Thermographic Characterization of the Asymptomatic Temporomandibular Joint

This study used electronic thermography, an alternative diagnostic imaging modality, to assess the thermal image characteristics of the normal TMJ in 30 asymptomatic subjects. Assessments made included: thermal pattern recognition and symmetry, absolute temperature measurements and differences in absolute temperature measurements, and mean temperature measurements and differences in five anatomic zones. Results indicated the presence of a common thermal TMJ pattern in two thirds of patients, with variations from this pattern in the remaining patients. All TMJ thermal patterns demonstrated marked thermal symmetry, with $\Delta T < 0.2\,^{\circ}C$ in the region of the TMJ and related regions of the face. This consistent symmetry demonstrated in normal subjects suggests that substantial thermal asymmetry may prove to be a reliable indicator of TMJ disease.

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The current diagnostic imaging methods for the assessment of the temporomandibular joint (TMJ) include plain film radiography, panoramic radiography, tomography, arthrotomography, arthroscopy, computerized tomography and magnetic resonance imaging. These techniques either require ionizing radiation, are invasive, or are costly. An alternative diagnostic imaging method, electronic thermography (ET), is nonionizing, noninvasive, and inexpensive.

Electronic thermography uses vascular heat emissions from the human face to display symmetric thermal patterns in normal subjects and asymmetric thermal patterns in patients with a variety of disorders.[1] Physical disorders that are related to the TMJ and have been reported to produce abnormal facial thermograms include (but are not limited to) myofascial pain syndromes,[2] myositis,[3] musculoligamentous injury,[4] TMJ disorders,[5–10] motor and sensory radiculopathy,[11] and the inflammation of arthritis[12] and bursitis.[13]

The dental literature has not adequately defined the normal TMJ as imaged on facial thermograms, nor has it described historical or clinical findings that may alter TMJ thermal patterns emitted from the face. This study was designed to characterize the normal thermal patterns of the TMJ.

Materials and Methods

The subject population consisted of 30 asymptomatic adult volunteers randomly chosen from patients, students, staff, and faculty at the UCLA Medical Center. All subjects completed a medical history questionnaire to document that they were asymptomatic; they

Table 1 Required Sample Size and Various Values of Mean ΔT When $\alpha = 0.05$, Power = 0.80, and SD = 0.2°C

Mean ΔT in normals (°C)	Mean ΔT in disease group (°C)	Minimum sample size (n)
0.1	0.4	9
0.1	0.3	17
0.2	0.4	17

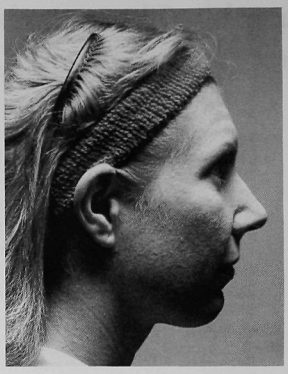


Fig 1 Hair held back with a headband allows for a high-quality facial thermogram.

also were found to be normal upon clinical examination[14] by one investigator (BMG). The combination of a negative health history and a negative clinical examination should be adequate to define normal TMJ status. Therefore, these patients were not followed over time, nor were additional diagnostic tests conducted to further establish normalcy.

In the design of this study, ΔT was used as the outcome variable of interest. Previous normal thermography studies of the face indicate that ΔT has a standard deviation no larger than 0.2°C.[14] Based on this standard deviation and the assumption that ΔT has an approximately normal distribution, a sample size of 30 implies that a change in mean ΔT of 0.15°C or more can be confirmed as significant with 80% power, using the usual $\alpha = .05$ criterion. Under these same assumptions, Table 1 gives the required sample size under various conjectured values of mean ΔT.

Based on the information presented in Table 1, a sample size of 30 should be more than adequate to establish the ΔT range among normal subjects.

Facial thermography was done using an Agema 870 thermovision unit; this includes an infrared scanner, control unit, thermal image computer TIC-8000 and Meds 1.0 software, cables, stands, supports, and color monitor (Agema Infrared Systems, Secaucus, NJ), coupled to a 35-mm camera using color film. Room conditions for thermographic examinations included a draft-free environment (no windows, doors closed), temperature control (ranging from 20°C to 22°C), variable lighting, a patient positioning chair, and a small hand-held electric fan.

Facial thermograms were taken on the 30 normal subjects using right and left lateral projections at two imaging sensitivities (0.5°C and 1.0°C). Before the examination, each patient's hair was tied back (Fig 1) and the face was wiped with a damp cloth and air dried for 15 to 30 seconds using a small electric fan. All subjects were non-bearded. Each patient was asked to sit quietly, without touching the face, for 15 minutes to allow for facial thermal equilibration with ambient room temperature.

Two series of facial thermograms were made. Images were stored on computer disk and photographed for evaluation.

Subjective thermal image assessments were made. These included thermal pattern characterization of individual TMJ images and thermal pattern symmetry assessments comparing paired TMJ images. Objective assessments also were made and involved absolute (spot) temperature measurements, differences in absolute (spot) temperature measurements of paired TMJ images (calculation of ΔT), mean temperature measurements of five anatomic zones related to the TMJ, and differences in the mean temperatures of these five anatomic zones (obtaining additional ΔT measurements). (Zones were not based upon common anatomic structures [eg, masseter muscle, temporalis muscle, etc] due to difficulty in identification and in the delineation of these structures as seen on thermal images. Instead, carefully configured zones were used based upon knowledge gained from a pilot study of normal facial thermography[15] and based upon the desire for high precision in repeated facial mappings.)

Color photographs (9 × 12.5 cm) of paired TMJ thermal images were evaluated independently by two expert thermographers. Both experts had taken or given formal courses in thermography

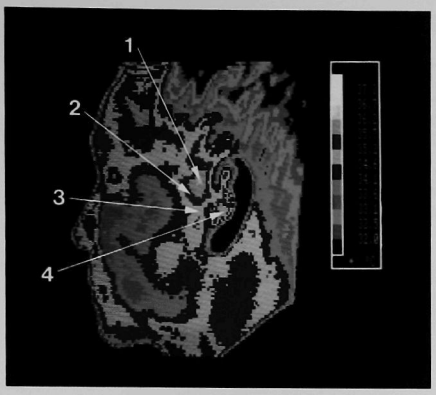


Fig 2 TMJ thermogram demonstrating locations for absolute temperature measurements at 0.1°C accuracy (imaged using 0.5 C color sensitivity). Measurements were made over the following regions: (1) the hot central TMJ temperature spot (hot yellow inner core), (2) the warm ring around the hot yellow core (red ring), (3) the surrounding field (pink area between the two hot yellow zones), and (4) the hot yellow area over the external auditory meatus (ear canal).

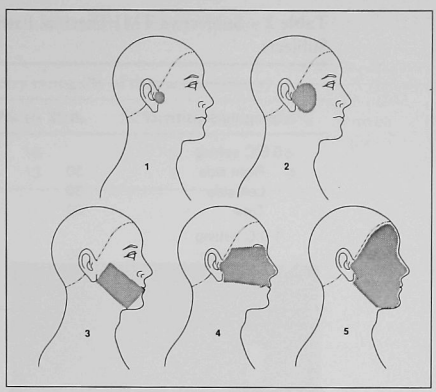


Fig 3 The five anatomic zones of the face that are related to the TMJ as measured in this study.

(mainly of the body), published peer-reviewed articles on thermography, and performed more than 300 thermography examinations each. Each examiner subjectively evaluated the individual cases (made up of two sets of thermograms) for regions of increased, average (normal), or decreased temperature. Image characterizations were made using lateral projections, at 1.0°C and 0.5°C imaging sensitivty. An estimation (by percentage) was made of the occurrence of the most common image pattern.

The same prints used in the subjective thermal pattern characterization were used for assessment of thermal symmetry. The temperature distribution (color patterns) over the anatomic region of the TMJ was compared with the corresponding region of the opposite side of the face. Scoring ranged from 1 to 6 using the following scale: 1 = > 80% symmetry; 2 = 65% to 80% symmetry; 3 = 50% to 65% symmetry; 4 = 35% to 49% symmetry; 5 = 20% to 34% symmetry; 6 = 0% to 19% symmetry; 0 = can't be evaluated (poor image, poor positioning, etc). This scale was selected because its discriminant points were easy to estimate on a repeatable and routine basis. Matching assessments were made using lateral projections, at 0.5°C and 1.0°C imaging sensitivity.

All 60 TMJ images were measured for absolute temperature at 0.1°C sensitivity. Measurements were made of the following regions (Fig 2): the hot central TMJ temperature spot (hot yellow inner core), the warm (red) ring around the hot yellow core, and the surrounding field (pink area between the two hot yellow zones). In addition, an absolute (spot) temperature measurement was made of the hot yellow area over the external auditory meatus (EAM; ear canal).

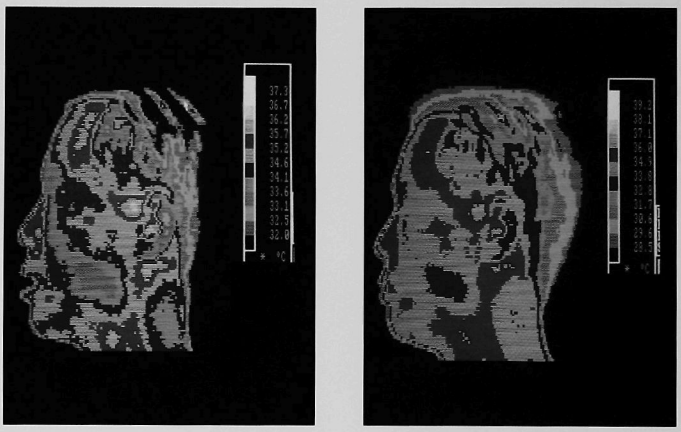
The absolute (spot) temperature measurements on the right and left sides were compared for each subject. Calculation of differences produced four ΔT values for each set of paired images.

Five anatomic zones related to the TMJ were measured for mean temperature (Fig 3). Zone 1 included the area directly over the TMJ. Zone 2 included a larger area over and anterior to the TMJ. Zone 3 was limited to the region over the body of the mandible. Zone 4 included the whole midregion of the face, including the TMJ region. Zone 5 covered the entire half of the face, including the TMJ. Mean temperature measurements

Table 2 Subjective TMJ Thermal Pattern Classification of 30 Asymptomatic Subjects

Imaging sensitivity	n	Color thermal patterns	
		Common* (%)	Normal variant (%)
0.5°C setting			
Right side	30	21 (70)	9 (30)
Left side	30	19 (64)	11 (36)
Total	60	40 (67)	20 (33)
1.0°C setting			
Right side	30	21 (70)	9 (30)
Left side	30	20 (67)	10 (33)
Total	60	41 (68)	19 (32)

*See text for description.



Figs 4a and 4b Multicolored thermograms of the TMJ imaged using 0.5°C sensitivity (left) and 1.0°C sensitivity (right). Both images are examples of the most common thermal patterns seen when imaging asymptomatic (normal) subjects.

were made using all 60 TMJ images. Differences in the mean temperatures were calculated for the five anatomic zones, producing ΔT values for each set of paired images.

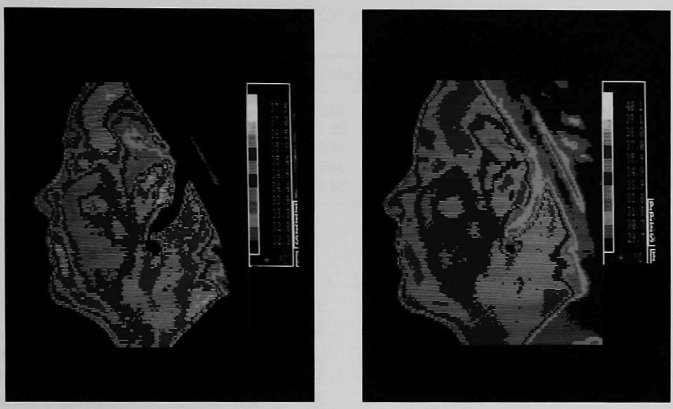
Results

Subjective characterization of color thermal images of the TMJ identified a common pattern in approximately two thirds of cases (Table 2). At 0.5°C imaging sensitivity (Fig 4a), this pattern consisted of four distinct components. A hot (yellow) spot in the area of the EAM measured 1.2 × 1.2 cm (approximately the size of a finger tip). Another hot (yellow) spot of approximately the same size (±50%) lay anterior and superior to the first hot spot and was superimposed over the TMJ itself. Each of these hot spots was surrounded by a warm (red) ring. Finally, both hot spots, surrounded by their red rings, were partially or completely surrounded by a somewhat cooler field of pink.

At 1.0°C imaging sensitivity (Fig 4b), the standard color pattern of the asymptomatic (normal) TMJ consisted of two hot (yellow) spots, each surrounded by a warm field of red. One hot spot lay

Table 3 Subjective Assessment of TMJ Thermal Pattern Symmetry Using 30 Paired Thermograms

		Symmetry rating (% of thermal symmetry)			
Imaging sensitivity	n	>80%	66% to 80%	50% to 65%	<50%
0.5°C	30	14	13	3	0
1.0°C	30	15	13	2	0



Figs 5a and 5b Multicolored thermograms of the TMJ imaged using 0.5°C sensitivity (left) and 1.0°C sensitivity (right). Both images are examples of normal variant thermal patterns.

in the area of the EAM and measured 1.2 × 2.0 cm. The second overlayed the TMJ and was approximately the same size.

Variations from these standard thermographic patterns were noted, including elongation of the hot EAM region, increased size of the hot area over the TMJ, and combinations of these patterns. Figures 5a and 5b shows examples of TMJ thermograms demonstrating normal variant thermal patterns. These variant patterns were found in approximately one third of the cases reviewed (Table 2).

Results from the assessment of TMJ thermal symmetry are shown in Table 3: the highest of level of thermal symmetry (>80% thermal symmetry at both 0.5°C and 1.0°C imaging sensitivity) was seen in 45% of the subjects; another 45% showed thermal symmetry at the 65% to 80% level (at both 0.5°C and 1.0°C imaging sensitivity), and approximately 10% demonstrated only moderate (50% to 65%) thermal symmetry.

The mean temperatures and standard deviations of the four regions selected for spot measurement are indicated in Table 4. The hot central region overlying the TMJ (yellow inner core) was measured to be 36.1°C, approximately 0.5°C warmer than the (red) ring region surrounding the TMJ, which itself was 0.5°C warmer than the (pink) adjacent region. The EAM region was the hottest of all, measuring 36.5°C, 0.4°C warmer than the hot central region over the TMJ.

Results of the calculation of differences between the right side and the left side of the four TMJ spot regions demonstrated a high level of thermal symmetry, with ΔT values averaging only 0.1°C (Table 4). This high degree of thermal symmetry in normal subjects may prove useful if temporomandibular disorders (TMD) commonly produce areas of marked thermal asymmetry.

Table 5 shows the results of the mean thermal measurements over five anatomic zones of the face. The immediate region around the TMJ (small

Table 4 Absolute Temperature Measurements, in °C, for the Four Regions Around the TMJ Seen on Thermograms of 30 Asymptomatic Subjects

Region measured	Right side (SD)	Left side (SD)	Combined (SD)	ΔT (SD)
TMJ—center (yellow)	36.1 (0.43)	36.1 (0.38)	36.1 (0.41)	0.1 (0.12)
TMJ—ring (red)	35.5 (0.55)	35.5 (0.58)	35.5 (0.57)	0.1 (0.08)
TMJ—field (pink)	35.0 (0.61)	35.0 (0.63)	35.0 (0.63)	0.1 (0.11)
EAM (yellow)	36.4 (0.53)	36.5 (0.52)	36.5 (0.53)	0.2 (0.20)

Table 5 Sixty Mean Temperature Measurements, in °C, for the Five Anatomic Zones Seen on TMJ Thermograms of 30 Asymptomatic Subjects

Anatomic zone	Right side (SD)	Left side (SD)	Combined (SD)	ΔT (SD)
Small TMJ	35.5 (0.53)	35.5 (0.55)	35.5 (0.54)	0.1 (0.08)
Large TMJ	35.2 (0.61)	35.1 (0.61)	35.2 (0.61)	0.1 (0.09)
Mandible	34.6 (0.76)	34.6 (0.78)	34.6 (0.53)	0.1 (0.11)
Midface	34.8 (0.71)	34.7 (0.69)	34.7 (0.70)	0.1 (0.08)
Entire half-face	34.9 (0.62)	34.8 (0.63)	34.9 (0.62)	0.1 (0.07)

TMJ zone, see Fig 3) had the highest temperature, 35.5°C, followed by the midfacial zone at 35.2°C. The zone over the mandible was coolest, measuring 34.7°C. Standard deviations from these mean values ranged from 0.5°C to 0.66°C for all five zones.

Results of mean thermal symmetry difference calculations also are shown in Table 5. These indicate a very high level of thermal symmetry for all five zones, with ΔT values ≤0.1°C.

Discussion

The results of our subjective characterization of TMJ thermal patterns indicated the presence of a common thermal pattern in two thirds of the cases and a range of normal variant patterns in the remaining cases. All these patterns are easy to recognize, and we believe that they indicate the starting point from which thermal TMJ image interpretation should begin.

We also found thermal TMJ patterns to demonstrate a high level of symmetry in comparisons between the right and left sides. The ΔT values for all regions and areas of the face and TMJ were found to be very small (<0.2°C), also suggesting that the range of normalcy is sufficiently narrow to permit thermal differentiation of some TMJ-related diseases. Previous investigators also have reported high levels of thermal symmetry for the face and the TMJ regions, although their observations were less detailed and less rigorously controlled than ours.[16–18]

We wish to emphasize the importance of using proper clinical thermographic techniques to arrive at interpretable TMJ images. First, patients need to be comfortably seated. They must have their hair tied back so as not to obscure the TMJ region. An elastic headband is very effective for holding hair away from the ears. It is also inexpensive, easy for patients to place, and readily detected by thermal imaging (as a prominent dark line). Men with long, full sideburns (including beards) are not acceptable subjects for TMJ imaging. Similarly, some women have prominent sideburns and cannot be imaged adequately.

The skin should also be properly prepared for imaging: the face should be lightly cleaned and cooled and the patient should sit quietly to allow for thermal equilibration with ambient room temperature. (Refer to Methods and Materials section for a complete description of this procedure.) The electronic thermography unit then should be calibrated so that the full range of expected TMJ readings can be recorded. We found the EAM (near the TMJ) to be the warmest area on the face as seen on a laterally projected thermogram, with a mean temperature of 36.5°C. Care should be taken to maintain this area within the thermal window at 0.5°C sensitivity even if this results in cooler areas of the cheek being beyond the range of thermal imaging (thus appearing black in the image). At 1.0°C sensitivity, the range of recorded

temperatures is broad enough so that there should be no problem in displaying all facial structures within the thermal imaging window. We found, as have others,[14] that thermal sensitivity settings of both 0.5°C and 1.0°C are useful in the assessment of the TMJ. Care must also be taken to properly focus the thermal image. We used the high-resolution black-and-white image mode for focusing to obtain clear images of the TMJ region.

Previous investigators using thermometric analysis to study TMD have found promising clinical results. Berry and Yemm[5,6] noted that most patients with TMD had an elevated temperature over the masseter muscle on the painful side. These thermometric changes were found to return to normal after successful TMJ therapy. Pogrel et al[17] used liquid crystal thermography for making temperature measurements on both normal subjects and patients with TMD and myofascial pain. Their results indicated increased temperature (warm regions) over the TMJ of patients with painful internal derangement. After successful treatment, the thermograms were normal. In a study of pretreatment and posttreatment TMD patients, Stead[18] found liquid crystal thermography of the face to be reliable, valid, and efficacious as a diagnostic tool in 95% of her cases. Although these reports are promising, additional studies are needed before thermographic diagnosis of the TMJ will be accepted clinically.[19]

Conclusions

A common thermal pattern is identifiable in most electronic thermal images of the asymptomatic TMJ, as is a range of normal variant patterns. All normal TMJ thermal patterns demonstrate marked thermal symmetry over the region of the TMJ and within the surrounding regions of the face. Proper thermographic technique is important in obtaining high-quality TMJ thermal images.

Electronic thermography may have promise as a diagnostic test to evaluate the TMJ. Additional and more extensive studies are needed before thermographic diagnosis of TMD will be accepted clinically.

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References

1. Abernathy M, Abernathy TB. International bibliography of medical thermology. Thermology 1987;2(3):117–533.
2. Fischer AA, Chang CH. Temperature and pressure threshold measurements in trigger points. Thermology 1986;1:212–215.
3. Fischer AA, Chang CH. Thermographic documentation of trigger points: corroboration by pressure threshold measurement. Medical Thermology. Washington, DC: American Academy of Thermology, 1986:115–119.
4. Ignacio DR, Pavot A, Azer RN, Jackson H. Thermography and decompensated shoulder syndrome. Medical Thermology. Washington, DC: American Academy of Thermology, 1986:120–123.
5. Berry DC, Yemm R. Variations in skin temperature of the face in normal subjects and in patients with mandibular dysfunction. Br J Oral Surg 1971;8:242–247.
6. Berry DC, Yemm R. A further study of facial skin temperature in patients with mandibular dysfunction. J Oral Rehabil 1974;1:255–264.
7. Johansson A, Kopp S, Haraldson T. Reproducibility and variation of skin surface temperature over the temporomandibular joint and masseter muscle in normal individuals. Acta Odontol Scand 1985;43:309–313.
8. Tegelberg A, Kopp S. Skin surface temperature over the temporomandibular and metacarpophalangeal joints in individuals with rheumatoid arthritis. Odontologiska Kliniken, Report Series No. 31. University of Göteborg, Sweden: 1986:1–31.
9. Weinstein SA. Thermography and Personal Injury Litigation, ed 1. New York: John Wiley and Sons, 1987:157–164.
10. Gratt BM, Sickles EA, Ross JB. Electronic thermography in the assessment of the temporomandibular joint: A pilot study. Oral Surg Oral Med Oral Pathol 1991;71:364–370.
11. Getty CJ. "Bony sciatica"—the value of thermography, electromyography, and water-soluble myelography. Clin Sports Med 1986;5:327–342.
12. De Silva M, Kyle V, Hazleman B, et al. Assessment of inflammation in the rheumatoid knee joint: Correlation between clinical, radioisotopic, and thermographic methods. Ann Rheum Dis 1986;45:277–280.
13. Bird HA, Ring EFJ. Diagnosis of infected prepatellar bursa by thermography. Acta Thermographica 1976;1(2):80–82.
14. Alling CC. Differential Diagnosis of Oral Lesions, ed 3. St Louis: C.V. Mosby, 1985:8–9.
15. Gratt BM, Pullinger A, Sickles EA, Lee JJ. Electronic thermography of normal facial structures: A pilot study. Oral Surg Oral Med Oral Pathol 1989;68:346–351.
16. Weinstein SA, Gelb M, Weinstein, Weinstein EL. Thermophysiologic anthropometry of the face in homo sapiens. J Craniomand Pract 1990;8:252–257.
17. Pogrel MA, Erbez G, Taylor RC, Dodson TB. Liquid crystal thermography as a diagnostic aid and objective monitor for TMJ dysfunction and myogenic facial pain. J Craniomandib Disord Facial Oral Pain 1989;3:65–70.

18. Steed PA. The utilization of liquid crystal thermography in the evaluation of temporomandibular dysfunction. J Craniomand Pract 1991;9:120–128.
19. Mohl ND, Ohrbach RK, Crow HC, Gross AJ. Devices for the diagnosis and treatment of temporomandibular disorders. Part III. Thermography, ultrasound, electrical stimulation, and electromyographic biofeedback. J Prosthet Dent 1990;63:472–477.

Resumen

Caracterización termográfica de la articulación temporomandibular asintomática.

Este estudio utilizó termografía electrónica, una modalidad alternativa de diagnóstico a base de imágenes, para determinar la caracterización de imágenes térmicas de las articulaciones temporomandibulares (ATM) normales, en 30 individuos asintomáticos. Los parámetros evaluados fueron los siguientes: reconocimiento y simetría del patrón térmico, medidas de temperatura absoluta y diferencias en las medidas de temperatura absoluta, lo mismo que las medias de las medidas de temperatura y las diferencias en cinco zonas anatómicas. Los resultados indican la presencia de un patrón térmico común de la ATM en dos tercios de los pacientes, con variaciones de este patrón en el resto de los pacientes. Todos los patrones térmicos de la ATM demostraron tener una simetria térmica marcada, con $\Delta T < 0.2°C$ en la región de la ATM y las regiones relacionadas a la cara. Esta simetría consistente encontrada en los sujetos normales indica que una asimetría térmica considerable podría ser un indicador confiable de una ATM afectada.

Zusammenfassung

Thermographische Kennzeichnung des asymptomatischen temporomandibularischen Gelenkes

Diese wissenschaftliche Untersuchung gebrauchte elektronische Thermographie, welche eine alternative, diagnostische, bildliche Modalität ist, um die thermale, bildliche Kennzeichnung des normalen TMJ in 30 asymptomatischen Subjekten zu bewerten. Die gemachten Einschätzungen haben einbezogen: Erkenntnis von thermalen Mustern und Symmetrie, Messungen der absoluten Temperatur and Unterschiede in Messungen der absoluten Temperatur, und Messungen der durchschnittlichen Temperatur and Unterschiede in fünf anatomischen Zonen. Die Resultate haben die Gegenwart eines gemeinsamen, thermalischen Musters in zwei drittel der Patienten angezeigt; die übrigen Patienten zeigten Variationen von diesem Muster. Alle TMJ thermalen Muster haben deutliche thermalische Symmetrie nachgewiesen, mit $\Delta T < 0.2°C$ im Gebiet des TMJ und den damit verbundenen Gegenden des Gesichts. Diese folgerichtige Symmetrie demonstriert in normalen Subjekten schlägt vor, dass eine beträchtliche Asymmetrie möglicherweise eine verlässliche Anzeige einer TMJ Krankheit sein kann.