The 19th International Conference on Lung Sounds

Presented by

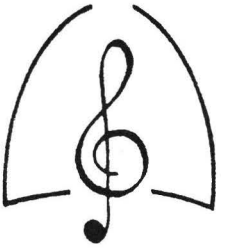
International Lung Sounds Association

September 28-30, 1994
Rappaport Family Institute for Research in the Medical Sciences
Technion - Israel Institute of Technology
Haifa, Israel

Pulmonary Physiology Unit
Department of Physiology and Biophysics
Rappaport Institute for
Research in the Medical Sciences
and
Bruce Rappaport Faculty of Medicine
Technion - Israel Institute of Technology
Haifa, Israel

Rappaport Institute

Rappaport Family Institute for Research in the Medical Sciences



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FINAL PROGRAM AND ABSTRACTS

Organization

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Wilmot Ball, MD	Baltimore, Maryland
Raphael Beck, MD	Calgary, Canada
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Filiverto Dalmasso, MD	Torino, Italy
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Raymond Murphy, MD	Boston, Massachusetts
Hans Pasterkamp, MD	Winnipeg, Canada
Anssi Sovijärvi, MD	Helsinki, Finland
Stuart Stoneman, MD	Swansea, United Kingdom

Local Organizers

Noam Gavriely MD, DSc	Coordinator
Yael Shabtai-Musih, DSc	
Moshe Nissan, PhD	
Muhammad Mahagna, MD	
Abbie Rosner	Administrator

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Address of the International Lung Sounds Association

INTERNATIONAL LUNG SOUNDS ASSOCIATION
Raymond L.H. Murphy, Jr., MD
1153 Centre Street
Boston, Massachusetts 02130 U.S.A.
Tel. (617) 522-5800, Ext. 1968

General Information

Conference Venue

Rappaport Medical Sciences Building, Efron St. Bat Galim, Haifa

Official Language

English

Registration

Registration will be held at the Rappaport Building, first floor on:

Wednesday September 28th	8:00 -	9:00 am
	12:30 -	2:00pm

Registration fees

Participants: $200, Spouses/companions: $50

Certification of attendance

Duly registered participants will be issued a certificate of attendance.

Posters and Poster - Discussion

Posters will be displayed at the conference room entrance from 1:30 pm on September 28th through 12:00 noon on September 30th. During the Poster Discussion Session (Session C, September 29th) each poster will be briefly presented and discussed (5 min, 3 slides maximum per poster).

Hotel accommodation

Nof Hotel, Hanasi Ave., Mount Carmel, Haifa, Israel
Fax 972-438-8810.
Telephone 972-435-4311

Lunch and coffee

Lunches and dinners on September 28th and 29th and coffee during coffee breaks are included in the registration fee of active participants. Dinners on September 28th and 29th are included in the spouse/companion registration fee.

Program outline

September 27th or earlier, arrival at the Hotel

September 28th

7:00- 8:00	Breakfast
8:00- 8:30	Transportation to the Rappaport Institute
8:30- 9:00	Registration
9:00- 9:20	Welcome address
9:20-12:30	Scientific Session A
12:20-14:00	Photo and Lunch; Registration; Poster hanging
14:00-17:00	Scientific Session B
20:00	Israeli Dinner- HaMoshava Haktana

September 29th

7:00- 8:00	Breakfast
8:00- 8:30	Transportation to the Rappaport Institute
8:30-10:00	Scientific Session C (Posters)
10:00-12:30	Scientific Session D
12:30-14:00	Lunch
14:00-17:00	Scientific Session E
20:00	Festive Dinner - National Museum of Science and Technology Old Technion Building, Balfour St, Hadar Hacarmel

September 30th

7:00- 8:00	Breakfast
8:00- 8:30	Transportation to the Rappaport Institute
8:30-12:00	Methodology Workshop
12:00	Conclusion

Sponsors

The organizers gratefully acknowledge the generous support of the Rappaport Family Institute for Research in the Medical Sciences.

The 19th International Conference on Lung Sounds

Rappaport Family Institute for Research in the Medical Sciences
Technion - Israel Institute of Technology. Haifa, Israel

Program

Wednesday, September 28th

7:00 - 8:00	*Breakfast*	
8:00 - 8:30	*Transportation to the Rappaport Institute*	
8:30 - 9:00	*Registration*	
9:00 - 9:05	Foreword	Prof. Noam Gavriely
9:05 - 9:20	Welcome Address,	Prof. Peretz Lavie, Dean, Bruce Rappaport Faculty of Medicine

Scientific Session A
Mechanisms and Physiology of Breath Sounds Generation and Transmission

Chairmen: A. Sovijärvi and D. W. Cugell

9:20 - 9:40	The Effect of Lung Volume on Lung Sound Transmission Using an Esophageal Accelerometer	Schreur
9:40 - 10:00	Gas Density does not affect pulmonary acoustic transmission in normal men	Mahagnah
10:00 - 10:20	'Vesicular' Sound Patterns in Tracheostomized Patients	Dalmasso
10:20 - 10:40	Airflow and Lung Volume Dependence of Inspiratory Normal Lung Sounds	Vanderschoot
10:40 - 11:00	*Coffee Break*	
11:00 - 11:20	Initial Cough Sound as Measures of Cough Intensity	Loudon
11:20 - 11:40	Acoustic Analysis of Capsaicin Induced Coughing in Normals	Doherty (Earis)
11:40 - 12:00	Sound Patterns of Snores and Their Mechanical Correlates	Beck
12:00 - 14:00	*Photo and Lunch; Registration; Poster Hanging*	

Scientific Session B
Algorithms and Hardware for Breath Sound Measurements

Chairmen: H. Schreur and H. Pasterkamp

14:00 - 14:20	Waveform Analysis of Percussion Sounds	Mori
14:20 - 14:40	Validation of a Method for Localizing an Intrathoracic Sound	Murphy
14:40 - 15:00	A New Crackle Detection Method Based on the Time-Frequency Representation of Respiratory Sounds	Sankur (Güler)
15:00 - 15:20	Feature Extraction and Classification of respiratory Sound Signals Based on the Multi-resolution Signal decomposition	Sankur (Güler)
15:20 - 15:40	*Coffee Break*	
15:40 - 16:00	A realistic Model for Air-Coupled Microphones as Stethoscopes	Sakao
16:00 - 16:20	Effect of Microphone air Cavity Width, Shape and Venting on Lung Sound Measurements	Kraman
16:20 - 16:40	Clinical Effectiveness of Wireless Stethoscope	Murata
17:00	*Transportation to Hotel*	
	(Steering Committee Meeting)	
20:00	*Israeli Dinner- HaMoshava HaKtana*	

Thursday, September 29th

7:00 - 8:00	*Breakfast*	
8:00 - 8:30	*Transportation to the Rappaport Institute*	

Scientific Session C - Poster Discussion

Chairmen: A. Rubin and S. Kudoh

9:00 - 9:10	Computer Aided Learning Program for Respiratory Sound Analysis	Helistõ
9:10 - 9:20	From Computer Assisted Instruction to Virtual Reality: Validating competency in the College Laboratory	Murphy M.
9:20 - 9:30	Lung Sounds Terminology in Case Reports	Loudon
9:30 - 9:40	Subjective Assessment of the Relative Duration of Lung Sounds	Murphy R.
9:40 - 9:50	Effect of Flow Rate on Breath Sound Intensity and Frequency Content in Normal Men	Gavriely
9:50 - 10:00		
10:00 - 10:20	*Coffee Break*	

Scientific Session D
Clinical Implementation of Breath Sound Analysis

Chairmen: M. Mori and R. Loudon

10:20 - 10:40	Variations of Breath Sound Parameters in Healthy Non-smoking Men and in Patients with Fibrosing Alvelolitis	Sovijärvi
10:40 - 11:00	The Phonospirometry	Dalmasso
11:00 - 11:20	Spectral Characteristics of Breath Sounds in Patients with Obstructive Lung Disease and with Healthy Lungs	Malmberg
11:20 - 11:40	Lung Sounds in Clinical Lung Disease: COPD vs. Chronic Bronchitis	Rubin
11:40 - 12:00	The PPG as a Complimentary Diagnosis Method - Final Research Summary	Nissan
12:00 - 14:00	*Lunch*	

Scientific Session E
Crackles, Bronchodilation, Bronchoconstriction, and Cough

Chairmen: S. Kraman and F. Dalmasso

14:00 - 14:20	Investigation on the Possibility that Crackles Belonging to a Single Inspiration Constitute a Significant Sample for Statistical Analysis	Rossi
14:20 - 14:40	Spatial Distribution of Crackles over the Chest Wall Surface	Davidson
14:40 - 15:00	The Effect of Bronchodilation on Intensity an Frequency Content of Lung Sounds	Schreur
15:00 - 15:20	*Coffee Break*	
15:20 - 15:40	Adenosine is More Specific Than Methacholine for the Diagnosis of Asthma in Young Children Performing the Auscultative Bronchial Challenge Method (PCw)	Avital
15:40 - 16:00	The Effects of Methacholine on Cough Sounds Spectra	Ishikawa
16:00 - 16:40	*ILSA Business meeting*	
17:00	*Transportation to Hotel*	
20:00	*Festive Dinner -* *National Museum of Science and Technology* *Old Technion Building, Balfour St., Hadar Hacarmel*	

Friday, September 30th

7:00 - 8:00	*Breakfast*	
8:00 - 8:30	*Transportation to the Rappaport Institute*	

Methodology Workshop

Bronchial Challenge Test - the Roll of Breath Sounds Assessment and its Standardization

Chairmen: S. Godfrey and J. Earis

9:00 - 9:20	Change in Normal Lung Sounds During Induced Airway Narrowing	Pasterkamp
9:20 - 9:40	3 Year Experience with Histamine Challenge with Computerized Lung Sounds Analysis Performed on Young Children	Beck
9:40 - 10:00	Measurement of Bronchial Hyperresponsiveness Based on Frequency Content of Respiratory Sounds in Asthmatic Children	Malmberg
10:00 - 10:20	*Coffee Break*	
10:20 - 11:20	Panel Discussion	
11:20 - 11:50	Summary and Perspectives - Guest Scientist: **Julian Solway M.D.**	
11:50 - 12:00	Concluding Remarks **Raymond L.H. Murphy Jr. M.D.**	

ABSTRACTS

THE EFFECT OF LUNG VOLUME ON LUNG SOUND TRANSMISSION USING AN ESOPHAGEAL ACCELEROMETER. H.J.W. Schreur, A.D. Van Dijk[&], J.G.J. Chin[&], J. Vanderschoot[#], J.H. Dijkman, P.J. Sterk. Departments of Pulmonology, [&]Cardiology, and [#]Medical Informatics, University of Leiden, The Netherlands.

Normal breath sounds are considered to originate in the central airways, and are strongly filtered by the parenchyma [Olson, Hammersley, Semin Respir Med 1985;6:171-9]. The transmission of these sounds to the chest wall is supposed to be dependent on lung density [Rice, Semin Respir Med 1985;6:166-170], but this has not been studied yet. Considering the proximity to the central airways, a sensor located in the esophagus will record virtually unfiltered breath sounds, thereby allowing the measurement of sound transmission to the chest wall.

We studied the influence of lung volume on breath sounds in 7 healthy men (age 21-42 yrs) during quiet standardized breathing for 30 s with airflows up to 1.5 L/s [Schreur *et al*, ARRD 1992;145:A496] in 3 lung volume ranges. Airflow and lung volume changes were recorded simultaneously with lung sounds at 3 locations on the right chest wall (over the 2nd (Mic1) and 5th (Mic2) intercostal space mid-clavicularly, and 9th intercostal space mid-scapularly (Mic3)) and 1 over the trachea (Mic4) using air-coupled microphones, and by one intra-esophageal accelerometer at the level of the main carina. Airflow-dependent power spectra were computed by fast Fourier transform for each 0.1 l/s, and averaged for subsequent breaths. From these spectra transmission characteristics from esophagus to external microphones were computed: the overall transmission (TR) and transmission power quartiles (T1, T2, T3). The effects of lung volume range were analyzed for airflows $\geq$ 0.8 L/s using ANOVA.

During inspiration TR was highest in the lowest lung volume range for Mic1 and Mic3 ($p \leq 0.035$), whereas TR decreased with decreasing lung volume range for Mic2 ($p = 0.015$). Table: at an inspiration 1.0 L/s TR (dB $\pm$ SD):

	TLC-1.5 L $\pm$ 1 L		TLC-0.4 $\times$ VC $\pm$ 1 L		TLC-0.6 $\times$ VC $\pm$ 1 L	
Mic1:	-12.1	(4.9)	-11.6	(6.8)	-6.4	(5.0)
Mic2:	-19.6	(8.1)	-22.6	(6.2)	-25.0	(6.5)
Mic3:	-20.3	(6.0)	-22.1	(9.2)	-17.3	(6.8)
Mic4:	-4.2	(4.3)	-5.0	(6.6)	-1.4	(7.0)

During expiration the effect of lung volume on TR was relatively small: TR increased with decreasing lung volume for Mic1 ($p = 0.028$) and tended to increase for Mic3 ($p \leq 0.058$). The transmission of sounds to Mic4 did not change with lung volume range ($p > 0.3$). T1-T3 were not dependent on lung volume range for any Mic.

We conclude that the magnitude of the transmission of lung sounds from the central airways to the chest wall is dependent on lung volume. This suggests that lung sounds at the chest wall reflect differences in the density of the parenchyma.

Supported by a grant of the Netherlands Asthma Foundation.

Gas density does not affect pulmonary acoustic transmission in normal men

Muhammad Mahagnah and Noam Gavriely

Department of physiology and biophysics, the Bruce Rappaport Faculty of Medicine and the Rappaport Institute for Research in the Medical Science. Technion-Israel Institute of Technology, Haifa, Israel.

Fremitus - the transmission of sound and vibration from the mouth to the chest-wall has long been used clinically to examine the pulmonary system. Recently, modern technology has become available to measure the acoustic transfer function (TF) and transit times (TT) of the pulmonary system. Since sound speed is inversely proportional to the square root of gas density in free gas, but not in porous media, we measured the effect of air and Heliox (80% He + 20% O_2) breathing on pulmonary sound transmission in six healthy subjects, in order to investigate the mechanism of sound transmission. Wide-band noise (75-2000 Hz) was "injected" into the mouth and picked up over the trachea and the chest wall. The averaged power spectra, TF, phase, and coherence were calculated using a fast Fourier transform (FFT)-based algorithm. The phase data were used to calculate TT as function of frequency. TF was found to consist of a low-pass filter property with essentially flat transmitted energy to 300 Hz and exponential decline to 600 Hz at the anterior right upper lobe (CR), and flat transmission to 100 Hz with exponential decline to 150 Hz at the right posterior base (BR). TF was not affected by breathing Heliox. The average TT values, calculated from the slopes of the averaged phase, were 1.5 ± 0.46 ms, for trachea to CR , and 5.2 ± 0.5 ms for trachea to BR transmission during air breathing. During Heliox breathing the values of TT were 1.48 ± 0.5 ms and 4.9 ± 0.4 ms from the trachea to CR and from the trachea to BR locations, respectively These results suggest that sound transmission in the respiratory system is dominated by wave propagation through the parenchymal porous structure.

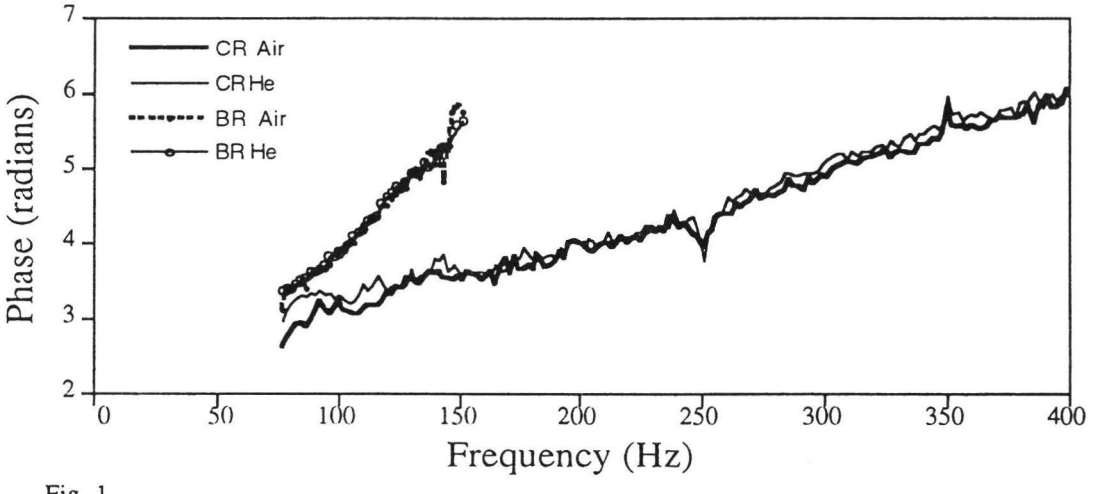


Fig. 1
The averaged phase of TR - to - CR and TR - BR acoustic transmission (average of six subjects) during air and heliox breathing. Note that there are no density effects on range or slopes.

'VESICULAR' SOUND PATTERNS IN TRACHEOSTOMIZED PATIENTS

F. Dalmasso, P.Righini, R.Prota, *G.Righini.

Divisione di Pneumologia, Ospedale Mauriziano di Torino;
*Unità di Acustica, Istituto Elettrotecnico Nazionale Galileo Ferraris, Torino, Italia.

Aim of the study was to determine the acoustic characteristics of the 'vesicular' sound(VS) in tracheostomized patients (Pts) during 3 breathing situations. In 6 Pts with stable tracheal stoma carried out owing to their respiratory failure, VS were detected on the chest wall during quiet deep breaths, by electret microphone, then analyzed by personal computer (PC) for Power Spectrum (PS) calculated by Fast Fourier Transform (FFT) algoritm. Ins-expirations were detected by abdominal band. In A Situation (AS) the Pts breathe freely via cannula and via mouth-nose. In B Situation (BS) Pts breathe via mouth-nose without cannula with closed stoma. In C Situation (CS) Pts breathe via stoma without cannula, closed mouth-nose. In AS the PS shows a monotonic decreasing from lower (50Hz) to higher frequency (750Hz) at a rate ranging from 9.5 to 16.5 dB per octave, like in normal VLS, in spite of emphisematous lungs of Pts. In CS the PS shows a peak frequency near 100 Hz (90-125Hz) and non monotonic decreasing with two different rates (depending on the Pts) across 300 Hz. The BS is more similar to AS. The sounds relative amplitudes (Intensity) are comparable in AS, BS, CS for each patients. During expiration non substantial differences have been detected in the 3 Situations. The finding demonstrate that PS pattern of CS differs substantially from others ones, and this fact is due to the 'sonorant' source of the stoma. We can conclude that extra-pulmonic or extra-lobar source can modifie the inspiratory components of the 'vesicular' sounds.

AIRFLOW AND LUNG VOLUME DEPENDENCE OF INSPIRATORY NORMAL LUNG SOUNDS

J. Vanderschoot, H.J.W. Schreur*,
Medical Informatics, University of Leiden
* Dept. of Pulmonology, University Hospital of Leiden
POBox 2086, NL-2301 CB Leiden, The Netherlands

The flow and volume dependent Auto Regressive modeling technique, for short AR(q, v), has been presented earlier by our group [Vanderschoot, Schreur, Meth Inform Med 1994;33:24–7]. In that publication, a simple breathing manoeuvre was applied. Currently our subjects are asked to breath in such a way that the flow-volume trajectory is like a spiral, covering as much as possible the complete (q, v)-plane. The AR(q, v) technique with spiral manoeuvres has allowed us now to determine, accurately and reproducibly, dependencies of inspiratory lung sound characteristics on flow and volume. The characteristics considered are the residual variance and 3 prediction parameters. Together these characteristics determine Lung Sound Intensity and the form of the power spectrum. Recordings from 2 healthy male subjects on 2 different occasions have been analysed. Several remarkable, as yet undiscovered, features during inspiration have been observed in each of the recordings. For example, there exists not merely a dependence on flow, but also a pronounced dependence of all characteristics on volume *and* flow-volume crossterms. It is shown that the application of a breathing manoeuvre which does not cover the (q, v)-plane in a dense manner, is likely to produce misleading results. Moreover, it is shown that some normalization of the flow axis, similar to the normalization of the volume axis in lung function recordings, is essential to reduce inter patient variability. In other words, the common practice of breathing manoeuvres with a fixed flow, produce lung sound parameters with an unnecessary high inter patient variability. An important conclusion is also that the accuracy and reproducability of the results could only be achieved by applying a modern parametric technique (AR) instead of some non-parametric (FFT-based) spectral estimation technique.

Initial Cough Sound as a Measure of Cough Intensity. RG Loudon. University of Cincinnati Medical Center, Cincinnati, OH, USA.

Coughs vary in their intensity, affecting their efficacy, their sound, and the discomfort and even risk presented to the cougher. The intensity of cough has no agreed dimensions, but the integral with respect to time of the positive intrathoracic pressure exerted has been proposed as a measure. The bechic blast - the acceleration of the blast of air which typifies cough - and the peak flow rate achieved are also likely to relate to cough intensity. Efforts to quantitate the effects of antitussive drugs are based on subjective responses to questions and on objective cough counts. The former may be influenced by cough intensity, but the latter have not as yet extended beyond simple enumeration. In a study intended to relate sounds of cough to physiological measures, six healthy subjects each made a series of five coughs of increasing intensity. Sound was recorded from a microphone attached over the larynx. Esophageal pressure, flow rate at the mouth, and lung volume change were measured by esophageal balloon, pneumotachygraph, and respiratory inductance plethysmograph respectively. Cough sounds tend to have three components: the explosive opening sound, the sound during expiratory airflow, and the sound of glottic closure; the first of these was compared with the peak flow achieved. Only the sound prior to peak flow was considered, and the peak sound intensity was related to peak flow for each cough. Mean peak flow and peak sound were as follows (flow in L/sec, sound in mv):

Cough No.	1	2	3	4	5
Peak Flow	7.0	8.5	9.4	10.4	11.6
Peak Sound	1741	2463	2968	3552	3721

Analysis of variance showed significant contributions from subject and from cough number for peak flow; for sound intensity the major contribution came from cough number. Peak flow correlated significantly with the preceding peak sound.

ACOUSTIC ANALYSIS OF CAPSAICIN INDUCED COUGHING NORMALS

M Doherty, *L Jong, S Donoghue, MG Pearson, *S Stoneman, and Dr. J E Earis.
*Department of Mechanical Engineering, University College Swansea, Swansea, and The Aintree Chest Centre, Fazakerley Hospital, Liverpool, UK.

The cough reflex can be tested by many inhaled substances including the extract of red pepper (Capsaicin) which when inhaled in low concentrations produces both dose related and reproducible coughing. Cough is an in easily recognisable sound, however there is little published work on the analysis of this acoustic signal and we know of no such study on Capsaicin induced cough in normals.
We studied 13 healthy subject (6 male) who had normal spirometry and no respiratory symptoms. The Capsaicin challenge was performed with a custom made dosemeter using doubling dilutions. The cough sound was recorded onto a stereo tape recorder by a microphone set 225 m from the subject at an angle of 45° from the axis of the cough. The sound was digitalised at 20 kHz and the data displayed as a spectrograph, and RMS sound pressure graph. Frequency quartiles and spectral edge frequencies were computed from the spectrographs.
Results showed spectrographs contained energy up to 10 kHz which is considerably higher than reported in previous studies. In all individuals the spectral patterns were similar, both within day and between days, however, there were considerable variations between individuals. Analysis of the RMS data showed individual coughs had between 1 and 3 peaks (the commonest pattern being 3 peaks). During peels of coughs in a single expiration the amplitude of each successive cough decreased. Analysis of the quartile frequencies showed no overlap of the 25, 75 and 95% within this group of individuals. Comparative speech spectrographs showed considerable overlap suggesting cough is not primarily a voiced sound. These data enable objective characterisation of cough sounds in normals and give indications of mechanisms of sound production.

Sound patterns of snores and their mechanical correlates.

Raphael Beck M.D.[1] and Noam Gavriely M.D., D.Sc.[2]

1. Dept. of Pediatrics, University of Calgary, Alberta Children's Hospital, Calgary, Canada.
2. Dept. of Physiology and Biophysics, Faculty of Medicine, Rappaport Family Institute for Research in Medical Sciences, Technion - Israel Institute of Technology, Haifa, Israel.

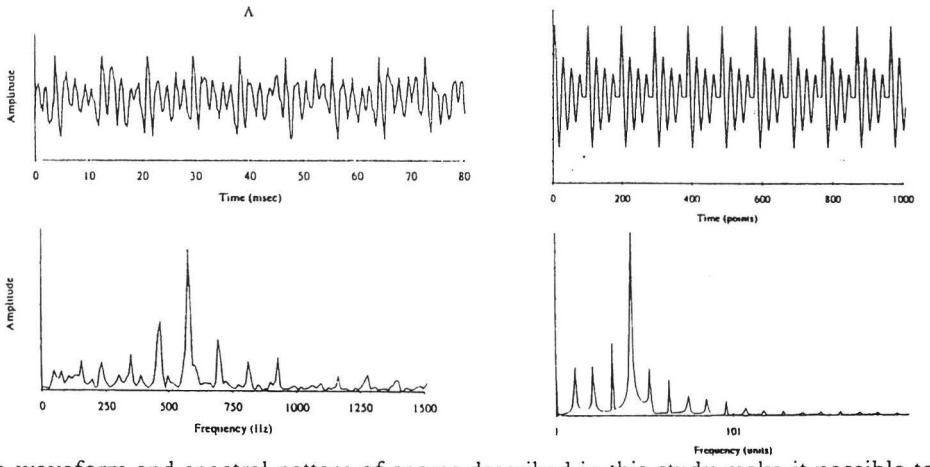
We systematically analyzed snoring sounds recorded from experimental animals and numerous snoring subjects. Snores were recorded from: 1) a dog model of upper airway obstruction (13th ILSA Conference, Chicago, 1988); 2) simulated snores from humans (18th ILSA Conference, Lake Louise, 1993); 3) subjects with heavy snoring but no OSA during polysomnography; 4) subjects with OSA during polysomnography (14th ILSA Conference, Winnipeg, 1989). Snores recorded from all of these experiments showed identical acoustic characteristics, both in their waveform appearance and their spectral pattern. After analyzing hundreds of snores, we were able to identify two distinctly different dominant patterns: the simple waveform and the complex waveform. The complex waveform snore is characterized by repetitive, equally spaced train of sound structures, starting with a large deflection followed by a decaying-amplitude oscillation. In the frequency domain, it is characterized by multiple, equally spaced peaks of power (comb-like spectrum). Simple waveform snores have a quasi-sinusoidal waveform, and almost no secondary internal oscillations. The power spectrum shows simple waveform snores to have higher frequencies (142 ± 21 [SD] Hz, range 98-192 Hz) than complex waveform snores (96 ± 26 [SD] Hz, range 38-152 Hz), but contains only 1-3 peaks of which the first is the most prominent. These waveform and spectra can be represented by a simple mathematical model:

$$(1)\quad Y = \sin(2\pi f t).e^{(t/\tau)}$$

More complex waveforms can be generated, by expanding the formula to:

$$(2)\quad Y = \sin(2\pi f t).\left[e^{(t/\tau_1)} + e^{((t/\tau_2)}\right]$$

Examples of natural snores (A) and waves generated from formula 2 (B) are shown below:



The waveform and spectral pattern of snores described in this study make it possible to identify snoring sounds and distinguish them from other sounds (physiologic or ambient) that may be encountered during sleep studies in an uncontrolled environment (e.g. home, sleep lab noises).

WAVEFORM ANALYSIS OF PERCUSSION SOUNDS

Masashi Mori, Hirohumi Katayama, Mariko Ono, Kouji Tanaka, Fujihiko Sakao, Hiroshi Sato

Tokyo National Chest Hospital
Kiyose-shi Takeoka 3-1-1, Tokyo 204, Japan.

To prove the usefulness of percussion, we studied the waveforms of the percussion sounds to see how they are reproducible and what characterizes their waveforms.
The mediate percussion sounds were recorded by a microphone positioned about 5 cm above the site of percussion and stored on a digital tape recorder (DAT,SONY TCD-D3).
The results are as follows.
1. Percussion sounds are quite reproducible.
2. Waveforms of percussion sounds are composed of two segments, the initial(IS) and the delayed(DS).
3. IS is primarily dependent on the pleximeter, and the surface structure, however, the initial deflection is reversed if the underlying tissue is airless, such as over the heart or over the thigh muscle(quadriceps).
4. DS is primarily dependent on physical properties of the underlying tissues because it changes with the lung volumes and the volume of chest cavities after pneumectomy and also by inhaling Helium-Oxygen.
Our results are in agreement with those reported by Murray and Neilson (Murray A, Neilson JMM:Diagnostic percussion sounds, Medical and Biological Engineering, 13:19-28, 1975). To extend our studies we have to design a device which, with a microphone attached at a fixed position in relation to the percussor, can always provide the same impact over the site of percussion.

VALIDATION OF A METHOD FOR LOCALIZING AN INTRATHORACIC SOUND

R. Murphy, F. Davidson, J. Shane, M. Griffin, T. Fitzgerald, and J. Gee

To localize the origin of sounds in the chest, we employed a computerized lung sound analytic system with the capability of obtaining sounds simultaneously from multiple channels. The program utilizes the arrival time differences at 4 of 5 microphones to compute the coordinates of the origin of the sound. As the speed of sound in the lung of humans is unknown, the arrival times at a second group of 4 of these 5 microphones is also used to compute the coordinates. By requiring the second calculation to equal the first, the lack of knowledge of the sound speed can be circumvented. The method was initially validated by placing microphones in various locations in a room and then generating a sound signal. This signal was located with a 3.5% error. During a therapeutic bronchoscopy, the signal made by the suction catheter placed at the level of the entrance to the right mainstem bronchus was detected at multiple microphones and the coordinates of the beginning of this signal were calculated and compared to those measured from a CT scan of the chest of this patient. The results are as follows:

Comparison of Acoustically Calculated and Roentgenographically observed coordinates

	Calculated	Observed
X	1.285	0.930
Y	13.95	13.90
Z	8.41	8.93

A NEW CRACKLE DETECTION METHOD BASED 0N THE TIME-FREQUENCY REPRESENTATION OF RESPIRATORY SOUNDS

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In this work, we propose a novel crackle detection method based on time-frequency representations of respiratory sound signals, that yields the epochs and the waveshapes accurately. Crackle detection methods based on time-frequency or time-scale analysis of respiratory sound signals (Kaisla *et. al.*, 1991, Güler *et. al.*, 1993) offer themselves as a more flexible technique that can be tuned to perform on a scale varying between pure Fourier transform techniques and matched filtering. We have preferred to implement the discrete wavelet transform. The DWT is well stuied in the analysis and detection of nonstationarities (e.g., abrupt changes, discontinuites) in signals.

The rationale of our detection method is given below:

(i) A prediction error filter is applied to the recorded signal, in order to decorrelate the respiratory sound signal background while preserving as much as possible the nature of the abrupt change phenomena namely the crackles that do not belong to the background activity.

(ii) The signal is then expanded in the time-scale space using the DWT. This dyadic expansion occurs typically on 4-5 scales.

(iii) Nonlinear operators applied to wavelet components prove useful. In this way more of the background activity can be removed by thresholding each band separately, and by applying, for instance, an energy operator to enhance transients further. In other words these operations purport to increase the transient-to-background ratio.

(v) Output signals are synthesized from the combination of selected subbands; this subband combination logic is used to focus on transients at different scales.

(vi) An all-pole filter is applied to the combined prediction residuals to synthesize back a signal where now transients can be seized by straightforward thresholding.

We have assessed the performance of our crackle detector comparatively with respect to two other crackle detection methods proposed in literature, respectively, by Ono *et al.*, 1989, and Kaisla *et al.*, 1991. An expert observer counted crackles from the time expanded waveforms choosing a single inspiration or expiration phase from each recorded respiratory sound. Total number of crackles counted from 14 inspiration or expiration phases is 132. Performance tests yield that the sensitivity and positive predictivity of our method are 96.35% and 91.03%, respectively, while the sensitivities and positive predictivities of the previous methods are { 91.66%, 83.54% }, and { 79.51%, 86.27% }, respectively. These results indicate that our method is clinically applicable.

FEATURE EXTRACTION AND CLASSIFICATION OF RESPIRATORY SOUND SIGNALS BASED ON THE MULTIRESOLUTION SIGNAL DECOMPOSITION

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In this work a new method for respiratory sound signal parametrization and classification that utilizes the information obtained by the subband decomposition of a signal is presented. Multiresolution analysis of the signals is implemented using the discrete wavelet transform . More explicitly, the signal is decomposed into (M+1) octave bands in order to reduce the degree of nonstationarity. A separate feature vector is extracted from each band and a "time-frequency feature matrix" is formed using these vectors. Autoregressive (AR) and cepstral coefficients are used as feature sets. This parametrized version of the time-frequency plane is then used in the classification stage. Time-frequency feature matrix is then inputted to the first stage of a two-stage classifier including (M+1) individual classifiers where a generalized version of the k-nearest neighbor (k-NN) classification rule and soft decision method is used. Final decision is given at the second stage by combining the decisions of the (M + 1) classifiers using the Borda count decision combination function.Classification stage combines the decisions of individual subband classifiers using a decision combination function.

The proposed method has several advantages. Decomposition of the respiratory sound signal spectrum into its subbands allows operation on different resolution levels where the degree of nonstationarity is reduced. Also, observation of features both in time and frequency through multiresolution analysis may be advantageous when the signal contains transients such as crackles which have little effect on the total spectrum but may have bearing on one of the spectral bands. Another advantage is the possibility of treating each subband separately, i.e., determination of the combination of the most meaningful subbands in terms of high classification scores. The use of multiple classifers for each subband also avails us of the possibility to use different feature sets and different types of classifiers for each subband.

Our preliminary studies show that the performance of the new classifier is better than that of our previous work (Sankur *et. al.*, 1994) where the respiratory sound signal was directly inputted to a k-NN classifier without any subband decomposition.

A REALISTIC MODEL FOR AIR-COUPLED MICROPHONES AS STETHOSCOPES

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Electronic stethoscopes of air-coupled microphone type is examined for its frequency characteristics. Existing theories on the characteristics are, to the author's knowledge, based on the assumption that the sensor is rigidly fixed spatially without any movement. The acoustic wave is assumed to come through infinitely thick medium, while actually the sensor is often set on the skin essentially backed with air. The effect of soft contact between the sensor and skin is not considered, to our knowledge.

Calibration experiments by the present authors for a model skin backed with air revealed that conventional modeling is inadequate. Experimental results revealed that the two factors, 1, the sensor is allowed to move, 2, the skin is neither a rigid plate nor a uniform infinite medium, can not be ignored.

A simple theoretical model for an air-coupled microphone is devised, based on the assumptions that the sensor is essentially free to move, and the skin beneath the sensor is soft.

The frequency characteristics is found to be of a conventional second order system, despite of rather many participating factors, of which the resilience of the contact part of the sensor and skin, the mass of the sensor, and the equivalent mass of the skin within the sensor periphery are essential.

EFFECTS OF MICROPHONE AIR CAVITY WIDTH, SHAPE AND VENTING ON LUNG SOUND MEASUREMENTS.

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We have previously investigated the effects of microphone type and coupler air-chamber depth on lung sound characteristics. We now report the results of experiments exploring the effects of air chamber width, shape and venting on lung sounds. We used a single electret microphone (Sony ECM-155) for all experiments. Plastic couplers were custom manufactured and were identical except for the diameter and shape of the air chamber between the microphone diaphragm with the skin. The depth of the air chamber was 2mm in all couplers. We used cylindrical and conical chambers of 5, 10 and 15 mm diameter at the skin and compared the inspiratory lung sound spectra obtained by each of the couplers. To examine the tendency of a chamber vent to transmit artificial (25 Hz square wave) and natural ambient noise to the microphone, we used vents varying between 23 gauge, 20 mm length, to 18 gauge, 7.5 mm length in one of the couplers.

Results: Shape and diameter had no important effects on the lung sound spectrum below 500 Hz. From approximately 500 Hz. to 1500 Hz. (the upper limit of detected lung sounds), all conical couplers provided approximately 5 to 10 dB more sensitivity than the cylindrical couplers. All vents allowed some ambient noise to enter the chamber compared to no vent. The amount was trivial using the 23 gauge, 20 mm length vent but grew more important as the vent was shortened and widened. Noise contamination was primarily at frequencies over 800 Hz. but sensitivity was also decreased at low frequencies by the larger vents.

We conclude that the ideal electret microphone coupler chamber should be conical in shape, between 5 and 15 mm diameter at the skin, and either not vented or vented with a tube of 23 gauge or narrower and 20 mm length or longer.

Clinical Effectiveness of Wireless Stethoscope

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Auscultation of lung and heart sounds has to be mastered as a basic means of physical examination in medical education program. At present, students use their several stethoscopes for learning auscultation, but they don't necessary to auscultate the same lung sounds due to sound unstableness and location variability. In some institutions, a special stethoscope in which plural stethoscope are connected each other by a tube and the teaching materials such as records or tapes are used for simultaneous auscultatory education. However they have some problems and so they don't spread at the educational scene. Therefor, we developed a new FM wireless stethoscope(β fon ; Kenz Medico Co. Ltd.) which was able to be auscultated simultaneously and presented their effectiveness for the lung sounds education using it at the 18th international conference on Lung sounds. In result, we recognized that the wireless stethoscope has better abilities than regular one for lung sounds education.

So at this time, we improved their functions of the wireless stethoscopes such as widening frequency range, feeble controling sound volume and lightening their weights, and then we investigated clinical condition of use at many fields and the effectiveness of simultaneous clinical auscultatory education for plural person.

A Computer Aided Learning Program for Respiratory Sound Analysis

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A computer program for teaching principles of respiratory sound analysis and signal processing techniques is described. The present version is designed for students of biomedical engineering and signal processing, but a version for students of medicine is planned. The system requirements are a 486 PC, Microsoft Windows and a compatible sound card.

The program starts with an overview of lung sound recording, then it presents the basic concepts of signal processing such as spectrum estimation, windowing and pattern vectors. Also lung anatomy and acoustics are explained. The final part of the program are case studies: the student studies various types of respiratory sound signals both aurally and visually and forms pattern vectors from the samples to realize how signal classification is done in practice.

An essential part of the program are exercises. The student must type essay-type answers to questions in all phases of the program. The teacher can then check the answer files from each student. The program has been used by students of biomedical engineering in Helsinki University of Technology in their signal processing course with good results.

FROM COMPUTER ASSISTED INSTRUCTION TO VIRTUAL REALITY: VALIDATING COMPETENCY IN THE COLLEGE LABORATORY

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Raymond L.H. Murphy, M.D. , D.Sc.
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Faulkner Hospital

The current high technology environment presents an opportunity to utilize continuing software advances to improve the teaching of lung auscultation to nurse practitioner and medical students. Although tape recording and visualization of time expanded respiratory patterns are currently used to enhance traditional lecture and slide presentations, few attempts at self-contained, computer assisted instructional modules have appeared.

A state of the art interactive production, utilizing full motion video, digitized sound and graphic images in a coordinated user friendly mode is being developed. Graphics are scanned from original art work, slides, and photographs. Sounds are prerecorded in clinical settings, digitally compressed and archived. In part one, the program offers a review of sound basics, anatomy and physiology, recognition of crackles, wheezes and friction rubs and their association with disease states.

Full motion video allows for realistic clinical examples in part two and the user can access additional patient information through the query mode. The program calls for clinical decisions to be made by the student. These are evaluated against actual conditions and students are directed to return to the appropriate laboratory mode for review when wrong diagnoses are made.

Transfer to the virtual reality platform will transform nursing and medical education and allow faculty to validate competency before the student begins clinical experiences.

LUNG SOUND TERMINOLOGY IN CASE REPORTS. RG Loudon. University of Cincinnati Medical Center, Cincinnati, OH, USA.

Lung sound nomenclature has been inconsistent and at times misleading. Efforts to standardize the terms used have been made by the International Lung Sounds Association and by the ACCP-ATS Joint Committee on Pulmonary Nomenclature. We surveyed lung sound terminology in case reports published in leading US and UK subspecialty and general medical journals prior to these recommendations (*Chest* 1979; 76:690-92). It was stated that repeat studies of this kind would show if attempts to standardize terminology and convert "rale" to "crackle", for example, would have any influence on the choice of words. The ACCP-ATS Joint Committee commented that "There is considerable confusion in the use of terms 'rale' and 'rhonchus' to describe adventitious sounds...Alternative acceptable terminology substitutes crackles for rales and wheezes for rhonchi (Forgacs. *Lancet* 1967;2:203)". Our earlier study has now been repeated for subspecialty journals, and shows that indeed this alternative terminology has been accepted in most published case reports. One hundred case reports each were reviewed from the Amer Rev Respir Dis, Chest, and Thorax, starting with the June 1993 issue and working back, and the relative frequency of the use of terms was compared with that found in the earlier survey. For rales, crackles and crepitations the percentages were 81.1, 1.8 and 17.1 in 1977 and 33.3, 61.1, and 5.6 in 1993. For rhonchi, wheezes and stridor the percentages were 44.2, 49.7 and 6.2 in 1977 and 20.8, 56.3, and 22.9 in 1993. Both differences were highly significant on chi-squared testing. Practice is apparently following recommendations, with progress towards the standardization of terms.

SUBJECTIVE ASSESSMENT OF THE RELATIVE DURATION OF LUNG SOUNDS

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Reports of physical examinations commonly include the comment that the "expiratory phase is prolonged", presumably to aid in diagnosis. Obstructive lung diseases are believed to be frequently associated with prolongation of the expiratory phase and restrictive disorders with relatively shorter expiratory phases. To our knowledge, the utility of this observation has not been well studied except perhaps for observations at the trachea. Accordingly, we investigated this relationship in a series of 20 patients with obstruction, 20 with restriction and 15 normals. A trained technician listened at 50 proscribed sites over the chest as well as over the trachea and classified the duration of sounds as follows: 1) inspiration > expiration; 2) inspiration equal to expiration; and 3) inspiration < expiration, Results are presented in Table I:

TABLE I

Relationship of the Duration of Inspiration and Expiration

	COPD	IPF	Normal
Inspiration > Expiration	35.3	54.3	37.9
Inspiration = Expiration	30.7	32.4	61.6
Inspiration < Expiration	27.9	4.3	0
Absent Sound	6.1	9.0	0.5

The observation that expiration was longer than inspiration varied considerably at different sites. It was more common in obstructive lung diseases at sites near large airways and in the left axilla. In 18 sites expiration was longer than inspiration in 35% or more of the COPD patients. In no sites was expiration longer than inspiration in more than 10% of patients with IPF or normals. Prolonged expiration was associated with the presence of continuous sounds (wheezes, rhonchi) in 11.5% of patients. These observations are consistent with the hypothesis that prolonged expiration at selected sites while not particularly sensitive is relatively specific for obstructive lung diseases.

EFFECT OF FLOW RATE ON BREATH SOUND INTENSITY AND FREQUENCY CONTENT IN NORMAL MEN

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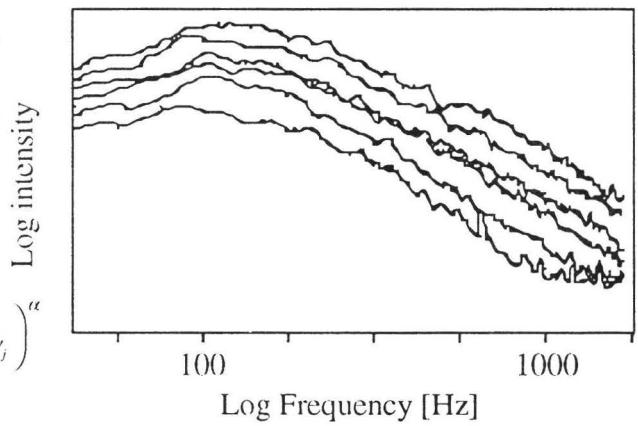
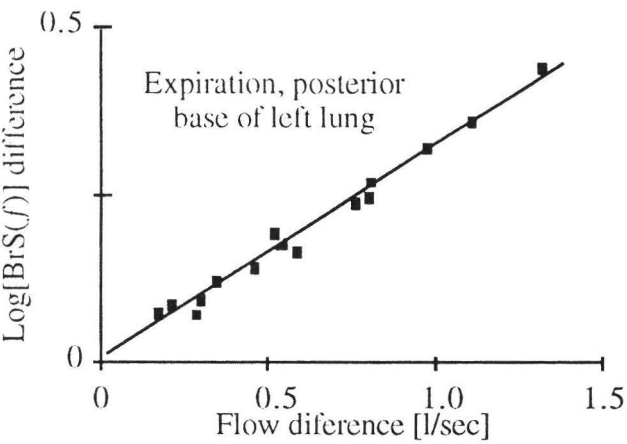
The intensity of breath sounds (BrS), picked up over the chest wall, has been previously shown to increase with flow rate. However, controversy exists over the quantitative nature of the relationship and its dependency on sound frequency. This information is needed for applications that use BrS to monitor the respiratory system. The average spectra (AvSp) of BrS were calculated from sounds picked up simultaneously from three chest wall and one tracheal sensors. The AvSp of inspiratory and expiratory sounds were correlated with the mean flows during controlled breathing at 0.5, 1.0, 1.5, 2.0, 2.5 and 3.0 l/sec in 6 healthy, non-smoking sthenic men. Parallel upwards shift of the logarithmic AvSp curves [$BrS(f)$] was found in all the subjects with incremental (linear) increases of flow (V) (Figure 1). Semi-logarithmic regression analysis revealed linear relationship between the exponential flow ratio and breath sound intensity (Equation) which is valid



$$BrS(f)_s = BrS(f)_j \cdot \left(10^{\dot{V}_s} / 10^{\dot{V}_j} \right)^{\alpha}$$

from 100 to 1000 Hz). Where s and j indicate the standard and actual flow conditions, respectively, and α is the slope of the semi-log regression line (Figure 2). α is specific for each pick up location and respiratory phase (range 0.2-1.0). This relationship and its constant value within the frequency range, permit normalization of BrS with respect to flow, facilitating the accurate measurement of AvSp in less cooperative subjects.



Supported by Northwestern U. Dept of Anesthesia and by the U.S.-Israel Binational Science Foundation.

VARIATION OF BREATH SOUND PARAMETERS IN HEALTHY NON-SMOKING MEN AND IN PATIENTS WITH FIBROSING ALVEOLITIS.

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Variation of breath sound parameters, based on spectral analysis, have been studied in 10 healthy non-smoking men (age 23-41 yrs) and in 12 patients with fibrosing alveolitis (age 35-82 yrs). Flow controlled breath sounds during 10 tidal breathing cycles were recorded on two days (interval 1-3 days) simultaneously from chest wall and from trachea. The signals were averaged over 10 successive cycles and analyzed using Unix workstation. The intraindividual variation of the following parameters were calculated of expiratory and inspiratory phases: median frequency (F50), frequency of maximum intensity (Fmax) and sound intensity RMS as coefficient of variation (CoV%). The results of healthy people and of patients with fibrosing alveolitis (FA) were the following, the CoV values of healthy people (H) indicated at first:

a) Inspiratory sounds, at trachea(H/FA):
RMS 27/33, Fmax 8.7/8.1, F50 6.5/10.2
b) Inspiratory sounds, on chest (H/FA):
RMS 41/47, Fmax 5.7/14.9, F50 5.0/10.1
c) Expiratory sounds, at trachea (H/FA):
RMS 33/23, Fmax 8.2/6.7, F50 5.0/8.2
d) Expiratory sounds, on chest (H/FA):
RMS 47/35, Fmax 4.7/8.5, F50 8.5/5.3

The variation of intensity is high, but that of frequency spectra parameters markedly similar. The variation in fibrosing alveolitis was usually somewhat higher than in healthy subjects. The repeatability of power spectra of averaged breath sounds seems good enough for clinical purposes.

THE PHONOSPIROMETRY

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We carried out and experienced a new system: the PHONOSPIROMETRY (PSM), in order to evaluate the possibility of improving the Spirometry (SM) as tool of screening and diagnosis with the analysis and measure of lung sounds (LS). It measures lung volumes, analysing the flow signal, and simultaneously the lung sounds during well defined maneuvers, using the same computer and printing. The LS detected on the chest at lateral, posterior rigth bases, were analyzed for frequency spectrum with FFT, Sonogram and Time Expanted Waveform (TEW: IDW-2CD-LDW for crackling sounds). Anamnesis (ANA), Physical Examination (PE), X-Ray, Phonometry (PM), PSM were evaluated using an arbitrary score (SC) from 0 to 1 for each parameter in 96 Patients (Pts): 50 healty(H); 22 with COPD; 10 with restrictive pulmonary disease(RPD); 8 with brochitis-asthma(BA); 6 with Mycoplasma Pneumonia(MP).

		ANA		PH		X-Ray		SM		PM		PSM		
	Pts	S	Pts	S	Pts	S	Pts	S	Pts	S	Pts	S	Pts	
H	50	0	0	0	0	0	0	0	0	1	2	1	2	
COPD	22	1	17	1	18	0.5	12	1	18	1	21	1	+3	
RPD	10	1	6	1	7	1	5	0.5	6	1	10	1	+4	
BA	8	1	6	0.5	6	0	0	1	1	1	6	1	+6	
MP	6	1	4	0.5	3	1	4	0	0	1	6	1	+6	
Tot	96	4	33	3	34	2.5	21	2.5	25	5	45	5	(66)	

The sensitivity of total score for SM alone increased from 2.5 to 5 for PSM and the number of the diagnosed Pts from 25 to 65 (+20). The PHONOSPIROMETRY very significantly increase the possibility of evaluate and detecte the various pulmonary disorders earlier than SPIROMETRY alone.

SPECTRAL CHARACTERISTICS OF BREATH SOUNDS IN PATIENTS WITH OBSTRUCTIVE LUNG DISEASES AND WITH HEALTHY LUNGS

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Spectral characteristics of breath sounds in patients with COPD (N=17) and stable asthma (N=10) with significant airways obstruction, and in control patients without any respiratory disorders (N=11) were compared. Breath sounds of 8-10 tidal breathing controlled respiratory cycles were recorded at the chest; inspiratory F50 (mean ± SD) was higher in asthmatics (205±26 Hz) and lower in patients with COPD (160±24 Hz) than in control patients (178±17 Hz) ($p=0.010$ and $p=0.0099$, respectively). Expiratory F50 was higher in asthmatics than in control patients ($p=0.004$). In COPD, inspiratory F50 was significantly lower in patients with reduced specific diffusing capacity (KCO) than in those with normal KCO ($p=0.037$). Breath sound intensity was not significantly different between the patient groups. The observed differences in frequency content of breath sounds in obstructive pulmonary diseases may reflect alterations in sound generation or transmission due to structural changes of the bronchi and the surrounding lung tissue. Spectral analysis of breath sounds may provide a new non-invasive method for diagnosis of obstructive pulmonary diseases.

LUNG SOUNDS IN CLINICAL LUNG DISEASES: COPD vs CHRONIC BRONCHITIS

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Clinical Chronic Bronchitis (ChB) is considered an early stage in the development of full fledged, PFT measurable chronic obstructive lung disease (COPD). It is defined by subjective complaints by the patient describing a long period (at least 3 months in succession each year during the last 3 years) of caughing and morning sputum, with normal PFT.
PPG was presented as a possible objective complementary lung diagnosis method[1]. The method was tested over the last 6 years with 758 subjects, in combination with PFT and the completion of a computerized pulmonology questionnaire. 148 of the subjects were found to have lung diseases, out of them 86 with COPD and 31 with clinical ChB.
PFT is highly sensitive in COPD cases, being the main diagnostic tool. We found sensitivity of 95%. PPG is only 55% sensitive, and the combined test is nearly 100% sensitive. At earlier stage, in case the only findings are usually subjective report by the patient (ChB), PFT has a 0% sensitivity. But PPG has 58% sensitivity in ChB patients. Therefore it is possible to describe the PPG as an objective early detection method for ChB and COPD.

Sex	Disease	n	Smokers	Path PFT	Path LS	Path LS or PFT
F	ChB	2	2(100%)	-	2(100%)	2(100%)
M		29	22(76%)	-	16(55%)	16(55%)
All		31	24(77%)	-	18(58%)	18(58%)
F	COPD	20	11(55%)	18(90%)	12(60%)	20(100%)
M		66	49(74%)	64(97%)	36(54%)	65(98%)
All		86	60(70%)	82(95%)	48(55%)	85(99%)
F	All Sick	33	16(48%)	26(79%)	22(33%)	32(96%)
M		115	83(72%)	83(72%)	62(54%)	101(88%)
All		148	99(67%)	109(74%)	84(57%)	133(90%)
F	Healthy	163	51(31%)	2(1%)	22(13%)	24(14%)
M		447	260(58%)	12(3%)	47(11%)	55(13%)
All		610	311(51%)	14(2.3%)	69(11%)	79(13%)
ALL		**758**	**410(54%)**	**123(16%)**	**153(20%)**	**212(28%)**

1) Gavriely N., Nissan M., Cugell DW., Rubin AHE (1994) "Respiratory health screening using PFTs and LS analysis." Eur Respir J. 7:35-42.

THE PPG AS A COMPLIMENTARY DIAGNOSIS METHOD. FINAL RESEARCH SUMMARY.

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Lung sounds (LS) analysis was long established as a valid diagnostic tool beside the Pulmonary Function Test (PFT). The introduction of phonopneumography (PPG) in recent years enabled the objective, fast and recordable LS analysis.

Our group conducted a long study into LS in the working population. We have developed a computerized system that recorded PFT, LS and a questonnaire in each patient. We tested 758 workers out of which 148 (20%) were found ill, based on an independent pulmonary assessment by the first author, see table. Chronic obstructive lung disease (COPD) was found in 86 cases (11%). Further 31 cases had chronic bronchitis (4%), 3 had emphysema. 18 others (3%) had restrictive lung disease. Asthma was found in 10 cases (1%).

The continuous LS were analysed using the PPG according to theprotocol and methods described in Gavriely et al, 1994[1]. The change in sensitivity and specificity of PFT alone or combined with PPG was measured and calculated. The sensitivity of the combined test was 90% while for PFT alone it is only 74%. The specificity of PPG was 89% and for PFT - 98%. The combined specificity was 87%.

Disease	n	Smokers	Path PFT	Path LS	Path LS or PFT
Asthma	10	3(30%)	7(70%)	7(70%)	9(90%)
Chr.Bron	31	24(77%)	-	18(58%)	18(58%)
COPD	86	60(70%)	82(95%)	48(55%)	85(99%)
Emphysem	3	3(100%)	2(67%)	2(66%)	3(100%)
RLD	18	9(50%)	18(100%)	9(50%)	18(100%)
HEALTHY	610	311(51%)	14(2.3%)	69(11%)	79(13%)
ALL	**758**	**410(54%)**	**123(16%)**	**153(20%)**	**212(28%)**

COPD - Chronic Obstructive Pulmonary Disease;
RLD - Restrictive Lung Disease;

Conclusion: PPG is significantly improving the sensitivity of lung diagnosis.

1) Gavriely N., Nissan M., Cugell DW., Rubin AHE (1994) "Respiratory health screening using PFTs and LS analysis." Eur Respir J. 7:35-42.

INVESTIGATION ON THE POSSIBILITY THAT CRACKLES BELONGING TO A SINGLE INSPIRATION CONSITUTE A SIGNIFICATIVE SAMPLE FOR STATISTICAL ANALYSIS

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We develoded a method to detect crackles based on the observation of their first two deflections. Good sensibility and specificity of the method suggest that in this "zone" could be great part of information related to phenomenon. We decided to investigate the behavior of six parameters measured between the starting point and the second zero-crossing of crackle. This parameters are: T1 (IDW), T2 (second deflection width), T1+T2, E and P (Energy and Power during the first cycle), Pos% (position measured as percentage of the whole inspiration).

In this study we focused the behavior of these parameters in a single patient a time, in order to establish if crackles belonging to a single inspiration consitute a significative sample of general patient status.

We extracted crackles from more than thirty inspiratory acts and we estimated the Probability Density Function of each parameter by its Frequency Histogram. Then we compare a sample to the whole population of crackles using the statistic tests t-Student, F-Fisher, Kolmogorov-Smirnov **.

Results show that a sample coming from few inspirations well represent the whole population. This is a comforting issue because initial condition for operating a good statistical analysis is to choice significative samples.

** W.H. Press, S.A.Teukolsky, W.T. Vetterling, B.P. Flannery; Numerical Recipes in C.
Cambridge University Press 1992.

SPATIAL DISTRIBUTION OF CRACKLES OVER THE CHEST WALL SURFACE

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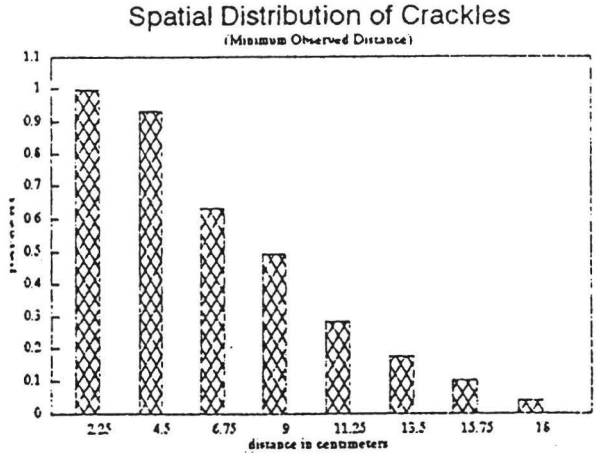
We have previously reported that crackles in a patient with bronchiolitis obliterans pneumonia had an average dispersion over the chest of 5.3 cm (± 1.8 cm). These observations were made on 68 crackles from a single patient with the simultaneous use of 2 tape recorders. There were technical difficulties in synchronizing the tape recorders used in this study. Accordingly, we repeated these studies using a computerized multichannel lung sound analyzer. This avoided the difficulty of synchronization and facilitated data processing. We studied 1050 crackles from 4 patients. Microphones were placed over the right base posteriorly in the manner previously described (a central microphone with 6 microphones placed in circular arrays successively 2.25 cm, 4.5 cm, 6.75 cm and 9.0 cm away from the central one). The average distance observed for crackles identified at two or more microphones is presented in Figure 1. Ninety-three percent of crackles travelled at least 4.5 cm and 50% at least 9.0 cm. Less than 5% travelled 18 cm. Crackles with shorter initial deflection widths (IDW's) were detected over a smaller area at the 2.25 cm position than those with longer IDW's. Twenty crackles from a patient with biopsy proven interstitial pulmonary fibrosis with an average IDW of .82 ± .17 (range .5 to 1.3) were detected at an average of 4.8 ± 1.3 microphones, whereas twenty crackles from a patient with bronchiectasis with an average IDW of 1.2 ± .33 (range .63 to 1.97) were detected at 6.2 ± 1.07 microphones. As crackles are likely to be the most localized of lung sounds, these findings have implications for the choice of the number of microphones to detect lung sounds and for the study of their mechanisms of production.

Figure 1



THE EFFECT OF BRONCHODILATION ON INTENSITY AND FREQUENCY CONTENT OF LUNG SOUNDS. H.J.W. Schreur, M. Timmers, C. Van Kan, J. Vanderschoot#, J.H. Dijkman, P.J. Sterk. Departments of Pulmonology and #Medical Informatics, University of Leiden, The Netherlands.

In a previous study, the effect of acute bronchodilation on lung sound intensity has been investigated in children and adults with acute asthma using non-standardized breathing [Tinkelman, Lutz, Conner, Ann Allerg 1991;67:339-344]. The finding of a lowered lung sound intensity after bronchodilation in that study might have been due to a reduction in the extent of wheezing, or to the non-standardized breathing manoeuvres.

To investigate the effect of acute bronchodilation on the characteristics of normal lung sounds in moderately severe asthma, 9 stable asthmatic men (age 23-35 yrs, baseline FEV_1 48-82 %-pred) performed airflow- and lung volume standardized quiet breathing manoeuvres for 30 s [Schreur *et al*, ARRD 1992;145:A496] at baseline, and 15 min after inhalation of placebo, and 100, 200, 400 and 800 μg salbutamol per metered dose inhaler. Airflow and lung volume changes were recorded simultaneously with lung sounds at 2 locations on the right chest wall (over the 2nd (Mic1) intercostal space mid-clavicularly, and 9th intercostal space mid-scapularly (Mic2)) and 1 over the trachea (Mic3) using air-coupled microphones. Airflow-dependent power spectra were computed by fast Fourier transform for each 0.1 l/s, and averaged for subsequent breaths. From these spectra sound intensity (LSI) and frequency content (in power quartiles: Q25%, Q50% and Q75%) were computed, and wheezing was excluded. The effects of bronchodilation were analyzed using ANOVA.

The mean improvement of FEV_1 between baseline and recordings after inhalation of 800μg salbutamol was 15-45 %-pred. With decreasing airways obstruction, LSI decreased for Mic1 ($p \leq 0.012$) and Mic2 ($p \leq 0.054$) during expiration, whereas Q25%-Q75% decreased for Mic 1 and Mic2 during expiration ($p \leq 0.010$), and for Mic2 also during inspiration ($p \leq 0.007$). No changes were found for Mic3.

We conclude that the intensity and frequency content of normal lung sounds recorded over the chest wall change as a result of bronchodilation in moderately severe asthma, whereas no changes were found over the trachea. This suggests that normal lung sounds at the chest wall reflect differences in the pathophysiology of the airways in asthma.

Supported by a grant of the Netherlands Asthma Foundation.

ADENOSINE IS MORE SPECIFIC THAN METHACHOLINE FOR THE DIAGNOSIS OF ASTHMA IN YOUNG CHILDREN PERFORMING THE AUSCULTATIVE BRONCHIAL CHALLENGE METHOD (PCW).

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Bronchial reactivity to methacholine (MCH) is increased in children with asthma but also in other types of pediatric chronic obstructive pulmonary disease (PCOPD). Adenosine 5'-monophosphate (AMP) is a potent bronchoconstrictor, probably activating mast cells, and has been found more specific as a challenge for asthma in older children and in adults. In young children unable to cooperate with standard lung function tests, the chest auscultation method can be used. We performed MCH and AMP challenges in 38 young children (age 4.4 + 1.6 years) with clinical asthma and in 14 children (age 4.6 + 1.5 years) with PCOPD without clinical asthma (5 children with chronic cough and sinusitis, 4 with recurrent pneumonia, 3 with bronchiolitis obliterans and 2 with cystic fibrosis). The logarithmic mean concentration of MCH causing wheeze (PCW) in asthmatics (0.34 mg/ml, range 0.12 to 1.01 mg/ml) was not significantly different ($p=0.77$) from that of the PCOPD group (0.39 mg/ml, range 0.08 to 1.85 mg/ml). The logarithmic mean adenosine PCW in asthmatic patients (8.32 mg/ml, range 1.79 to 38.65 mg/ml) was significantly ($p<0.0001$) different from that in the PCOPD group (344.75 mg/ml, range 108.18 to 1098.68 mg/ml). Methacholine is a good indicator of bronchial hyperreactivity in children with pulmonary diseases, but AMP challenge is more specific for the diagnosis of asthma.

THE EFFECTS OF METHACHOLINE ON COUGH SOUNDS SPECTRA

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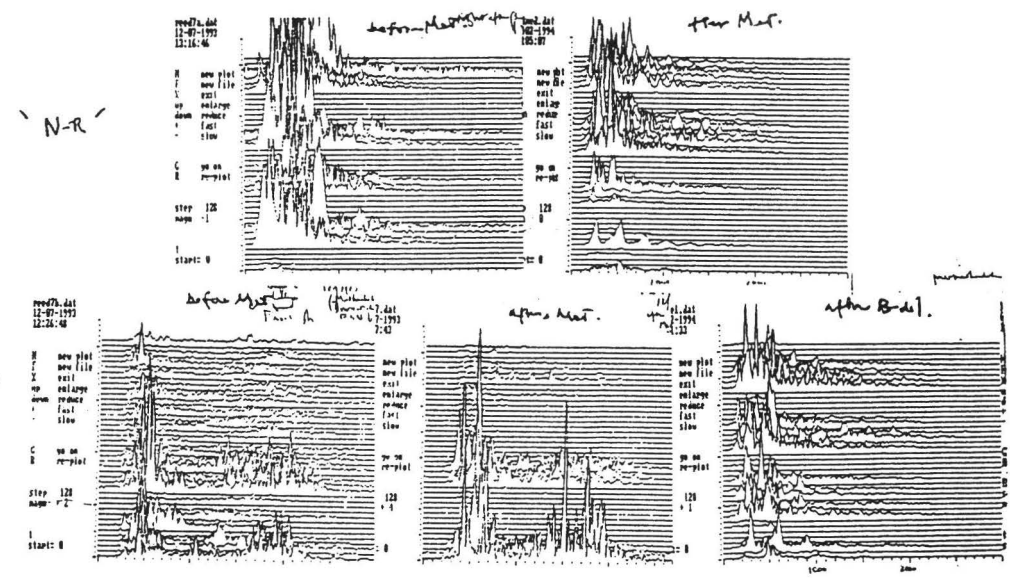
We have studied the cough sounds spectra before and after the methacholine challenge and subsequent brochodilatation in 20 consecutive patients who were referred to our laboratory as having suspected bronchial hyperreactivity.
Subjects were instructed to make 6 voluntary coughs within 6 seconds. Sound signals recorded at the neck with contact microphone were digitized and real time spectrograph displayed using a fast fourier transform spectrum analyzer. "Nonresponders to methacholine" showed all signals were within 1 kHz and peak energy 550±52 Hz before and 585±45 Hz after methacholine. "Responders to methacholine" showed two distinct spike complexes. One of which were within 1 kHz and peak energy 540±45 Hz before and 560±48 Hz after methacholine. The second between 1 and 2 kHz with peak energy 1300±520 Hz and 1423±621 Hz after methacholine.

After brochodilatation with salubuterol, from the "Responder"s' spectrum the second component of high frequency spike had diminished.



Change in normal lung sounds during induced airway narrowing

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We have previously reported that the intensity of normal inspiratory sounds decreases over the posterior lower lung during methacholine induced airway narrowing. We have now extended our observations to a total of 15 boys with asthma, mean age 11.3 y (range 8 to 15), who underwent a standard methacholine challenge. Contact sensors (Siemens EMT25C) were attached over the superior segments of the right (#1) and left (#2) lower lobe, over the posterior basal segments of the right (#3) and left (#4) lower lobe, over the anterior segments of the upper lobes on the right (#5) and left (#6), over the anterior right middle lobe (#7) and over the trachea at the suprasternal notch (#8). Airflow was measured at the mouth. Sound and flow signals were acquired for >40 sec after each step of the methacholine test, with a sampling rate of 10 kHz per channel (12bit sampling, 6th order Butterworth low-pass filter at 2.5 kHz). Average inspiratory sound spectra were calculated after subtraction of background noise from samples within a flow range of 0.8 to 1.2 l/sec. Compared to baseline **(A)** there was a reduction of power within the frequency band from 100 to 200 Hz at the pre-final dose **(B)** when $FEV_{1.0}$ had fallen by 10.7% ± 1.8, with a further drop at the final dose **(C)** when $FEV_{1.0}$ was 34.6% ± 3.7 below baseline. Sound power in this frequency band increased after inhalation of 400 µg of salbutamol **(D)**, with a return of $FEV_{1.0}$ to 6.4% ± 2.0 below baseline. These changes were significant (repeat measures ANOVA) at all sites except the right middle lobe and trachea. The table shows values in dB (mean ± S.E.M.) for 10 of 13 subjects who had a positive response to methacholine (3 boys were too wheezy for analysis of normal sounds):

	#1	#2	#3	#4	#5	#6	#7	#8
A	46.7 ± 1.3	49.6 ± 1.2	48.3 ± 1.7	50.1 ± 1.7	52.4 ± 1.2	52.2 ± 1.3	49.0 ± 1.4	52.6 ± 2.1
B	44.8 ± 1.3	47.9 ± 1.1	46.1 ± 2.0	47.8 ± 1.9	50.3 ± 1.5	50.1 ± 1.7	49.5 ± 1.8	53.5 ± 1.5
C	42.8 ± 1.5	44.8 ± 1.4	44.1 ± 1.8	45.4 ± 2.0	49.7 ± 1.4	48.5 ± 1.6	48.7 ± 1.7	53.3 ± 2.7
D	48.2 ± 1.4	51.2 ± 1.4	49.7 ± 1.5	51.5 ± 1.8	55.4 ± 1.1	53.6 ± 1.3	52.5 ± 1.5	54.9 ± 1.8

Our findings confirm the value of lung sound analysis as a non-invasive method to monitor airway responses during bronchial provocation, independent of the occurrence of wheeze. Acoustical mapping can help to localize the origin of wheeze but is not required for routine testing. Our observations put into perspective the increase in median frequency of lung sounds during histamine challenge reported by Anderson et al. (ARRD 1990), and the finding by Spence et al. (Thorax 1992) of inconsistent changes in tracheal sound spectra during methacholine induced airway narrowing. We speculate that the drop in power at low frequencies may be explained by increased lung volumes during airway obstruction. Higher frequency sounds may be less affected because of a longer transmission path within airways.

* Dr. Consunji-Araneta is a Fellow of the Manitoba Lung Association.

Discussion Paper
Workshop on Standardization of the use of breath sounds for Bronchial Provocation

3 year experience with Histamine Challenge with computerized lung sounds analysis performed on young children

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62 Histamine Challenge tests with computerized lung sounds recording and analysis (HCT/LS) were performed at the Pulmonary Function Laboratory of the Alberta Children's Hospital from January 1991 to December 1993. Subjects were 47 boys and 15 girls, aged 2-6 years. Histamine was administered by nebulizer for 2 minutes in increasing concentrations, according to a protocol adapted from Cockroft (1), starting with 0.03 mg/ml, and doubling the concentration every 5 minutes until a positive reaction was identified or a concentration of 8 mg/ml was reached. The technique for Lung Sounds recording and analysis was described in previous LSA meetings (New Orleans, 1990, Helsinki 1992) and published (CHEST 1992; 102: 759-763).
We use a HP21050A or Rappaport Institute contact sensor applied over the trachea with an elastic band. Sounds are amplified and band filtered and digitized into a Macintosh computer. Analysis is performed off-line. during the first two years we used SoundWave™ hardware and software, and for the past year we have been using GW Instruments 8ain digitizer with SuperScope software. During the test we have been asking children old enough to cooperate to take "medium-size" breaths while lung sounds were recorded. Some teaching and demonstration was done prior to the test itself, until desirable depth of breathing was performed consistently by the child. Children who were unable to learn this, were recorded during spontaneous tidal volume breathing (8 children). Follow up information was available on 58 of the children, with hollow up time ranging from 4 months to 2 years. The clinical information was correlated with the Histamine Challenge result, to determine positive and negative predictive value of the test. The main information sought was whether asthma medication was used and the response to it, and whether documented clear asthma symptoms developed later.
Of the 58 children, 48 had positive HCT/LS and 10 were negative. All 48 children had clinical course or response to therapy indicative of asthma. Of the 10 children with negative HCT/LS, 3 had a clinical course suggestive of asthma, with 2 having documented response to asthma medication. The other seven resolved their symptoms and are presumed healthy.

	HCT/LS +	HCT/LS -
Clinical Asthma	48	3
No Asthma	0	7

Conclusion: Our experience suggests that for asthma diagnosis, HCT/LS in young children is highly sensitive (positive predictive value - 100%), but that specificity is not very high (negative predictive value - 70%). For clinical purposes of diagnosing asthma, strict control of airflow is not required, as long as basic precautions are taken. This is in agreement with previous data showing that increasing flows result mostly in increased amplitude, but no basic change in the spectral appearance of tracheal lung sounds. This, however, may not be true when physiological studies are done, where inter- and intrasubject comparisons with different challenges and at different times may be required.

MEASUREMENT OF BRONCHIAL HYPERRESPONSIVENESS BASED ON FREQUENCY CONTENT OF RESPIRATORY SOUNDS IN ASTHMATIC CHILDREN

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Suitable methods for measurement of bronchial hyperresponsiveness in young children have been lacking. Recording of lung sounds does not require active cooperation and methods based on respiratory sounds analysis may be adapted for children. Therefore, we studied the changes in frequency distribution of respiratory sounds induced by acute bronchoconstriction and -dilation in 11 asthmatic children (age from 10 to 14) during a graded dosimetric histamine challenge test, to be compared with simultaneous changes in FEV1. In those children who responded to histamine with a decrease in FEV1 of more than 15% (N=7), there was a significant relationship between percentage change in FEV1 (ΔFEV1) and percentage change in median frequency (ΔF50) of expiratory breath sound recorded at the chest (r=0.865l b=0.706, p=0.0001) and at the trachea (r=0.888; b=1.12, p=0.0001). The increase of F50 during the challenge test was significantly larger in children who responded to histamine than in those who were non-responsive (p=0.0016). A decrease of 15% in FEV1 corresponded an increase of 8% in expiratory F50 recorded at the chest. The provocative dose of histamine inducing a decrease of 15% in FEV1 (PD15FEV1) and the provocative dose causing an increase of 8% in F50 (PD8F50) were significantly related (r=-.927, p=0.003). In one child who did not wheeze during the provocation, F50 increased 8% from the baseline at the stage of bronchial obstruction. We conclude that changes in frequency content of respiratory sounds reflect changes in airways obstruction during bronchial challenge tests in children. We suggest that methods based on respiratory sounds analysis can be developed for measurement of bronchial hyperresponsiveness in young children.