EIGHTH INTERNATIONAL CONFERENCE

ON LUNG SOUNDS

第8回 国際肺音学会

SEPTEMBER 22 & 23, 1983

JOHNS HOPKINS HOSPITAL
BALTIMORE, MARYLAND

PRESENTED BY

INTERNATIONAL LUNG SOUNDS ASSOCIATION

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Eighth International Conference on Lung Sounds

Baltimore, Maryland

Program

Thursday, September 22, 1983

Registration	8:30 am
Opening Remarks - Dr. Wilmot C. Ball	9:00 am
Keynote Address - Dr. Steven S. Kraman	9:10 am
Session A - Dr. J. Grotberg, Chairman	9:20 am - 12:00 pm
Lunch	12:00 pm - 1:15 pm
Session B - Dr. Y. Ploysongsang, Chairman	1:15 pm - 4:30 pm
Cocktails and Buffet	7:00 pm

Friday, September 23, 1983

Session C - Drs. S. Ishikawa and R. Mikami, Chairmen	9:00 am - 12:00 pm
Lunch	12:00 pm - 1:00 pm
Business Meeting	1:00 pm - 1:15 pm
Session D - Dr. M. Mori, Chairman	1:15 pm - 3:30 pm
Cracklefest	3:30 pm - 4:10 pm
Summary - Dr. D. Cugell	4:10 pm - 4:40 pm

Session A

Chairman: J. Grotberg

9:20 am	The Production of Wheeze in Relation to Lung Volume, Transpulmonary Pressure, and Flow Rate	R. Baughman Y. Ploysongsang R. Loudon M. Rashkin
9:40 am	Site and Mechanism of Production of Wheezes During Maximal Forced Expiratory Maneuvers	Y. Ploysongsang R. Baughman R. Loudon M. Rashkin
10:00 am	What causes the "choke point"?	M. Mori N. Honda H. Morinari K. Kinoshita S. Koike
10:20 am	Coffee Break	
10:40 am	Frequency and Time Domain Analysis of Wheezing	N. Gavriely Y. Palti G. Alroy
11:00 am	Theoretical Analysis of Experimental Data from Wheezing Patients	J. Grotberg
11:20 am	Breath Sounds Coincide with Lobar Airflow During Experimental Proximal Airway Narrowing	P. Krumpe
11:40 am	The Relationship Between Sound Pressure of Tracheal Sounds and Flow Rate at the Mouth	T. Uetake
12:00 pm	Lunch	

The Production of Wheeze in Relation to Lung Volume, Esophageal Pressure, and Flow Rate

R. P. Baughman
Y. Ploysongsang
R. G. Loudon
M. C. Rashkin

We recorded lung sounds, esophageal pressure, plethysmographic lung volumes, and flow rates in 6 healthy subjects. The subjects performed maximal expiratory flow-volume curves breathing room air (air) and a mixture of 80% He-20% O_2 (He) before and after methacholine inhalation. The sounds were recorded from the chest wall using a contact microphone. All signals were recorded on magnetic tape and analyzed by a sound spectrum analyzer and computer. Using an analog-to-digital converter, the volume, flow, and pressure were digitized and the value compared to a calibrated value. With replay of the magnetic tape, the computer looked at the digitized value of the flow rate. When a previously determined value was reached, the lung volume and esophageal pressure were simultaneously recorded and the next 100 milliseconds of the sound signal were analyzed using the Fast Fourier Transform (FFT) technique. By varying the effort in performing the expiratory maneuvers, we were able to obtain different pleural (esophageal) pressures and lung volumes at the same flow rate. We analyzed the FFT tracing corresponding to each pressure and volume at isoflow. A wheeze was considered present when the spectral analysis had at least one peak with a frequency greater than 150 Hz and an amplitude of three or more times maximal inspiratory lung sound. The absence or presence of wheezes was plotted at isoflow with various pleural pressures and lung volumes. Scattergrams were plotted for room air and He before and after methacholine inhalation. The results of our analysis will be discussed in a separate paper.

Site and Mechanism of Production of Wheezes During Maximal Forced Expiratory Maneuvers

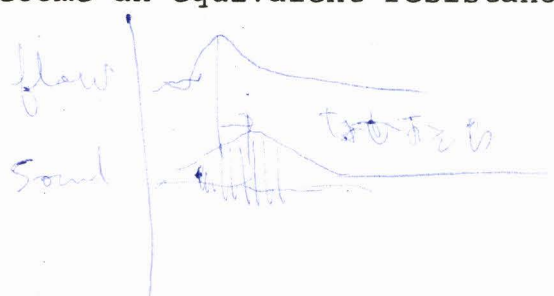
Y. Ploysongsang
R. P. Baughman
R. G. Loudon
M. C. Rashkin

We recorded wheezes, pleural pressures (P_{pl}), plethysmographic lung volumes and mouth flow rates in 6 healthy subjects during maximal forced expiratory maneuvers breathing air and a mixture of 80% He-20% O_2 (He) before and after methacholine inhalation. A certain critical amount of P_{pl} must be attained before wheezes occurred. All wheezes occurred during flow limitations. At a flow rate of 2 L/sec, the critical P_{pl} breathing air was 21 ± 6 cm H_2O ($\bar{X}$ + SD) whereas that of breathing He was 32 ± 8 cm H_2O ($P<0.01$). Furthermore the wheezes occurred at lower lung volumes (which have smaller airway diameters) when He was breathed. These findings suggest that a lighter gas such as He has less kinetic energy during turbulence to vibrate bronchial wall to produce wheezes, therefore it requires narrower bronchi (from either increased compression by a larger P_{pl} or smaller lung volumes) to cause enough turbulence to produce wheezes. After methacholine inhalation the critical P_{pl} both breathing air (18 ± 7.5 cm H_2O) and He (20 ± 8.9 cm H_2O) decreased significantly and were also comparable. These confirm our above data interpretation that narrower bronchi from the action of methacholine predispose to easier compression with a lesser amount of P_{pl} to generate enough turbulence to produce wheezes. In addition methacholine moved the equal pressure point (EPP) and flow limited segments upstream to the place where flow is less density dependent, hence the air and He critical P_{pl} becomes similar. Our results suggest that (i) wheezes are produced in flow limited segments downstream from the EPP, (ii) wheezes are produced by turbulence which in turn vibrates the flow limited bronchial segments.

What Causes the "Choke Point"?

Masashi Mori
Norinari Honda
Hajime Morinari
Kojiro Kinoshita
Shigeo Koike

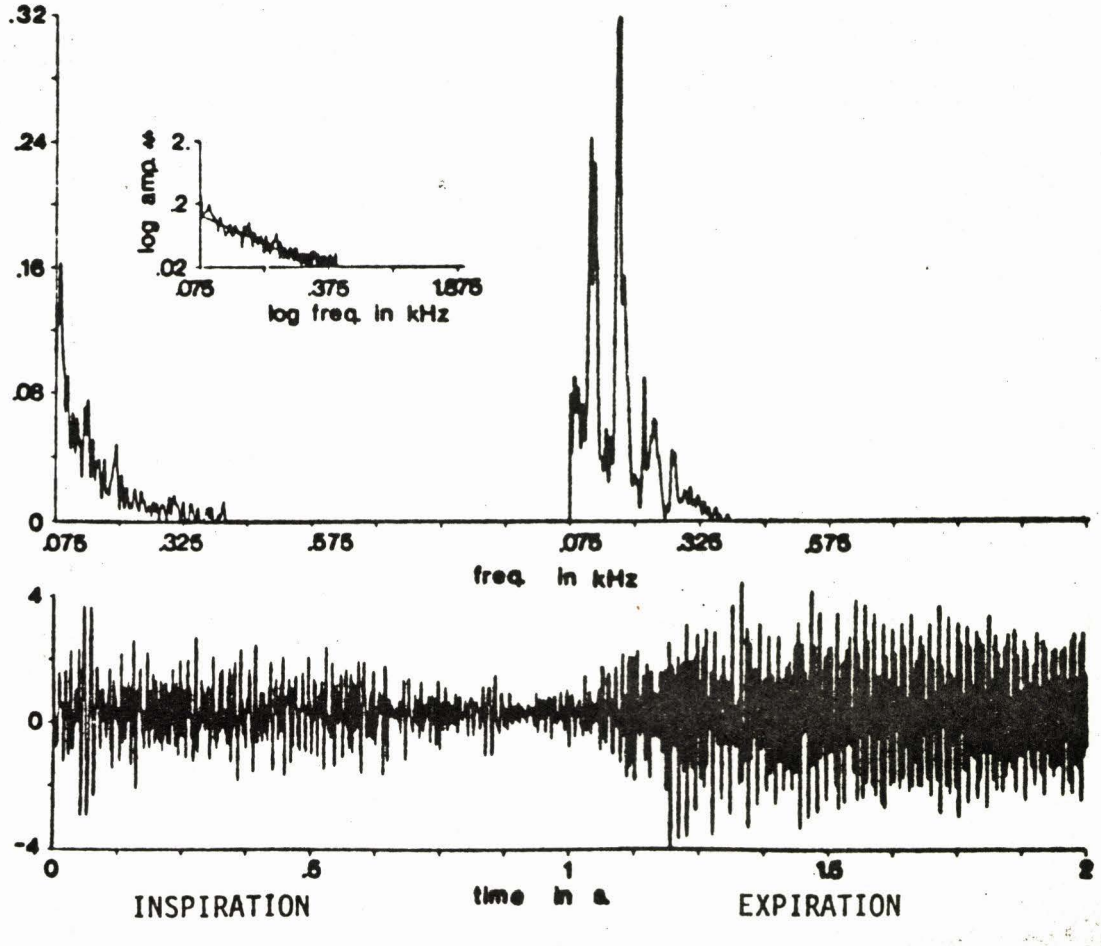
During forced expiratory maneuver we made simultaneous recordings of expiratory flow, tracheal sounds and lung sounds. The flow was measured by a hot-wire anemometer (Minato AS 4500), the tracheal and the lung sounds by condenser-type microphones (SONY ECM 150) attached to the neck and the chest wall (the second intercostal space mid-clavicular line, bilaterally). The signals were recorded on an FM recorder (TEAC XR510) and displayed on a multichannel paper recorder (Siemens Mingograf). Three normal subjects and a patient with right mainstem bronchus stenosis were studied. In every subject the flow reached maximum earlier than the amplitude of the tracheal sound. The sounds recorded at the chest wall were smaller in amplitude with lower frequency components than those recorded over the trachea. During forced expiration we observed, especially in a patient with bronchial stenosis, an increase in the amplitude of the tracheal sound with a decrease in the flow. It seems to us that the flow limiting mechanism during forced expiration is the development of vortices which consume the bulk of kinetic energy and become an equivalent resistance as a choke point.



Frequency and Time Domain Analysis of Wheezing Breath Sounds

Noam Gavriely
Yoram Palti
Gideon Alroy

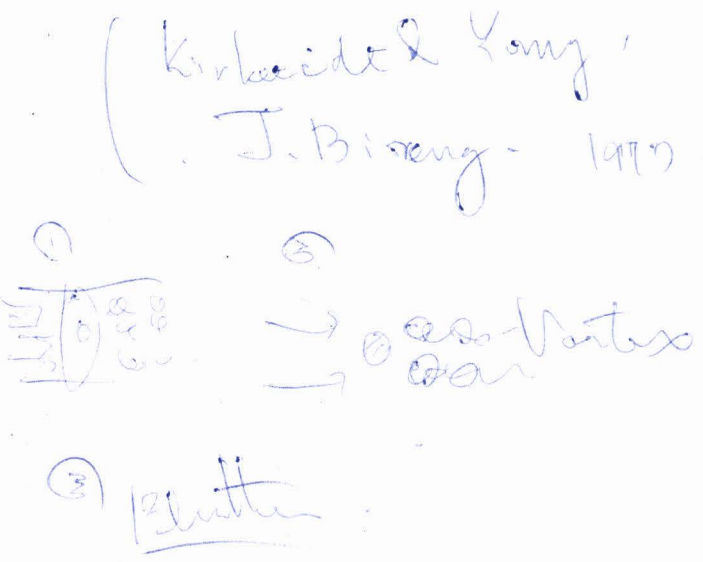
In search for means to enhance the information extracted from auscultation of wheezing lung sounds we measured the time and frequency domain characteristics of breath sounds from seven asthmatic and three non-asthmatic wheezing patients. The existence or absence of an exponential pattern of the spectral curve (typical of normal vesicular sounds) and frequency, amplitude and time of appearance of peaks of power in the power spectra were evaluated. The two asthmatic patients who were in the most severe clinical condition were found to have a total elimination of the exponential pattern of the spectral curves. Other asthmatic patients showed an exponential pattern at least in some of their analyzed segments. The slopes of their log power vs. log frequency curves ranges from 5.7 to 17.3 dB/oct (normal range 9.8 to 15.7 dB/oct). The non-asthmatic wheezing patients had normal exponential patterns. All the patients had sharp peaks of power in their spectra during expiration and inspiration. The frequency range of the power peaks was 80 Hz to 1600 Hz. Some of these peaks were of constant frequency throughout numerous inspiratory or expiratory segments recorded from one or more pick-up locations.



Theoretical Analysis of Experimental Data from Wheezing Patients

James B. Grotberg

Measurements of wheezing breath sounds have been made by Gavriely et al (1983) with a high degree of resolution in both time and frequency domains. It appears that certain characteristics of these data are relatively invariant. These include: sudden onset and termination; constant amplitude; sharp, narrow frequency peaks; harmonics of even and odd multiples; and reproducibility. Several mechanisms have been proposed to explain the production of wheezes. Among these are: the mass-spring resonator; the Helmholtz resonator; vortex-induced vibrations; and flutter instability. Each of these mechanisms has certain distinguishing features which will be discussed, in view of the data. Although definitive experiments have not yet been done to separate out the primary mechanism, some initial review of the data suggest that flutter and vortex-shedding are leading candidates. Comparisons and contrasts will be made to suggest future experiments that could help to elucidate these issues.



Breath Sounds Coincide with Lobar Airflow During Experimental Proximal Airway Narrowing

Peter E. Krumpe

In order to evaluate the relationship between inspiratory breath sounds and lobar air entry, the intensity of breath sounds (I_B) recorded over 4 pairs of homologous lobes was compared to tracheal airflow ($\dot{V}_T$ trach) and airway pressure (P_{AW}) in excised dog lung. The peak I_B envelope (high pass filtered above 100 Hz, integrated with 10 msec time constant, and graphed at 50 mm per second chart speed) of both lobe pairs coincided with peak $\dot{V}$ trach in over 100 breaths. Lobar airway narrowing (LAN) was produced by tying rigid plastic 1 cm long stints into the proximal airway. The % LAN was varied between 20% and 80% of the maximum airway diameter at P_{AW} = 30 cm H_2O by decreasing the stint's internal diameter. During LAN, a time delay (TD) developed between peak I_B of the homologous control lobe (I_B control) and peak I_B over the lobe with LAN (I_B LAN). TD increased from 100 ± 30 msec when % LAN was 80% to 300 ± 90 msec when % LAN <50%. I_B LAN decreased and finally became absent when % LAN <30%.

Next I_B lobe during LAN was correlated with lobar air flow ($\dot{V}$ lobe, measured using a 4 liter volume displacement plethysmograph) and with lobar pressure upstream (P_{us}) from the site of LAN (measured using a 3mm retrograde catheter).

Under baseline conditions peak $\dot{V}$ lobe and I_B lobe each coincided with peak $\dot{V}$ trachea and I_B control (TD was 20 msec). During LAN, peak $\dot{V}$ trach and peak I_B control remained coincident, peak $\dot{V}$ lobe and peak I_B lobe remained coincident but a TD of both $\dot{V}$ lobe and I_B lobe occurred, which increased as % LAN increased.

Finally, the effect of increasing lung volume (by increasing P_{us} and PAW at FRC from 0 through 15 cm H_2O PEEP) on TD was observed. I_B lobe and V lobe remained coincident with and without LAN and TD remained unchanged despite increasing P_{us} and PEEP.

Since peak I_B coincides with peak $\dot{V}$ before and after LAN, I conclude that lobar I_B can be used to evaluate regional air entry, and that the development of a TD of I_B lobe vs I_B homologous control indicates a delay of $\dot{V}$ lobe vs $\dot{V}$ trach. Furthermore since these changes are independent of changes in distal airway size caused by PEEP, I conclude that flow disturbances in proximal airways are the primary source of generation of I_B.

The Relationship Between Sound Pressure of Tracheal Sounds and Flow Rate at the Mouth

T. Uetake
S. Kudoh
H. Kimura
Y. Yoshida
A. Shibuya

The tracheal sounds were measured by a microphone which was attached to the median neck below the laryngeal prominence, and were converted into effective sound pressure, i.e., root mean square value, by a sound pressure level meter. Flow at the mouth was measured by a pneumotachograph. After both sound pressure and flow were low pass filtered at 10 Hz, flow-sound pressure curves were recorded on an X-Y recorder during VC and panting maneuver.

The results were as follows:

1) Time constant of the integral circuit in the sound pressure level meter should be less than 5 msec. in order to avoid phase difference.

2) The curves were described as a smooth arc in both expiratory and inspiratory phase. The relationship between sound pressure and flow rate could be equated with a straight line on logarithmic scale ($r=0.92-0.98$).

3) The sound pressure during panting maneuver was lower than that during VC maneuver at the same flow rate in both respiratory phases.

   The sound pressure during VC maneuver rose at a rate of approximately 16 dB in both respiratory phases as flow rate increased twofold, while, during panting maneuver, it increased 12-13 dB.

   The difference of sound pressure among two maneuvers suggests that the glottis opening influences the production of the tracheal sounds.

Session B

Chairman: Y. Ploysongsang

1:15 pm	Nomenclatural onomatopoeia	R. Loudon
1:30 pm	Turbulent Sound Production Within the Trachea	D. Olson
1:50 pm	Narrow Band Transpulmonary Sonic Transit Time	D. Rice D. Stahl J. Rice M. Wegmann
2:10 pm	Variation of Sound Transmission in Pulmonary Diseases	N. Shioya A. Shibuya S. Kudoh R. Mikami
2:30 pm	The Application of Auscultatory Percussion for the Study of the Transfer Function of the Lung	H. Morinari N. Honda K. Kinoshita M. Mori
2:50 pm	Coffee Break	
3:10 pm	The Relationship Between Airflow and Lung Sound Amplitude in Normal Subjects	S. Kraman
3:30 pm	The Effect of Low Density Gas Breathing on Vesicular Lung Sounds	S. Kraman O. Austrheim
3:50 pm	Spectral Feature Variations of Normal Breath	G. Charbonneau J. Racineux M. Sudraud E. Tuchais
4:10 pm	Multimode Spectral Analysis	C. Druzgalski J. Eddleman A. Wilson
4:30 pm	Flow and Volume Dependent Spectral Analysis of Lung Sounds	P. van Spiegel O. Rompelman G. Boxelaar

Turbulent Sound Production within the Trachea

D. E. Olson

Simultaneous measures of sound and turbulence within the lumen of straight tubes, tubes with orifice constrictions similar to the larynx, and within cast replicas of human and dog upper and central airways have been obtained to further understand the mechanisms of breath sound generation. Measures were obtained along the center line of the test model and within the boundary layer by hot wire anemometry for velocity (mean and fluctuation) and by microphone sound probes (B+K #4170) with each sensing device positioned within 1 mm of the other. Signals were time averaged and analyzed via Fast Fourier techniques through a spectral analyzer and the resultant frequency spectrum of both turbulent velocity and turbulent kinetic energy compared to the sound (pressure) frequency spectrum.

Results within straight tubes are consistent with theoretical predictions (Jour Fluid Mech 32:765, 1968) of aerodynamic sound generation. The sound spectrum has close correlation to the turbulent (RMS velocity) kinetic energy spectrum with superimposed resonance peaks related to the internal diameter of the tube. When an orifice is introduced immediately upstream in the tube, the turbulence energy spectrum develops an intense peak superimposed on the usual turbulent energy spectrum and in the sound spectrum. The frequency of this peak is related to the flow constricting dimension of the orifice and is presumed related to vortex shedding. Aerodynamic sound measured within rigid cast models of dog and human airways from pharynx to subsegmental bronchi show similar characteristics as observed in tubes with constrictions. The sound frequency spectrum measured within the cast lumen has high correlation to the turbulent energy spectrum except for two superimposed sound peaks in the 1 to 1.4 KHz and 1.8 to 2.2 KHz frequency range. These peaks seem to depend on tracheal diameter and laryngeal aperture and are most easily measured at the lower turbulent Reynolds Numbers (less than 5K), corresponding to resting inspiration rates.

Narrow Band Transpulmonary Sonic Transit Time

D. Rice
D. Stahl
J. Rice
M. Wegmann

We measured the time it took sound to travel from the trachea to the thoracic surface in normal adults. Sound was injected into the trachea using a mouth cannula. Microphones are placed over the trachea on the neck and at various places on the back. Transit time is the time it takes the sound to travel from the trachea to the back. Signals were sinusoidal pulses shaped to create a narrow band spectrum. Four frequencies (250, 300, 420, 650 Hz) and 8 locations on each side of the back were investigated at two lung volumes (FRC, TLC). Transit times ranged between 1 and 6 ms, with the lower lobes having greater values. Higher frequencies generally exhibited smaller transit times than lower frequencies. This effect was most pronounced for the lower lobes. Lung volume did not show a significant effect. The observed dispersion may indicate that sound speed in the lung varies with frequency but might also result from varying mixtures of a fast and a slow sound speed.

Supported in part by the Edward C. Schlieder Educational Foundation and NIH, NHLBI grant HL30359.

Variation of Sound Transmission in Pulmonary Diseases

Naohisa Shioya
Atsuo Shibuya
Shoji Kudoh
Riichiro Mikami

Acoustic transmission of the respiratory system was studied in some pulmonary diseases using sinusoidal sound waves (100 Hz-1 KHz) introduced through the mouth. The transmitted sound was detected with microphones placed on the anterior neck over the trachea and on the chest wall. The sound intensity at the chest was normalized by that at the trachea to avoid the influence of the opening of the glottis. The attenuation of the transmitted sound was shown in Bode diagram.

The normal thorax produced rapid attenuation with increasing frequency at a rate of 40dB/dec (12dB/oct), and cut off frequency was 300 Hz at the apex and 150 Hz at the base as reported last year. The attenuation rate with increasing frequency was samely 40dB/dec in patients with pulmonary emphysema, asbestosis and stenosis of the main bronchus. Cut off frequency was higher in asbestosis and lower in emphysema than in normal subjects.

We have recently devised a new acoustic transmission meter of the lung for rapid analysis by normalizing with the sounds at the trachea, and are now applying it clinically to various pulmonary diseases.

The Application of Auscultatory Percussion for the Study of the Transfer Function of the Lung

Hajime Morinari
Norinari Honda
Kojiro Kinoshita
Masashi Mori

By assuming the percussion sound over the sternum as an input signal and the transmitted sounds recorded at the posterior chest wall as output signals we calculated transfer functions of the lung. The sternum was percussed by a mechanical percussor and the sounds were recorded by condenser-type microphones (SONY ECM 150) attached to the sternum and the back (four pairs of the same microphones positioned 5 cm from the spine and 5 cm apart vertically from the C7 level). Each signal was digitized at 20 KHz and stored in a memory of 2 K bytes for the Fourier transform. Three normal subjects and three patients with lung diseases (lung cancers and pneumothorax) were studied. In normal subjects the transfer functions were near symmetrical and at FRC level had peaks at 60 to 80 Hz and decayed at a rate of about 18 dB/octave. At 400 Hz the attenuation was about -30 dB. The transfer functions were different depending on the lung volumes and at RV level the response was more flat (about -10 dB at 1 KHz). The results agreed favourably well with those of our model experiment. In patients with unilateral lung diseases the transfer functions were asymmetrical.

The Relationship Between Airflow and Lung Sound Amplitude in Normal Subjects

S. S. Kraman

Few studies have examined the relationship between airflow and lung sound amplitude and the data available are contradictory. To examine this relationship in detail, I measured airflow at the mouth and compared the peak flow ($\dot{V}max$) to mean and peak lung sound amplitude (MEAN AMP and PEAK AMP) at four sites on the chest wall (right and left anterior apices and posterior bases) in four healthy young adults. At each site, the sounds produced by 20 breaths at $\dot{V}max$ ranging between 1.5 and 4 l/s ($\dot{V}var$) were measured by an automated technique. Ten breaths during nearly constant $\dot{V}max$ breathing ($\dot{V}con$) were also measured at each site. The normalized lung sound amplitudes at the four sites in each subject were grouped and compared to $\dot{V}max$ by linear regression analysis. The same sounds were also submitted to an automated $\dot{V}$-correction procedure to evaluate its adequacy in automatically adjusting for the effect of variations in $\dot{V}max$ on lung sound amplitude. The data showed that lung sound amplitude (mean or peak) was linearly related to $\dot{V}$ in all subjects (r for MEAN AMP vs $\dot{V}max$:0.77, 0.85, 0.69, 0.89; r for PEAK AMP vs $\dot{V}max$:0.80, 0.83, 0.79, 0.88), $P<1 \times E^{-7}$ in all cases. The average MEAN AMP vs $\dot{V}max$ regression line slope was 0.42, and the average PEAK AMP vs $\dot{V}max$ regression line slope was 0.45. $\dot{V}$-correction decreased the coefficient of variation of the $\dot{V}var$ sounds by 61% and flattened the average regression line slopes to 0.128. For the $\dot{V}con$ series, $\dot{V}$-correction diminished the coefficient of variation from 12.2% to 10.0%. I conclude that lung sound amplitude is linearly related to airflow at the mouth and that this relationship can be used to effectively adjust for substantial variations in airflow.

The Effect of Low Density Gas Breathing on Vesicular Lung Sounds

O. Austrheim
S. S. Kraman

Turbulence (largely gas density dependent) in larger airways is believed to be the mechanism responsible for the generation of vesicular lung sounds. To test the validity of this concept, the lung and tracheal sounds of subjects alternately breathing air and a low density gas mixture (80% helium, 20% oxygen) were analyzed. We studied 6 lifetime non-smoking men ages 27 to 38 years. Lung sounds were recorded from 3 chest wall sites: anterior right upper lobe (RUL), posterior and posterolateral right lower lobe (RLL), and a site over the proximal trachea below the larynx. The subjects rebreathed into an electronic spirometer filled with the test gas, and achieved a peak inspiratory and expiratory airflow of 2-2.5 l/s. Lung sound amplitude was determined by an automated, flow-corrected measurement procedure. The mean decrease in sound amplitude when breathing $He-O_2$ compared to air was: trachea, inspiration - 44%; trachea, expiration - 45%; RUL, inspiration - 13%; RUL, expiration - 25%, RLL inspiration 15% (expiration at the RLL was too quiet to record). Cross-correlation and frequency analyses of the sounds recorded at the two RLL sites on both test gases revealed no consistent change in frequency or time relationships, indicating no detectable effect of gas density on sound transmission. These data suggest that the mechanism of production of the inspiratory vesicular lung sound is not simply gas density dependent turbulence but some other relatively gas density independent mechanism. The tracheal sounds and expiratory lung sounds do behave as if produced by a density dependent turbulent mechanism.

Spectral Feature Variations of Normal Breath Sounds at Constant Flow Rate

G. Charbonneau
J. L. Racineux
M. Sudraud
E. Tuchais

We recorded breath sounds at the trachea of normal subjects. Subjects were asked to maintain the flow rate at three given constant values, namely 0.25, 0.5 and 1 l/s. The purpose of the experiment was to obtain long plateaus at constant flow rate both for inspiration and expiration. Flow rate and breath sounds were recorded simultaneously. The sound is digitized at 5120 Hz and analyzed using Fast Fourier Transform on 1024 - sample blocks.

We present statistical results of different spectral characteristics over periods at constant flow rate inside a single inspiration/expiration as well as over several cycles. Results will be discussed considering mechanical parameters.

Multimode Spectral Analysis

Christopher K. Druzgalski

Relatively large and expensive computer systems and/or special purpose spectrum analyzers which usually by their nature have limiting processing capabilities have been utilized for frequency and time domain analysis of respiratory sounds. However, the complexity of these systems limits their broad clinical applicability. Proliferation and expanding capabilities of personal computers allow their utilization for on-line recording, analysis of respiratory sounds and storage of patient data.

In order to overcome these limitations, an Apple II personal computer and developed associated hardware and software which allow on-line analysis were used to study spectral characteristics of respiratory sounds which are user selectable in reference to respiratory airflow, respiratory volume, thoracic chest wall movement, or other reference signal. The system allows one viewing of the discrete spectra in a compressed or expanded form, and to study their variability as well as to determine the dominant frequency characteristics in averaged spectra for given physiological conditions such as levels of ventilation or respiratory phase. In addition, the system allows continuous scanning of any desired number of respiratory cycles and the determination of composite spectral characteristics typical for the selected conditions of ventilation and selected side of respiratory sounds detection in one third-octave bands. This spectral data can be also viewed in a sequential fashion by plotting discrete spectral characteristics at selected time intervals and selected and calibrated levels of sound intensity thus providing spectral surface maps.

We believe that the system provides capabilities of comprehensive studies of spectral characteristics of respiratory sounds in discrete, composite, and averaged modes and spectral surface characteristics. Examples of system utilization in a variety of applications will be discussed.

Flow and Volume Dependent Spectral Analysis of Lung Sound

O. Rompelman
G. Boxelaar
P. van Spiegel

Poster Presentation

Lung sound generation is supposed to be mainly located in the greater airways. Furthermore it is assumed that the sounds are of a noiselike character, their spectral properties varying with time.

An obvious way to study these sounds is by means of time dependent spectral analysis, a technique which has proven to be useful in the analysis of comparable signals such as speech.

In the case of lung sounds we are faced with the problem that we want to know which components of the signal are systematic (i.e. correlated with the respiratory cycle) and which components are random.

We therefore developed a method which resembles the coherence averaging technique as it is used in evoked response analysis. Either the respiratory flow signal or the corresponding volume signal is used as a reference signal. Contrary to the evoked response analysis we do not average the signal itself but the power spectra of those signal segments that are attributed to particular values of the flow (or volume respectively).

In this case we generate average flow (or volume) dependent power spectra of the lung sounds. These three dimensional plots reveal the varying spectral properties of the lung sounds in relation to respiratory flow (or volume).

It is of course possible to relate the spectral properties of the signals to other parameters such as intrathoracic pressure.

Session C

Chairmen: S. Ishikawa and R. Mikami

9:00 am	Crackles in Chronic Obstructive Lung Disease (Type B)	M. Munakata H. Ogasawara M. Matsuzaki Y. Homma H. Kusaka Y. Kawakami
9:20 am	Prevalence of Crackles in a Coronary Care Unit	E. Del Bono C. McFadyen R. Murphy
9:40 am	Relation of Lung Volumes and Fine Crackle Generation in Pulmonary Fibrosis	M. Matsuzaki Y. Homma M. Munakata H. Ogasawara H. Kusaka Y. Kawakami
10:00 am	Mechanism of Producing Crackles Studied by Simultaneous Recording from Oral Cavity and Chest Wall	T. Abe T. Kawashiro T. Yokoyama
10:20 am	Coffee Break	
10:40 am	Histology of Crackling and Non-Crackling Pig Lung	F. Davidson R. Murphy E. Del Bono
11:00 am	Observation on the "Breath Sound" Spectra from a Single Human Bronchial Bifurcation	J. Seiner J. Hardin J. Levasseur J. Patterson
11:20 am	Guest Lecture - "Generation and Transmission of Flow-Induced Sound"	
	Richard H. Lyon Professor, Mechanical Engineering Massachusetts Institute of Technology	
12:00 pm	Lunch	

Crackles in Chronic Obstructive Lung Disease (Type B)

Mitsuru Munakata
Hideki Ogasawara
Michiyuki Matsuzaki
Yukihiko Homma
Hirotaka Kusaka
Yoshikazu Kawakami

Auscultation has been recently re-evaluated with the advance of lung sound analysis. In the patients with airway obstruction, coarse crackles have been pointed out to be mainly heard in early inspiratory and expiratory phase.

We analyzed the discontinuous sounds recorded from 14 patients with COLD (type B) using our phonopneumograph, and studied the clinical usefulness of auscultation in evaluating the severity of this disease, in terms of correlation to pulmonary function data. Coarse crackles were defined to have TB (the first ¼ cycle duration of each sound wave) more than 0.5 msec, and fine crackles less than that in their time-expanded waveform.

The obtained results were:

1) in the 341 crackles sampled from 14 patients, all but one were classified into coarse crackles,

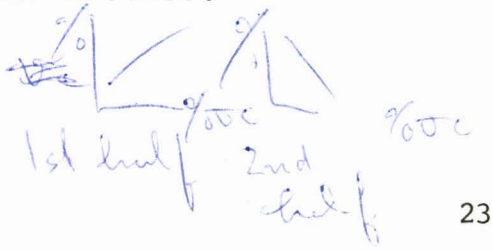
2) ½ of the total coarse crackles appeared in early inspiratory and ¼ in late inspiratory as well, and 1/6 in early expiratory and 1/12 in late expiratory phase,

3) the more vital capacity decreased and/or RV/TLC increased, the earlier the crackles appeared in inspiratory phase,

4) in the patients with lower PaO_2, crackles increased in number, and

5) in the patients with severer restrictive changes, crackles became more high-pitched.

We concluded that auscultation in COLD patients was considerably useful, especially in evaluation of severity of the disease.



Prevalence of Crackles in a Coronary Care Unit

E. Del Bono
C. McFadyen
R. Murphy

As crackles are considered signs of congestive heart failure, atelectasis and pneumonia, chest auscultation is commonly done on patients in Coronary Care Units. Crackles occur in apparently healthy individuals and the interpretation of the meaning of crackles in any given patient may be difficult. A review of lung sound literature provided little information on the prevalence, character and degree of crackles in the coronary care setting. Accordingly, we examined 20 consecutive patients admitted to a Coronary Care Unit, with the diagnosis of suspected myocardial infarction. Lung sound maps, as previously described, were made daily from within 24 hours of admission to discharge from the Unit. A total of 52 sites per patient were examined daily in a total of 50 patient examinations by two observers, whose performance was validated by use of teaching tapes and time expanded waveform analysis. Seven patients were diagnosed as having myocardial infarctions and excluded in the remainder. On admission to the study, crackles were present in at least one site in all 20 patients. Of the crackles heard, 85.1% were over the lower one-half of the chest, 14.9% were over the upper chest; 32.3% of the lower sites auscultated were positive for crackles as compared to 12% of upper chest sites. This prevalence was considerably higher than in industrial workers, student nurses and office outpatients with chest illnesses. Of the sites examined in patients with myocardial infarctions 22.6% were positive for crackles as compared to 31.2% of sites in those of whom the diagnosis was excluded. One hundred percent of the sites auscultated were positive for crackles in one of the two patients with frank pulmonary edema; in the other, only 22% were positive. There were few differences in the timing and quality of crackles between these patient groups. We conclude that crackles commonly occur in the coronary care setting. Their meaning is often unclear, especially when few in number. As crackles can be an index of worsening of the clinical condition, and can also be present without evidence of other apparent illness, further study of this problem is indicated.

Relation of Lung Volumes and Fine Crackle Generation in Pulmonary Fibrosis

Michiyuki Matsuzaki
Yukihiko Homma
Mitsuru Munakata
Hideki Ogasawara
Hirotaka Kusaka
Yoshikazu Kawakami

The purpose of this study is to determine lung volumes at which fine crackles occurred in order to speculate its generating mechanism, especially in relation to the closing volume. Lung sounds and flow signals were recorded simultaneously from the patients with pulmonary fibrosis. The patients were asked to breathe tidally, then breathe from TLC to RV twice or three times, and again tidally. Flow signals were integrated, and the lung volumes at which the initial fine crackles occurred (initial crackle level:IC level) were determined. VC, FEV_1, TLC, FRC, RV and CV were also calculated on the same day of lung sound recording.

(1) FRC levels and IC levels during tidal breathing were sufficiently above the closing volumes. This can be a conflicting finding against the airway-opening-theory for fine crackle generation. Because, if closing volume phenomenon shows all of airway closing events, no airway closure could be present at FRC in our series of pulmonary fibrosis.

(2) The relationships between functional impairment and IC level will be discussed.

Mechanism of Producing Crackles Studied by Simultaneous Recording from Oral Cavity and Chest Wall

Tadashi Abe
Takeo Kawashiro
Tetsuro Yokoyama

Crackles were recorded simultaneously from the oral cavity as well as from two different loci of the posterior chest wall using the electret condenser microphones on eight patients of upright position. One microphone was placed on the chest wall over the right middle lung region and the other over the right basal lung region. The direction of the initial deflection of recorded waveform for each crackle was analyzed.

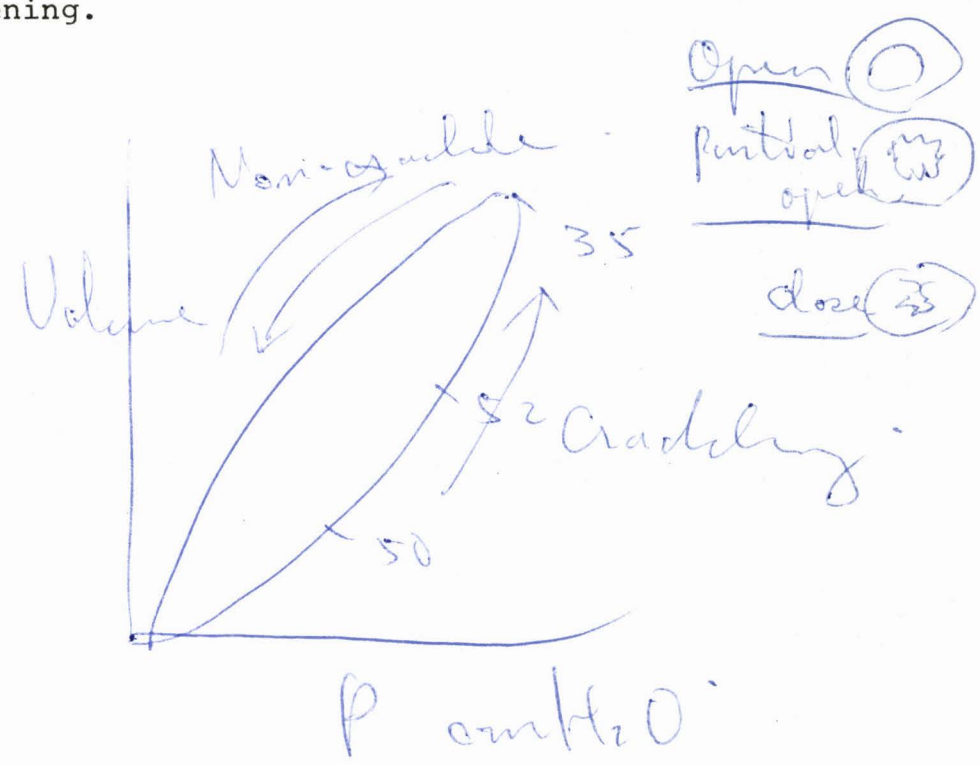
The initial deflection for every crackle recorded from the oral cavity was negative on inspiration and positive on expiration. On the middle lung region, the initial deflection for most crackles was negative on inspiration and positive on expiration. In contrast, on the basal lung region, it was positive on inspiration and negative on expiration.

We speculated that one of the mechanisms of producing crackles investigated in this study might be the sudden disappearance of the airway pressure difference across the airway obstruction.

Histology of Crackling and Non-Crackling Pig Lung

F. Davidson
E. Del Bono
R. Murphy

We have been interested in histologic confirmation of the hypothesis that crackles result from the sudden opening of closed airways. It is possible to inflate excised pig lung segments with aliquots of air so that the lung will crackle or not depending on its volume history. Isovolumetric points on the volume pressure hysteresis loop of this preparation can be found where the lung will reproducibly crackle when inflated, when it was previously at lower lung volume, but not when it was previously at higher lung volumes. This is analogous to the volume history dependence of crackles in humans. We studied histology of these isovolumetric sections of crackling and non-crackling pig lung. Thirty-five percent of airways from crackling lung in contrast to 81% of airways of non-crackling lung was open. These observations are consistent with the theory that crackling is caused by airway opening.



According to the results of our experiment, presented yesterday, the sound pressure of tracheal sound recorded on the neck ~~was~~ raised ~~to a rate of~~ (2nd ~ to 3rd power ~~of~~ ~~in~~ flow rate ~~increasing~~.

It seemed that the ~~is~~ in influence of Qual. mechanism (to generating tracheal sounds.

Observations on the "Breath Sound" Spectra from a Single Human Bronchial Bifurcation

John M. Seiner
Jay C. Hardin
Joseph E. Levasseur
John L. Patterson, Jr.

A single human bronchial bifurcation, dissected from a necropsy specimen, was subjected to spectral sound analysis over "expiratory" airflow ranges of 2.6 to 4.7 liters per minute. The diameters of the individual bronchi were 4.0/2.5/2.0 mm (parent/daughter/daughter).

Pure tones of large amplitude and one or more harmonics were recorded up to flows of 3.7 liters/minute; higher flow rates were associated with both pure and more complex tones. The 4-vortex pattern in the parent tube was visually confirmed with water/glycerol fog. Associated with higher flow rates were indications of instability of the vortex structure. The relationship between the fundamental frequency and the square root of Reynolds number was roughly linear. The frequencies recorded from the human bifurcation were higher for a given flow than with our Plexiglas(R) model of 4.0/3.4 mm dimension, due to the smaller and unequal size of the daughters. We are studying with motion pictures the vortex patterns with symmetric and asymmetric daughter tubes in single bifurcations.

$f = 403.6\sqrt{Re} - 11850.$

Monopole $P_m = \frac{\dot{M}(t - r/c)}{4\pi r}$

Dipole $P_d = \left\{ \frac{\dot{P}(t - r/c)}{4\pi r^2} + \frac{\ddot{P}(t - r/c)}{4\pi r c} \right\} \cos\theta$

$= \frac{\dot{P}\cos\theta}{4\pi r^2} \left\{ 1 + \frac{r}{f_a} \right\}$

Quad $P_Q = \left\{ \frac{\dddot{T}(t - r/c)}{2\pi r^3} + \frac{\ddot{T}(t - r/c)}{2\pi r^2 c} + \frac{\dddot{T}(t - r/c)}{4\pi r c^2} \right\} \cos\theta \sin\theta$

$= \frac{\dddot{T}(t - r/c)}{2\pi r^3} \left(1 + \frac{r}{f_a} + \frac{1}{2}\left(\frac{r}{d_a}\right)^2 \right) \cos\theta \sin\theta$

Session D

Chairman: M. Mori

1:00 pm	Business Meeting	
1:15 pm	Correlation of Lung Sounds with Pulmonary Function in Patients with COPD	S. Ishikawa S. Doss B. Johnston J. Zebniak S. Maskwa K. MacDonnell
1:35 pm	Poor Breath Sounds, Good Voice Sounds: An Auscultatory Sign of Bronchial Stenosis	F. Jones, Jr.
1:55 pm	Chest Roentgenograms, Pulmonary Function Studies and Lung Sounds in the Diagnosis of Some Common Lung Diseases	R. Murphy E. Del Bono F. Davidson P. Bettencort
2:15 pm	Cardiovascular Sounds: Possible Interference with Analysis of Breath Sounds in Normal Children	H. Pasterkamp R. Fenton A. Tal V. Chernick
2:35 pm	The Use of Tracheal Breath Sounds for Apnea Detection	R. Beckerman
2:55 pm	Breath Sound Monitoring for Apnea	R. Beckerman
3:15 pm	Coffee Break	
3:30 pm	Cracklefest: Auditory presentations by participants	
4:10 pm	Summary of Conference	D. Cugell

Correlation of Lung Sounds with Pulmonary Function in Patients with COPD

S. Ishikawa
S. Doss
B. Johnston
J. Zebniak
S. Maskwa
K. MacDonnell

During quiet breathing, the lung sounds of patients with "clinically diagnosed COPD" were recorded using an electronic stethoscope and a stereo tape recorder. The central airway (trachea) along with six peripheral sites were monitored. The recordings were then transcribed onto photographic paper at a speed of 100 mm/sec. Sound intensity was measured manually from the tracings. Adventitious sounds were eliminated visually from the tracings. Standard pulmonary function tests were performed following lung sound recordings.

- "Auscultatory perception" was influenced a great deal by former training. It was frequently wrong.

- There were clearly 2 types of COPD on lung sounds characteristics "one with noisy and significant Heterophony, the other quiet and Homophony".

- When dyspnea is the predominant symptom in a patient with x-ray and clinical signs of hyperinflation, the lung sounds intensity was often low and homophony was observed.

  RV, TLC and RV/TLC ratio were inversely correlated reasonably well with lung sounds intensity and degree of heterophony.

  Peak flow, diffusing capacity, FEV_1, FEV_1/FVC ratio were correlated with lung sounds intensity while no significant correlation was observed between MMFR and lung sound intensity.

- "BSI score" employed by Pardee and others is often misleading especially during auscultation of COPD patients. Auscultation during quiet breathing is recommended instead of "deep inspiration from residual volume to generate as loud a sound as possible".

Poor Breath Sounds, Good Voice Sounds:
An Auscultatory Sign of Bronchial Stenosis

Frederick L. Jones, Jr.

Disparity rather than the expected similarity of breath and voice sounds - specifically, diminished or absent breath sounds unilaterally but good voice sounds bilaterally - is a useful auscultatory sign of stenosis of a main or lobar bronchus. Stenosis limits airflow and consequently reduces turbulence, causing diminution or absence of breath sounds over the poorly ventilated area. However, flow-independent voice sounds are not significantly impaired and pass easily through a narrow orifice. This sign was present in three patients, each of whom had marked stenosis of a major bronchus confirmed by bronchoscopy. Sound recordings made at bilateral corresponding sites on the chest wall demonstrated in each case marked diminution of breath sounds and preservation of voice sounds over the affected area.

CHEST ROENTGENOGRAMS, PULMONARY FUNCTION STUDIES AND LUNG SOUNDS IN THE DIAGNOSIS OF SOME COMMON LUNG DISEASES

By

R. Murphy, E. Del Bono, F. Davidson, P. Bettencourt, L. Faling

To study the diagnostic value of lung sounds we examined patients from the practice of three chest physicians. Lung sound maps, as previously described were made by a technician who was unaware of the clinical diagnoses at the time of auscultation. The technician observed the intensity of the inspiratory and expiratory sounds, the relative duration of inspiration and expiration and the presence and character of adventitious sounds in each of 52 designated chest wall locations. Observations were also made at the mouth and over the trachea. Chest roentgenograms were evaluated by a panel of three internists with subspecialty board certification in pulmonary disease. Subjects were classified as having obstructive lung disease alone, restrictive lung disease alone or combined obstructive and restrictive lung disease using all available clinical information. The diagnosis made by reviewing only the chest roentgenograms agreed with the clinical diagnosis in 29%; pulmonary function interpretation alone agreed in 63%. The diagnostic categories of the obstructive diseases (asthma, bronchitis, and emphysema) were detected by roentgenogram in 52% of cases as compared to 94% by lung sounds. Diagnosis of the restrictive processes, interstitial fibrosis and CHF by roentgenogram agreed in 60% of the cases with the clinical diagnosis as compared to 71% for the lung sound maps. These preliminary findings suggest that lung sound maps have potential clinical applications.

Cardiovascular Sounds: Possible Interference with Analysis of Breath Sounds in Normal Children

H. Pasterkamp*
R. Fenton
A. Tal
V. Chernick

We have used Fast Fourier transform and power spectra analysis to determine possible interference of cardiovascular sounds with the analysis of breath sounds in normal children. Eight boys and 2 girls, ages 8-13 yrs., were studied with contact transducer positions over midprecordium, anterior right upper and posterior right lower lobe. R-wave triggered samples of 100 ms were obtained at different flow levels. Power spectra analysis was done between 10-100 Hz and 100-400 Hz. Sound intensities of samples taken with a given time delay after the R-wave and during breath-holding served as baseline values. Precordial heart sounds were 21 db $\pm$ 5 (mean $\pm$ SD) above baseline and 99.4% $\pm$ 0.6 of their intensity was 100 Hz with sharp peaks between 30-50 Hz. This intensity was attenuated - 3 db $\pm$ 2.7 at the right upper lobe and - 15 db $\pm$ 4.4 at the right lower lobe. Inspiratory breath sounds at 0.5 l/sec flow were 17 db $\pm$ 4.8 above baseline for 100-400 Hz and 12 db $\pm$ 2.7 for 10-100 Hz over the right upper lobe. Values for the right lower lobe were 15 db $\pm$ 3.2 and 9 db $\pm$ 4.4 above baseline respectively. This illustrates that a) breath sounds in normal children contain a variable amount of power in the low frequency range of heart sounds and b) interference of cardiovascular sounds is significantly less over the right posterior base of the lung.

*Supported by a fellowship from the Manitoba Lung Association

The Use of Tracheal Breath Sounds for Apnea Detection

Robert C. Beckerman

Impedance pneumography (IMP) and airflow (AF) sensing devices are the standards for detection of central (CA) and obstructive apnea (OA) in hospitalized patients. We have studied a system that detects normal breath sounds (BS) and periods of CA and OA by using a miniature unidirectional microphone coupled to the chest wall. We evaluated 10 sleeping infants and children (ages 2 months to 8 years) who were referred because of symptoms of severe sleep disturbance. The tracheal breath sounds (TBS) system was compared to IMP using AF (thermistor, CO_2 catheter) as the reference technique for apnea detection.

% Breath Detected		% CA Detected		% OA Detected	
TBS	IMP	TBS	IMP	TBS	IMP
$\bar{X} \pm 1$ SD		$\bar{X} \pm 1$ SD		$\bar{X} \pm 1$ SD	
95 $\pm$ 2.6	98.2 $\pm$ 3.6	99.4 $\pm$ 1.7	100	95.2 $\pm$ 6	0

There were no statistically significant differences among the methods of breath or apnea detection. We found TBS to be as good a method as IMP or AF in detection of normal BS and periods of CA and OA in closely observed children. TBS had several advantages over the other techniques. It was easier to measure the apneic interval and was less easily dislodged by movement. Filtering of heartsounds and background noise and more efficient coupling of the TBS detector has allowed even greater sensitivity. We feel that TBS may have practical application in hospital and home monitoring for apnea.

Breath Sound Monitoring for Apnea

Robert C. Beckerman

A breath sound detection/monitoring system was compared to a standard impedance (respiration/ECG) monitor and nasal thermistors (airflow) in three sleeping infants who were being monitored for apnea. The thermistor was considered the standard for normal respirations, and both central and obstructive apneas. There were no significant differences between the impedance and breath sound monitors in the detection of normal breathing or central apnea. The breath sound monitor, however, detected 85% of obstructive apnea, alarmed four times for obstructive apnea greater than 10 seconds in duration and false alarmed three times when respirations were shallow. Our study suggests that a breath sound monitoring system may offer a practical alternative to impedance respiratory monitoring for the detection of normal respirations, central and obstructive apneas in infants.

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