Joint-Sounds in Gonoarthrosis — Clinical Application of Phonoarthrography for the Knees —

Yoshiyuki NAGATA

Department of Orthopaedic Surgery, School of Medicine, University of Occupational and Environmental Health, Japan. Kitakyushu 807, Japan

Abstract : Auscultation is one of the oldest methods of diagnosis. It has been extensively used in examining various organs of the body, but its use for studying joint-sounds is still an unexplored area of research. In our clinic, a new analyzing system has been developed and its clinical application has been practiced since 1980. The joint-sounds are analyzed with a narrow band spectrum analyzer and a computer. The spectrum of background noise is then subtracted from the linear averaged spectrum to obtain the phonoarthrograph. Our study showed that all the joint-sounds exist at a point lower than 3.5 kHz with the majority of them being lower than 2.5 kHz. Therefore, we believe that there are mainly two kinds of joint-sounds, that is, at the low frequency sound level (L type) and at the high frequency sound level (H type). The significance of joint-sounds at the high frequency sound level is unknown but we suggest that it is due to the thickness and the hardness of the articular surface. Next the significance of joint-sounds at the low frequency sound level were investigated. We think that joint-sounds reflect not only on the change of bone but also on something else due to osteoarthritis. The sounds which are concerned with the changes as seen on the X-ray films exist at the low frequency sound level mainly from 0.5 kHz to 1.0 kHz. We believe that this method is noninvasive and useful for the diagnosis of osteoarthritis of joints.

Key words : knee joint, osteoarthritis, joint-sounds, diagnosis, phonoarthrograph.

(Received 16 November 1987)

Introduction

The author studied sounds which occur in the joints during motion. If it is possible to make a diagnosis of gonoarthrosis by analyzing joint-sounds, radiation hazards and pain at the time of examination will be eliminated and much time will be saved. However, studying joint-sounds is still in an unexplored area of research.

In our clinic, a new analyzing system has been developed and its clinical application has been practiced since 1980.

Materials and Methods

Two groups of subjects were included in this study. One was NS (no symptoms) group which had no clinical complaints even though some changes in the bone structure were seen on the X-rays, and the other was OA (osteoarthritis) group. In this paper, the

subject's knees were selected, for example, the right knee which was normal was in the NS group and the left knee which was osteoarthritis was in the OA group. The NS group consisted of 187 knees and the age of the subjects ranged from 10 to 83 years (average, 31.8 years). The OA group consisted of 139 knees and the age of these patients ranged from 23 to 83 years (average, 59.4 years). In order to equalize the dispersion of ages between the NS group and OA group, we separated the data of the subjects of NS group who were older than 40 years (N group). This group consisted of 49 knees (average, 57.1 years).

The basic experimental setup is shown in Fig. 1. A subject is seated on the edge of a firm bed with his lower extremities hanging freely in an anechoic chamber. One examiner holds one of the subject's lower legs and moves his knee joint passively in three or four cycles. A cycle is defined as a passive motion from an extension (about 0 degree) to a flexion (about 90 degrees) within about four seconds. The other examiner holds a special condenser microphone (Bruel & Kjaer 4165-2619) on the subject's prepatellar skin throughout the passive motion. The coupler of the silicon tube, which has ventilation holes in order to decrease the low frequency noise, is attached to the microphone head. Ultra-sonic gel is also applied over the prepatellar skin to decrease the friction noise which occurs due to the slight rubbing of the microphone against the skin.

The joint-sounds are analyzed with a narrow band spectrum analyzer (B & K 2031) and a computer (Tektronix 4051). The linear averaged spectrum is obtained over 128 spectra every 200 ms. The spectrum of background noise is then subtracted from the linear averaged spectrum to obtain the phonoarthrograph. Because of the high sound pressure level at the low frequency of background noise, we calculated the sound pressure level every 500 Hz band width from 0.5 kHz to 5.0 kHz. The sound pressure levels were then determined as band spectrum (BS) and the over all value to be the total band sound pressure level. The peak sound pressure level of phonoarthrograph was then defined and less than 5 dB was determined as "silent joint-sounds", and the peak greater than 5 dB was "joint-sounds" because of measurement error.

Fig. 1. Schema of sound analytic apparatus.

Next the subject's knees were X-rayed from three angles (antero-posterior, lateral, and axial view). We checked roentgenographic changes at 6 sites—that is, in both the patello-femoral joint (P) and the tibio-femoral joint (T), joint narrowing (Na), sclerosis (Sc), spur formation (Sp) at both medial (M) and lateral (L). For example, if medial joint narrowing of the patello-femoral joint and medial and lateral spur formation of the tibio-femoral joint were seen on the X-rays, they were written as PNaM, TSpM, and TSpL. We then classified the grading of roentgenographic change of each site as follows: 0 point, no change; 1 point, moderate change; 2 points, severe change. We finally calculated the total grade of roentgenographic change as an index of total points/numbers of joint.

Differences during sound pressure levels and during changes seen in the bone structure on the X-rays were evaluated statistically by the t-test and Mann-Whitney U-test.

Results

1. Background noise

The spectrum of background noise in an anechoic chamber is shown in Fig. 2. There was an extremely high sound pressure level at the very low frequency.

2. Relationship between the classification by spectrum patterns of phonoarthrograph and the changes seen in the bone structure on the X-rays

Joint-sounds were classified into two types by the spectrum patterns of phonoarthrograph. One was joint-sounds which occurred at the low frequency sound level (L

Fig. 2. Background noise.

type) and the other was at the high frequency sound level (H type). Further, we classified four types of each joint-sound as follows: L-0, silent sound at the low frequency sound level; L-1, sounds lower than 1.5 kHz; L-2, sounds lower than 2.0 kHz; L-3, others; H-0, silent sound at the high frequency sound level; H-1, the peak of sounds was about 1.5 kHz; H-2, the peak was about 2.5 kHz; H-3, others (Table 1).

A) Joint-sounds at the low frequency sound level

A typical joint-sound at the low frequency sound level is illustrated (54 years old, female, left osteoarthrotic knee) (Fig. 3). This was classified into L-1 · H-0 and had many changes as seen on the X-rays, that is, PSpM, PSpL, TNaM, TScM, TSpM and TSpL.

Table 1. Classification of spectrum pattern

L \ H						Total
		0	1	2	3
0	153	46	56	2	257
1	21	10	16	1	48
2	20	8	54	5	87
Others	3	15	3	20	23	61
Total		209	67	146	31	453

Fig. 3. Phonoarthrograph [type L-1 · H-0] and roentgenograph (A 54-year-old female, left OA knee).

Silent sound knees (L-0 · H-0) were compared with joints in which sounds occurred at the low frequency sound level only (L-1 · H-0; L-2 · H-0). More changes were shown on the X-rays of the latter — PSpM, PSpL, TNaM, TScM and TSpM — than the former (Fig. 4).

B) Joint-sounds at the high frequency sound level

A typical joint-sound at the high frequency sound level was illustrated (23 years old, male, left normal knee) (Fig. 5). This was classified into L-0 · H-2 and showed little

Fig. 4. The site of roentgenographic changes within the low frequency sound level.

- L-0·H-0 (153 knees)
 - ▲---▲ L-1·H-0 (21 knees)
 - L-2·H-0 (20 knees)
[P: patello-femoral joint	Na: narrowing	M: medial
T: tibio-femoral joint	Sc: sclerosis	L: lateral
	Sp: spur	

Fig. 5. Phonoarthrograph [type L-0 · H-2] and roentgenograph (A 23-year-old man, left normal knee).

change as proven on the X-rays.

Next, silent sound knees (L-0 · H-0) were compared with joints in which sounds occurred at the high frequency sound level only (L-0 · H-1; L-0 · H-2). There was little difference in changes as seen on the X-rays between the former and the latter (Fig. 6).

3. Comparison of N group with OA group

A) Comparison of N group with OA group using changes as seen on the X-ray films

In spite of sounds, there were significant differences at PSpM, TNaM, TScM, TSpM and TSpL between the two groups (Fig. 7).

B) Comparison of N group with OA group from the points of view of the band spectrum and the over all value

The frequency sound level of joint-sounds existed at lower than 3.5 kHz. A significant difference was seen at the two band spectrum levels — BS01 (0.5 — 1.0 kHz) and BS02 (1.0 — 1.5 kHz) — and at the over-all value between N group and OA group (Fig. 8).

C) Relationship between joint-sounds and changes as seen on the X-rays (Table 2)

There was no significant difference between joint-sounds and changes as seen on the X-rays in N group. In the case of OA group, when we compared the joints (OA- II) in which sounds occurred within BS01 (0.5 — 1.0 kHz) with the joints (OA- I) in which no sounds occurred, there were significant differences at PSpM, PSpL, TScM, TSpM, and TSpL as shown on the X-rays. But there was no significant difference at the over-all value (Fig. 9). When the joints (N- I) in which no sounds occurred were compared with OA- II, there were significant differences at PSpM, PSpL, TNaM, TScM, TSpM and TSpL (Fig. 10). On the other hand, when the joints of OA- I were compared with N- I, there

Fig. 6. The site of roentgenographic changes within the high frequency sound level.

○-----○ L-0·H-0 (153 knees)
 ▲-----▲ L-0·H-1 (46 knees)
 ●-----● L-0·H-2 (56 knees)

P: patello-femoral joint	Na: narrowing	M: medial
T: tibio-femoral joint	Sc: sclerosis	L: lateral
	Sp: spur	

was a significant difference at only TSpM in BS01, but there were significant differences at PSpM, TNaM, TSpM and TSpL at the over-all value. Further, we compared the joints of OA- I with N- II and found that there was no significant difference between joint-sounds and changes as proven on the X-rays. Next, when the osteoarthrotic joints (L-1) in which sounds occurred within 1.5 kHz were compared with those (L-2) higher than 1.5 kHz, there was no significant difference between them (Fig. 11).

Fig. 7. The site of roentgenographic changes. [N group vs. OA group]

○---○ N group (49 knees) [N: normal (the subjects are over 40 years)]
 ●---● OA group (139 knees)

[P: patello-femoral joint Na: narrowing M: medial
 T: tibio-femoral joint Sc: sclerosis L: lateral
 Sp: spur]

* : $P < 0.05$
 ** : $P < 0.025$
 *** : $P < 0.01$
 (U-test)

Fig. 8. Comparison of N group with OA group from the band spectrum and the over-all.

○---○ N group (49 knees) [N: normal (the subjects are over 40 years)]
 ●---● OA group (139 knees)
 BS : band spectrum

* : $P < 0.05$
 ** : $P < 0.025$
 (t-test)

Table 2. The relationship between joint sound level and roentgenographic changes

	N/OA	N-I/N-II		N-I/OA-I		N-I/OA-II		N-II/OA-II		OA-I/OA-II		N-II/OA-I	
		BS01	over-all	BS01	over-all	BS01	over-all	BS01	over-all	BS01	over-all	BS01	over-all
(knees)	49/139	31/18	37/12	31/58	37/85	31/81	37/54	18/81	12/54	58/81	85/54	18/58	12/85
P.F.J.													
Na-M													
Sc-M													
Sp-M	***				*	***	***	*		***			
Na-L													
Sc-L													
Sp-L						***	**			***			
T.F.J.													
Na-M	**				**	**	**						
Sc-M	*					**	*	*		**			
Sp-M	***			**	***	***	***	*		***			
Na-L													
Sc-L													
Sp-L	***				**	***	***	*		***			

*: $P < 0.05$, **: $P < 0.025$, ***: $P < 0.01$ (U-test)

P.F.J.: patello-femoral joint

Na: narrowing
Sc: sclerosisM: medial
L: lateral

N: normal (the subjects are over 40 years)

BS: band spectrum

BS01: 0.5–1.0 kHz

T.F.J.: tibio-femoral joint

Sp: spur

OA: osteoarthritis

I: joint sound level < 5 dBII: joint sound level ≥ 5 dB **Fig. 9.** The site of roentgenographic changes within BS01 (0.5–1.0 kHz) and at the over-all. [OA-I vs. OA-II]

[P: patello-femoral joint Na: narrowing M: medial I: joint sound level < 5 dB
T: tibio-femoral joint Sc: sclerosis L: lateral II: joint sound level ≥ 5 dB
Sp: spur

*: $P < 0.05$ **: $P < 0.025$ ***: $P < 0.01$ (U-test)

Discussion

Auscultation is one of the oldest methods of diagnosis. It has been extensively used in examining various organs of the body, such as the respiratory and circulatory system, but why has this method not been utilized as a diagnostic tool of joint disease ?

For many years, various investigators have tried with little success to use the sounds emitted by the knee joint during articulation as a noninvasive diagnostic tool. Heuter re-

Fig. 10. The site of roentgenographic changes within BS01 (0.5—1.0 kHz). [N-I vs. OA-II]

○—○ N-I (31 knees) [N: normal (the subjects are over 40 years)]
●—● OA-II (81 knees)

[P: patello-femoral joint T: tibio-femoral joint	Na: narrowing Sc: sclerosis Sp: spur	M: medial L: lateral	I : joint sound level < 5 dB	* : $P < 0.05$ * * : $P < 0.025$ * * * : $P < 0.01$ (U-test)
			II : joint sound level ≥ 5 dB

Fig. 11. The site of roentgenographic changes. [OA-II: within 1.5 kHz vs. over than 1.5 kHz]

○—○ OA-II : within 1.5 kHz (18 knees)
●—● OA-II : over than 1.5 kHz (47 knees)

[P: patello-femoral joint T: tibio-femoral joint	Na: narrowing Sc: sclerosis Sp: spur	M: medial L: lateral	II : joint sound level ≥ 5 dB

ported an attempt to localize loose bodies in the knee joints by auscultation in 1885. Later Blodgett studied the knee joint sounds with the stethoscope in 1902. Walters, after examining 1,600 joints, reported in 1929 that joint sounds were audible with aging. The first to use a microphone was Erb (1933). Peylan (1953) was first to use the word "phonoarthrograph". He studied joint sounds by using an electronic stethoscope. In 1960, Fischer and Jonson analyzed knee joint sounds using a binaural microphone held to the knee by suction. However, the above-mentioned investigators were unable to eliminate extraneous noise, such as background noise, skin friction, hand tremor and snapping noise. Further, the instrumentation setup was of rather poor quality, for example, the microphones used had a rather limited frequency response in the audio sound level.

Using modern instrumentations in 1976 Chu *et al.* reported that a double microphone method to eliminate extraneous noise and a computer. They also studied joint-sounds in an anechoic chamber. They mentioned in 1978 that "the recently developed computer-aided, electro-acoustical technique, utilizing the acoustic energy emitted by the joint during active articulation, appears to be a promising noninvasive clinical tool". They further stated, "the recent additions of a three-dimensional spectral history plot graphically presents the extent and location of cartilage in a clinically related form". On the other hand, Mollan *et al.* (1982) analyzed not sounds but vibration emissions from joint and tissues by using piezo-electric accelerometers. Further Cowie *et al.* (1984), Wallace *et al.* (1985) and McCrea *et al.* (1985) published the following reports: "Vibration Emission in Detecting Congenital Dislocation of Hip", "Preliminary Report on a New Technique to Aid Diagnosis of Some Disorders Found in Hands", and "Vibrationsarthrographie in der Diagnostik von Kniegelenkskrankheiten" in the same way as Mollan.

This method of analyzing vibration emissions eliminates most of the background noise and helps to determine the site where emits vibrations in the joint. However there are the disadvantages of being easy to have influence on extravibration of the accelerometer's cord and the difficulty in attaching it to the skin. However, even with these disadvantages we believe that this method is worth supplementary examination.

Our method is similar to that of Chu's group, but their double microphone method was a serious defect. That is, Inoue *et al.* (1986) proved that because of the appearance of peak and dip frequencies in a spectrum, the use of a double microphone with a differential amplifier to subtract the signals between two microphones was not suitable for the measurement of knee joint sounds. We contrived a method to eliminate extraneous noise and to analyze joint sounds: 1) Background noise is minimized by measuring the joint-sounds in an anechoic chamber. 2) Coupler noise is eliminated by ventilation holes. 3) Skin friction noise is eliminated by using the ultra-sonic gel. 4) It is possible to obtain the actual spectrum of knee joint-sounds by subtracting the spectrum of background noise from the spectrum of recorded knee joint-sounds.

Our study showed that joint-sounds exist at a point lower than 3.5 kHz and the majority of them being lower than 2.5 kHz. We believe that there are two main kinds of joint-

sounds, that is, at the low frequency sound level and at high frequency. Chu *et al.* (1978) reported the presence of joint-sounds at about 1600 Hz but he concluded that it was due to the background noise. We think this may be a mistake as background noise in an anechoic chamber exists lower than 200 Hz. The significance of joint-sounds at the high frequency sound level is unknown but we think that it is due to the thickness and the hardness of the articular surface, because joint-sounds at the high frequency sound level frequently occur in the joints of young people and those who participate in sports.

Next we investigated the significance of joint-sounds at the low frequency sound level. In a normal knee there are little differences in changes as seen on the X-ray films between joint-sounds and silence. On the other hand, in an osteoarthrotic knee there are five different sites as shown on the X-rays—medial and lateral spur formation of the patello-femoral joint (PSPM, PSpL); medial sclerosis, medial and lateral spur formation of the tibio-femoral joint (TScM, TSpM, TSpL)—between joint-sounds and silence. We think that joint-sounds reflect not only on changes of bone but also on something else due to osteoarthrosis. There are few differences in changes as proven on the X-rays between the osteoarthrotic knees in which joint-sounds do not occur and the normal knees. This means that the change as shown on the X-rays of the osteoarthrotic knees in which joint-sounds do not occur is mild. Further the sounds which are concerned with the degenerative changes as seen on the X-rays exist mainly from 0.5 kHz to 1.0 kHz.

Conclusion

The joints cause two kinds of sounds: at the low frequency sound level and at the high frequency sound level. The sounds which are concerned with the changes as seen on the X-rays exist at the low frequency sound level. We believe that this method is noninvasive and useful for the diagnosis of osteoarthrosis of joints.

Acknowledgments

I wish to thank Prof. K. Suzuki and Assist. Prof. Y. Kobayashi for direction of this manuscripts, and also extended my gratitude to Mr. J. Inoue and Mr. H. Takyu for their assistance in the preparation of this paper.

This study was supported in part by a Grant-in-Aid for Scientific Research from the Ministry of Education, Science and Culture (No. 60771150).

A summary of this paper was presented at the 58th Annual Meeting of Japanese Orthopaedic Association (Gifu, 1985) and at the 15th Symposium of European Society of Osteoarthrology (Kuopio, Finland, 1986).

References

- Blodgett, W. E. (1902): Auscultation of the knee joint. *Boston Med. Surg. J.*, 146 (3): 63-66.
- Chu, M. L., Gradisar, I. A., Railey, M. R. *et al.* (1976): An electro-acoustical technique for the detection of knee joint noise. *Med. Res. Engineering*, 12 (1): 18-20.
- Chu, M. L., Gradisar, I. A., Zavodney, L. D. (1978): Possible clinical application of a noninvasive monitoring technique of cartilage damage in pathological knee joints. *J. Clin. Engineering*, 3: 19-27.
- Cowie, G. H., Mollan, R. A. B., Kernohan, G. W. *et al.* (1984): Vibration emission in detecting congenital dislocation of hip. *Orthop. Rev.*, 13: 73-78.
- Erb, K. H. (1933): Über die Möglichkeit der Registrierung von Gelenkgeräuschen. *Dtsch. Z. Chir.*, 241: 237-245.
- Fischer, H. & Jonson, E. W. (1960): Analysis of sounds from normal and pathologic knee joints. *3rd. Int. Congr. Phys. Med.*, 50-57.
- Heuter, C. (1885): *Grundriss der Chirurgie* 3. Aufl. Vogel, Leipzig. (quotation from Steindler, 1937)
- Inoue, J., Nagata, Y., Suzuki, K. (1986): Measurement of knee joint sounds by microphone. *J. UOEH*, 8: 307-316.
- McCrea, J. D., McCoy, G. F., Kernohan, W. G. *et al.* (1985): Vibrationsarthrographie in der Diagnostik von Kniegelenkskrankheiten. *Z. Orthop.*, 123: 18-22.
- Mollan, R. A. B., McCullagh, G. C., Wilson, R. I. (1982): A critical appraisal by auscultation of human joints. *Clin. Orthop.*, 170: 231-237.
- Peylan, A. (1953): Direct auscultation of the joints. *Rheumatism*, 9: 77-81.
- Steindler, A. (1937): Auscultation of joints. *J. Bone Joint Surg.*, 19: 121-136.
- Wallace, R. G. H., Mollan, R. A. B., Kernohan, W. G. (1985): Preliminary report on a new technique to aid diagnosis of some disorders found in hands. *J. Hand Surg.*, 10-B: 269-272.
- Walters, C. F. (1929): The value of joint auscultation. *Lancet*, May 4: 920-921.

 関節と音 — 変形性膝関節症に対する臨床応用 —

永 田 善 之

産業医科大学整形外科教室

要 旨: 関節から音が生じることは昔から知られているが、その意味についてはほとんどわかっていない。著者はコンピュータを用いた新しい分析方法を開発し、膝関節を用い臨床診断に応用したので、その結果を報告する。まず関節から得られた音の平均スペクトラムから関節音響図を求め、その型分類を行った。そして関節の音は、低周波領域の音と、高周波領域の音とに分けられ、骨変化の影響を大きく受けるのは、低周波領域の音であることがわかった。また正常な膝関節では音と骨変化に関連は見られないが、変形性膝関節症では音の生じる場合、音のしない関節に比べて膝蓋大腿関節における内、外側の骨棘形成、そして脛骨大腿関節における内側の骨硬化、さらに内、外側の骨棘形成の5箇所骨変化が有意に進行していた。すなわち、音の検査は変形性膝関節症の骨変化の程度を推測でき、診断的価値がある。

J. UOEH (産業医大誌), 10 (1): 47-58 (1988)