# A Preliminary Investigation of a Method of Detecting Temporomandibular Joint Sounds

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*This study established a method of detecting temporomandibular joint sounds based on signal-to-noise ratios. After comparing the temporomandibular joint signals obtained from three different sites over the skin, the articular eminence was found to be the best site for detecting temporomandibular joint sounds; this site provided the highest mean amplitude in the time domain waveform. However, using an electret condenser microphone at the intra-auditory meatus provided a broader, 20-decibel signal-to-noise bandwidth, which resulted in minimized artifacts. This method may be useful for recording temporomandibular joint sounds in the differential diagnosis of various temporomandibular joint conditions using spectral analysis.*
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Over the past several years, many techniques have been proposed to objectively diagnose various craniomandibular disorders by recording and analyzing the acoustic characteristics of sounds emitted by the temporomandibular joint (TMJ). These methods are noninvasive, inexpensive, and do not require technical skill or exposure to radiation. The techniques can be classified into two approaches: evaluation by intensity, duration, and relationship to mandibular movement,[1-10] and evaluation by spectral analysis, which shows the distribution of sound energy as a function of frequency.[11-19] Spectral analysis is based on the hypothesis that different mass and/or stiffness properties corresponding to different intracapsular disorders in the TMJ will produce sounds that are spectrally unique for various joint conditions. Many investigators have reported that various pathologic conditions in the TMJ can be differentially diagnosed by characteristic patterns in the energy level variations at specific frequencies.[12-17] However, Widmer[20] indicated that, in comparing all the studies using spectral analysis, the high degree of variability and the overlap of peak frequencies from different TMJ conditions obstructs differentiation of the various pathologic states from normal states and from one another. He also pointed out the very different results reported from one study to another, owing to five uncontrolled variables.[20] In addition to the uncontrolled variables, some procedural problems have been identified[8,12,21] that may complicate efforts to obtain a standardized peak frequency.

In previous recordings of TMJ sounds,[8,10,12,20] artifacts such as room noise, skin and hair noise, respiration, arterial blood flow, and cross-over noises from the contralateral joint were probably included, because separating the TMJ sounds from the surrounding noise and vibration is difficult. The present authors minimized these artifacts by reassessing both the properties of the detecting device and its physiologic location. This allowed the development of a recording method that provides a suitable signal-to-noise ratio over a broad bandwidth.

First, sites for detecting TMJ sounds on the skin were evaluated. Temporomandibular joint signals were then recorded using various detecting devices at the most suitable sites, and these were compared with simultaneous recordings obtained from the intra-auditory meatus.

## Detector Site Evaluation

### Materials and Methods

The TMJ sounds were measured from eight joints in five patients (three men and two women; age range 11 to 26 years) during opening and closing of the mandible. Three sites on the skin were selected for placement of detectors: the superoposterior area of the auricular fossa of the temporal bone (site U); the anterior area of the articular eminence (site ZA); and the most anterior area of the zygomatic arch (site Z) (Fig 1). These sites were considered to be the least affected by movement and vibration of skin and muscles during the opening and closing of the mandible. Accelerometers (TEAC 501, Tokyo, Japan) were used as detectors and attached to two of the three sites with adhesive tape. Each patient held the head naturally while seated in an upright position in a sound-proofed room with an ambient noise amplitude of less than 25 dB. The patient repeated natural opening and closing of the mouth five times at a rate of 40 cycles per minute as synchronized with the beat of a metronome. The TMJ sounds were simultaneously detected at two sites in each patient using accelerometers and were recorded as digital signals on a video tape recorder (VTR) (Sony EV-500, Tokyo) through a pulse cord modulation (PCM) processor (Sony 501-ES). Later, the recorded sounds were reproduced from the VTR through the PCM processor as an analog signal and passed through a low-pass filter with a cutoff frequency of 3.9 kHz and an attenuation characteristic of 42 dB/octave. The resulting filtered signal was finally sampled at 10 kHz, 12 bit for A-D conversion and then stored on magnetic floppy disk. For analysis of each sample, the peak amplitude of both the TMJ signal and ambient noise was scaled in the time domain waveform at every opening-closing cycle. If the peak amplitude of the TMJ signal was lower than that of ambient noise in a particular sample, that sample was excluded from further analysis.

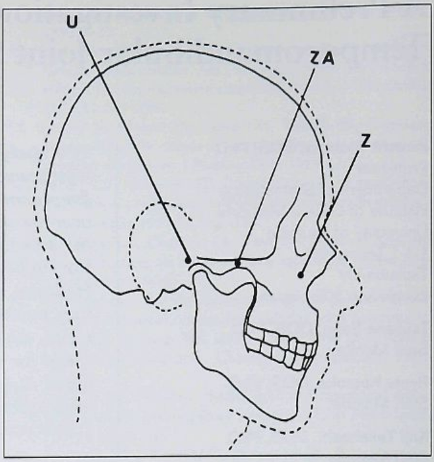


**Fig 1** Three sites on the skin selected for placement of detecting devices: site U, the superoposterior area of the auricular fossa of the temporal bone; site ZA, the anterior area of articular eminence; and site Z, the most anterior area of the zygomatic arch.

In the analysis, the amplitude in the time domain waveform was expressed by the numbers of points in A-D conversion at 12 bit with the maximum value of 2 (2048) points.[11] The mean of the peak amplitudes of TMJ signals in the five iterations was calculated for both opening and closing phases. Results from the two sites at which samples had been simultaneously recorded were then compared. Following comparison of the mean peak amplitude obtained from sites U and ZA, the higher of these was compared with the mean peak amplitude obtained from site Z.

### Results

Comparisons of the mean peak amplitudes obtained at sites U and ZA revealed higher amplitudes at site ZA than at site U during the opening phase at six of the eight joints. Also, six joints were found to have mean peak amplitudes in the closing phase that were higher than the ambient noise, and three of these were higher at site ZA than at site U (Table 1). These findings suggested that site ZA was superior to site U for recording TMJ sounds.

**Table 1** Comparison of Mean Peak Amplitudes at Sites U and ZA in the Time Domain Waveform*

| Joint no. | Opening phase | | Closing phase | |
|---|---|---|---|---|
| | Site U | Site ZA | Site U | Site ZA |
| 1 | 226.6 | 259.4 | 106.0 | 72.8 |
| 2 | 132.0 | 168.6 | 195.6 | 310.0 |
| 3 | 226.6 | 374.8 | 226.8 | 232.6 |
| 4 | 332.2 | 377.2 | – | – |
| 5 | 263.0 | 244.8 | – | – |
| 6 | 424.0 | 180.4 | 77.4 | 86.0 |
| 7 | 630.8 | 645.2 | 118.2 | 102.4 |
| 8 | 559.0 | 752.4 | 180.8 | 116.4 |

*Amplitude was expressed by the numbers of points.

**Table 2** Comparison of Mean Peak Amplitudes at Sites ZA and Z in the Time Domain Waveform*

| Joint no. | Opening phase | | Closing phase | |
|---|---|---|---|---|
| | Site Z | Site ZA | Site Z | Site ZA |
| 1 | 209.8 | 335.8 | 62.4 | 63.0 |
| 2 | 136.8 | 186.0 | 101.6 | 216.0 |
| 3 | 146.2 | 146.4 | 211.6 | 186.8 |
| 4 | 157.6 | 415.0 | — | — |
| 5 | 84.2 | 202.4 | — | — |
| 6 | 153.2 | 175.4 | 87.6 | 102.6 |
| 7 | 422.0 | 668.6 | 99.8 | 61.2 |
| 8 | 200.4 | 738.6 | 128.8 | 88.4 |

*Amplitude was expressed by the numbers of points.

In comparing site ZA with site Z, all eight joints showed higher mean peak amplitudes at site ZA during the opening and closing phases, and three of six joints showed higher amplitudes at site ZA (Table 2). According to these findings, site ZA showed the highest mean peak amplitude in the time domain waveform among the three detector sites, and it was considered to be the most suitable location for placement of the detector for TMJ sounds.

## Evaluation of Spectral Analysis of TMJ Sounds Obtained From Intra-Auditory Meatus and Skin

### Materials and Methods

Subjects consisted of two patients with TMJ sounds (subjects A and B) and two participants with palpated sounds but no previous history or present symptoms of TMJ disorders (subjects C and D). All subjects ranged in age between 22 and 27 years. The TMJ sounds to be studied were selected on the side with greater amplitude. The TMJ sounds were simultaneously sampled at site ZA and at the intra-auditory meatus (site AM), using two detectors during five iterations of mouth opening and closing, at a rate of 40 cycles per minute, in a sound-proofed room. An electret condenser microphone (Knowles EA 1842) was used as the acoustic sampling detector at site AM and was secured by an ear rod made of acrylic resin that was inserted into the auditory meatus. At site ZA, three different detectors were used: an accelerometer (TEAC 501), a condenser microphone (Tokyo Ricoh MR-112), and an electret condenser microphone (Knowles EA 1842). The accelerometer was attached with adhesive tape, the condenser microphone was held in place by hand, and the electret condenser microphone was mounted in a custom-made headphone. The TMJ signals simultaneously picked up at sites ZA and AM were high-pass filtered with a cut-off frequency of 22.4 Hz and an attenuation characteristic of 46 dB/octave (Rion SA-33D). They were then stored as digital signals in separate digital audio tape decks (Sony PTC-300ES). Artifacts, such as room noise, respiration, and other ambient noises with the subjects at rest, were also stored as a noise sample in a digital audio tape deck. The sounds recorded from each joint were reproduced as analog signals, low-pass filtered with a cut-off frequency of 3.9 kHz and an attenuation characteristic of 42 dB/octave, and then sampled at 10 kHz for A-D conversion and storage on magnetic disks.

The power spectrum, which plots relative amounts of energy (in dB) involved in sound production across a range of frequencies (in Hz), was calculated by means of fast Fourier transform spectrum analysis of TMJ signals and noise. The sound spectrum in five opening-closing cycles was averaged and smoothed with noise to reduce random noise present at different frequencies in each recorded sound. This also accentuated frequencies that share common characteristics of the specific motion producing the sound.[13,15] Smoothing is also a useful aid to visualization.[13,15] Using the spectral patterns of TMJ signals and noise below 3 kHz, the frequency ranges over which the signal-to-noise ratio was more than 20 dB (the 20-dB signal-to-noise

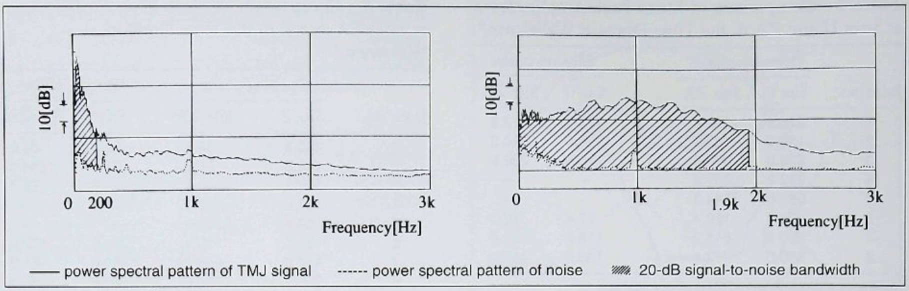


**Fig 2** The 20-dB signal-to-noise bandwidth in the spectral pattern of TMJ signals and noise at frequencies below 3 kHz during the mouth opening phase with subject A; waveforms indicate *(left)* bandwidth obtained with an accelerometer at site ZA, *(right)* bandwidth obtained with an electret condenser microphone at site AM.

**Table 3** The 20-dB Signal-to-Noise Bandwidths (in kHz) in the Spectral Patterns of TMJ Signals and Noise at Frequencies Below 3 kHz*

| | Opening phase | | Closing phase | |
|---|---|---|---|---|
| | site ZA | site AM | site ZA | site AM |
| Subject | AC | ECM | AC | ECM |
| A | 0–0.2 | 0–1.9 | 0–0.25, 1.1–1.2 | 0–1.7 |
| B | 0–0.2 | 0.65–1.6 | 0–0.2 | 0.6–1.5 |
| C | – | 0–1.1 | – | 0–0.8 |
| D | 0–0.05 | 0–1.8 | 0–0.05, 0.45–0.55 | 0–1.3 |
| | CM | ECM | CM | ECM |
| A | 0–0.25 | 0–2.4 | 0–0.2 | 0–1.9 |
| B | – | 0.7–1.5 | – | 0.45–1.2 |
| C | – | 0–1.0 | – | 0–2.1 |
| D | – | 0–1.4 | – | 0–1.0 |
| | ECM | ECM | ECM | ECM |
| A | 0–0.8 | 0–1.9 | 0–0.9 | 0–3.0 |
| B | 0–3.0 | 0–3.0 | 0–3.0 | 0–3.0 |
| C | – | 0–0.75 | – | 0–1.0 |
| D | – | 0–3.0 | – | 0–2.0 |

*ECM = electret condenser microphone; AC = accelerometer; M = condenser microphone.

bandwidths) were compared between detector sites ZA and AM (Fig 2).

## Results

**Comparison of Electret Condenser Microphone at Site AM With an Accelerometer at Site ZA.** The 20-dB bandwidth of an electret condenser microphone at site AM on the opening phase in the four subjects extended from 0 to 1.9 kHz, from 0.65 to 1.6 kHz, from 0 to 1.1 kHz, and from 0 to 1.8 kHz. On the closing phasing, it ranged from 0 to 1.7 kHz, from 0.6 to 1.5 kHz, from 0 to 0.8 kHz, and from 0 to 1.3 kHz. The corresponding 20-dB bandwidths obtained with an accelerometer at site ZA were from 0 to 0.2 kHz for two subjects, 0 to 0.05 kHz for another, and there was no detected 20-dB bandwidth for the remaining subject during the opening phase. During the closing phase, two subjects exhibited dual 20-dB bandwidths with the accelerometer: 0 to 0.25 kHz and 1.1 to 1.2 kHz for one and 0 to 0.05 kHz and 0.45 to 0.55 kHz for another. One of the remaining subjects showed a single bandwidth from 0 to 0.2 kHz, and the other had no detected 20-dB bandwidth on the closing phase (Table 3).

**Comparison of an Electret Condenser Microphone at Site AM With a Condenser Microphone at Site ZA.** While 20-dB bandwidths were observable in both opening and closing phases in every subject when using an electret condenser microphone at site AM, only one of the subjects could provide a 20-dB signal-to-noise ratio when a condenser microphone was used at site ZA, and that bandwidth was narrower than that obtained by the electret condenser microphone (Table 3).

**Comparing an Electret Condenser Microphone at Sites AM and ZA.** Every subject provided some 20-dB signal-to-noise bandwidths during both opening and closing phases when using an electret condenser microphone at site AM. At site ZA, the ranges were narrower than or equal to those found at site AM in two subjects and nonexistent in the remaining two subjects (Table 3). According to these results, an electret condenser microphone at site AM was considered to be the most suitable for detecting TMJ sounds.

## Discussion

Previous reports of TMJ sound recording methods used a wide variety of sites for detectors: the neck of the condyle,[6,14] a joint area,[8,10,13,16–18] the center of the forehead,[4] the midpoint of the outer rim of the articular fossa,[1] the mandibular canine,[15] and the temporal and zygomatic bones.[11] These reports also employed many different detecting devices: the bell of a stethoscope,[14] a miniature condenser microphone mounted on a headband,[13,18] a piezoelectric microphone,[4] a contact microphone,[10] a standard condenser microphone element mounted in a lead housing and coupled with a metallic bell,[6] a moving coil microphone,[17] a constant-velocity transducer microphone,[1] a small condenser microphone,[8] an accelerometer,[15] a digital stethoscope and specially designed external auditory canal listening device,[12] and a hearing aid–type crystal microphone.[11] In these reports, however, criteria for selecting the detectors and their locations were not described in detail, nor was there any comparative investigation of the different devices or detection sites. In the present study, three physiologic sites were selected for placement of the detector based on ease of placement, minimal unwanted effect from mandibular movement, and relatively small volume of soft tissue between the detector and underlying bone. An accelerometer was selected as a detecting device because of its flat frequency response characteristic. Of the three detector sites investigated in this study, site ZA was considered to be particularly suitable based on the finding of the highest mean amplitude in the time domain waveform.

Three types of detectors that provide wide frequency response characteristics were used to detect TMJ sounds at site ZA, and only an electret condenser microphone that was small and light enough to be inserted into the auditory meatus was used at that site.

To evaluate the acoustic characteristics of TMJ sounds, the characteristics of extraneous noise must be considered to determine the signal-to-noise ratio and isolate usable signals from the noise. No past study has reported measuring the frequency spectrum of the noise, which would be necessary to obtain a usable signal-to-noise ratio measurement. To separate the TMJ signals and noise, the authors considered a difference of more than 20 dB in the frequency characteristics of the TMJ signals and noise to be a suitable signal-to-noise ratio in this study. In addition, the spectra from the five repeated measurements were averaged because the acoustic system has little reproducibility.[2,5]

In the present study, the accelerometer exhibited a suitable signal-to-noise ratio only at frequencies below 1 kHz in most subjects. It has been reported that when an accelerometer is attached to the skin, a contact resonance resulting from its weight and the extensibility of the skin works as a low-pass filter to cut off high frequencies.[22] Accordingly, it is suggested that an accelerometer has difficulty obtaining a high signal-to-noise ratio at high frequencies. Similarly, the hand-held condenser microphone provided a suitable signal-to-noise ratio only at frequencies below 0.25 kHz, because the weight of this condenser microphone combined with its associated preamplifier was too heavy to be easily secured to the skin. The electret condenser microphone could be easily secured to the skin because of its small size and light weight. These properties of the electret condenser microphone allowed suitable signal-to-noise ratios to be obtained across a wide frequency range.

The difference in results obtained from similar electret condenser microphones at sites AM and ZA might be attributed to separation of the TMJ signal from surrounding noise vibration at site AM, which may be because of the tubal structure of the auditory meatus. Since the resonant frequency of the external auditory meatus was reported to be from approximately 3 to 3.5 kHz,[23] it was considered that this physical characteristic also had little effect on the frequencies below 3 kHz analyzed in this study.

## Conclusion

To establish a suitable method of detecting TMJ sounds, TMJ signals obtained by various detecting devices at several physiologic sites were compared. Results in the small sample of this study revealed that the most suitable method of detecting TMJ sounds was an electret condenser microphone located at the intra-auditory meatus, because this method provided the broadest 20-dB signal-to-noise bandwidth. It was suggested that this method is useful for differential diagnosis of various craniomandibular disorders using spectral analysis of TMJ sounds.

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## Resumen

Investigación preliminar sobre un método para detectar sonidos en la articulación temporomandibular.

Este estudio estableció un método para detectar sonidos en la articulación temporomandibular (ATM) basados en valores de la proporción señalsonido. Después de comparar las señales de la ATM obtenidas de tres sitios diferentes sobre la piel, se determinó que la eminencia articular es el mejor sitio para detectar sonidos en la ATM, ya que este lugar provee en promedio la mayor amplitud en el tiempo durante el que se ejerce la onda. Sin embargo al utilizar un micrófono condensador eléctrico polarizado en el meato intra-auditorio, éste produjo una banda (señal-sonido) más ancha de 20 decibeles lo cual redujo los artefactos. Este método puede ser útil para grabar los sonidos de la ATM en el diagnóstico diferencial de las diversas condiciones que pueden afectar a la ATM, por medio del uso del análisis espectral.



## Zusammenfassung

Eine Voruntersuchung für eine Methode zur Erfassung von Kiefergelenksgeräuschen.

Diese Studie entwickelte eine Methode zur Erfassung von Kiefergelenksgeräuschen basierend auf dem Signal/Rausch-Verhältnis. Aufgrund eines Vergleichs der Kiefergelenksgeräusche an drei verschiedenen Stellen auf der Haut ergab die eminentia articularis die höchste mittlere Amplitude. Ein Electret-Condenser Mikrophon im äusseren Gehörgang lieferte ein noch klareres Signal mit einem Signal/Rausch-Abstand von 20 dB und nur minimalen Artefakten. Diese Methode kann nützlich sein für die Aufzeichung von Kiefergelenksgeräuschen und deren Differentialdiagnose mit Spektralanalyse.