuses.^{34,35} Simultaneously, it would limit the number of incorrect results connected with interpreting results by the examining person.^{33–35} The use of thermographic cameras for screening examinations requires further research and establishing certain patterns which would enable quick automatic assessment of numerous thermograms produced during a screening examination.

In conclusion, a thermographic examination can be only an auxiliary examination in the diagnostics of the diseases of the maxillary sinuses and helpful in the initial assessment of a chronic unilateral pathology.

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