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A novel method for detecting airway narrowing using breath sound spectrum analysis in children

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ABSTRACT

Background: Using a breath sound analyzer, we investigated new clinical parameters that are rarely affected by airflow in young children.

Methods: A total of 65 children with asthma participated in this study (mean age 9.6 years). In Study 1, the intra- and inter-observer variability was measured. Common breath sound parameters, frequency at 99%, 75%, and 50% of the maximum frequency (F_{99}, F_{75}, and F_{50}) and the highest frequency of inspiratory breath sounds were calculated. In addition, new parameters obtained using the ratio of sound spectra parameters, i.e., the spectrum curve indexes including the ratio of the third and fourth area to the total area and the ratio of power and frequency at F_{75} and F_{50}, were calculated. In Study 2, 51 children underwent breath sound analyses. In Study 3, breath sounds were studied before and after methacholine inhalation.

Results: In Study 1, the data showed good inter- and intra-observer reliability. In Study 2, there were significant relationships between the airflow rate, age, height, and spirometric and common breath sound parameters. However, there were no significant relationships between the airflow rate and the spectrum curve indexes. Moreover, the spectrum curve indexes showed no relationships with age, height, or spirometric parameters. In Study 3, all parameters significantly changed after methacholine inhalation.

Conclusions: Some spectrum curve indexes are not significantly affected by the airflow rate at the mouth, although they successfully indicate airway narrowing. These parameters may play a role in the assessment of bronchoconstriction in children.

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Abbreviations: FEV_1, forced expiratory volume in 1 s; FVC, forced vital capacity; Rrs, respiratory resistance; Dmin, minimal dose of methacholine; A_T, total area of sound spectrum; A_3/A_T, ratio of third area to total area; B_4/A_T, ratio of fourth area to total area; dB_{max}, power at the maximum point of power spectrum; F_{99}, frequency at 99% of the maximum frequency; F_{75}, frequency at 75% of the maximum frequency; F_{50}, median frequency of power spectrum; HFI, the highest frequency of inspiratory breath sound; RPF_{75}, ratio of power at F_{75} to frequency value ($F_{99}-F_{75}$); RPF_{50}, ratio of power at F_{50} to frequency value ($F_{99}-F_{50}$)

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1. Introduction

Although the use of pulmonary function tests in adults is well established, most infants and preschool children are not able to perform the physiological maneuvers required to complete these tests, because significant cooperation and perseverance is required of them during the test. Commercial devices using the forced oscillation technique have become available for application in younger children [1,2], but infants cannot be evaluated using this method, as they are unable to use the mouthpiece. These serious problems in the accuracy of the measurements of pulmonary function in infants and younger children have made the diagnosis of childhood asthma difficult and remain challenging for all physicians.

However, lung sounds are sensitive to airway changes. Recent developments in signal processing methods have improved the possibility of extracting physiologically and clinically relevant information from respiratory sounds [3–5]. Even in the absence of adventitious sounds, breath sounds may show changes when disorders of the respiratory system are present in terms of the frequency distribution [6–8]. In asthmatic children, the highest frequency of inspiratory breath sounds (HFI) indicates airway narrowing [9,10].

Moreover, breath sounds are strongly affected by pulmonary function [11]. In particular, the maximum airflow rate (L/s) has a potent effect on the sound spectrum [12,13]. Of course, pulmonary function also has a major effect on the airflow of breathing, and age and body size remarkably affect pulmonary function in children [14]. In consideration of these findings, we defined new parameters. The aim of the present study was to evaluate clinical sound parameters that are not significantly affected by the airflow rate of breathing or by age, height, or pulmonary function in order to assess bronchial constriction in younger children.

2. Patients and methods

2.1. Study subjects

The study participants included 65 pediatric outpatients treated at Tokai University Hospital from April 1, 2012, to March 31, 2014. All individuals had physician-diagnosed atopic-type asthma (age range 4–16 years, mean age 9.6 ± 3.0 years, male to female ratio = 43:22). The diagnosis of asthma was made according to international guidelines [15,16]. All drugs were withdrawn for 12 h before testing. None of the subjects had respiratory symptoms on the day of testing. Written informed consent was obtained from all children or their legal guardians, and the study protocol was approved by the institutional review board of Tokai University Hospital (No. 11R-158, approved December 21, 2011).

2.2. Study protocol

As a general rule, each subject was requested to take five airflow breaths in turn: tidal, large, small, very large, and tidal. Each kind of breath was repeated more than three times

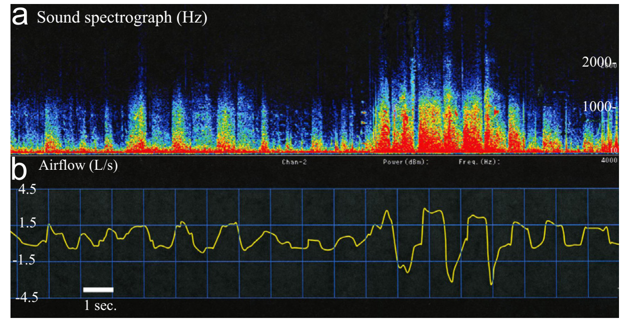

Fig. 1 – Sound spectrograph and airflow. (a) The spectrograph after a Fourier analysis, with the vertical axis showing the frequency in Hz and the horizontal axis showing time in seconds. The sound intensity of the breath sounds is indicated by the color. (b) The airflow recording with the vertical axis showing the airflow rate at the mouth (L/s) and the horizontal axis showing time (seconds).

at 1-second intervals signaled by a metronome (Fig. 1a and b). The airflow rate at the mouth was measured in all participants. It was confirmed that the breath sound samples included no wheezing or rales based on the findings of the breath sound analyzer. After a sound analysis, pulmonary function was tested using spirometry.

In Study 1, to examine the reliability of the parameters, one doctor measured these variables twice in each subjects at an interval of a few minutes to determine the intra-observer variability. To examine the validity of the measurements, two physicians measured the parameters in the same subjects at an interval of a few minutes to determine the inter-observer variability [17]. Individual representative sound samples were conventionally prepared for clinical use: (1) a sample with the median airflow rate at the mouth for six tidal breaths (first three and last three of 15 breaths), and (2) an assumed value 2.0 L/s airflow calculated based on an individual regression analysis formula for each subject, as the mean airflow value among the 65 participants was 1.74 L/s.

In Study 2, 51 of the 65 asthmatic children who agreed to participate in Study 2 underwent a breath sound analysis to evaluate new parameters. We assessed the correlations between the respiratory flow rate and each parameter. In Study 3, we performed a breath sound analysis in 14 children who agreed to participate in Study 3, and the assessments were performed before and after the methacholine inhalation test [10].

2.3. Pulmonary function tests

Pulmonary function was determined via spirometry using a calibrated computerized spirometer (Chestgraph HI-105; Chest Co., Bunkyo ward, Tokyo, Japan). The resting baseline was selected using the best of three results based on the highest sum of the forced vital capacity (FVC) and forced expiratory volume in 1 s (FEV_1). The results are shown as the percent predicted value applying prediction equations for Japanese children in Study 3.

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