ORIGINAL ARTICLE

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측두하악 관절잡음의 진동 분석

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ABSTRACT

Vibration Analysis of the Temporomandibular Joint Sounds

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관절잡음의 발생은 측두하악 관절의 구조적, 기능적 이상의 징후로 여겨져왔다. 이러한 관절잡음을 평가하는데 electrovibratography가 비침습적이고 신뢰할만한 방법으로 제시되어 왔으며 이를 통해 관절잡음의 진동수와 진폭 및 전체 에너지 양상을 숫자화하고 도식화 하는 것이 가능하게 되었다. 기존의 연구에서 여러 가지 관절잡음의 양적, 질적 분석이 시도되어 왔다. 이번 연구의 목적은 관절 잡음이 도식화되어 나타나는 frequency spectrum pattern을 integral 〉300Hz/〈300Hz ratio와 함께 분석하는 것이다.

본 실험에서는 Joint Vibration AnalysisTM를 사용하여 측두하악 관절 장애의 증상이 없는 10명의 대조군과 관절 잡음과 동통이 있으나 개구제한을 보이지 않는 정복성 관절원판 변위의 범주에 있는 20명의 실험군에서 관절진동을 분석하였으며 관절진동 기록 시에 Jaw tracker를 함께 사용하여 개폐구시 관절잡음 발생의 위치를 감별하고 치아접촉음을 배제하여 관절잡음을 분석하였다. 그 후 실험군을 frequency spectrum pattern에 따라 4가지 하위 그룹으로 나누어 분석하였다.

실험 결과 실험군과 대조군의 하위 그룹 1에서 유사한 frequency spectrum pattern과 ratio범위를 보였으며 실험군의 하위 그룹 2,3,4 에서는 더 불규칙한 에너지 양상을 보이는 frequency spectrum pattern과 더 큰 ratio가 관찰되었다.

이번 연구를 통해 Joint Vibration AnalysisTM가 악관절 진동의 특성을 감별하는데 유용함을 알 수 있었고 Joint Vibration AnalysisTM를 이용한 지속적인 진동 분석이 환자 교육뿐 아니라 성공적인 턱관절 기능이상의 진단과 치료에 유용할 것으로 사료된다.

Key words : elecgtrovibratography, frequency spectrum, temporomandibular Joint sounds, vibration analysis

Ⅰ. INTRODUCTION

The phenomenon of temporomandibular joint(TMJ) noise, such as a clicking or crepitus, has long attracted the attention of clinical researchers. Studies on the etiology of joint sounds suggest that the sounds can originate from an incorrect relationship between condyle and disk[1,2]. But in most studies of TMJ joint epidemiology, the presence of TMJ sounds is not correlated with diagnostic imaging[3~11]. Ishigaki et al.,[12] reported nearly one half of symptomatic patients unmanageable by conservative therapy had confirmed internal derangements. In addition, other studies have reported an incidence of disk displacement approaching 20% in asymptomatic subjects[13].

Several qualitative and quantitative classification methods have been suggested for classification of TMJ sounds, and electro-acoustical systems for recording and characterizing the sounds objectively have been introduced. Furthermore, several authors have associated different power spectra with various pathologies[14]. Some authors previously reported that the joint vibration analysis using electrovibratography (EVG) is most reliable than physical examination alone and can serve as a non-invasive method for screening patients with internal derangements[15].

Using electrovibratography, It is possible to identify and show: 1. The frequencies (in Hertz), as well as the amplitudes of the vibrations, which can be expressed mathematically. i.e., Numeric analysis; 2. The visualization of the types of waves created by the sound. i.e., Graphic analysis; 3. The precise moment that the sound happens in the opening and closing cycles.

We used Joint Vibration Analysis(JVA) in the BioPAK system(Bioresearch, Inc, Milwaukee, USA) as the electrovibratography, and Jaw tracker(JT)-3 device in the BioPAK system (Bioresearch, Inc, Milwaukee, USA). Using the JT-3 device allowed the computer to estimate where a joint vibration occurred in the open/close cycle and let us distinguish tooth contact from joint sound precisely.

JVA provides excellent conduction of subtle vibrations (tissue borne vibration) because of its density of silicone while sonography increases the recording of room nose(air borne vibration). Furthermore no magnet in the sensors allows it to be used with jaw tracker for accurate timing evaluations.

The vibratory energy in the symptomatic group was higher than in the asymptomatic group which agrees with the observations of several studies[16,17,18]. This is because the highest amount of vibration happens in the articular structures because of lubrication deficiency[19], lengthening of the ligaments[20] and an alteration in the relationship of the condyle/disk[21,2] or spasms of the lateral pterygoid muscle[22]. Ishigaki et al. suggested that when using total power density only(total integral), EVG is useful in the separation of meniscal displacement[6]. Gallo et al. reported that healthy TMJs produced sounds which were distinctly different from baseline and background noises at lower frequencies. Ishigaki et al. reported that a disc displacement with reduction generates a "click" in the lower frequencies(under 300Hz)[23]and a degenerative condition generates "crepitus" in the higher frequencies(over 300Hz)[24].

However, despite all these attempts to quantify, qualify, and use joint sounds for diagnosis of joint pathologies, we found few studies based on the frequency spectrum patterns associated with the integral 〉300Hz/〈300Hz ratio. The aim of this study was to examime the TMJ sounds with repect to the integral 〉300 Hz/〈300Hz ratios and frequency spectra patterns in subjects showing Disc displacement with reduction.

Ⅱ. MATERIALS AND METHODS

This study was done using 30 individuals whose ages ranged from 23 to 33 years with a mean average of 26.2 years. Through palpation and auscultation of the TMJs during maximum active mouth opening/closing, subjects were examined for the clinical presence/absence of TMJ noises. When subjects showed an absence of TMJ noises, pain at palpation (any of the masseter, temporalis, pterygoid, digastric muscles) and jaw movement or chewing, they were screened out, which agreed with objective EVG findings. Then they were designated as our control group(group I) composed of 9 males and 1 female. Group II, designated as our experimental group, was composed of 8 males and 12 females and showed the presence of TMJ noises, normal range of jaw movement during opening and pain at palpation and jaw movement of chewing. So they could be differentiated as disc displacement with reduction.

In each subject, EVG analysis were performed three times. A magnet was attached to the labial surface of the mandibular incisors of the subjects in order to bring the midline of the magnet in line with the labial frenum and the groove of the magnet was located on the left side of the subjects. If the subjects tended to have deep bites so that it was impossible to attach the magnet, it was attached to the labial gingival surface or lingual tooth surface. One transducer was placed on the skin over the right TMJ, and the other over the left TMJ. Then the JT-3 device was put on the subjects. Once the horizontal and vertical standard points were set, we controlled them to fit the subjects' heads. We made sure controlled that the bar of the front side was parallel to the interauditory axis and the lateral side to the Frankfort Horizontal plane. The accessory bar for approaching the magnet was fixed temporally and operated in order to set the exact midline (Fig. 1).

As the subject performed metronome-guided maximun active opening/closing with JVA, the condyles rubbed against the various surfaces in the joints creating characteristic vibrations which were then, in turn, detected by the accelerometers.

They converted those specific vibrations to an electronic signal. The signal from the accelerometers was amplified by a small, light-weight amplifier which was placed around the patient's neck. The amplified signals were then transmitted to the PC computer where they are recorded and analyzed with a software program and then displayed on CRT. After the best performed of the three recordings was selected, the vibrations showing highest amplitude were screened priorly. When we excluded tooth contact precisely, the reproducible joint sound was analyzed for each opening & closing cycle. Finally an average episode was determined for each subject(Fig. 2).

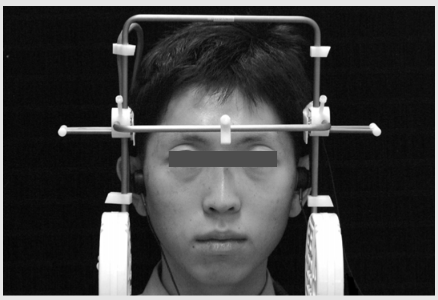

Fig 1. JVA and JT-3 device placed on the subjects. (BioPAK system®, Bioresearch Inc., USA)

Ⅲ. RESULT

Joint vibrations are analyzed using a mathematical technique known as the Fast Fourier Transform(FFT). Complex vibrations can be thought of as a sum of fundamental pure sine waves, each with a different pitch(frequency) and loudness(amplitude). The FFT extracts the amplitude of each of these fundamental frequencies to show the frequency spectrum which represents the amplitude(energy) at each frequency. The

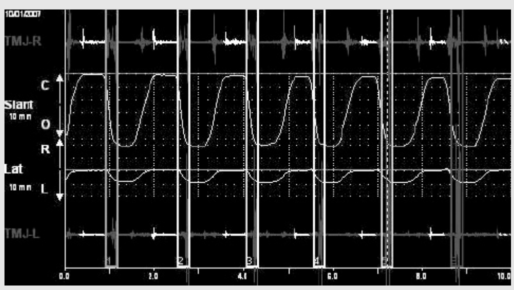

Fig 2-a.

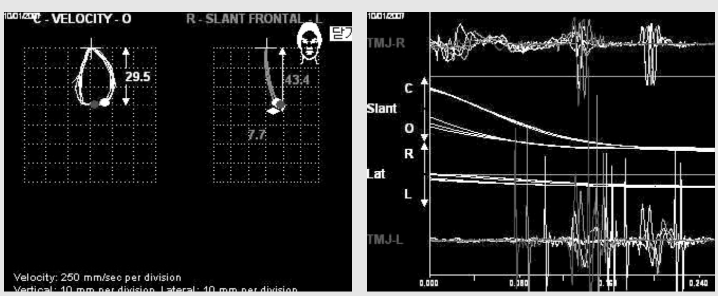

Fig 2-b.

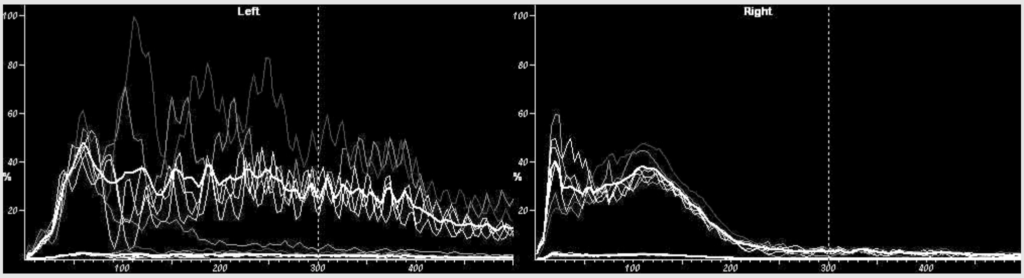

Fig 2-c.

Help / Narrative	Average		Window 1		Window 2		Window 3	
	Left	Right	Left	Right	Left	Right	Left	Right
Total Integral	69.5	32.7	24.6	33.6	58.5	31.4	67.4	34.9
Integral <300Hz	47.4	30.1	21.3	31.2	37.9	28.7	44.2	31.9
Integral >300Hz	22.1	2.6	3.3	2.5	20.5	2.8	23.3	3.0
>300/<300 Ratio	0.47	0.09	0.15	0.08	0.54	0.10	0.53	0.10
Peak Amplitude	2.5	2.1	2.5	3.2	2.5	2.4	2.4	2.6
Peak Frequency	60	21	60	21	48	17	221	21
Med. Frequency	221	111	107	103	232	107	236	103
Slant Distance	40.5	40.5	38.2	38.5	42.1	37.5	41.1	38.4
Velocity	78.6	79.4	122.2	119.1	57.0	127.5	74.2	129.8
Max. Slant	43							

Fig 2-d.

Fig 2. Graph of the registration of joint vibrations occurring at the late of the mandibular opening(a) and superimposed amplitude and duration data from 6 open/close cycles.(b) Frequency spectrum computed from fast Fourier transform algorithm. The thick line represents the average spectrum of all the marked vibrations' spectra.(c) Numerics of JVA summary view based upon absolute frequency spectra.(d)

frequency spectra view plots amplitude(vertical axis) versus frequency(horizontal axis). The height of the curve is directly proportional to the energy of the spectrum at each frequency. The thick line represents the average spectrum of all the marked vibration spectra. Two spectra are plotted for each side; the smaller of the two represents the absolute magnitude of the vibration spectra as recorded(N/m2), the larger one is scaled to the maximum range(at the recorded amplification) and is known as the relative plot. The relative plot accentuates features that may not be visible in the absolute plot. The numeric values that are calculated and displayed in the JVA summary view are based on the absolute frequency spectra.

For the numerics, the following variables were used. The peak frequency(Hz) was the frequency having the highest amplitude in the frequency spectrum, and the median frequency(Hz) was the frequency dividing the frequency spectrum into two regions with equal power. The total integral(arbitrary units) was the area under the curve of the frequency spectrum. The peak amplitude indicates the highest numeric point of the vibration analyzed expressed in Pascals.

Characteristics of the frequency spectrum are described as the durations(short/long) standardized from below/above 300Hz and the

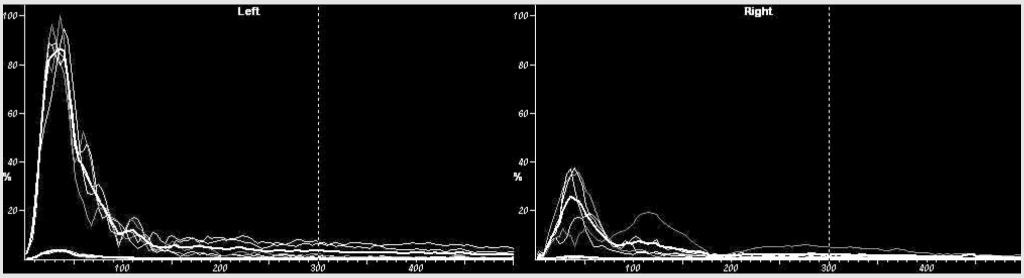

Fig 3. Frequency spectrum represents Group I . In this subject, No.7, integral >300Hz/<300Hz ratio was 0.10 and 0.15 respectively and the right joint was selected for frequency spectrum analysis and was characterized by short, smooth patterns.

patterns(smooth/irregular) of the relative plot(Table 3). The joint having the higher value between the left and right side is selected for the description of the frequency spectrum.

In Group I the frequency spectrums(Fig 3) showed short durations below 300Hz and smooth patterns. The integral >300Hz/<300Hz ratio ranged variously from 0.04 to 0.3.

Group II divided in 4 subgroups by the obtained characteristics of frequency spectrum. In Group II 16 subjects showed reciprocal click and integral >300Hz/<300Hz ratio was selected according to the higher value from the reciprocal click as well as the right and left joint vibrations.

Table 1. Integral>300Hz/<300Hz ratio in Group I .

No.	Lt.ratio	Rt.ratio
1	0.04	0.02
2	0.13	0.13
3	0.07	0.19
4	0.14	0.09
5	0.05	0.09
6	0.13	0.08
7	0.10	0.15
8	0.20	0.30
9	0.17	0.13
10	0.18	0.10

In subdivision 1 the frequency spectrums showed short durations below 300Hz and smooth patterns similar to the control group. Integral >300Hz/<300Hz ratio ranges varied from 0.05 to 0.31 and 7 subjects were included. In subdivision 2 the frequency spectrums showed short durations below 300Hz and irregular patterns which had the integral >300Hz/<300Hz ratios ranged from 0.12 to 0.19 with a mean average of 0.16 and 4 subjects were included. In subdivision 3 the frequency spectrums showed short, irregular patterns below 300Hz accompanied by simultaneous long durations, lower amplitude patterns. The integral >300Hz/<300Hz ratios ranged from 0.23 to 0.42 with a mean average of 0.31 and 7 subjects were included. Subdivision 4 showed long durations, irregular patterns which had the integral >300Hz/<300Hz ratios ranged from 0.43 to 0.47 with a mean average of 0.45 and 2 subjects were included.

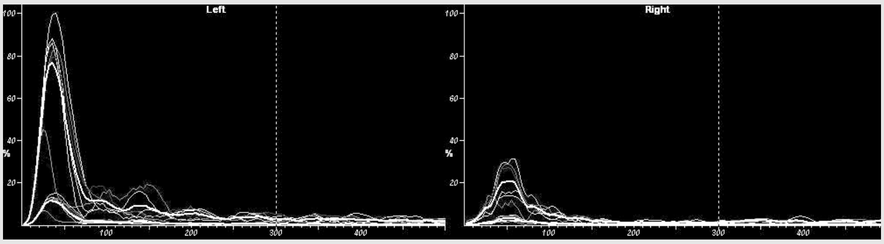

Fig 4. Frequency spectrum represents Group Ⅱ, subdivision 1. In this subject, No.3, the integral 〉300Hz/〈300Hz ratioss were 0.11 and 0.24 respectively and the right joint was selected for frequency spectrum analysis and characterized by short, smooth patterns.

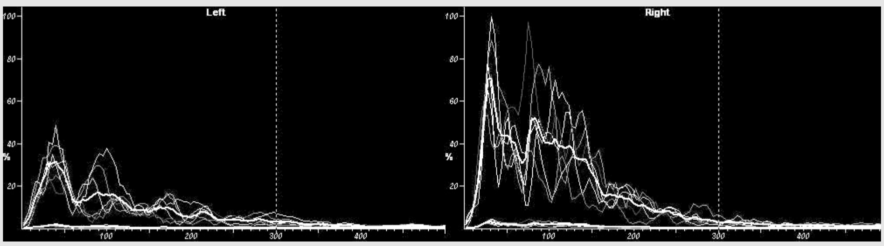

Fig 5. Frequency spectrum represents Group Ⅱ, subdivision 2. In this subject ,No.8, the integral 〉300Hz/〈300Hz ratios were 0.17 and 0.04 respectively and the left joint was selected for frequency spectrum analysis and characterized by short, irregular patterns.

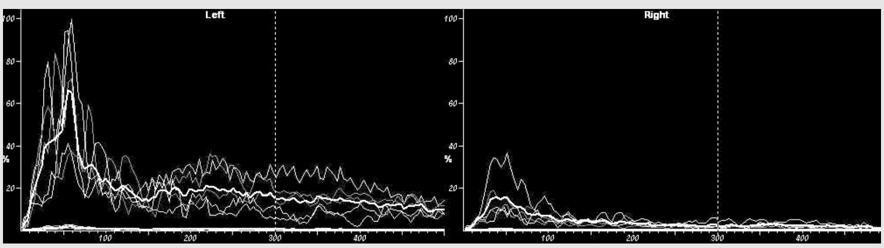

Fig 6. Frequency spectrum represents Group Ⅱ, subdivision 3. In this subject, No.18, the integral 〉300Hz/〈300Hz ratios were 0.38 and 0.26 respectively and the left joint was selected for frequency spectrum analysis and characterized by short, irregular patterns accompanied by lower amplitude, long and irregular patterns.

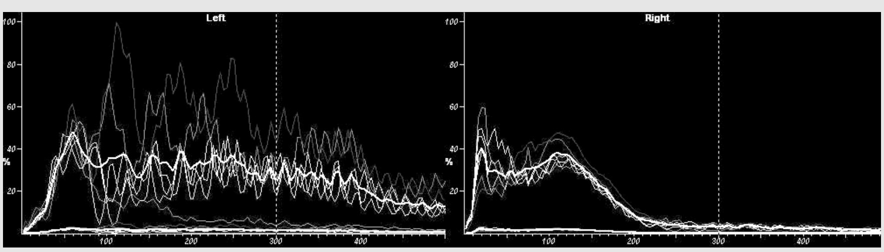

Fig 7. Frequency spectrum represents Group Ⅱ, subdivision 4. In this subject, No.20, the integral 〉300Hz/〈300Hz ratios were 0.47 and 0.09 respectively and the left joint was selected for frequency spectrum analysis and characterized by long, irregular patterns.

Table 2. The integral 〉300Hz/〈300Hz ratios in Group II.

No.		Lt. ratio	Rt. Ratio
1	subdivision 1	0.31	0.17
2		0.06	0.26
3		0.11	0.24
4		0.02	0.09
5		0.05	0.06
6		0.08	0.09
7		0.05	0.04
8	subdivision 2	0.19	0.04
9		0.16	0.19
10		0.17	0.04
11		0.07	0.12
12	subdivision 3	0.27	0.25
13		0.25	0.07
14		0.14	0.23
15		0.27	0.34
16		0.27	0.32
17		0.24	0.42
18		0.38	0.26
19	subdivision 4	0.43	0.15
20		0.47	0.09

Ⅳ. DISCUSSION

Like all wave energy, the joint vibration wave has both amplitude and frequency. As a sound waves moves through a medium, each particle of the medium vibrates at the same frequency. These frequencies are commonly referred to as the pitch of a sound. A low pitch sound corresponds to a low frequency and a high pitch sound corresponds to a high frequency. The human ear can detect sound waves with a wide range of frequencies ranging between approximately 20Hz to 20,000Hz. The quality of loudness is an expression of the vibration wave amplitude. The greater the amplitude of vibrations, the greater the rate at which energy is transported through the medium and the more intense the sound wave is. We often note where the sound occurs in the patient's open-close cycle. This is defining location.

Joint vibrations are analyzed using a mathematical technique known as the Fast Fourier Transform (FFT). The FFT extracts the amplitude of each of these fundamental frequencies to show the frequency spectrum which represents the amplitude(energy) at each frequency. The integral is the amount of vibration energy from each joint and the area under the curve of the frequency spectrum expressed in % power times Hertz.

The soft tissue vibrations generally have frequencies below 300Hz and the hard tissues vibrations will generally have frequencies above 300Hz. Likewise the low integral indicates

Table 3. Description of frequency spectrum as the duration (short/long) standardized from below/above 300Hz, and the patterns (smooth/irregular).

	Group I (10)	Group II (20)			
		subdivision1(4)	subdivision2(7)	subdivision3(7)	subdivision4(2)
duration	short	short	short	short&long	long
pattern	smooth	smooth	irregular	irregular	irregular
range of ratio	0.04-0.3	0.05-0.31	0.12-0.19	0.23-0.42	0.43-0.47
mean ratio	0.152	0.157	0.167	0.316	0.45

energy below 300Hz and the high integral indiocates energy above 300Hz. Ishigaki et al reported that a disc displacement with reduction generates a "click" in the lower frequencies(under 300Hz)[23]and a degenerative condition generates "crepitus" in the higher frequencies(over 300Hz).[24] With regard to the ratio between the intergals above and below 300Hz which provide information on the relative distribution of high and low vibration frequencies, it is conceivable that the higher the integral 〉300Hz/〈300Hz ratio number, the more advanced degenerative condition could exist.

In this study, Group Ⅰ and Group Ⅱ, subdivision1 represented similar frequency spectrum patterns and showed a variable range of the integral 〉300Hz/〈300Hz ratios ranging from 0.04 to 0.3 and 0.05 to 0.31 respectively. While Group Ⅱ, subdivision1, 2 and 3 represented irregular energy patterns and showed relatively higher integral 〉300Hz/〈300Hz ratios. Furthermore Group Ⅱ, subdivision 3 and 4 could be represented as having a degenerative condition. Thus normal healthy joints could be differentiated from those in degenerative condition by analysis of clinical examinations along with integral 〉300Hz/〈300Hz ratios and patterns of frequency spectrums.

SUMMARY

We used Joint Vibration Analysis(JVA) in the BioPAK system(Bioresearch, Inc, Milwaukee, USA) as the electrovibratography, and Jaw tracker(JT)-3 device in the BioPAK system (Bioresearch, Inc, Milwaukee,USA) to distinguish precisely tooth contact from joint sound. The aim of this study was to examime the TMJ sounds with repect to integral 〉300 Hz/〈300Hz ratio and frequency spectra pattern in subjects showing Disc displacement with reduction.

This study was done using 30 individuals whose ages ranged from 23 to 33 years with a mean average of 26.2 years. Group Ⅰ with 10 subjects had an absence of subjective TMJ complaints(noises and pains) while showing objective EVG findings. GroupII with 20 subjects showed symptoms of disc displacement with reduction. In each subject EVG analyses were performed three times and the best performed recording was selected from the three recordings. Prior to screening out vibrations showing highest amplitude tooth contact was excluded and reproducible joint sounds were analyzed for each opening & closing cycle. Finally, the average episodes were recorded in each subject.

Joint vibrations are analyzed using a mathematical technique known as the Fast Fourier Transform(FFT). The frequency spectra view plots amplitude(vertical axis) versus frequency(horizontal axis). The soft tissue vibrations generally have frequencies below 300Hz and the hard tissues vibrations will generally have frequencies above 300Hz. With regard to the ratio between the integrals above

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Since the clinical examination alone is not entirely accurate, an alternative cost-effective technique must be found. Through constant observations, it could be suggested that clinicians consider using this JVA protocol to differentiate the characteristics of TMJ sound. And JVA will provide the clinician with the visible patterns of TMJ sound for patient management.

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