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Estimation algorithm of the bowel motility based on regression analysis of the jitter and shimmer of bowel sounds

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ABSTRACT

Bowel sound (BS) signals can be used clinically as useful indicators of bowel motility. In this study, we devised a modified iterative kurtosis-based detector algorithm, in order to enhance the de-noising performance of BS signals, and an estimation algorithm of bowel motility based on the regression modeling of the jitter and shimmer of BS signals obtained by auscultation. The correlation coefficient, coefficient of determination and errors between the colon transit times measured by a conventional radiograph and the corresponding values estimated by our method were 0.987, 0.974 and 3.5 ± 3.3 h, respectively. These results demonstrated that our method could be used as a complementary tool for the non-invasive diagnosis and monitoring of bowel motility, instead of conventional radiography.

1. Introduction

Bowel motility is known to be mainly controlled by the vagus and hypogastric nerves and the nervi erigentes, which are complexly connected between the spinal cord and intestine wall [1]. Radiological scoring methods such as the Barr and Blethyn scores [2] and colon transit time (CTT) [3–5] which operate by means of X-rays and MRI, have generally been used for the assessment of bowel motility and, among these methods, the CTT described by Metcalf [3] is considered to be the 'gold standard'. The CTT is easily assessed in clinical practice by measuring the movement of radiopaque markers taken at a fixed time after their ingestion. This test is highly reproducible and most useful in determining whether constipation symptoms are associated with normal or slow transit. However, the assessment of the CTT needs an expensive, bulky and cumbersome radiological instrument, as well as at least 7 days for the test, and could do harm to the health of the subjects, due to their frequent exposure to radiation.

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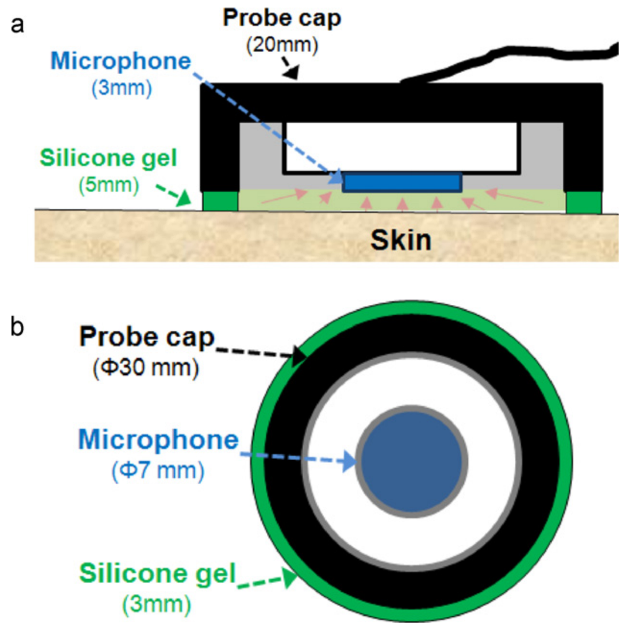

Fig. 1 – (a) Longitudinal and (b) transverse sectional views of noncontact-type probe devised for reducing the background sound noise.

In an attempt to overcome these problems, many researchers have continued to assess motility using bowel sound (BS) signals obtained by means of auscultation [6–12]. Recently, combination with manometric and BS-based studies have been conducted in order to quantify gastrointestinal motility using various features (time-duration analysis, motility-/sound-index, sound to sound interval, number of events, etc.) [13–18]. These BSs are produced by the movement of the intestinal contents in the lumen of the gastrointestinal tract during peristalsis, hence they can be used clinically as useful indicators of bowel motility. Nevertheless, besides the inherent BSs, various background sound (BGS) signals such as heart sounds, breathing, blood flow or ambient sounds, as well as the noise due to the acoustic effects of the stethoscope, might be unnecessarily superimposed onto the informative BS signals recorded from the abdomen by means of auscultation and could therefore inhibit the correct detection of the inherent BS. Several researchers have continued to analyze BS signals using adaptive filtering, wavelet transforms, fractional dimension-based detectors, and auto-regressive and neuro-fuzzy modeling [16–22]. Nevertheless, these techniques have not been widely used for the diagnosis of bowel syndrome as yet, due to its non-stationary and multi-component characteristics. Also, the conventional iterative stationary/nonstationary signal separation techniques (i.e. wavelet transform-based or fractal dimension-based filters) can provide erroneous BS detection and segmentation due to misinterpretation of regularly sustained (RS) signals (i.e. crepitating, musical/whistling BS) frequently presented during auscultation [16,23]. Recently, Rekanos and Hadjileontiadis [24] proposed an iterative kurtosis-based detector (IKD) algorithm for the detection of BS and demonstrated its effectiveness. However, unfortunately, in this algorithm, since the threshold used for the detection of the BS portions is adjusted by varying the power of the overall BGS signals rather than the kurtosis of the inherent BS signals at a particular time, significant numbers of relatively subtle BS segments could be missed or incorrectly detected. Moreover, even though there have been some comparative studies on the BSs of normal subjects and those of patients with bowel dysfunction, few studies have been conducted on quantified estimation algorithms of bowel motility based on the jitter and shimmer of the BS signals.

The aim of this study is to develop an improved de-noising algorithm, in order to enhance the performance of BS detection, and a non-invasive estimation method of bowel motility, based on regression modeling using the acoustical features, such as the jitter and shimmer of the BS signals and their trace, during the digestive process for the continuous monitoring of the bowel motility. This approach has not been attempted in previous studies. We devised a modified IKD algorithm, in order to enhance the performance of the conventional IKD algorithm, and a portable BS measurement system. Also, we calculated the acoustical features of the BS signals obtained by an auscultation, derived a regression equation between these features and the measured CTT, and finally determined the feasibility of the proposed method.

2. Materials and methods

2.1. *Bowel sound measurement system*

The developed system consists of a stethoscope-like probe, sensor module for signal conditioning and monitoring software used to store the data and calculate the characteristic parameters. Fig. 1 shows the noncontact-type probe newly designed for the purpose of selectively logging the inherent BS signals and minimizing the BGS. A piezo-polymer microphone (CM-01B, Measurement Specialties Inc., U.S.) with a frequency bandwidth of 8–2200 Hz is installed inside the probe cap perpendicular to the auscultation site. The use of silicone gel enables to minimize the noise due to friction, as well as provide good acoustic contact. The frequency content of the BS signals is known to be energetic mainly between 100 and 500 Hz: only approximately 0.5% of the signal energy is located beyond 1000 Hz, and this percentage goes up to approximately 2% for frequencies beyond 500 Hz [9,18]. Thus, the sensor module consists of a 60 Hz notch filter for removing the power noise and 5–600 Hz band-pass filter for reducing the motion artifact noise caused by respiration activation and unwanted BGSs. After being conditioned, the signals are digitized by an A/D converter (USB-6009, National Instruments^{TM}, U.S.) at a sampling rate of 8 kHz and resolution of 14 bits. LabVIEW-based (ver. 8.6, National Instruments^{TM}, U.S.) monitoring software was developed for this system. This can continuously show the traces of the BS signals on a monitor and play the sounds of the selected channel via a speaker, as well as simultaneously store the data on the hard-disk drive.

2.2. *Data acquisition*

Ethical approval for this study was obtained from the Institutional Review Board (IRB) of Chonbuk National University