Temporomandibular joint sounds: Correlation to joint structure in fresh autopsy specimens

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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. (Am J Orthod Dentofac Orthop 1992;101:60-9.)

Sounds from the temporomandibular joint (TMJ) 1-11 have been reported in both epidemiologic and clinical studies of TMJ disorders. 12-26 The cause of the sound has been in many respects, an enigma. Studies have suggested that reciprocal clicking 27 indicates with disk displacement with reduction, 28-32 but other studies have shown that reciprocal clicking may also occur in joints with disk displacement without reduction. 7 The picture is made even more complex by the observation that there are joints with disk displacement with reduction that do not demonstrate reciprocal clicking. 33,34 This means even for a sound, such as reciprocal clicking that for awhile was thought to be well-defined, there is still incomplete understanding of the morphologic background. Crepitation has been associated with degenerative joint disease, 8 but for this type of joint sound also, there is not a clear understanding of the precise relationship between sound and joint structure.

It may not be possible at this time to understand the significance of the different characteristics of the joint sounds without access to direct observation of the structure of the articular surfaces and of the function of the disk. Those are factors that probably play a significant role in the origin of joint sounds. Studying the joint directly can be done in patients who are surgically or arthroscopically treated, however, with the obvious disadvantage of including only abnormal joints. Correlation to imaging findings from radiographs or magnetic resonance images may also be possible, but the information from imaging studies about the status of the articular surfaces is probably at this time not sufficient to make a meaningful correlation to the joint sound. Several previous studies have shown that it is possible to produce joint sounds in fresh autopsy specimens by manually moving the mandibular condyle as during opening and closing the mouth. 29,31,32 A way to further understand the cause of joint sound may therefore be to use fresh autopsy material, where joint structure can be accurately studied at dissection.

The technology for displaying joint sound recordings has recently been improved by a technique where the time frequency distribution of the sound can be displayed as a three-dimensional graph with more de-
Reciprocal clicking in a joint with disc displacement with reduction.

Fig. 1. Reciprocal clicking in joint with anterior disk displacement with reduction. A, Analogue registration during opening (a) and closing (b). Opening click is 28.6 dB, and closing click is 35.4 dB above the noise level. B, Time frequency distribution opening (a) and closing (b) clicking. The energy peaks are in the area of about 800 Hz. C, Magnification of the opening sound shown in B. D, Magnification of the closing sound shown in B.

tails and less artifacts than in earlier techniques. The purpose of this study was to record joint sounds from fresh autopsy specimens, display the time frequency distribution of the sound as a three-dimensional graph, and correlate these sounds to joint structure as seen during subsequent dissection.

MATERIAL

The material consisted of 27 fresh TMJ autopsy specimens obtained in association with a routine autopsy examination that included the brain. The mean age of the persons was 72 years with a range from 56 to 82 years. We had no information about the clinical history of TMJ symptoms or treatment in these persons. The specimens were removed through the middle cranial fossa within 48 hours after death, and were kept in a deep-frozen state until a few hours before sound recording when they were thawed to room temperature.

METHODS

Sound recording

During sound recording, the temporal component of the specimen was fixed in a specifically designed holder. The term vibration was not used here since we only recorded frequencies within the audible range.

The mandibular component of the joint was manually moved in an anteroposterior direction corresponding to opening and closing movements including rotation and translation. The joint capsule and the muscles of mastication around the joint remained. There were generally no difficulties in identifying the natural pattern of movement of the condyle.

Joint sounds were recorded with an accelerometer (Model 207A, BioResearch, Milwaukee, Wis.) that was attached to the holder, with double-coated tape, as close to the specimen as possible. This was within 5 to 10 mm in all specimens. The accelerometer was calibrated before the experiments. It had a resonant frequency of 3800 Hz and a flat response between 20 and 3600 Hz. To record background noise, we did one recording from each specimen without moving the joint. Thereafter we recorded sound during at least five opening and closing movements. We amplified the sounds 10 times with a specially designed amplifier (BioResearch Milwaukee, Wis.) with a low frequency cut-off at 20 Hz and a high frequency cut-off at 3600 Hz, which is well below the resonance frequency of the accelerometer giving a single-ended output. A high-speed programmable gain analog/digital I/O expansion board (μCDAS-16G1, Keithley Metabyte, Taunton, Mass.) with an industry standard HI-674A successive approximation converter with 12 μsec conversion time was used for digitization of the recorded sound signal. The board was set in unipolar mode. Resolution was 12 bits (4096 steps).
during jaw movement, was less than 3 dB above the maximal noise level when recording without joint movements. A sound was classified as clicking when it had a short duration and only one to three dominant energy peaks close in the time domain (Figs. 1 through 4). A sound was classified as crepitation when there were several energy peaks spread out in the time domain (Figs. 5 through 7).

The sound recordings were also examined for presence or absence of high frequency (>400 Hz) components. The recordings were repeated after 4 to 12 weeks in 12 specimens.

**Dissection**

A small opening was made in the lateral capsular wall. Through this opening, the function of the disk was studied during opening and closing movements as reported in a previous study. The function of the disk was classified as normal, disk displacement with reduction, or disk displacement without reduction according to previously described criteria. After the study of joint function, the opening in the lateral capsule was extended to expose the entire upper joint space. The condyle and disk were disarticulated from the temporal component. The surface of the temporal component was visually inspected and classified as normal (smooth without irregularities) or arthrotic (exposure of bone). Articular surfaces with remodeling (deviation in form but with an intact articular surface layer) were included in the normal group.

The lower joint space was then opened and inspected, and the articular surface of the condyle was classified in the same way as for the upper joint space. We studied the joint surfaces both with the naked eye and under stereomicroscope with magnification of up to 10 times.

After the completion of dissection, the joint components were replaced in their original position, and the specimens were again deep frozen. Cryosections were obtained in the sagittal (12 joints) and coronal planes (3 joints). These 15 joints and their plane of cryosection were selected on the basis of being representative examples of different pathologic conditions and different joint sounds.

**Statistical Method**

Correlation between presence of joint sound and status of the joint was performed with Fisher's exact text.

**RESULTS**

Eleven of the 27 joints exhibited joint sounds, whereas 16 joints were silent. The correlation between joint sound and joint structure is seen in Table I. All of the joints that exhibited joint sound showed various degrees of pathologic changes. These included displacement and/or perforation of the disk and/or arthrosis of the articular surfaces. Joint sound was not registered in any of the joints with normal articular surfaces and normal position and function of the disk. All joints with arthrotic changes showed joint sounds, and the association between joint sounds and arthrotic changes was significant at the 0.001 level (Table II).
Fig. 2. Reciprocal clicking in a joint with medial disk displacement. A, Time frequency distribution of sound recording from a joint with clicking during opening (a) and closing (b). Opening click is 34.6 dB, and closing click is 26.3 dB above noise level. The closing click may, however, sound louder at auscultation since it is in a frequency range for which the human ear is more sensitive. B, Opening click magnified. C, Closing click magnified. D, Coronal cryosection of joint showing medial displacement and folding of the disk (arrow). The articular surfaces were intact.

**Table I. Correlation between joint sound and status of the joint**

<table>
<thead>
<tr>
<th>Status of joint</th>
<th>No joint sound</th>
<th>Reciprocal clicking</th>
<th>Crepitation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal articular surface and normal disk function</td>
<td>14</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Normal articular surface and disk displacement with reduction</td>
<td>2</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Normal articular surface and disk displacement without reduction</td>
<td>1</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Arthrosis of articular surface and disk displacement with reduction</td>
<td>0</td>
<td>1*</td>
<td>0</td>
</tr>
<tr>
<td>Arthrosis of articular surface and disk displacement without reduction</td>
<td>0</td>
<td>5**</td>
<td>3</td>
</tr>
</tbody>
</table>

*This clicking was not reciprocal and occurred only during opening.
**Clicking was not reciprocal in one joint and occurred only during opening.

Clicking was registered in eight joints. Two joints with clicking showed anterior disk displacement with reduction (Fig. 1). The displacement was in a medial direction in three joints (Fig. 2). The disk had a perforation in one of the two joints with disk displacement with reduction. The other six joints showed disk displacement without reduction with four of the six disks being perforated (Fig. 3). There were arthrotic changes...
Fig. 3. Reciprocal clicking in joint with medial disk displacement without reduction. A, Three dimensional time frequency distribution showing sound on opening (a) and closing (b). Sound during opening is 12.2 dB, and sound during closing is 19.4 dB above the noise level. B, Magnification of clicking during opening. C, Magnification of clicking during closing. D, Anterior view of condyle with disk. There is a perforation over the lateral pole of the condyle, and the disk is anteriorly and medially displaced. E, Coronal cryosection of same joint showing medial disk displacement and folding of the disk.

Table II. Association between high frequency (>400 Hz) joint sounds and arthrotic changes of articular surfaces

<table>
<thead>
<tr>
<th></th>
<th>Arthrotic changes</th>
<th>Normal or remodeling</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Joint sound with components &gt;400 Hz</td>
<td>9</td>
<td>2</td>
<td>11</td>
</tr>
<tr>
<td>Joint sound &lt;400 Hz</td>
<td>0</td>
<td>16</td>
<td>16</td>
</tr>
<tr>
<td>TOTAL</td>
<td>9</td>
<td>18</td>
<td>27</td>
</tr>
</tbody>
</table>

Fisher’s exact test: p < 0.001.

of the articular surfaces in four of the eight joints with clicking (Fig. 4).

Crepitation was registered in three joints. All showed disk displacement without reduction (Fig. 5), perforation, and arthrotic changes of the articular surfaces (Fig. 6). In addition adhesions between the joint components were seen in two of the joints with crepitation (Fig. 7).
Sixteen joints did not exhibit any sounds on movement. Of these, fourteen showed normal articular surfaces and normal position and function of the disk (Fig. 8). Two silent joints showed disk displacement with reduction. In these joints normalization of disk position on opening occurred without irregularities of the movement and no clicking or crepitation could be registered.

When the recordings were repeated after 4 to 12 weeks, the same type of sounds were identified at the second session as at the initial session, except for two arthrotic joints that were silent at the first but exhibited sounds at the second session. The amplitude varied both within and between sessions, but further comparisons of amplitude were not attempted in this study. Sound did not occur at every movement in the joints classified as joints with sounds. The occurrence of the sound was dependent on how the joints were moved. The upward force holding the condyle into the fossa was of course determined by the pressure of the operator’s hand. While efforts were made to minimize differences in pressure, slight variations could lead to the absence of sounds in some trials and variations in sound amplitude. When the sound occurred, however, the character of the sound was the same in multiple five registrations.
DISCUSSION

TMJ sound has been of long-term interest, but only limited firm information is available on what the sound means or what specifically is causing the sound. The main reason is that it has been difficult to systematically correlate joint sounds to joint structure. The most important observation in this study was that joint sounds, such as clicking and crepitation, occurred only in joints with disk dysfunction and/or athrotic changes of the articular surfaces. In these autopsy specimens, we were not able to produce joint sounds in joints with normal disks and normal articular surfaces. It is also important to point out that extensive changes could be present in joints without sounds occurring at all movements. This means that pathologic changes or dysfunction of the disk appears to be necessary but not always sufficient for the occurrence of joint sounds. The results of this study were in accordance with previous studies on joint sounds in autopsy specimens\textsuperscript{29} and in patients who were surgically treated.\textsuperscript{30} The observations in this small autopsy series do not permit any further differentiation of the significance of the different types of sound when categorized the classical way as clicking or crepitation. However, the use of reduced interference time frequency distributions made it possible to visualize more
Fig. 7. Crepitation in joint with arthrosis, disk displacement, and adhesions. A, Time frequency distribution showing crepitation with a maximal amplitude 10.9 dB above maximal noise level. B, Lateral aspect showing adhesions (arrow). The disk is anteriorly displaced, and there are extensive adhesions between the disk and the temporal component.

precisely the sound characteristics. This should increase our analytic capability in future studies on larger material.

Absence of sound in joints with advanced disease is understandable if we explain the sound as caused by irregular surfaces sliding against each other. There will not be any sound unless the irregularities are located on the surfaces that make contact during movement, nor will sound occur if some smooth soft tissue is interposed between the irregular components.

Our conclusion that normal joints do not produce sound is, of course, based on our definition of sound as vibrations at a level of at least 3 dB higher than the background noise. For technical reasons there will always be some noise in electronic recordings. Sounds cannot be observed unless they are above the noise level of the recording system. We chose the average noise level during recording without joint movement as the arbitrary zero decibel level. The human ear can normally detect a difference in sound levels only if it is at least 3 dB. We therefore chose to recognize a recorded signal as a joint sound only if it was at least 3 dB above maximal peak-to-peak noise level in the recording without joint movement. Thus we used only recordings that would be possible to identify by auscultation against the background noise in a clinical application. Amplification does not change this situation since the noise is amplified along with the TMJ sound. Sound can

Fig. 8. Time frequency distribution showing no evidence of joint sound in normal joint. A, An artificial signal with a peak energy at about 400 Hz and an amplitude equal to 34 decibel is indicated at (a). B, Sagittal cryosection of joint with normal superior disk position and normal articular surfaces. C, Anterior superior aspect of disk remaining on condyle showing normal smooth articular surface and a disk in normal superior position.
certainly be recorded in every joint if the amplification is large enough and the noise level is zero. Then a new zero decibel reference level has to be chosen similar to the standards used in conventional measurements of sound levels. The range in the recorded joint sounds was 0 to 40 dB, which seems adequate when compared with the decibel values of other familiar sounds listed on audio scales.

From this and previous studies it is obvious that the same types of sounds can be produced in autopsy specimens as those that occur in the TMJs of living subjects. This is not surprising because sound is a mechanical phenomenon not inherent to the muscles of mastication or other organs that are nonfunctional postmortem. Sounds may occur when the condyle or disk is not functioning properly or when irregularities of the articular surfaces slide against each other.

Joint sounds have generally been recorded by auscultation and/or palpation. Electronic recordings of joint sounds offers several advantages over auscultation and palpation such as the possibility to store and compare observations at different times, to record frequency sound and vibrations that would not be perceived by the human ear, to eliminate differences resulting from differences in hearing and perception of the observer, to make objective documentation of the sound and its character, and finally, the possibility to analyze the recorded signal with respect to amplitude energy content and time frequency distribution. The reduced interference distribution is a step further along the line of refinement of presentation of electronically recorded sounds. For these reasons, we consider electronic recording of joint sound to be superior to auscultation and palpation in scientific work. It is, however, still an unsolved question how this information should be interpreted and used in a clinical situation. The different types of sound probably reflect different morphologic alterations in the joint, although in this small sample we were not able to identify any statistically significant associations to precise morphologic groups related to specific types of these sounds. However, in a larger sample, this may be possible.

A statistically significant association was found between the presence of TMJ sound and arthritic changes of the articular surfaces. To the best of our knowledge there are no other studies published where compatible methods have been used to study the time frequency distribution of TMJ sounds. However, all the sounds we recorded from the specimens with arthritic changes had frequency components above at least 400 Hz, some of them well above 1000 to 1200 Hz. This supports previous observations that arthritic changes and high frequency sounds are correlated. It indicates also that the sampling rate should be at least about 2500 Hz.

In conclusion this study has shown that TMJ sounds could only be produced in joints with disk or articular surface abnormalities. Normal joints were consistently silent. A few abnormal joints, however, were also silent. Different forms of joint sound, such as clicking and crepitation, was not associated with specific types of joint disease in this small sample. A high frequency component appeared to be associated with arthritis of the articular surfaces. Thus the presence of joint sound is probably a reasonably good indicator of joint abnormalities. The absence of joint sound, however, cannot be used to rule out joint abnormality. The type of joint sound (clicking or crepitation) appears not to be as characteristic of the different types of intraarticular pathosis as previously thought.

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REFERENCES

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