Research Articles Using the BioPAK System

(as of Feb. 2003)

Joint Vibration Analysis:

1. Sano T, Widmalm SE, Westesson PL, Yamaga T, Yamamoto M, Takahashi K, Michi KI, Okano T. Acoustic characteristics of sounds from temporomandibular joints with and without effusion: an MRI study. J Oral Rehabil 2002 Feb;29(2):161-6

   Joint effusion has been associated with temporomandibular joint (TMJ) pain but can only be diagnosed by magnetic resonance imaging (MRI). For screening of patients with suspected effusion a simple and less expensive method would be desirable. We recorded joint sounds during jaw opening and closing movement from 34 TMJs with internal derangement (ID). Seventeen joints had joint effusion seen on MRI. Spectrograms of the sounds were displayed as waterfall plots showing profiles of the consecutive Hamming windows. If the profiles were similar, as judged by initial evaluation, the displayed pattern was classified as stable. If some profiles were distinctly deviating in their pattern, this was classified as unstable. Joints with effusion showed unstable sound pattern more often than joints without effusion ($P < 0.001$). It was concluded that TMJ sound analyses have a potential to identify joints with effusion based on their unstable sound pattern.

2. Widmalm SE, Williams WJ, Ang BK and McKay DC. Localization of TMJ sounds to side. J Oral Rehabil. 2002 29()1-7.

   Differential diagnosis depends in cases with disk displacement on accurate identification of sound source. Mistakes may occur when clicking from one temporomandibular joint (TMJ) is heard on both sides of the head at auscultation and neither examiner nor patient is sure about the side. The hypothesis was that the head tissues affect spectral characteristics of TMJ sounds and that differences due to different positioning of sensors can be used in the localization of source. The aim was to compare bilateral electronic recordings of unilateral TMJ sounds to obtain and compare attenuation, phase shift and time delay. Recordings were made from 12 subjects with unilateral clicking. Small electret condenser microphones, bandwidth 40 – 20,000 Hz were placed at the openings of the auditory canals and the sounds were recorded at a sampling rate of 48,000 Hz. The head tissues acted as a filter causing a frequency dependent attenuation and phase shift. There was a time difference between the ipsi- and the contra lateral recordings, the latter always having a longer delay time (range 0.2 – 1.2 ms, group mean 0.68, sd 0.292 ms). In conclusion, spectral analysis of bilateral electronic TMJ sound recordings is of diagnostic value when bilateral clicking is heard at auscultation and can help to avoid diagnosing a silent joint as clicking.

3. Radke J, Garcia R Jr, Ketcham R. Wavelet transforms of TM joint vibrations: a feature extraction tool for detecting reducing displaced disks. Cranio 2001 Apr;19(2):84-90.

   The objective of this study was to determine if wavelet transforms (WTs) of vibrations recorded from temporomandibular joints (TMJs) with reducing displaced disks could be visually separated from WTs of vibrations recorded from normal TM joints by blinded observers. From a continuous series of 124 diagnosed TMD patients, 28 were confirmed with at least one reducing displaced disk. Vibrations were recorded from each affected joint, together with incisal point movements, using BioPAK (BioResearch, Inc., Milwaukee, WI) during

opening, closing, and lateral excursions. Identical recordings were taken from 28 patients who were determined to have normal "nondisplacing, nondisplaced" joints. A 3x7 Biorthogonal Spline Wavelet Transform was used to create three-dimensional time-frequency graphs of the vibration events for each subject. Printed copies of the graphs were then shown sequentially to seven blinded observers who were asked to separate them into two groups without any knowledge of their significance. Each observer was independently able to separate the two groups without committing more than one error. We conclude that the vibrations generated by reducing displaced disks are sufficiently different from the vibrations of normal joints to be separable by visual inspection of their respective wavelet transforms.

4. Garcia AR, Madeira MC, Paiva G, Olivieri KA. Joint vibration analysis in patients with articular inflammation. Cranio 2000 Oct;18(4):272-9.

   The study of articular sounds using a computerized system (SonoPAK) in patients with temporomandibular disorders (TMD) of inflammatory origin revealed an increase of vibratory energy when compared to asymptomatic individuals. The following conclusions were reached: 1. The amount of vibratory energy registered in these patients ranged from 8.50 to 57.61 Hz. The major vibrations occurred in the middle of the mandibular opening cycle; 2. The mean vibratory energy measured at less than 300 Hz was between 5.70 and 48.64 Hz and at higher than 300 Hz was between 3.70 and 8.99 Hz; 3. The peak amplitude in the patients with inflammation ranged from 0.35 to 3.96 Pascal and the peak of frequency from 83.20 to 120.20 Hz.

5. Olivieri KA, Garcia AR, Paiva G, Stevens C. Joint vibrations analysis in asymptomatic volunteers and symptomatic patients. Cranio 1999 Jul;17(3):176-83.

   The joint sound is a common sign in TMD. The diagnosis is important to establish the treatment of pathological alterations which occur in the TMJ. In this study, two groups were selected: 1. Asymptomatic volunteers; and 2. Symptomatic patients who were diagnosed in a clinical examination. After the initial examination, they were submitted to evaluation using electrovibratography (SonoPAK II, BioResearch Assoc., Inc., Milwaukee, Wisconsin). The analysis of results indicated that the averages of the vibratory energy in the symptomatic group presented higher values in all stages of the mandibular movement when compared to the averages of vibratory energy registered in the asymptomatic group.

6. Widmalm SE, Christiansen RL, Gunn SM. Crepitation and clicking as signs of TMD in preschool children. Cranio. 1999 Jan;17(1):58-63.

   Children [N = 540, age 5.1 +/- 0.72 (SD)], were tested for association between temporomandibular (TM) joint sounds and symptoms of TM disorder (TMD). The prevalence of TMJ sounds as found by auscultation and confirmed by self-report was 16.7%. There was significant association after Bonferroni correction between the presence of TM joint sounds, as reported by the children, and all but one of the eleven pain/dysfunction variables. There was significant association also between crepitation as heard at auscultation and palpation tenderness in the TMJ and masseter areas ($p < 0.001$), but not between clicking and any of the TMD variables. Agreement between subjects and examiners regarding the presence of TMJ sounds was poor (kappa = 0.097). The results indicate that joint sounds and TMD symptoms are common already in small children and thus demonstrate a possible early onset of TMD.

Patients' own reports of TMJ sounds may have more clinical relevance than auscultation findings.

7. Widmalm SE, Williams WJ, Yang KP. False localization of TMJ sounds to side is an important source of error in TMD diagnosis. J Oral Rehabil. 1999 Mar;26(3):213-4.

   The results of the study indicate that the head tissues act as a band pass filter that is far from flat. Instead there seems to be strong frequency variations in attenuation of transmitted sounds. The sounds are subject to phase shift and time delay, which can be used to decide from which TMJ the sound comes. Bilateral electronic recording with high sampling rate (>> 44 kHz) is needed to accurately and consistently identify the origin of a TMJ sound. Further studies on autopsy specimens and large subject groups are motivated.

8. Sano T, Widmalm SE, Westesson PL, Takahashi K, Yoshida H, Michi K, Okano T. Amplitude and frequency spectrum of temporomandibular joint sounds from subjects with and without other signs/symptoms of temporomandibular disorders. J Oral Rehabil. 1999 Feb;26(2):145-50.

   Temporomandibular joint (TMJ) sound is one of the most commonly recognized signs in patients with temporomandibular disorders (TMD) but is also frequently seen in asymptomatic individuals. Sound recording is therefore only meaningful if the sounds from a normal healthy joint can be differentiated from those in patients. In this study, the amplitude and power spectrum of the TMJ sounds from symptomatic patients and asymptomatic individuals were recorded and compared. The result showed that TMJ sounds from symptomatic patients had a larger amplitude than sounds from asymptomatic subjects. A significant proportion of sounds had frequencies between 2000 and 3000 Hz. It was concluded that the characteristic amplitude is worthy of further study as a sign of possible diagnostic value. Secondly, the bandwidth of the sensors used at electronic TMJ sound recording should not be less than 3000 Hz.

9. Donegan SJ, Christensen LV, McKay DC. Canine tooth guidance and temporomandibular joint sounds in non-patients and patients. J Oral Rehabil 1996 Dec;23(12):799-804.

   In 46 non-patients and 46 patients, the authors examined the presence (+) and absence (-) of canine tooth guidance (CG), i.e. dynamic dental articulation events in contrast to static dental occlusion events. During a right and a left laterotrusion of the mandible, the number of simple, mutually exclusive and exhaustive tooth guidance events (possibilities) was four. In addition, the authors examined the associations between temporomandibular joint (TMJ) sounds and canine guidance events. In non-patients, CG+ was relatively infrequent (30%), and CG- was relatively frequent (70%). In patients, CG+ was relatively infrequent (22%), and CG- was relatively frequent (78%). In both non-patients and patients, bilateral CG+ was rather infrequent (15%). In both non-patients and patients with the presence of TMJ sounds, CG+ was relatively infrequent (38%) while CG- was relatively frequent (61%). In non-patients as well as patients, no evidence was found that distal CG+ (putative lateral retrusive guidance) was associated with ipsilateral TMJ sounds (relative risk = 0%), nor that the association between mesial CG+ (putative lateral protrusive guidance) and ipsilateral TMJ sounds was beyond that of mere chance (relative risk = 50%).

10. Christensen LV, Donegan SJ, McKay DC. Mediotrusive tooth guidance and temporomandibular joint sounds in non-patients and patients. J Oral Rehabil 1996 Oct;23(10):686-98.

    In 46 non-patients and 46 patients, the authors examined the presence (+) and the absence (-) of laterotrusive (LG) and mediotrusive (MG) tooth guidance, i.e. dynamic dental articulation events in contrast to static dental occlusion events. During a right and left laterotrusion/mediotrusion of the mandible, the number of compound, mutually exclusive and exhaustive tooth guidance events (possibilities) was six. In addition, the presence and the absence of temporomandibular joint (TMJ) sounds, provoked TMJ pains, and the associations between TMJ sounds and tooth guidance events were examined. In non-patients, LG+ and MG+ was relatively infrequent (30%) while LG+ and MG- was relatively frequent (70%). In patients, LG+ and MG+ was relatively frequent (58%) while LG+ and MG- was relatively infrequent (42%). LG- and MG+ was absent in non-patients and rare in patients (3%). Either unilateral or bilateral MG+ was relatively infrequent in non-patients (30%) and relatively frequent in patients (59%). Bilateral MG+ was relatively infrequent in non-patients (20%) and relatively frequent in patients (52%). Either unilateral or bilateral TMJ sounds were relatively infrequent in non-patients (39%) and relatively frequent in patients (74%). Either unilateral or bilateral provoked TMJ pains were absent in non-patients and relatively frequent in patients (72%). The authors found no evidence that TMJ sounds were associated with the ipsilateral absence of so-called balancing contacts (MG-) in non-patients and patients. Finally, no evidence supporting the use of a so-called positive predictive value, and "extension concept' of probability theory was found.

11. Widmalm SE, Williams WJ, Adams BS. The wave forms of temporomandibular joint sound clicking and crepitation. J Oral Rehabil. 1996 Jan;23(1):44-9.

    The aim of the present study was to determine the sound wave forms which correspond to auscultatory findings of temporomandibular joint (TMJ) clicking and crepitation. Such knowledge is important when selecting parts of digital recordings for spectral analysis. Electronic digital recordings were made with a sampling rate of 44,100 Hz from 60 subjects, including 51 patients referred for suspected rheumatological disease and nine healthy subjects. Accelerometers with the bandwidth 20-3600 Hz were used for all subjects and complementary recordings were made from a subgroup of nine subjects using a measurement microphone with the bandwidth 20-20,000 Hz. The clicking sounds could be classified into different types according to differences in temporal period duration (T) as measured on the analogue display. One type of clicking, found in 51% of the patients, had a T of 2-20 ms. Another type, found in 70% of the subjects, had a T of less than 1 ms, often as low 0.2 ms. This type of clicking was not seen at all in the analogue display if the sampling rate was below 3,000 Hz. The character of the two types of clicking differed: the short duration sounds had a very high pitch, while the pitch of the longer duration sound was lower. Crepitation was found in 63% of the subjects and was observed to be composed of a series of short duration sounds, occurring with brief (less than 10 ms) intervals. It is concluded that the accelerometer (or microphone) bandwidth should cover the entire audible range (20-20,000 Hz), and that sampling rates must be much higher than 3000 Hz, and preferably greater than 10,000 Hz, before the true significance of electronically recorded joint sounds/vibrations can be determined.

12. Widmalm SE, Williams WJ, Christiansen RL, Gunn SM, Park DK. Classification of temporomandibular joint sounds based upon their reduced interference distribution. J Oral Rehabil. 1996 Jan;23(1):35-43.

Temporomandibular joint (TMJ) sounds were recorded in 98 orthodontic retention patients, mean age 19 +/- 8.6 (s.d.) years, by interview, auscultation and electronic recording. Sounds were found by auscultation in 41% and by interview in 32% of the subjects, more often in females than in males ($P < 0.05$). A new method for time-frequency analysis, the reduced interference distribution (RID), was used to classify the electronic sound recordings into five subclasses, RID types 1-5, based upon location and number of their energy peaks. RID types 1-3 had a few energy peaks close in time. RID types 4-5, typical of subjects with crepitation, had multiple energy peaks occurring close in time for a period of 20-300 ms. RID type 1, found in 45% of the subjects, typical of patients with clicking, had its dominant energy peak located in a frequency range < 600 Hz and was significantly more common in the female than in the male subjects ($P < 0.01$). RID type 2, found in 68% of the subjects, with the dominant peak in the range 600-1200 Hz, and RID type 3, found in 38% of the subjects, with the peak in the frequency range > 1200 Hz, were found to have a similar gender distribution. RID type 4, found in 49% of the subjects, had the energy peaks distributed in the frequency range < 600 Hz. RID type 5, found in 43% of the subjects, more often in females than in males ($P < 0.05$), had the peaks distributed over the whole frequency range from about 30 Hz up to about 3000 Hz. In conclusion, a more detailed classification could be made of the TMJ sounds by displaying the RIDs than by auscultation. This suggests that RID classification methods may provide a means for differentiating sounds indicating different types of pathology.

13. Widmalm SE. Temporomandibular joint sounds. J Dent Res. 1995 Sep;74(9):1532-4.

14. Ishigaki S, Bessette RW, Maruyama T. Diagnostic accuracy of TMJ vibration analysis for internal derangement and/or degenerative joint disease. Cranio. 1994 Oct;12(4):241-5; discussion 246.

Lower joint arthrography and videofluoroscopy were used to diagnose 297 joints from temporomandibular disorders (TMD) patients. The surface vibrations of the temporomandibular joints (TMJs) were recorded by electrovibratography and a parameter set was derived through frequency analysis. Total vibration energies were used as the primary separating threshold for abnormal joints. The following conditions were statistically discriminated by multi-variate analyses: I) meniscal displacement with reduction; II) meniscal displacement with a partial disk reduction; III) meniscal displacement without reduction; and IV) degenerative joint disease and/or perforation of the disk. Using the total vibration energy as a threshold, the diagnostic sensitivity for the abnormal joints was 82%, while the diagnostic specificity for the joints with no evidence of internal derangement was 75%. Discriminant analysis for the above-mentioned four conditions revealed a diagnostic sensitivity of 79.0%, 85.7%, 77.1% and 76.3% for conditions I, II, III and IV, respectively. The diagnostic specificity was 76.2%, 79.9%, 59.0% and 77.9% for conditions I, II, III and IV, respectively. It was concluded that vibration analysis of the TMJ could be clinically useful as a screening examination for TMD patients.

15. Ishigaki S, Bessette RW, Maruyama T. Vibration analysis of the temporomandibular joints with degenerative joint disease. Cranio. 1993 Oct;11(4):276-83.

The surface vibrations of 42 temporomandibular joints (TMJ) with degenerative joint disease (DJD) and/or perforation of the disk were evaluated using electrovibratography and compared to the surface vibrations of 83 joints with normal TMJ imagings and 61 joints with meniscal displacement without reduction. Through the frequency spectrum analysis, TMJs with DJD showed higher vibration energy above 350-450 Hz and TMJs with perforation showed higher vibration energy between 100-150 and 300-450 Hz. The presence of perforation did not seem to affect the characteristic of vibrations when TMJs were associated with DJD. A threshold was set for the total vibration energy as described in our previous report and used as a parameter in order to separate patients with internal derangement from a pool of TMJ dysfunction patients (diagnostic specificity = 75%, diagnostic sensitivity = 80.2%). Using this criteria, the following were correctly identified as internal derangement and/or DJD: a) 100% of the TMJs with meniscal displacement without reduction associated with DJD; b) 87.0% of the TMJs with meniscal displacement without reduction associated with perforation; c) 88.9% of the TMJs with meniscal displacement without reduction associated with DJD and perforation; and d) 100% of the TMJs with perforation.

16. Ishigaki S, Bessette RW, Maruyama T. Vibration analysis of the temporomandibular joints with meniscal displacement with and without reduction. Cranio. 1993 Jul;11(3):192-201.

    The vibrations of 102 joints demonstrating meniscal displacement with either early or late reduction (MDR-early/MDR-late) and 70 joints displaying meniscal displacement without reduction either incomplete or complete (MD-incomplete/MD-complete) were analyzed and compared to 83 arthrographically normal but symptomatic joints (NID) using electrovibratography (EVG). The total power density of the vibration [I(T)], peak power density [I(max)] and power density at each 50Hz range between O to 600 Hz [I(f)] showed the highest in the MDR-late group followed by the MDR-early group, suggesting that the level of vibration is related to the degree of disk displacement and reduction. The wave characteristic parameters such as the correlation coefficients between I(T) and each I(f) showed higher correlation at higher frequency ranges as the degree of disk displacement progressed, from MDR-early to MDR-late to MD-incomplete. The diagnostic sensitivity of EVG when using I(T) as a determining parameter was 96.6% for the MDR-early group, 91.8% for the MDR-late group, 77.8% for the MD-incomplete group and 57.4% for the MD-complete group with the specificity for the NID group at 75%.

17. Paiva G, Paiva PF, de Oliveira ON. Vibrations in the temporomandibular joints in patients examined and treated in a private clinic. Cranio 1993 Jul;11(3):202-5.

    Patients indicated for examination, evaluation and treatment of the temporomandibular joint (TMJ) in the Centro de Diagnostico e Tratamento da ATM (CDTATM) were submitted to computerized BioPAK system tests. Special attention was placed on the SonoPAK test (electrovibratography), seeking to evaluate the articular sound problem in differentiated patients for specific TMJ treatment. The percentage of sounds (148 joints, 74 patients) was high (75.67% in the opening movement and 50.00% in the closing movement) which suggests the necessity to give more attention to the TMJ sounds during a clinical exam. And also, if possible, give more attention to the utilization of specific tests to obtain a clear definition of the type of sound the patient presents.

18. Ishigaki S, Bessette RW, Maruyama T. Vibration of the temporomandibular joints with normal radiographic imagings: comparison between asymptomatic volunteers and symptomatic patients. Cranio. 1993 Apr;11(2):88-94.

In order to estimate the effect of a background noise during temporomandibular joint (TMJ) vibration analysis, 40 recordings from sensors not attached to subjects and sensors attached to subjects without any jaw movement were evaluated. Both of them showed very small energy density, close to 0, throughout 0 to 600 Hz and flat frequency distributions. To evaluate the vibration energy of asymptomatic TMJs with normal joint anatomy and symptomatic TMJs with normal arthrographic imagings, 20 TMJs from 10 clinically normal and asymptomatic volunteers with bilateral normal TMJ computerized tomography (CT) scanning (N-control) were analyzed at four mandibular positions. Results from intercuspal position and maximal opening were identical to the background noise. Results from closing and opening phase showed higher energy, especially below 150 Hz, than the background noise. Surface vibrations of 83 TMJs from patients with arthrographically normal imagings but having symptoms (NID) showed significantly higher energy than the N-control group above 300 Hz. When the total vibration energy (I(T)) is used to set the threshold for the separation of internal derangement, at I(T) = 2.06, the diagnostic specificity for the NID group is 75%, while the diagnostic sensitivity is 82.4% for internal derangement. At the same time, 98.3% of the N-control group was involved below the threshold.

19. Ishigaki S, Bessette RW, Maruyama T. A clinical study of temporomandibular joint (TMJ) vibrations in TMJ dysfunction patients. Cranio. 1993 Jan;11(1):7-13; discussion 14.

Using electrovibratography (EVG), the vibrations of 309 temporomandibular joints (TMJs) from 213 patients with clinical symptoms of temporomandibular joint dysfunction (TMD) were compared to TMJ arthrography. Of 309 imaged joints, 221 had an internal derangement (ID) and 88 were arthrographically normal (NID). Among the parameters derived from the power spectrum function of joint vibration, the total power density from 0 to 600 Hz (I(T)), the peak power density I(max)), and the power density at each 50 Hz frequency range (I(f)), each of these was significantly greater in ID than in NID patients. The frequency range that included (I(max) and the frequency range containing 50%, 75%, and 90% of I(T) was significantly lower in ID than in NID patients. The diagnostic sensitivity and specificity of a patient's perception of TMJ sounds were 43% and 80%, respectively, while those for a doctor's perception were 54% and 72%. When using I(T) as a parameter, the sensitivity and specificity of the EVG were 75% and 77%, respectively. By using these parameters of TMJ vibration energy analysis, a separation may be made between patients with normal joint anatomy and internal derangement.

20. Christensen LV. Physics and the sounds produced by the temporomandibular joints. Part II. J Oral Rehabil 1992 Nov;19(6):615-27.

In clinical dentistry, the solidborne vibrations (tissue pressure waves) produced by the temporomandibular joints (TMJ) may signify dysfunction or disease of the mandibular locomotor system. This article discusses aspects of the applied mathematics and electronic recording of solidborne vibrations of the TMJ (electrovibratography).

21. Ishigaki S, Bessette RW, Maruyama T The distribution of internal derangement in patients with temporomandibular joint dysfunction--prevalence, diagnosis, and treatments. Cranio. 1992 Oct;10(4):289-96.

This study consisted of 355 patients referred to a surgical practice complaining of facial pain, temporomandibular joint (TMJ) sounds, and limited jaw opening. In 247 patients, 360 TMJs were evaluated by arthrography. While 72.2% of them had internal derangement, the remaining 27.8% had normal arthrograms (NID). Among the patients with internal derangement, meniscal displacement with reduction (MDR) was the largest group (47.3%), followed by meniscal displacement without reduction (MD) (32.3%), meniscal displacement without reduction associated with perforation (MDP) (15.4%), and perforation with normal disk position (P) (5.0%). The NID, MDR, and MD groups showed similar age distributions. The MDP and P groups showed a significantly older mean age. Gender distribution was biased toward females (82.0%). Of the total number of joints, 183 (50.8%) had a history of trauma, 69.9% of which had an internal derangement. In terms of treatment, 100% of the NID group was treated by splint therapy. The MDR group was mostly treated by partial meniscectomy (49.6%) and splint therapy (41.5%). The MD group was mostly treated by total meniscectomy (53.6%) followed by splint therapy (32.1%). The MDP or P groups mostly underwent total meniscectomy (72.5% and 61.5%, respectively).

22. Christensen LV. Physics and the sounds produced by the temporomandibular joints. Part I. J Oral Rehabil 1992 Sep;19(5):471-83.

    In clinical dentistry, the sounds (clicking) and noises (grating) produced by the temporomandibular joints (TMJ) usually signify dysfunction or disease of the mandibular locomotor system. In an attempt to provide guidance to the general practitioner, this article discusses some pertinent parameters defining the physics of airborne and solid-borne vibrations.

23. Christensen LV, Orloff J. Reproducibility of temporomandibular joint vibrations (electrovibratography). J Oral Rehabil 1992 May;19(3):253-63.

    Surface electrovibratographic (EVG) recordings were obtained from the temporomandibular joints (TMJ) of clinically normal subjects (absence of TMJ sounds) and clinically abnormal subjects (presence of TMJ sounds). As examined through single factor analyses of variance and coefficients of intraclass correlation, the EVG recordings showed excellent reproducibility. The analyses showed also that, in comparison with clinically normal TMJs, the vibrations of clinically abnormal TMJs had higher median (+79%) and peak (+137%) frequencies, higher peak amplitudes (+740%), and higher intensities as expressed through the estimated total energy contents (+1843%) and the integrals (+1215%) of power spectrum density functions.

24. Widmalm SE, Westesson PL, Brooks SL, Hatala MP, Paesani D. Temporomandibular joint sounds: correlation to joint structure in fresh autopsy specimens. Am J Orthod Dentofacial Orthop. 1992 Jan;101(1):60-9.

    In an attempt to better understand the cause of different types of temporomandibular joint (TMJ) sounds, we recorded joint sounds from 27 fresh autopsy specimens, displayed the time frequency distribution of the sound as a three-dimensional graph, and correlated the sound character to morphologic observations at subsequent dissection. Eleven joints elicited sounds, and 16 joints were silent. All joints with sounds had different degrees of intraarticular changes. These ranged from disk displacement with reduction to displacement without reduction and arthrosis of the articular surfaces. Reciprocal clicking occurred both in joints with disk

displacement with and without reduction, as well as in joints with arthrotic changes. Crepitation only occurred in joints with arthrosis and perforation. The sample was too small to demonstrate any statistically significant association between the joint sound classified as clicking or crepitation and joint structure types of joint pathosis in this small sample. A high frequency component to the sound appeared to be associated with arthrosis of the articular surfaces. It was concluded that joint sounds indicate joint abnormality but that the absence of joint sound does not exclude intraarticular pathosis.

25. Christensen LV, Donegan SJ, McKay DC. Temporomandibular joint vibration analysis in a sample of non-patients. Cranio 1992 Jan;10(1):35-41; discussion 41-2.

    In a sample of 20 non-patients, 60% of the subjects had an absence of subjective temporomandibular joint (TMJ) complaints (noises/sounds) that agreed with objective joint vibration analyses (electrovibratography). Among the remaining 40% of subjects, only 50% of the examined joints showed agreement between subjective and objective findings. Subjects appeared to be unable to reliably detect "weak" (early) symptoms of TMJ dysfunction but were able to reliably detect "strong" (late) symptoms of TMJ dysfunction and possibly disease. As measured through active protrusion and laterotrusion of the mandible, the guidance angles of the anterior teeth could not explain the absence and presence of TMJ vibrations.

26. Widmalm SE, Williams WJ, Zheng C. Time frequency distributions of TMJ sounds. J Oral Rehabil. 1991 Sep;18(5):403-12.

    For analysis of time-varying signals such as the TMJ sounds, it is often desirable to know how the frequency components change with time, using methods of time-frequency analysis. The aim of this study was to compare two of the most familiar methods for energy density representation with a newly developed technique. The sounds were recorded with a microphone fastened to the subject's forehead, transformed to the time-frequency domain and displayed as 3D- and contour plots using spectrogram, Wigner distribution (WD), and the reduced interference distribution (RID) to display their time-frequency energy distributions. The spectrogram resolved only the low-frequency components. The WD provided higher resolution but also exhibited strong interference between components. The RID gave a detailed representation of the TMJ signals' relative energy distribution in the time and frequency domains, with a great reduction in the interference or cross terms. The RID therefore appears to be most useful in the application of time-frequency distributions in classification of TMJ sounds.

27. Christensen LV, Orloff J: Reproducibility of temporomandibular joint vibrations (electrovibrotography). J Oral Rehab; 1992:253 – 263.

    Surface electrovibratographic (EVG) recordings were obtained from the temporomandibular joints (TMJ) of clinically normal subjects (absence of TMJ sounds) and clinically abnormal subjects (presence of TMJ sounds). As examined through single factor analyses of variance and coefficients of intraclass correlation, the EVG recordings showed excellent reproducibility. The analyses showed also that, in comparison with clinically normal TMJs, the vibrations of clinically abnormal TMJs had higher median (+79%) and peak (+137%) frequencies, higher peak amplitudes (+740%), and higher intensities as expressed through the estimated total energy contents (+1843%) and the integrals (+1215%) of power spectrum density functions.

28. Christensen LV, Donegan SG, McKay DC: Temporomandibular Joint vibration analysis in a sample of non-patients. J Craniomandib Pract 1992;10:35 – 41.

    In a sample of 20 non-patients, 60% of the subjects had an absence of subjective temporomandibular joint (TMJ) complaints (noises/sounds) that agreed with objective joint vibration analyses (electrovibratography). Among the remaining 40% of subjects, only 50% of the examined joints showed agreement between subjective and objective findings. Subjects appeared to be unable to reliably detect "weak" (early) symptoms of TMJ dysfunction but were able to reliably detect "strong" (late) symptoms of TMJ dysfunction and possibly disease. As measured through active protrusion and laterotrusion of the mandible, the guidance angles of the anterior teeth could not explain the absence and presence of TMJ vibrations.