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CLASSFICATION OF ARTHRITIC PATHOLOGY USING ACOUSTIC SIGNAL PROCESSING

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Abstract: We have evaluated and classified arthritic pathology by using acoustic analysis of knee joint sound signals. Six normal and 11 patients with knee problem were enrolled. Patients were divided into the 1st patient group needed an orthopeadic surgery because of the ruptured wounds of meniscus or ACL (Anterior Cruciate Ligament) and 2nd patient group diagnosed as osteoarthritis. In sitting and standing, subjects flexed and extended the knee joint, the sounds and angle of knee joint were collected. Dynamic Time Warping (DTW) was applied for normalizing a time-axis. The fundamental frequency, the mean amplitude of pitch, jitter, shimmer were analyzed according to a position and among 3 groups. The results showed that the fundamental frequency of the 2nd patient group or standing groups were higher than the others and the pitch of sounds was varied unstably.

Key words: knee joint sound, fundamental frequency, mean amplitude, jitter, shimmer

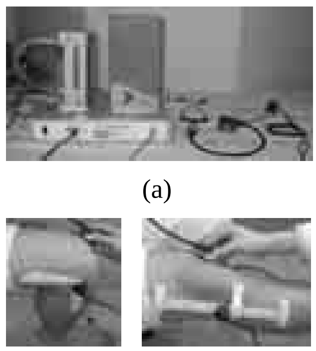
Introduction

The knee is the most commonly injured in the body. Arthritic degeneration of injured knees is a well-known phenomenon, and is known to result from a variety of traumatic causes. However, the major problems in discerning the causes or progression of knee joint disorders are the simple inability to detect articular cartilage changes until they are gross, either anatomically or symptomatically. X-rays, CT and MRI scans offer some hope for non-invasive detection of major cartilage pathology, but do nothing to characterize the functional integrity of the cartilage. An interesting possibility for quantitative, non-invasive analysis of cartilage pathology is by the analysis of joint sounds. Chu at. al. began the true scientific analysis of joint sounds in a series of papers dealing with methods to reduce skin friction and ambient noise; the use of statistical parameters such as autocorrelation function of the knee sound signal for classification of signals into categories, such as rheumatoid arthritis, degenerative arthritis and chondromalacia patella; and the relation-ship between signal acoustic power and articular cartilage damage [1-2]. Mollan reported contact vibration sensors are better suited to the recording of vibration emitted by knee joints [3-7]. Another report from a Japanese researcher discussed procedures for the reduction of noise in the recording of knee joint sounds and the potential of frequency analysis of the sound signals using a narrow band spectrum analyzer in the diagnosis of osteoarthrosis [8]. In this study, we removed skin frictional noise added during collecting the sound using the pre-processing algorithm and normalized a time axis using dynamic time warping. And we analyzed acoustic characteristic parameters between normal and patient group during the knee movement and classified patient groups by an articular pathology.

Materials and Methods

Eleven patients (7 males and 4 females) who were diagnosed as meniscus tearing of the knee joint by physical examination and MRI took part in this study as an experimental group and they were divided into two groups. The 1st patient group needed an orthopaedic surgery because of the ruptured wounds of meniscus or ACL and the 2nd patient group was diagnosed as osteoarthritis. Six normal subjects(4 males & 2 females) were enrolled as the control group.

An electro-stethoscope (SP-S1™, Hanbyul Meditec, Korea), utilizing a high efficiency piezo-polymer sensor was used. Joint sound signals were stored in PC through the A/D converter (MP-100™, Biopac systems, USA). The recorded signals were then digitized with a sampling rate of 1.7 kHz and 12 bit/sample. An electro goniometer to measure the angle of the limb movement was placed on the lateral aspect of the knee with the axis of rotation at the joint line. A silicon gel was located between the stethoscope and knee joints in order to remove any noise which occurred in the electronic stethoscope and the interface of the knee joint. In sitting and standing, each subject was underwent active knee flexion and extension between 90° and 0° for 20 seconds keeping the velocity regularly using the Metronome.



(a) (b) (c)

Figure 1: (a) Experimental device (b) knee joint in 90° flexion, (c) knee joint fully extended (0° flexion)

Pre-processing algorithm removing a noise and DTW normalizing a time-axis was applied. The characteristic parameters - the fundamental frequency (F0), the mean amplitude of pitch (A0), jitter and shimmer were calculated by these formulas.

$$F0(Hz) = \frac{1}{N}\sum_{i=1}^{N}\frac{1}{P_i} \quad (1)$$

$$A0(dB) = \frac{1}{N}\sum_{i=1}^{N} 20\log(A_i) \quad (2)$$

$$Jitter\ (\%) = \frac{\frac{1}{N-1}\sum_{i=1}^{N-1}\left|P_i - P_{i+1}\right|}{\frac{1}{N-1}\sum_{i=1}^{N} P_i} \quad (3)$$

$$Shimmer(\%) = \frac{\frac{1}{N-1}\sum_{i=1}^{N-1}\left|A_i - A_{i+1}\right|}{\frac{1}{N-1}\sum_{i=1}^{N} A_i} \quad (4)$$

The fundamental frequency means the variation of pitch per 1 second. The mean amplitude means the average amplitude of signal during 1 cycle of pitch. Jitter and shimmer means the variation ratio of pitch. The higher jitter or shimmer is, the unstable the period and amplitude is. P_i is the period of pitch, A_i is the amplitude and N is a number of total pitch.

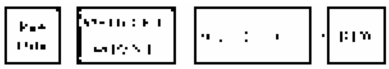


Figure 2: Pre-processing algorithm

Results

According to a position. The characteristic para-meters of each group in sitting or standing were evaluated and statistical difference was analyzed using unpaired T-test and ANOVA test. As a result, there was no difference in control group. But in experimental group, the mean of characteristic parameters in standing was higher than values in sitting ($p<0.05$). This result showed that the pitch perturbation of the knee joint sounds in standing was more unstable than in sitting.

According to groups. The F0, jitter, shimmer had statistical differences among three groups and A0 had no meaning. Without reference to a position, the mean of characteristic parameters of the 1st Patient group was lower than others except A0 ($p<0.05$). Comparing the control group ($p<0.05$). It showed that the fundamental frequency and the pitch perturbation of the control and the 2nd patient group was higher than the 1st patient group and the pitch of joint sound signal varied rapidly and unstably. The significant difference of the mean of parameters between the control and the 2nd patient group was not revealed.

Table 1: The mean values of characteristic parameters in each group according to a position

		F0 (Hz)	Jitter (%)	A0 (dB)	Shimmer (%)
Control	Sitting	# 175.61 (115.18)	# 53.14 (26.34)	0.8737 (4.8464)	# 36.47 (20.70)
	Standing	# 210.02 (122.52)	# 57.51 (23.86)	0.7436 (4.4563)	# 40.27 (20.83)
1st Patient	Sitting	* # 140.43 (105.37)	* # 45.93 (23.35)	0.6968 (3.5460)	# 34.55 (18.41)
	Standing	* # 179.95 (111.44)	* # 51.49 (20.39)	0.3973 (1.9199)	# 36.17 (15.12)
2nd Patient	Sitting	* # 182.14 (120.02)	* # 55.51 (25.94)	0.5613 (3.2915)	* # 40.01 (19.67)
	Standing	* # 235.29 (120.75)	* # 62.19 (23.08)	0.4796 (3.1033)	* # 44.25 (18.85)

( ): S.D
***:** comparison between sitting and standing, $p<0.05$
#: comparison between control and experimental group, $p<0.05$

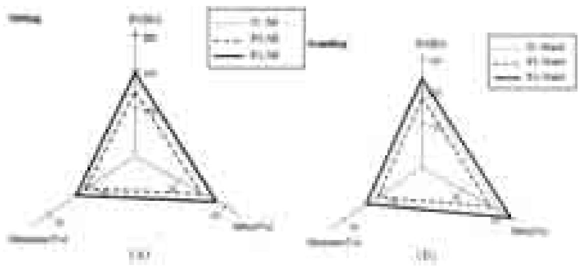
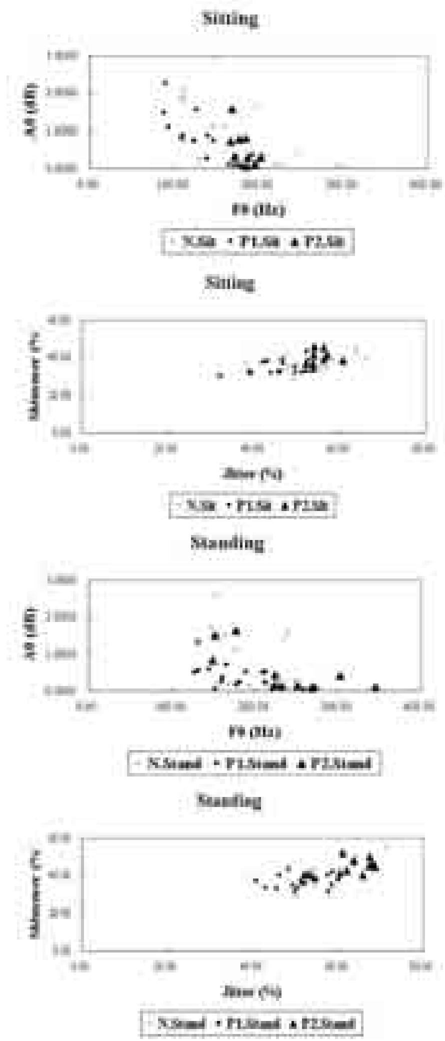


Figure 3: Characteristic parameters in each group; (a) sitting, (b) standing



(a)
(b)
(c)
(d)

Figure 4: The distribution of characteristic parameters: sitting (a) F0-A0, (b) jitter-shimmer; standing (c) F0-A0, (d) jitter-shimmer (N: control group, P1: the 1st patient group, P2: the 2nd patient group)

Discussion

The fundamental frequency and pitch perturbation in standing were higher than others, so knee joint sounds revealed an unstable aspect. The more stress was forced into the knee joint by the weight of subjects, the higher pitch of joint sound varied more rapidly and unstably. In case of the 1st patient group, the knee joint was injured at the particular partial region by some accident so pitch changed at the special angle of knee movement. And also, due to the instability of the inner structure of the knee joint, a contact region between the patella and the femur was narrow or blood and an exudation in articular cartilage made the coefficient of friction lower. But in case of the 2nd patient group, inflammation and cartilage degeneration affect seems to be the knee joint evenly, so pitch perturbation changed intensively at all angle regardless of the particular angle.

Conclusions

In this study, we collected the joint emanating sounds during the knee movement and evaluated the characteri-stic parameters and analyzed differences between sitting and standing position and differences among 3 groups. The results showed that the fundamental frequency and the pitch perturbation of the 2nd patient group or standing groups were higher than others. Further detailed studies of knee joint disorder must be made with a large number of patients. These results suggest that detection of knee joint problems via analysis of knee joint sound signals could help avoid unnecessary exploratory surgery, and also aid better selection of patients who would benefit from surgery.

References

1. Chu ML, Gradisar IA, Railet MR, Bowling CF, Detection of knee joint disease using acoustical pattern recognition technique, J. Biomechanics, 1976; 9: 111-114
2. Chu ML, Gradisar IA, Railey MR, Bowling GF, A non-invasive electroacoustical evaluation technique of cartilage damage in pathological knee joints, Medical & Biological Engineering & Computing, 1978; 16: 437-442
3. Mollan RAB, McCullagh GC, Wilson RI, A critical appraisal of auscultation of human joints, Clinical Orthopaedics and Related Research, 1982; 231-237
4. Kernohan WG, Mollan RAB, Microcomputer analysis of joint vibration, J. Microcomputer Applications, 1982; 5: 287-296
5. Mollan RAB, kernohan WG, Watters PH, Artefact encountered by the vibration detection system, j. Biomechanics, 1983; 16: 193-199
6. Kernohan GW, Beverland DE, McCoy GF, Shaw SN, Wallace RGH, McCullagh GC, Mollan RAB, The diagnostic potential of vibration arthrography, Clinical Orthopaedics and Related Research, 1986; 106-112
7. McCoy GF, McCrea JD, Beverland DE, Kernohan WG, Mollan RAB, Vibration arthrography as a diagnostic aid in disease of the knee, J. Bone and Joint Surgery, 1987; 69-B: 288-293
8. Nagata Y, Joint-sounds in gonoarthrosis : Clinical application of phonoarthrography for the knee, J. UOEH, 1988; 10: 47-58
9. Song CG, Kim JM, Lee MH, Perturbation analysis of EGG for Detecting Laryngeal Pathology, Proc. 15th Int. IEEE EMBS Conf., San Diego, U.S., 1994; 1344-1345
10. Myers C, Rabiner LR, Performance tradeoffs in dynamic time warping algorithms for isolated word recognition, IEEE trans., 1980; ASSP-28: 6: 575-582
11. Frank CB, Rangayyan RM, Bell GD, Analysis of knee joint sound signals for noninvasive diagnosis of cartilage pathology, IEEE Engineering in Medicine and Biology Magazine, 1990; 9: 65-68

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