First International Conference on Lung Sounds

Presented by the Tufts University School of Medicine,

the Massachusetts Thoracic Society

and the University of Cincinnati College of Medicine,

at the Faulkner Hospital

October 14-16, 1976

Faulkner Hospital

Boston, Massachusetts, U.S.A.

Steering Committee:	Raymond L.H. Murphy, Jr.	- Boston
	Robert G. Loudon	- Cincinnati
	Paul Forgacs	- London

Table of Contents

Objectives of the Conference

Studies of lung sounds have been reported with increasing frequency in recent years. This conference is convened to provide an opportunity for exchange of ideas and experience among those who have an active interest in the subject. Clinicians, physiologists, engineers, and perceptual psychologists can each contribute towards a better understanding of what lung sounds mean. They will have a better chance of doing so after talking together.

We hope that comparisons of methods of recording, analyzing, and describing lung sounds will reduce ambiguity. We hope that discussions about work in progress may prevent unnecessary duplication of effort. We hope that investigators will save time and avoid some mistakes by learning what others have done.

First International Conference on Lung Sounds

Faulkner Hospital, Boston, Massachusetts

Program

Thursday, October 14, 1976

Registration			8:30 AM
Introduction ----------------------	Raymond L.H. Murphy, Jr.		8:45 AM
Objectives and Scope of the Conference ----------------------	Robert G. Loudon		8:50 AM
Session A	9:00 AM - 12:00 Noon		
Lunch	12:30 PM - 1:30 PM	Hallowell Hall, Faulkner Hospital	
Session B	1:30 PM - 4:15 PM		
Film "Lung Sounds" and Discussion---	Leslie H. Capel		4:30 PM
	Cocktails and Buffet		7:00 PM

Friday, October 15, 1976

Session C	8:30 AM - 12:00 Noon		
Lunch	12:30 PM - 1:30 PM	Hallowell Hall, Faulkner Hospital	
Session D	1:30 PM - 4:00 PM		
Summary of the Conference ----------	Giles F. Filley		4:00 PM

Saturday, October 16, 1976

Committee on Lung Sound Nomenclature

Session A

Chairman: C. Forbes Dewey

Session A

Chairman: C. Forbes Dewey

9:00 am	Source and Transmission of Breath Sounds	Paul Forgacs
9:20 am	Physical Basis for Breath Sounds - Aerodynamic Sound Generation	D.E. Olson and G.F. Filley
9:40 am	Production and Analysis of Speech Sounds	K. Stevens and V. Zue
10:00 am	Coffee	
10:20 am	Density Dependence of Normal Breath Sounds	P. Krumpe, L. Peress, L.A. Engel and P.T. Macklem
10:40 am	Wave Propagation in the Airways of the Lung	Jeffrey Fredberg and Alan Hoenig
11:00 am	Stress and Motion Transduction at the Body Surface	Jeffrey Fredberg
11:20 am	General Discussion	
11:30 am	Historical Review	J.L. Andrews, Jr. and T. Badger
12:30 pm - 1:30 pm	Lunch - Hallowell Hall Faulkner Hospital	

SOURCE AND TRANSMISSION OF BREATH SOUNDS

Paul Forgacs

Breath sounds at the mouth contain a wide range of evenly distributed frequencies. A linear correlation exists between their amplitude and the instantaneous respiratory flow rate. The breathing of a healthy subject at rest is barely audible but in chronic bronchitis and asthma it is abnormally noisy. A significant correlation has been demonstrated between the intensity of the inspiratory noise, the FEV_1 and other indices of airflow obstruction.

The spectrum of breath sounds heard throughout the chest is restricted to a narrow range of low frequencies. Their loudness reflects the rate of gas flow into the underlying territory of the lung and may be modulated by the heart beat. They are audible throughout inspiration but fade out in early expiration. Noisy breathing at the mouth may be accompanied by faint breath sounds over the chest and vice versa.

The source and transmission of breath sounds will be discussed in the light of these observations.

PHYSICAL BASIS FOR BREATH SOUNDS - AERODYNAMIC SOUND GENERATION

D. E. Olson
G. F. Filley

Sounds heard at the chest wall are a composite of individual noises generated by multiple sources within the chest which then undergo modulation during transmission to the chest wall. The observer will thus hear a pneumonic chorus which has multiple permutations with each clinical state. To understand what the lung is saying to the clinician one must comprehend each voice within the chest. This study tries to develop plausible physical arguments for the sounds generated by sources within the chest and then relates them to what is clinically heard. Sounds originating in the chest can be generated by, basically, two modes: tissues vibrating from physical displacement or aerodynamic sound generation. This presentation will discuss highlights of the latter.

Sounds generated by the motion of air in the chest can be grouped into three classifications physically described as monopole, dipole and quadrapole.

Monopole production (as its name suggests) comes from one point (or pole) and, in the lung, requires the existence of air and water together. The noise is generated by "popping" of bubbles and can be characterized by: 1) short duration sounds (rales); 2) uniform, low frequency (less than 200 Hz); and 3) occurrence throughout the negative pressure cycle (inspiration when without a ventilator). The frequency (or pitch) of the sound is characteristic of the surface tension of the excess or abnormal fluid within the air spaces. These sounds are characteristically heard as rales in advanced congestive heart failure (a transudate in the air spaces), peripneumonia rales (exudate in the incompletely consolidated air spaces) and alveolar proteinosis (highly proteinaceous fluid in air spaces). Pulmonary edema is another example of "popping" rales but here the monofrequency is distorted by flow, implying abnormal fluid in the airways.

Dipole aerodynamic sound production requires an acceleration-deceleration in the flowing stream. The sound produced is of prolonged duration with a composite of several (but grouped) frequencies, and with amplitude which is proportional to the magnitude of velocity change. All sounds heard in the cardiovascular system originate from this phenomenon. Wheezes are the most prominent respiratory example. The frequency of the wheeze will depend on the size of the airway which is being vibrated by the flow disturbance from within--higher frequencies from smaller airways. The amplitude of the noise will depend on the magnitude of acceleration of the flow--i.e. louder sounds from central airways, or with higher total volume flows.

Quadrapole sound production is the sound heard from the interaction of the eddies within a turbulent flow. This is often referred to as "white noise" and can be heard in the pharynx and trachea in both normal and pathologic states. With stenosis of the upper airways the lower frequency components of this sound will be enhanced making the composite noise sound rougher or more coarse.

PRODUCTION AND ANALYSIS OF SPEECH SOUNDS

K. N. Stevens
V. W. Zue

A review is given of the acoustic theory of speech production, which accounts for the sources of sound that are generated in speech, the filtering of these sources by the acoustic system surrounding them, and the radiation of sound, usually from the mouth opening. Aspects of speech production that are particularly relevant to sound production in the lungs are discussed in more detail. These include the generation of turbulence noise in the airstream at the glottis and in the supraglottal region, the sound arising from vocal-fold vibration, and the acoustic properties of the subglottal system. Procedures for measuring and calculating the resonances of the subglottal system are described.

DENSITY DEPENDENCE OF NORMAL BREATH SOUNDS

P. Krumpe
L. Peress
L. A. Engel
P. T. Macklem

The intensity of breath sounds (I_B) was studied in six trained subjects breathing each of three different gas mixtures: 80% He/O_2, room air, and 80% SF_6/O_2 (density ratio 0.33:1:4.35). I_B was measured from the amplified, rectified, filtered (150-550 Hz band pass filter), and integrated signal of a microphone fixed to the chest wall of the anterior second intercostal space. Flow rate ($\dot{V}$) was obtained by differentiating a volume (V) signal from a spirometer. Plots of I_B vs $\dot{V}$ were obtained which were curvilinear so that with increasing $\dot{V}$, I_B increased even more. I_B was uninfluenced by V over the range studied, was greater during inspiration than expiration, and was greater the greater the gas density.

Sound transmission through the chest was studied by applying white noise from a speaker cone at the mouth. Transmitted white noise intensity was measured with the microphone in the same location as above, while subjects maintained an open glottis at FRC. The intensity of transmitted white noise decreased as gas density increased.

The results suggest that I_B in normal subjects is gas density dependent. Sound transmission through the chest filled with different gases does not account for the differences observed. Hence it is the generation rather than transmission of breath sounds which determines the change in I_B when breathing gases of different density. Furthermore, the results point to the larger airways as the site of generation of normal breath sounds.

WAVE PROPAGATION IN THE AIRWAYS OF THE LUNG

Jeffrey J. Fredberg
Alan Hoenig

The nature of sound transmission in the airways of the lung is a key element in the mechanistic interpretation of breath sounds detectable at the chest surface and in other areas of high frequency respiratory mechanics. We have developed a theoretical framework for analyzing and identifying the dynamic and geometric parameters which control the nature of wave propagation in the airways. This analysis includes gas density and bulk modulus, thermal and viscous losses in the gas, airway wall compliance, inertance and resistance, and flare of the airway cross-sectional area. The role of these parameters in the dispersion relationship has been evaluated for several airways, and the magnitude and frequency dependence of phase speed, group speed, and attenuation coefficients were computed. The results indicate that airways are a highly dispersive medium, especially at frequencies below 2 kHz. At frequencies approaching 10 kHz the dispersiveness is diminished and wave speeds approach the free wave speed in air. Wave dispersion exhibits strong dependence upon airway wall inertance and airway wall resistance.

This work was supported in part by NHLI Contract No. N01 HR-6-2901.

STRESS AND MOTION TRANSDUCTION AT THE BODY SURFACE

Jeffrey J. Fredberg
T. S. Klitzner

Internally generated tissue vibrations or oscillating stresses detected at the skin surface are called physiologic "sounds" and include cardiac sounds, vascular sounds, and breath sounds. The transduction of these "sounds" by electro-mechanical devices is a complex process that can lead to a high degree of output waveform variability from device to device and researcher to researcher. In most cases it is not clear whether output waveforms correspond to surface stress, surface motion, or a combination of the two; nor is it clear how these waveforms correspond to surface motion in the absence of mechanical loading of the surface by the transducer, or the surface stress when surface motion is uniformly constrained. The resolution of these issues depends upon the details of transducer design, the mechanical load of the transducer on the surface, and the mechanical input impedance of the body surface at the point of transduction. A general method of analysis of mechanical transduction of body surface stress and motion is put forward and applied to a specific transducer. It is shown for this transducer that surface motion is greatly diminished due to mechanical loading of the surface, but that the output waveform is a reasonable replica of the surface velocity in the <u>absence</u> of the transducer.

This work was carried out in the Fluid Mechanics Laboratory, Department of Mechanical Engineering, and the Arteriosclerosis Research Center, Massachusetts Institute of Technology, and was supported by NHLI Grant No. HL 14209, and the National Dairy Council.

SESSION B

CHAIRMAN: JERE MEAD

Session B

Chairman: Jere Mead

1:30 pm	Correlation between Regional Breath Sounds and Regional Ventilation	Y. Ploy-song-sang, R. G. Loudon, R. R. Martin, L. Peress, L.A. Engel, P. T. Macklem
1:50 pm	Distribution of Regional Ventilation Measured by Breath Sounds	Y. Ploy-song-sang, R. G. Loudon, P. T. Macklem and D. R. Ross
2:10 pm	Effects of Pulmonary Disease on Respiratory Sound Peak Frequency in Man	R. Lemen, M. Wegmann, W. W. Waring, W. F. Anderson and J. B. Hill
2:30 pm	Influence of Diaphragmatic Breathing on Sequence of Breath Sounds	S. Balkenhol and R.G. Loudon
2:50 pm	An Acoustic Scanning Spectrometer for Determining Mechanical Properties of the Airways	D. W. Cugell, F. F. Mockros, J. D. Lewis and J. E. Jacobs
3:10 pm	Analysis of Frequency Response Data of the Respiratory System Measured by a Pulse Response Technique	A. C. Jackson, J.P. Butler and S. V. Dawson
3:30 pm	Sound Transfer Function of the Lung in Canine Pulmonary Edema Models	R. L. Donnerberg, C. Druzgalski R. L. Hamkin, G. W. Davis, R. M. Campbell and D. A. Rice
3:50 pm	General Discussion	
4:30 pm	Film: "Lung Sounds" and Discussion	L. H. Capel

CORRELATION BETWEEN REGIONAL BREATH SOUNDS AND REGIONAL VENTILATION

Y. Ploy-song-sang
R. G. Loudon
R. R. Martin
L. Peress
L. A. Engel
P. T. Macklem

We recorded phonopneumographically breath sound pressure index, Ib, and the transmission index of white noise from the mouth, Tn, over 4 lung regions between apex and base in 15 normal subjects upright and supine. In 10 subjects we correlated these measurements with the regional distribution of inhaled ^{133}Xenon. The ratio Ib/Tn corrects for differences in Ib due to differences in sound transmission. The ^{133}Xe and breath sound indices were expressed as a percentage of the value over the apex. In both postures Ib/Tn correlated best with raw counts after inhalation of a bolus of ^{133}Xe. Raw counts are measures of total ventilation i.e. the ventilation per alveolus x the number of alveoli "seen" by the scintillation counter. Ib/Tn correlated as well with raw counts after equilibration with ^{133}Xe which is a measure of the number of alveoli. Ib correlated less well than Ib/Tn with ^{133}Xe bolus raw counts in upright posture but did not correlate with ^{133}Xe bolus raw counts in supine posture. The same results happened when Ib was correlated with ^{133}Xe equilibration raw counts. These results strongly suggest that the uncompensated breath sounds (Ib) heard by clinicians cannot be used confidently both in upright and supine postures to assess total regional ventilation. The compensated breath sounds (Ib/Tn) which account for differences in Ib due to differences in sound transmissions (Tn) are much better indices of total regional ventilation (than Ib) and can be used confidently both in upright and supine postures to reflect total regional ventilation and also the ventilating lung volume under the microphone.

DISTRIBUTION OF REGIONAL VENTILATION MEASURED BY BREATH SOUNDS

Y. Ploy-song-sang
R. G. Loudon
P. T. Macklem
D. R. Ross

Up to date the only practical and acceptable way to study regional ventilation is by Xenon which creates radiation hazards. This study was designed to measure regional ventilation by using breath sounds. We recorded breath sound intensity (Ib) and the transmission of white noise (Tn) pneumophonographically, over 4 lung regions between apex and base in 5 normal subjects both in upright and supine postures. Ib and Tn were recorded over the whole lung volume ranging from residual volume to total lung capacity. Ib and Tn were computed and expressed as a fraction of the value over the apical region with the help of an analog divider. The ratio Ib/Tn corrected for differences in Ib due to differences in sound transmission, and was also expressed as a fraction of the value over the apex. Ib/Tn, which has been shown to measure total ventilation, increased from residual volume to total lung capacity in the lower part of the lung and did the opposite in the upper part. These findings suggest that as lung volume increases the ventilation to the upper part of the lung decreases whereas the ventilation to the lower part increased, conforming to previous Xenon ventilation studies. The differences between Ib/Tn of the upright and supine postures are due to the gravity effect on regional ventilation. Therefore the computed quotients between upright Ib/Tn and corresponding supine Ib/Tn are measurements of regional ventilation per unit volume of different regions. These regional ventilations per unit volume are very similar to those reported by Milic Emili.

Supported by MRC of Canada.

EFFECTS OF PULMONARY DISEASE

ON RESPIRATORY SOUND PEAK FREQUENCY IN MAN

R. Lemen
M. Wegmann
W. W. Waring
W. F. Anderson
J. B. Hill

The peak frequency (PF) of respiratory sound (the frequency with the highest amplitude) was determined in 15 normal subjects (ages 7 - 24y.) and in 20 patients (ages 4 - 19y.) with pulmonary disease (e.g. cystic fibrosis, asthma, congenital lobar emphysema or bronchiectasis). Each patient was free of adventitious sounds (e.g. crackles and wheezes). Respiratory sounds were recorded in a soundproof room on magnetic tape using 2 matched capacitor microphone systems. The spectral analysis of the recorded sound was determined with a real time spectrum analyzer. The relative amplitudes of each component of the respiratory sound spectrum (0-1000 Hz) were obtained by averaging 8-10 breaths and recorded on a storage oscilloscope. The PF was determined by 3 independent observers from photographs of these stored signals.

In normal subjects, PF was independent of age, height, breathing rate and lung volume. The mean PF was significantly ($p < 0.05$) lower over the bronchopulmonary segments of the lower lobes (136 ± 5 SE Hz) than over the upper lobes (153 ± 4 SE Hz). Normal subjects had a significantly ($p < 0.05$) lower PF ($\overline{x} = 142 \pm 11$ SE Hz) than patients with pulmonary disease ($\overline{x} = 200 \pm 37$ SE Hz). The PF was highest over bronchopulmonary segments with roentgenographic evidence of fibrosis or consolidation.

The explanation for differences in PF is unclear but these differences may reflect changes in the resonant frequency of diseased bronchopulmonary segments.

INFLUENCE OF DIAPHRAGMATIC BREATHING

ON SEQUENCE OF BREATH SOUNDS

S. Balkenhol
R. G. Loudon

Several factors other than ventilation influence the intensity of vesicular breath sounds, but the majority of these do not alter intensity at any given location over the chest. Changes in intensity with time during the respiratory cycle relate predominantly, although not entirely, to ventilation. We have developed methods for studying the time relationships between breath sounds recorded at different positions over the chest, and relating their intensity to one another during different respiratory maneuvers.

Ten normal subjects were trained in diaphragmatic breathing over a period of eight weeks. Sound recordings were made by microphones attached to the chest wall over the upper and lower part of the right lung, and simultaneous recordings of air flow at the mouth and volume change were made. The subjects were instructed to make a variety of respiratory maneuvers using thoracic and subsequently diaphragmatic breathing. These studies were conducted both in the seated and the supine posture. During inspiration from residual volume, using thoracic breathing in the seated posture, cross-correlation techniques show a time lag between the onset of breath sounds over the upper part of the lung and the lower part of the lung, the basal breath sounds lagging. By breathing diaphragmatically, the subjects could, after training, reduce the time lag to a significant degree. This reduction in breath sound asynchrony presumably reflects a reduction in asynchrony of regional ventilation.

AN ACOUSTIC SCANNING SPECTROMETER FOR DETERMINING MECHANICAL PROPERTIES OF THE AIRWAYS

David W. Cugell
Lyle F. Mockros
James D. Lewis
John E. Jacobs

This instrument introduces short bursts (typically 8 cycles) of discrete frequency tones through an acoustic coupler at the patient's mouth. The sound is transmitted down the airways and detected at the thoracic surface. Peak acoustic pressure at the rear of the mouth is 125 dB SPL. The differential phase of the received signal is measured by a coherent phase detection system to eliminate extraneous room sounds. Amplitude of transmitted acoustic pressure, and phase relative to the input acoustic pressure, are measured at 64 discrete frequencies between 500 and 2500 Hz. Two parallel amplitude and phase detection channels permit simultaneous measurements at two different sites during patient examination. The patterns of signal amplitude and phase at various locations on the chest are dependent on the geometric and elastic properties of the airways. Signal attenuation results from compression-expansion process of the wave, molecular exchanges* of energy, viscous shear on the airway walls, horn-like properties of the airway system, impedance mismatch at the airway-tissue interface, and viscous damping in tissues. The horn-like configuration attenuates the signal by spreading the energy over a larger area. Based on Weibel's geometry for the airways this attenuation is about 36 dB SPL. The impedance mismatch at the air-tissue interface causes an additional loss of about 30 dB SPL. Microphones placed on the back pick up signals of about 50 dB SPL, with greater attenuation at the higher frequencies. Phase shift between the microphone signal and the driver voltage depends upon (1) the time it takes for the signal to traverse the distance, and (2) frequency-dependent changes in wave speed. The transit-time effect produces a linear increase in phase change with frequency. Preliminary studies of patients with various degrees of airway disease indicate that these acoustic methods can identify alterations in airway function.

Supported in part by NIH grants HL 16218, GM00874 and HL 05694

ANALYSIS OF FREQUENCY RESPONSE DATA

OF THE RESPIRATORY SYSTEM MEASURED BY A

PULSE RESPONSE TECHNIQUE

Andrew C. Jackson
James P. Butler
Stanley V. Dawson

The input impedance of the respiratory system between 0.1 and 10 kHz was measured by an acoustic transient pulse response technique. The technique is based on Fourier analysis of the incident pressure wave generated by an electrical spark and its reflected wave resulting from changes in characteristic impedance along the airways. The response data was analyzed on the basis of the input impedance as well as a data inversion scheme (Ware and Aki. JASA. 45:911, 1968) based on an equivalent one-dimensional system assuming rigid walls and negligible energy loss. This inversion scheme provided an estimate of the area-distance function of an equivalent acoustic transmission line. When applied to systems of rigid tubes it was shown to reproduce the shape with acceptable accuracy. The frequency response of three excised dog lungs was then measured. Results indicated that there was a large degree of inter-individual variability in the data when displayed as the input impedance. However, the same data expressed as the equivalent area-distance function were not as variable and seemed to be largely dependent upon, and consistent with changes in, airway geometry.

Supported by NIH grant #17613.

SOUND TRANSFER FUNCTION OF THE LUNG

IN CANINE PULMONARY EDEMA MODELS

Roy L. Donnerberg
Christopher Druzgalski
Robert L. Hamlin
Gary W. Davis
Richard M. Campbell
David A. Rice

In his description of pectoriloquism, Laennec first identified and described alterations in sound transfer of the lung. Chest radiography with its high degree of accuracy in diagnosing pulmonary consolidation replaced the need for development and exploration of this phenomenon. We have studied sound transfer function of the lung in canine cardiogenic pulmonary edema models. Pulmonary edema was induced in dogs by graduated and controlled inflation of a balloon at the tip of a catheter placed into the left atrium. Pulmonary wedge pressure, respiratory flow (volume and rate), EKG and respiratory sounds (chest auscultation) were monitored during control states and after inflation of the left atrial balloon. Pulmonary edema was quantitated with post mortem wet to dry ratios and pathohistology. Sound transfer function of the lung was studied in control and pulmonary edematous states by inducing sinusoidal sound signals from 30 to 1800 Hz while simultaneously recording sound over the chest wall. Preliminary studies indicate this system will detect early changes in extravascular lung fluid.

Supported by NHLI Grant HL 16563.

SESSION C

CHAIRMAN: PETER T. MACKLEM

Session C

Chairman: Peter T. Macklem

8:30 am	Nonspecificity of Qualitative Descriptions of Rales	L.D. Hudson, R.D. Conn R. Matsubara and A.H. Pribble
9:00 am	Correlation of Adventitious Sounds and Pulmonary Physiology	E.A. Gaensler
9:30 am	Frequency Analysis of Respiratory Sounds	A. Pernice and M. Puglisi
10:00 am	Coffee	
10:30 am	Spectral Analysis of Normal and Adventitious Sounds	E. F. Banaszak
11:00 am	Psychometric Techniques in the Evaluation and Reduction of Error in Chest Auscultation	R. Pickett
11:30 am	Psychoacoustic Phenomena Related to the Use of the Stethoscope	W. Huggins
12:30 pm - 1:30 pm	Lunch - Hallowell Hall Faulkner Hospital	

NONSPECIFICITY OF QUALITATIVE DESCRIPTIONS OF RALES

L. D. Hudson
R. D. Conn
R. Matsubara
A. H. Pribble

One hundred consecutive patients admitted to hospital with the finding of rales (crackles) were examined usually by two and occasionally three observers without prior knowledge of the admission diagnosis. Rales were described by their timing in inspiration and by two qualitative adjectives (fine, medium, or coarse; moist or dry). Auscultation findings were later correlated with diagnosis by disease category (congestive heart failure [CHF], chronic obstructive lung disease [COPD], and pneumonia). Agreement between observers on a qualitative adjective occurred in only 47% of cases while agreement on timing of the rales occurred in 85%. Qualitative descriptions by any observer were not helpful in distinguishing between disease categories. Timing of rales did correlate with disease process. Rales in CHF usually occurred only late in inspiration (70%) but rales in COPD and pneumonia occurred only late in inspiration in 19% and 20% respectively ($p < .05$). The effects of cough, deep inspiration, or position change were not helpful in distinguishing the underlying disease. Qualitative descriptions of rales do not correlate with disease processes.

RALES IN INTERSTITIAL LUNG DISEASE

Clinical, pathologic and physiologic correlations

G. R. Epler, E. A. Gaensler, and C. B. Carrington

MATERIAL AND METHODS

Detailed coded information from over 6,000 patients seen at the Thoracic Services of B. U. Medical Center from 1950 to 1976 was available under the following headings: 1.) Fletcher-type respiratory questionnaire, 2.) Chest physical examination, 3.) Conventional history and clinical data, 4.) Diagnostic code, 5.) Detailed physiologic data, 6.) Radiologic: Modified ILO/UC scheme, 7.) Pathologic observation.

Coding of lung sounds included the quality of sounds, wheezing and rales. The code for rales was indicated as: none, "unilateral dry", "bilateral dry" or "moist". The same information was available concerning persons exposed to asbestosis and seen on surveys. We made an epidemiologic diagnosis of "asbestosis" if 3 or more of the following 6 criteria were present: 1.) Dyspnea Grade 2 or more, 2.) Definite finger clubbing, 3.) Bilateral "dry rales", 4.) Vital capacity $<$ 80% predicted (Kory), 5.) Single Breath D_L $<$ 80% (Gaensler & Wright), 6.) Radiographic combined profusion $>$ 1/2 (ILO/UC 1971).

SUMMARY OF RESULTS

1.) The concept of "dry rales", supplemented by various synonyms, appears to have been well understood by our physicians examining these 6,000 pulmonary patients. Among 39 persons who had 1.) a stable condition, 2.) no therapy, 3.) who were followed for at least 5 years and 4.) who had rales initially, 67% continued to have rales over the years.

2.) Among 55 persons with a tissue diagnosis of asbestosis, 51% had "dry rales" among other criteria, and 10% had none of the criteria for asbestosis. This suggests that pathologic changes can be recognized before any other abnormalities.

3.) There was a fair degree of correlation between predicted impairment from histology and the prevalence of rales.

4.) Among 479 exposed persons all those who had 5 criteria of "asbestosis" also had "dry rales". Among 33 (6.9%) who had only 2 criteria, the findings of "dry rales" helped to establish the "diagnosis".

5.) Among long term exposed shipyard and paper workers the initial prevalence of "asbestosis" ranged from 11% to 36% and rales were present in 8% to 30%. Among paper workers exposed for less than 7 years and among normal volunteers none had "asbestosis" and the prevalence of dry rales ranged from 3% to 4%.

6.) From earlier British work we hoped that "dry rales" might be the earliest sign suggesting "asbestosis". However, among 9 exposed persons who had rales as the only abnormal finding initially, none developed "asbestosis" during the next 5-6 years. Rales and one additional of the 5 criteria was much more significant: 6 of 13 such persons subsequently developed "asbestosis" as defined above.

7.) Among 92 persons with a clinical diagnosis of asbestosis, 73% had "dry" and 4% "moist" rales. In sarcoidosis (228 patients), emphysema (130) and chronic bronchitis (192), "dry rales" were heard in less than 15%. "Moist rales" were more common in chronic bronchitis (22%) than in emphysema (7%).

8.) Among persons with pathologically proven asbestosis (53), U.I.P. (59) and D.I.P. (51) more than 60% had dry rales while among those with granulomatous disease (Sarcoid (61), Eosinophilic granuloma (18), and miliary tuberculosis (4)), less than 30% had dry rales. Predominantly intra-alveolar disease was associated with fewer rales than predominantly interstitial disease.

9.) A detailed analysis of various pathologic features showed that the histologic finding of honeycombing correlated fairly well with both radiologic honeycombing and the prevalence of rales. However, the finding of granulomatous involvement of the airways in sarcoidosis failed to correlate with the presence of rales, cough or sputum.

10.) In persons with sarcoidosis and with COPD, rales were more common in those with sputum production while there was no such correlation in the interstitial pneumonias.

11.) Among all patients with pathologically proven interstitial disease there was a good correlation between decreasing single breath diffusing capacity and frequency of rales, a weaker association with decreasing vital capacity and no relationship with FEV_1/FVC. In COPD no relationship was found between any physiologic abnormalities and the prevalence of rales.

FREQUENCY ANALYSIS OF RESPIRATORY SOUNDS

A. Pernice
M. Puglisi

Respiratory sounds, as picked up by a microphone on the chest wall, have been processed both by analogue and digital techniques with the purpose of objectifying clinical records and of discriminating between healthy and pathological subjects.

The results, strip-chart recorded or displayed on computer video terminal, seem to allow particular alterations of the respiratory apparatus to be easily detected.

SPECTRAL ANALYSIS OF NORMAL AND ADVENTITIOUS SOUNDS

Edward F. Banaszak

Phonopneumography is a technic for the semiquantitative analysis of sounds generated in the chest during breathing. This technic was previously described and the influence of both the velocity of air flow and degree of lung inflation on spectral analysis was also presented. The present study reports the phonopneumograms taken from the right posterior base (vesicular sounds) as well as the sounds generated over areas such as the trachea (tubular sounds). Vesicular sounds characteristically show little sound components above 250 Hz whereas tubular sounds have significant components as high as 500 Hz. The report also illustrates basic differences between the patterns of discontinuous (rales) adventitious sounds and continuous (rhonchi) adventitious sounds. Not only the continuous or discontinuous nature but the location in the respiratory cycle seems to help differentiate these various sounds. The beginning patterns for objectively differentiating adventitious sounds are thus set.

PSYCHOMETRIC APPROACHES TO EVALUATION AND REDUCTION OF ERROR IN PULMONARY AUSCULTATION

R. Pickett

Accuracy and consistency in many aspects of medical judgment have been shown to be disconcertingly low. This report focuses on judgments involving sensory evaluation of symptoms, signs and laboratory specimens. Factors that determine the extent of error in sensory evaluation are described and psychometric methods for evaluating, analyzing and reducing error are outlined. Implications for improving pulmonary auscultation are discussed with examples from empirical studies.

SESSION D

CHAIRMAN: PAUL FORGACS

Session D

Chairman: Paul Forgacs

1:30 pm	Some Technical Aspects of Respiratory Sound Recording and Analysis	R.L. Donnerberg, C. Druzgalski, R.M. Campbell, R.L. Pimmel and M.C. Laurence
1:50 pm	Methodology of Breath Sound Analysis in Syrian Hamsters	P. Bernfeld and S. Ishikawa
2:10 pm	System for Spectral and Intensity Analysis of Respiratory Sounds	F.T. Wooten, W.W. Waring M.J. Wegmann
2:30 pm	Lung Sound Characterization by Time-expanded Waveform Analysis	R.L.H. Murphy and S. Holford
2:50 pm	Differentiation of the Rales of Pulmonary Asbestosis and Congestive Heart Failure	S. Holford and R.L.H. Murphy
3:10 pm to 3:30 pm	General Discussion	
4:00 pm	Conference Summary	Giles F. Filley

SOME TECHNICAL ASPECTS OF RESPIRATORY SOUND RECORDING AND ANALYSIS

Roy L. Donnerberg
Christopher K. Druzgalski
Richard M. Campbell
Russell L. Pimmel
M.C. Laurence

Investigation of the mechanisms of respiratory sound generation and the development of methods for objective display of respiratory sound patterns require a system of known characteristics for sound recording and analysis. For these reasons we have conducted tests related to the evaluation of acoustic sensors and have developed a system for undistorted respiratory sound storage and analysis. Studies of nonlinear characteristics and variation in static forces associated with the use of stethoscope as well as phonocardiographic microphones included:

- Performance characteristics of various stethoscopic elements including variation in attenuation and in the axial and cross resonance frequencies.
- Static and dynamic variation in frequency characteristics, and performance repeatability of phonocardiographic microphones. Studies have shown limitation in application of those sensors for quantitative studies of respiratory sounds.

The system used in respiratory sound recording is based upon the use of air-coupled microphone with a dynamic range of 98 dB. This electret-condenser microphone with coupling cavity and the amplification system provides undistorted measurements independent of various respiratory maneuvers. Sensitivity of all audio channels can be calibrated and standardized at a single frequency. Sound data is recorded simultaneously with respiratory variables including respiratory flow, volume, and transpulmonary pressure. Methods of analysis involve determination of sound density distribution over the respiratory cycle (envelope detection) as well as amplitude and frequency distribution for specific time intervals of the respiratory cycle. The analysis is conducted using computer processing (FFT on PDP9) and a ubiquitous spectrum analyzer. Sound data is displayed simultaneously with respiratory variables to provide a complete characteristic of acoustical and related mechanical events. Performance characteristics of acoustic sensors, methods for recording and analysis of respiratory sounds will be discussed.

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METHODOLOGY OF BREATH SOUND ANALYSIS IN SYRIAN HAMSTERS

Peter Bernfeld
Sadamu Ishikawa

A small microphone was attached to the left side of the chest of anesthetized hamsters which were immobilized in a near-soundproof box. Breath sounds, together with other physiological parameters, were amplified and recorded by a six-channel Grass Instrument Co. recorder, Model 7. The same parameters were also recorded on magnetic tape by means of a Tandberg-Sangamo recorder, series 100. The taped sound recordings were visualized with the aid of a Hewlett-Packard 130 C oscilloscope and were studied by means of Fourier analysis over a wide range of frequencies with a computer program prepared by Dr. Brian Hodgkin, Maine Medical Center, Portland, Maine.

The study included normal inbred hamsters of varying ages, hamsters treated with methacholine chloride, hamsters after tracheal instillation of saline, as well as hamsters exposed to cigarette smoke inhalation.

SYSTEM FOR SPECTRAL AND INTENSITY ANALYSIS OF RESPIRATORY SOUNDS

F. Thomas Wooten
William W. Waring
Michael J. Wegmann

An instrument has been developed for analysis of respiratory sounds. This instrument incorporates (1) a sound intensity monitor which records sounds bilaterally and simultaneously from homologous broncho-pulmonary segments, and (2) a real-time spectrum analyzer and signal averager.

The first part of this instrumentation allows the measurement of the intensity of respiratory sounds (the sound envelope) in order to compare homologous portions of each lung. Using a pressure microphone attached to an amplification system, sounds are presented to a dual channel sensing and amplifying system which integrates the sound information and displays only the intensity of the sound in each channel as a function of time. A stereo headphone allows the physician to assure that he is recording artifact-free sound. The information is displayed on a strip-chart recorder or a storage oscilloscope.

The second part of this instrumentation includes a real-time spectrum analyzer averager combination. This allows both instantaneous and time-averaged analysis of the frequency content of sounds over the range of 10 to 7,000 Hz. An optional 300 Hz high-pass filter can be utilized to reduce background noise. Respiratory sound pressure levels in normal pediatric patients range from 30 to 60 dB over the frequency range of 10 to 1,000 Hz. Above 1,000 Hz, the sound pressure level is below 40 dB.

Spectral information, phase relationships between homologous segments, and intensity envelopes of respiratory sounds (both breath and adventitious) can be carefully analyzed.

LUNG SOUND CHARACTERIZATION BY TIME-EXPANDED WAVEFORM ANALYSIS

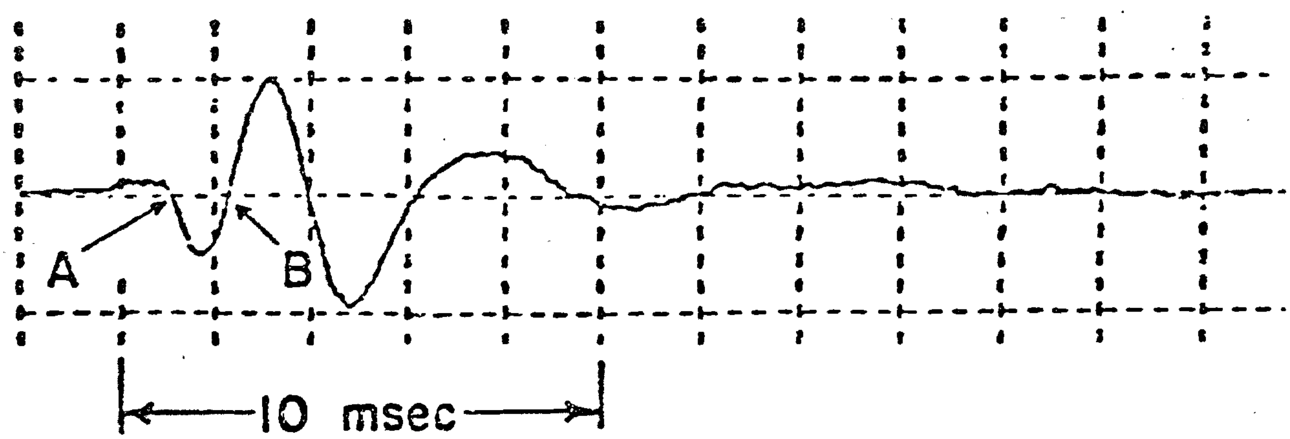
R. Murphy, Jr.
S. Holford

In an attempt to characterize lung sounds objectively, they were studied using visual displays. Amplitude time plots were made from tape recordings considered by six observers to be typical examples of the categories in a standard classification scheme. When the time scale of the plots was raised above 800 mm/sec, distinctive waveforms were observed that allowed objective separation of chest auscultatory phenomena. The characteristic features of these waveforms are not discernible in plots at conventional recorder speeds of 100 mm/sec or less. Examples of lung sounds from teaching tapes produced independently by other workers revealed the same characteristic waveforms despite differing recording techniques. Common artifactual sounds had waveforms distinct from sounds of pulmonary origin. Although the waveforms in this study were produced using a computer, simpler, less expensive technology can be used to expand the time axis of a sound amplitude-time plot and provide objective differentiation of lung sounds.

DIFFERENTIATION OF THE RALES OF PULMONARY ASBESTOSIS AND CONGESTIVE HEART FAILURE

S. Holford
R.L.H. Murphy, Jr.

To help evaluate the specificity of dry basilar rales as an early finding in pulmonary asbestosis, we studied computer generated amplitude VS time plots of the sounds on time scales of 3200 mm/sec which have been shown to facilitate the objective differentiation of lung sounds. We compared asbestotic rales to the similar rales heard in early congestive heart failure (CHF), using clinical roentgenographic, and physiologic test data to select ten patients each with asbestosis, CHF, and CHF with significant underlying lung disease. The width of the initial deflection (IDW) of the plotted rales (see figure) were measured for each patient. The rales in asbestosis and clear CHF had significantly different mean values of IDW, while the rales from patients with mixed CHF and lung disease fell in an intermediate range. Asbestotic (but not CHF) rales were often observed to occur in patterns that were closely repetitive in sequential breaths.



IDW = TIME BETWEEN A AND B
= 1.2 msec FOR THIS RALE

Committee on Lung Sound Nomenclature

Saturday, October 16, 1976

9:00 A.M. until 12:00 Noon

Chairman: Dr. William W. Waring

The purpose of the committee meeting is to consider how the information presented at the Conference can be applied to the comparison, classification and nomenclature of lung sounds. It is not expected that a new and improved set of terms will be agreed upon and recommended for instant acceptance by the medical profession. Possible outcomes might rather include proposals for cooperative studies, for comparisons among interested persons, for exploration of methods of analysis, or for standardized methods for recording.

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