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Original article

Evaluation of airflow limitation using a new modality of lung sound analysis in asthmatic children

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ABSTRACT

Background: Reliable assessment of not only symptoms but also lung function is essential in asthma management. We developed a new technology for analyzing lung sounds and assessed its clinical usefulness in asthmatic children.
Methods: Forty-four children underwent lung sound recording with simultaneous airflow measurement using a sensor on the upper right anterior chest. We calculated a sound parameter index from the amplitude of inspiratory lung sounds at 700 Hz (ic700). ic700 were compared depending on flow and body size. In addition, 184 asthmatic children and 16 non-asthmatic children underwent lung sound analysis and lung function test in an asymptomatic state. In the asthma group, 135 children received treatment continually. The untreated asthma group included 28 children who had never received treatment continually and 21 children who had not been treated for at least 1 year. The asthmatic children were divided into four classes according to asthma severity. ic700 were compared depending on spirometric parameters and asthma severity classification.
Results: The influences of flow and body size were negligible for ic700. ic700 correlated with FEV_1%, MMF and FEF50 ($r = -0.436$, -0.339 and -0.302, respectively). There was a significant difference of ic700 between asthmatic and non-asthmatic children ($p < 0.001$), and ic700 correlated with the classification of asthma severity ($p < 0.001$). The ic700 scores of the severe group were higher than those of the intermittent group and non-asthmatic children.
Conclusions: It was possible to evaluate airway dysfunction of asthma using ic700, which was calculated non-invasively by analyzing lung sounds alone, without measuring body size and airflow.

Introduction

Asthma control should include not only clinical manifestations, but also objective parameters of airflow limitation and airway inflammation.[1] Reliable assessment of asthma control is essential to manage asthma efficiently.[2] Therefore, objective monitoring will be a useful tool in the management of small asthmatic children. However, for small children, it is not easy to perform lung function tests.

Lung sound analysis is a non-invasive method that does not require the cooperation of small children. Airway inflammation and airflow limitation affect breath sounds even in the absence of adventitious sounds.[3–5] Recent developments in signal processing methods have improved the possibility of extracting physiologically and clinically relevant information from lung sounds.[3–5] It has been reported that acoustic transfer characteristics may be affected by airway wall compliance, airway diameter and energy dissipation caused by respiratory motion.[6–8]

We reported our indices of lung sound analysis that uses acoustic transfer characteristics of the pulmonary system, which were measured at 2 points, namely, trachea and chest surface, while evaluating asthmatic children. Our acoustic indices were not affected by body size and airflow.[9] We also reported that our index

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of lung sound analysis correlated with C-ACT score and indicated the level of control of asthma in this journal in 2013.[10] Subsequently, we attempted to simplify this measurement and developed a new index that requires the measurement of lung sounds at only one location on the chest surface and can also avoid the effects of body size and airflow. In this study, we investigate whether this new index of lung sound analysis can detect flow limitation.

Methods

Subjects and study design

We examined 44 healthy children (age: median 10 years, from 5 to 15 years; height: median 136 cm, from 113 to 171 cm; weight: median 33 kg, from 17 to 60 kg) and recorded lung sounds with airflow. All the patients changed their breath pattern, involving alternation between shallow and deep breathing. Lung sounds were recorded at the upper right anterior chest at the second intercostal space on the midclavicular line, using a sound sensor (MA-300; FUKUDA DENSHI, Tokyo, Japan) fixed with tape (H260; NIHON KOHDEN, Tokyo, Japan) on the chest wall. Airflow was measured using a Lilly-type flow meter, Lung Sound Analyzer (LSA-2000; KENZMEDICO, Saitama, Japan). The analog signal output of airflow was taken from LSA-2000 and recorded with lung sounds on a hard disk. Lung sounds were compared depending on airflow, height and weight.

In addition, 184 outpatients in Minami Wakayama Medical Center and 16 non-asthmatic children were examined. The non-asthmatic children were attendees at a regular health examination. The subjects' baseline characteristics are listed in Table 1. The diagnosis and classification of asthma were made according to international guidelines.[11,12] A total of 135 asthmatic children with mild, moderate and severe persistent asthma were treated continuously with inhaled corticosteroid and/or leukotriene receptor antagonists. The untreated asthma group included 28 children who had never received treatment continually and 21 children who had not been treated for at least 1 year.

All participants underwent lung sound recording for at least 20 s. After this recording, all participants underwent lung function testing (CHEST GRAPH HI-105; CHEST, Tokyo, Japan). All the tests were performed during the asymptomatic period. The asymptomatic period is defined as the period without any respiratory or systemic symptoms including asthma attack, upper or lower respiratory infections and upper respiratory infections with cough. It was also ensured that the breath sounds did not include wheezes or crackles on the basis of auscultatory findings or the findings of breath sound analysis.

Written informed consent was obtained from all the studied subjects or their legal guardians, and the study protocol was approved by the ethics committee of our institution.

Table 1
Patient characteristics.

	Total ($n = 200$)	Asthma ($n = 184$)	Non-asthma ($n = 16$)
Gender M/F	117/83	108/76	9/7
Median age (years)	10.6	11.6	7.4
Range (years)	4.3–15.1	4.3–15.1	6.0–14.9
Median height (cm)	138.0	139.0	123.3
Range (cm)	97.2–172.4	97–172	106–166
Median weight (kg)	33.3	34.1	21.5
Range (kg)	14.3–95.0	14.3–95.0	19.2–54.0

Sound recording and signal processing

A schematic block diagram of the recording system is presented in Fig. 1. Lung sounds were recorded at the upper right anterior chest at the second intercostal space on the midclavicular line, using a sound sensor (MA-300; FUKUDA DENSHI) fixed with tape (H260; NIHON KOHDEN) on the chest wall. The audio signal was digitized at 48 kHz and 24 bits per sample by an audio interface (Fireface UC; RME, Germany), and recorded on a hard disk of a notebook PC (Let's Note CF-C1; Panasonic, Osaka, Japan). The lung sounds were recorded in a quiet room for at least 20 s while the patients were able to breathe quietly.

Prior to sound analysis, we carefully listened to all recordings and reviewed the spectrogram to exclude noise such as friction and environmental noise. Since the audio signal of inspiratory breath sounds has greater amplitude than that of expiration, the inspiratory and expiratory phases can be identified.

Lung sounds were re-sampled at 6 kHz, and 512-point fast Fourier transformation (FFT) was performed with 75% overlap into adjacent segments, using a Hanning data window. Values of the index, which will be explained in the following section, were calculated for all inspiratory lung sounds, and then the median was calculated.

Index of chest at 700 Hz (ic700)

To avoid the effects of the influence of airflow on lung sounds, we used wide band power of breath sounds between 150 and 1550 Hz instead of measuring airflow directly. We determined the predicted value of sub-band power by regression analysis using the wide band power in normal subjects.[13] The frequency band of the sub-band power is between 650 and 750 Hz. We calculated the difference of lung sound power by subtracting the predicted value from the measured sub-band power of lung sounds. We called the difference of sub-band power (which has a central frequency of 700 Hz) ic700.

We set 0 dB of ic700 as the average power of lung sounds in normal subjects.

The lung sound power of asthmatic subjects who do not receive appropriate treatment is much larger than normal. The ic700 of these subjects was greater than normal.

Statistical analyses

The patients' demographic data are presented as median and range. The ic700 values are presented as median, range and mean ± SEM. Comparisons of ic700 between non-asthma and asthma groups were carried out using the unpaired *t*-test. The correlation coefficients were determined using Pearson's product–moment correlation coefficient. Comparisons of ic700 and spirometric parameters among all groups of asthma severity were made using the Kruskal–Wallis test. Values of $p < 0.05$ were considered statistically significant.

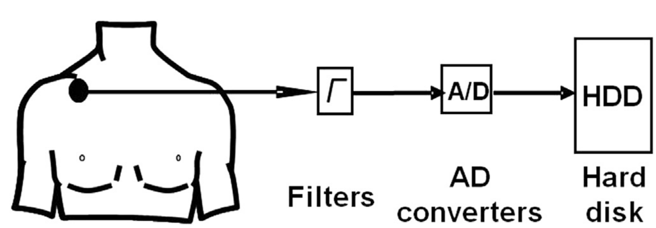

Fig. 1. Block diagram of the recording system. Breath sounds are measured at one location on the chest wall. The breath sounds are amplified and high-pass-filtered. Then, the breath sounds are converted from analog to digital form, and stored on a hard disk. A/D, analog-to-digital converter; HDD, hard disk.