# Fifth International Conference on Lung Sounds

# 第5回 国際肺音学会

September 15, 16, 1980
Imperial College
London, England

Conference Steering Committee:

| | |
|---|---|
| Leslie H. Capel | - London |
| Peter Wright | - London |
| Shoji Kudoh | - Tokyo |
| Riichiro Mikami | - Tokyo |
| David Cugell | - Chicago |
| Robert G. Loudon | - Cincinnati |
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| Sponsors: | | 32 |
| Participants: | | 33 |

FIFTH INTERNATIONAL CONFERENCE ON LUNG SOUNDS

IMPERIAL COLLEGE

LONDON, ENGLAND

PROGRAM

Monday, September 15, 1980

| | | |
|---|---|---|
| Registration | | 8:30 am |
| Welcomes ------------Drs. Capel and Wright | | 9:00 am |
| Introduction --------Dr. Paul Forgacs | | 9:10 am |
| Session A | 9:40 am - 12:30 pm | |
| Lunch | 12:30 pm - 1:30 pm | |
| Session B | 1:30 pm - 5:00 pm | |
| | Cocktails and Buffet | 7:00 pm |

Tuesday, September 16, 1980

| | | |
|---|---|---|
| Session C | 9:00 am - 12:00 Noon | |
| Business Meeting | 12:00 Noon | |
| Lunch | 12:20 pm - 1:20 pm | |
| Lung Sounds Nomenclature ---- Dr. David Cugell | | 1:20 pm |
| Session D | 1:40 pm - 3:40 pm | |
| Cracklefest | 4:00 pm | |
| Summary of the Conference --- Dr. M. Turner-Warwick | | 4:30 pm |
| Steering Committee | | 5:00 pm |

## Session A

Chairmen: Leslie Capel and Peter Wright

| | | |
|---|---|---|
| 9:40 am | Determination of the Extent of Crackle Propagation on the Chest Wall | S. Kraman |
| 10:00 am | Why are Crackles Localized? | M. Mori |
| 10:20 am | Quantitative Analysis on Dispersion Curve of Crackle | A. Shibuya<br>N. Aisaka<br>S. Shirai<br>S. Kudoh<br>R. Mikami |
| 10:40 am | Coffee break | |
| 11:00 am | Differentiation of Fine and Coarse Crackles by Time Sequence Analysis | M. Morinari<br>M. Mori<br>K. Kinoshita<br>N. Honda |
| 11:20 am | The Distribution of Fine and Coarse Discontinuous Adventitious Lung Sounds Over the Chest Wall | E. Kunica<br>S. Holford<br>C. Dewey, Jr.<br>R. Murphy, Jr. |
| 11:40 am | Gravity Dependence of Crackles | F. Davidson |
| 12:00 Noon | Signal Properties of the Lung Crackle Transient | B. McA Sayers<br>L. Capel<br>P. Wright<br>W. Bishop |

DETERMINATION OF THE EXTENT OF CRACKLE PROPAGATION ON THE CHEST WALL

S. Kraman

Studies were carried out to determine the size of the area on the chest wall over which individual crackles could be heard.

Crackles were recorded with 2 microphones over various areas of the chest wall at many different intermicrophone separations. The signals were then time expanded and displayed simultaneously at an effective paper speed of 400 mm/sec. The relative amplitude of each crackle was measured and compared to the same crackle on the other channel. As many crackles as could be identified were measured in this way. The degree of amplitude similarity between each crackle on both channels at different intermicrophone separations was used as an indicator of distance of propagation.

The results of these studies suggest that crackles originate in various sized small airways and propagate mostly through or along the airways to the chest wall. The area covered by a single crackle seems to reflect the area of the lung surface supplied by the airway that generated the crackle. In general, the largest area of lung surface affected seems to be a very irregular circle with a radius of roughly 4-6 cm. Dye injected through catheters of various diameters into airways of an excised and fixed normal human lung indicated that airways supplying this extent of surface area are $\geq$ 2 mm in diameter.

## WHY ARE CRACKLES LOCALIZED?

M. Mori
N. Honda
K. Kinoshita
S. Shiraishi
K. Koike
S. Murao

According to Forgacs the pattern of crackles changes when the stethoscope is moved over a short distance. To confirm this observation and to investigate why crackles are localized we recorded crackles from seven patients (bronchiectasis: 1, scleroderma: 2, fibrosing alveolitis: 1, rheumatoid arthritis: 1, and pulmonary edema: 2) using two identical microphones (Sony ECM 150) placed 4 cm apart. The recorded signals were time-expanded 160 times and displayed on different channels of a jet-type recorder (Mingograf). The waveform of crackles, when recorded 4 cm apart, appeared different and we confirmed Forgacs' observation. We speculate, however, that the difference is not due to poor transmission as suggested by Forgacs but due to directional transmission of sound energy in the airways.

# QUANTITATIVE ANALYSIS ON DISPERSION CURVE OF CRACKLE

S. Kudoh
K. Kosaka
F. Shirai
A. Shibuya

We already reported usefulness of dispersion curves of wave form, i.e., relation between period and time elapsed from IDW, for classification of crackles.

In this study, constants of dispersion curves were quantitatively determined for each kind of crackles. As materials, 85 waves in 24 cases as fine crackles, 25 waves in 5 cases as medium crackles and 47 waves in 17 cases as coarse crackles were chosen from some published tapes and recordsand authors' cases.

Results were as follows: dispersion curves could be approximated with an equation $Y = B + A \log_e X$, by the least square method. (Y = Periodic time, X = Time elapsed from IDW). The value of A ranged from 0.41 to 0.79 in fine crackles, from 1.43 to 1.52 in medium crackles and from 1.66 to 2.13 in coarse crackles. The value of B ranged from 1.25 to 1.88.

These results suggest that it is possible to classify crackles by dispersion curve of wave form quantitatively.

# DIFFERENTIATION OF FINE AND COARSE CRACKLES BY TIME SEQUENCE ANALYSIS

M. Morinari
M. Mori
K. Kinoshita
N. Honda

To clarify the difference between coarse (bubbling) and fine crackles, we recorded lung sounds from twelve patients with various lung diseases and measured time intervals between successive crackles and calculated moving averages of time intervals. The respiratory flow rate and lung sounds were simultaneously recorded and displayed (time scale: 12.5 msec/cm). We could separate crackles from background breath sound with ease by the use of a level slicer.

In fine crackles the peak of the frequency histogram of the time intervals was in the range of 5 to 10 msec, while in coarse crackles the peak was in the range of 20 to 25 msec. The moving averages of the time intervals became short (less than 10 msec) toward the end of inspiration in fine crackles, while in coarse crackles they were longer and remained about the same level. Our observations agreed with those of Nath and Capel (1968). We speculate that auscultatory impressions of "coarse or fine" are influenced not only by the waveforms but also by the time intervals between successive crackles.

THE DISTRIBUTION OF FINE AND COARSE DISCONTINUOUS ADVENTITIOUS LUNG SOUNDS OVER THE CHEST WALL

E. S. Kunica
S. K. Holford
C. F. Dewey, Jr.
R. L. H. Murphy, Jr.

If the site of origin of coarse crackles is in larger airways than that of fine crackles, then the distribution over the chest wall should be more widespread. The distribution of fine and coarse crackles on the chest of patients was investigated by simultaneous sound recordings using two microphones at site separations of 6 cm and 12 cm. The crackles were defined as coarse or fine by calculations based on initial deflection width and two cycle duration as previously described (1). Individual crackles were identified in time expanded waveforms at a given site and the simultaneous tracings at 6 and 12 cm were examined for their presence. Coarse crackles had a wider distribution than fine crackles. They appeared at two sites 6 cm apart in 86% of the recordings as compared to 22% for fine crackles.

The results for simultaneous recordings from sites 12 cm apart showed that individual fine crackles were present in both sites in only 6% of the recordings as compared to 60% for coarse crackles. These results present objective evidence that the site of origin of coarse crackles may be in larger airways than that of fine crackles.

Holford SK, Murphy RLH, DelBono EA, Workum P. Waveform correlates of terms for discontinuous lung sounds. (Abstract) Amer Rev Respir Dis 1978; 117:128.

# GRAVITY DEPENDENCE OF CRACKLES

F. Davidson
R. Murphy, Jr.

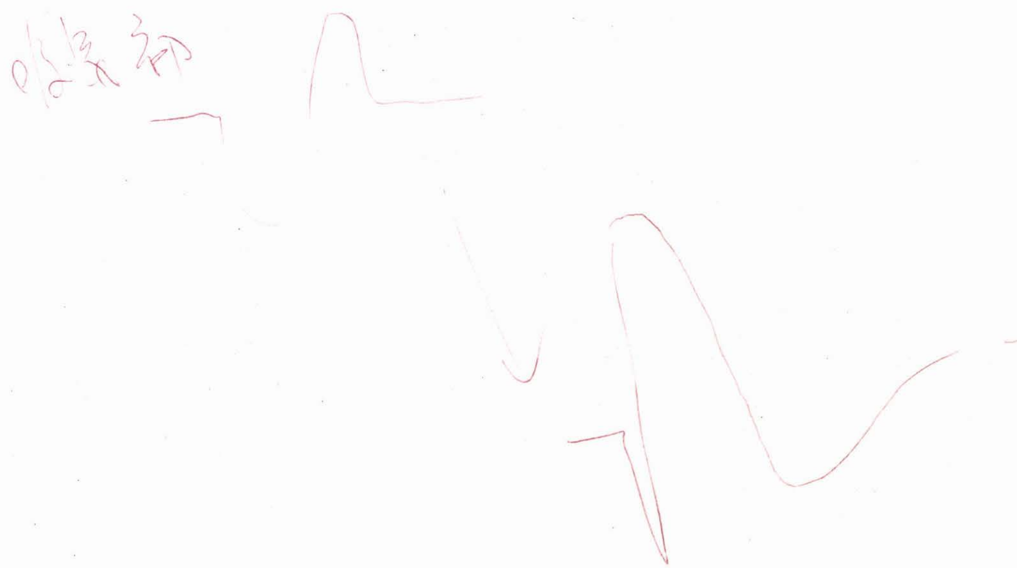
Crackles associated with interstitial fibrosis have been described as gravity dependent that is more numerous in dependent portions of the lung. We observed this gravity dependent vertical gradient of crackles in the lateral decubitus position in patients with congestive heart failure, interstitial fibrosis in adult respiratory distress syndrome. For example, crackle counts made from time-expanded wave-forms in a patient with congestive heart failure increase from 0-3 per breath on the non-dependent side to six in the lowest region of the dependent side. In these cases gravity dependence was observed immediately after changing to the opposite lateral decubitus position. Unexpectedly breath sound intensity decreased in the more dependent regions. This suggests that ventilation to the dependent lung is decreased in these diseased states rather than increased as has been observed in normals or that gravity dependent alterations occur in transmission characteristics of diseased lungs.

## SIGNAL PROPERTIES OF THE LUNG CRACKLE TRANSIENT

B. McA Sayers
L. Capel
P. Wright
W. I. Bishop

The hypothesis is studied, in a number of patients, that a systematic change in shape occurs in a lung crackle transient according to its location within the breath.

In connection with this presentation a demonstration of the equipment at Imperial College will be given.



## Session B

Chairman: C. Forbes Dewey

| | | |
|---|---|---|
| 1:30 pm | Clinical Role of Auscultation | P. Hugh-Jones |
| 2:20 pm | Collapse of a Flexible Channel: Non-Linear Effects | J. Grotberg |
| 2:40 pm | Genesis of Breath Sounds: Theory and Application | J. Patterson<br>J. Hardin |
| 3:00 pm | Rales in Experimentally Induced Lung Edema | Y. Minami<br>Y. Homma<br>M. Matsuzaki<br>M. Munakata<br>H. Ogasawara<br>M. Murao |
| 3:20 pm | Acoustic Attenuation in Liquid-Lined Tubes | J. Grotberg |
| 3:40 pm | Sound Speed in the Parenchyma of Excised Horse Lungs | D. Rice |
| 4:00 pm | Mechanical Impedance of the Thorax at High Frequency | J. Fredberg<br>G. Glass |

# COLLAPSE OF A FLEXIBLE CHANNEL: NON-LINEAR EFFECTS

J. B. Grotberg

In certain pulmonary disease states such as asthma, emphysema and bronchitis the collapse of airways leads to limitations on ventilatory flows and increased breath sound generation. These sounds may be produced from fluid-tube wall vibrations called flutter (wheezing) or from fluid motions such as turbulence or unsteady laminar vortices. The fluid speed associated with this static divergence (collapse) depends on the tube and fluid physical parameters as well as their geometry. Mathematical models which treat the small disturbance, linearized case predict the static divergence velocity where the tube initially becomes unstable by collapsing. Linear theory, however, cannot determine the final tube shape. The non-linear fluid and wall material effects combine to stabilize the tube in a new narrowed configuration.

A simple model is presented of an infinite, two-dimensional channel conveying an inviscid, incompressible fluid. The wall has thickness, bending resistance, mass, damping and non-linear, finite deformation geometric effects included in its elastic response. Essentially these account for increased longitudinal tension due to large lateral displacement. The model predicts the divergence instability and post-stability behavior both for the fluid and walls. Preliminary results for various support conditions such as springs (elastance) and pinnings are discussed.

# GENESIS OF BREATH SOUNDS: THEORY AND APPLICATION

J. L. Patterson, Jr.
J. C. Hardin

The precise mode by which "breath sounds" are generated has remained largely obscure since Laennec's auscultation early in the last century. We have confirmed, with the use of fine kerosene vapor, the observation by Schroter and Sudlow (1969) that vortices are formed by flowing gas in airway models, two on "inspiration" and four on "expiration", and applied ductal aerodynamics and acoustics to develop a theory of generation of the sounds produced.

The complex equations describing vortex behavior reduce to relatively simple form for definition of frequency and amplitude of sound generated from a given airway and its neighbors. For the expiratory situation and for an assumed angle of $70^{o}$ between branches, fn (frequency in nth order) is:

$$fn = \frac{0.212\ V_n}{D_n} \left(\frac{D_n}{D_{n+1}}\right)^2$$

where $V_n$ and $D_n$ are, respectively, the mean axial velocity and diameter in the nth order of bronchi, and $D_{n+1}$ represents the diameter of the upstream order of bronchi. For the inspiratory situation, the equation is the same except that the constant is 0.691 and $D_{n+1}$ is replaced by $D_{n-1}$. The expression for the amplitude (loudness) of sound is more lengthy but its derivation is straightforward, and will be presented.

Spectral analysis in 1/3 octave bands of the farfield during forced exhalation in 20 cigarette smokers, who abstained for 2 days, showed major changes in amplitude and frequency of sound, after inhalation of a single cigarette, in one-half of the subjects. These findings are in accord with the theoretical changes predicted from reduction in caliber of one or more orders of airways, and suggest that the state of the airways can be monitored effectively and non-invasively by spectral analysis of pulmonary sound.

# RALES IN EXPERIMENTALLY INDUCED LUNG EDEMA

Y. Minami
Y. Homma
M. Matsuzaki
M. Munakata
H. Ogasawara
M. Murao

We have clinically and experimentally investigated the occurrence mechanism of the pulmonary discontinuous sound or rales by means of Fourier technique and sound-spectrograph, and reported that the rales might be classified into two main groups with different mechanisms. One is crackles which contain crepitation and Velcro rale with acoustically resonant character produced in the certain condition where the movement of surrounded tissue wall is limited, and another is bubbling with acoustically explosive character produced by the explosion of the bubbles in the airways.

To ascertain these events, correlative morphologic and acoustic investigations on experimentally induced lung edema in canines were done. Methods to induce lung edema and recording or analyzing systems were the same as reported last year. Lung tissue specimens were excised under open-lung condition, and fixation of the specimens was performed by the rapid-freeze method using liquid nitrogen, then H-E staining was done.

As a result, it was noted that the sounds recorded in early stage of the experimentally induced lung edema were resonant sound or crepitation and the histologic examination at that time revealed lung congestion with alveolar walls markedly thickened without intraalveolar fluid filling, and that the sounds recorded in late stage of the lung edema after removal of PEEP maneuver were mainly explosive sound or bubbling and the histologic findings at this time revealed not only marked alveolar wall thickening but also fluid filling into intraalveolar spaces and peripheral airways.

These results suggest that our postulation mentioned above would be well acceptable.

ACOUSTIC ATTENUATION IN LIQUID-LINED TUBES

J. B. Grotberg

Current acoustic transmission theories for a branching network of flexible tubes attribute the attenuation of acoustic energy intensity to several phenomena. For dry tubes that are much shorter than the acoustic wavelengths, attenuation results largely from transverse spreading throughout the branching airways. Within any branch, local attenuation is due to oscillating viscous shear near the tube wall, heat conduction, molecular exchanges of energy and wave reflections. The lung airways, however, are lined by a double liquid layer. A simple interfacial force balance of a typical airway shows that this layer must oscillate with acoustic waves. Mucus and serous viscosities far outweigh that of air and since most shearing is near the wall (where these layers exist) large attenuation is possible. The higher the frequency the more concentrated the shearing near the wall.

We model an incompressible flow, oscillating at angular frequency , within a rigid channel whose width is $2d_2$. The liquid lining has thickness $(d_2 - d_1)$ for a single layer example. The dimensionless parameters are frequency

$\beta_2 = \left(\frac{\omega d_2^2}{\nu_2}\right)^{1/2}$, pressure gradient $A_1 = \frac{(\partial P/\partial x) d_2}{\mu_1 \omega}$ and thickness

ratio $t = d_1/d_2$. The $\mu_1$ is the liquid viscosity and $\nu_2 (= \mu_2/\rho_2)$

is the kinematic viscosity of the gas. Our results show attenuation increasing $\omega_1, \mu_1, \mu_2$, and decreasing t (thicker layers). This model can explain a previous finding in our labs of greater high frequency attenuation in smokers vs. non-smokers, presumably because of the increased thickness and viscosity of their mucus layers. It also is consistent with the description of the lung as a low pass filter.

SOUND SPEED IN THE PARENCHYMA OF EXCISED HORSE LUNGS

D. Rice

The time it takes sound to travel across a lobe of excised horse lung was measured at several points. Sonic propagation velocity was estimated using linear regression by relating this transit time to distance across the lobe. These resulting velocities ranged from 25 to 70 m/s. Sound travels through air and solid tissue at speeds of about 350 m/s and 1500 m/s respectively. Inflation of the lung with helium or sulfur hexafluoride, whose free field sound speeds are 970 and 140 m/s respectively changed velocity $\pm$ 10% relative to air. Therefore, sound propagation through the gas in the airways by circuitous routes cannot explain the low velocities because the velocities across the lung did not change in proportion to velocities in the gases. The velocities in the parenchyma approximate sound velocity calculated by traditional theory assuming that the parenchyma is a uniform fluid and that compressibility and density are the average of the gas and tissue phases. In the physiologic range lung density is more dependent upon lung volume than gas density since solid tissue density is much greater than gas density.

Supported by National Institutes of Health, R23-HL-21199.

# MECHANICAL IMPEDANCE OF THE THORAX AT HIGH FREQUENCIES

J. J. Fredberg
G. M. Glass

The mechanical impedance of thoracic surfaces influences the quantitative nature of lung sounds and heart sounds transduced by mechanical and electromechanical means. Barany (1942) recognized that the impedance match between a stethoscope and the thorax altered stethoscope performance, and he attempted limited thoracic impedance measurements. Later Takagi et al (1964) and von Vollenhoven et al (1968, 1970) analyzed quantitative aspects of chest auscultation for the cases of specific contact transducers, and also recognized the importance of thoracic impedance in the transduction process.

We have measured the mechanical driving point impedance of the human thorax from 200 to 5000 Hz in 6 normal subjects. The impedance varies strongly with static load, area of contact, and frequency, but is insensitive to lung volume and location on the thorax. Variability between subjects (expressed as s.d/mean) is 0.5, which is twice as great as measurement variability within individual subjects. With small contact area (2.01 $cm^2$) the reactance is mass-like, and the resistance is nearly constant up to 4000 Hz. With a large contact area (8.04 $cm^2$) the reactance is mass-like up to 2000 Hz, exhibits a peak at 3200 Hz, and a zero at 5000 Hz; the resistance in this case is strongly frequency dependent.

This research was supported by NHLBI grant HL 23335.

## Session C

Chairmen: Riichiro Mikami and Sadamu Ishikawa

| | | |
|---|---|---|
| 9:00 am | A New Phonopneumograph---High Speed, Real Time Tracing with Simultaneous Recording of Recording of Respiratory Flow Rate | Y. Homma<br>M. Matsuzaki<br>Y. Minami<br>M. Murao |
| 9:20 am | A Simple and Objective Method to Classify Normal and Abnormal Lung Sounds | N. Honda<br>M. Mori<br>K. Kinoshita<br>S. Shiraishi<br>S. Koike<br>S. Murao |
| 9:40 am | Selective Analysis of Sound Signals | C. Druzgalski |
| 10:00 am | Rales in Bronchiectasis | M. Matsuzaki |
| 10:20 am | Coffee break | |
| 10:40 am | Production of Rales During Low Volume Breathing | Y. Ploy-Song-Sang |
| 11:00 am | The Prevalence of Crackles in Young Adult Females | P. Workum<br>S. Holford<br>E. Del Bono<br>R. Murphy, Jr. |
| 11:20 am | Use of Laryngeal Sound Recordings to Monitor Apnea | P. Krumpe<br>J. Cummiskey |
| 11:40 am | Monitoring of Secretion Sounds | R. Loudon |

# A NEW PHONOPNEUMOGRAPH---HIGH SPEED, REAL TIME TRACING WITH SIMULTANEOUS RECORDING OF RESPIRATORY FLOW RATE

Y. Homma
M. Matsuzaki
Y. Minami
M. Murao

Recent advances of lung sound analysis have been made by the rapid development of recording systems such as A-D or D-A converting computer system or copy technics using two or three data recorders. By these systems, high speed recording by 500-1000 mm/sec which is required for analyzing the wave forms has become possible.

However, it was noted that these systems had some limitations as follows: 1) the recording length of the waves was short because the capacity of computer was limited, 2) Real time recording was impossible. Thus, the previous systems are inadequate for the analysis and inconvenient for clinical use. On the other hand, it has been pointed out by many investigators that the recognition of the phase of respiration where rales occur was important for detecting the sort of rales. According to these considerations, we made a new phonopneumograph. We adopted a thermal printer system which had minimal damping for wave recording. Moreover, a recording system of respiratory flow rate using Fleisch type pneumotachygraph was combined to the device. By this system, real time and non-time-limited recording with simultaneous information of respiratory flow rate has become possible. Several examples of lung sound tracings by this new apparatus will be presented and discussed.

# A SIMPLE AND OBJECTIVE METHOD TO CLASSIFY NORMAL AND ABNORMAL LUNG SOUNDS

N. Honda
M. Mori
K. Kinoshita
S. Shiraishi
S. Koike
S. Murao

The purpose of this study is to establish a simple and objective method to classify normal and abnormal lung sounds and when abnormal, to evaluate the degree of abnormality. A strip of time-versus-amplitude lung sound display (about 100 msec interval) was sliced into thirty divisions by drawing equally spaced horizontal lines from the top to the bottom (peak to peak). For each line the numbers of intersections were counted and plotted (the level from the base line of the corresponding horizontal line on the abscissa and the number of intersections on the ordinate). The distribution of the intersections thus obtained was normal with means of zero (N=30) and standard deviations (s) of about 6 in normal lung sounds, while in abnormal lung sounds with crackles normal distribution was observed only in the center (with lower "s" of about 3-4) and abnormal humps were observed in the tails. These abnormal humps (distributions) were separable into two components, tails of normal distributions representing background breath sounds and Poisson distributions representing crackles. The size of the humps and the value of "s" corresponded to the degree of abnormality.

# SELECTIVE ANALYSIS OF SOUND SIGNALS

C. K. Druzgalski

The presence of cardiovascular sounds and ambient noise of broad frequency spectrum incapacitates often diagnostic evaluation of low intensity respiratory sounds. In addition, even the incidence of higher intensity respiratory sounds, such as in acute disease states and/or forced respiratory maneuvers, characteristics of some auscultatory signs, cannot be fully revealed due to the acoustical masking effect.

In order to eliminate these limitations, a system for selective analysis of sound signals with a digital display of the center frequency has been designed. This system of tunable tracking active filters provides tuning of the center frequency in the range from 50 Hz to 5 kHz. An automatic and/or manual scanning of the center frequency allows one to perform search and evaluation analysis of auscultatory signs free of other frequency components interference. Thus, the system provides real time, on-line spectral analysis and digital values of predominant frequency components of respiratory sounds. These acoustic events may be directly evaluated at the patient's side and/or analyzed from a tape unit. The outputs allow one stethoscopic and/or audio speaker monitoring. Clinical evaluation of normal respiratory sounds and those including auscultatory signs such as rales and/or wheezes as well as conducted spectral analysis demonstrated the possibility of pre-emphasis of desirable respiratory sounds components.

Respiratory sounds characterized from both normal and diseased subjects, their spectral characteristics in standard and pre-emphasized forms will be demonstrated. It is believed that this approach has a potential for practical utilization and may improve auscultation.

Supported by NIH Grant HL24613 and CSULB Grant

# RALES IN BRONCHIECTASIS

M. Matsuzaki
Y. Honma
Y. Minami
M. Munakata
M. Murao

Last year, we reported that so-called pulmonary discontinuous sounds (rales) might be classified into two main groups, i.e. crackles as Velcro rales and crepitant rales, and bubbling rales as moist rales. The former seemed to be acoustically resonant sounds, the latter explosive sounds, after Fourier transform analyses of the two rales. Moreover, it seemed likely that these two rales were generated by different mechanisms respectively. To certify our postulations, we analyzed the rales heard in bronchiectasis as a suitable model which has both excess fluid secretion and stiffened walls of the airways in the light of acoustical characteristics and the phase of respiration.

Seven patients with typical bronchiectasis were examined. Recording and spectral analysis of the rales were done by almost the same methods as reported previously. Recording of respiratory flow rate was performed using a Fleisch-type pneumotachygraph connected to a polygraph.

As a result, the following was observed: 1) explosive sounds were found in holo-inspiratory phase, 2) resonant sounds were found only in mid to late phase of inspiration, 3) most of expiratory rales were thought to be explosive sounds.

We concluded that: 1) in bronchiectasis, we could identify two types of rales - bubbling rales with explosive characteristics and Velcro rales with resonant characteristics, 2) the timing of respiration where each two rales occurred was well explained by the mechanisms of generation according to our hypothesis.

# PRODUCTION OF RALES DURING LOW VOLUME BREATHING

Y. Ploy-Song-Sang
S. A. Schonfeld

We studied 5 normal volunteers during tidal breathing on air at functional residual capacity (FRC-air) and on oxygen (FRC-$O_2$). The subjects were then asked to breathe at low lung volumes near residual volume (RV) both on air (LVB-air) and on oxygen (LVB-$O_2$) with a tidal volume of about 50-75% of their closing volume (CV) which was predetermined by the residential gas technique. Two microphones were attached to the right posterior chest wall along the mid clavicular line 10 and 20 cm from the apex of the right lung respectively ($M_{10}$ and $M_{20}$). The subjects were seated upright in a flow integrated pressure compensated body plethysmograph while the physiologic and breath sounds measurements were done. During the control studies (FRC-air and FRC-$O_2$), the subjects breathed tidally for 2 minutes and were then asked to do a quasi-static pressure volume (QSPV) maneuver for the whole vital capacity (VC) range 3-5 times. The lung volume changes, the transpulmonary pressures ($P_L$) as measured by an esophageal balloon, and the breath sounds from $M_{10}$ and $M_{20}$ were recorded on an FM magnetic tape. Simultaneously the lung volume and the transpulmonary pressure signals were also plotted on a storage oscilloscope. FRC-air and FRC-$O_2$ maneuvers were repeated twice. The subjects were then asked to repeat the QSPV maneuvers again 3-5 VC breaths after breathing a small tidal volume near RV for 30 seconds (LVB-air). Finally the subjects washed out nitrogen from their lungs by breathing 100% $O_2$, performed LVB-$O_2$ for 60 seconds and 180 seconds, then repeated the QSPV maneuvers for 3-5 VC breaths. We found that after LVB-air and LVB-$O_2$, the oxygen trapped behind the closed airways in the dependent lung zone was absorbed. The absorption of oxygen (about 450 ml) was reflected in the change of RV level as measured by the body plethysmograph. The absorption caused a shift of both inspiratory and expiratory limbs of the QSPV curve to the right and occasionally a reduction of VC on the first inspiratory breath from RV and coughing after the LVB-air and/or LVB-$O_2$. Inspiratory rales occurred mostly at the upper third of VC after LVB-air and LVB-$O_2$ and were confined almost exclusively to the dependent lung zones ($M_{20}$). There were good correlations between $P_L$ at 25% ($P_{L25}$) and 50% ($P_{L50}$) and absorbed trapped gas volume ($\Delta$TGV) ($P<0.001$ and $P<0.001$ respectively); between the quantity of rales and $\Delta$TGV ($P<0.05$). There was no relationship between the quantity of rales and $P_{L25}$ and $P_{L50}$. We conclude that during low lung volume breathing airways in the dependent lung zones are closed leading to the absorption of oxygen beyond, causing reversible atelectasis. Upon reinflation air will go to the lung with open airways first and then to the closed dependent regions, producing rales recorded by the $M_{20}$ microphone. The rales are produced by inflation of atelectatic lung.

## THE PREVALENCE OF CRACKLES IN YOUNG ADULT FEMALES

P. Workum
S. Holford
E. Del Bono
R. Murphy, Jr.

A proposed mechanism for the generation of crackles is the sudden reopening of closed airways. Since airway closure and opening is believed to occur in normals, crackles should be present in subjects without lung disease, a finding not generally accepted. Because of this apparent discrepancy, we examined 79 female nursing students to measure the prevalence of crackles in a group of subjects which, we anticipated, would have normal respiratory function. A respiratory questionnaire, physical examination, and routine spirometry were completed. Three trained observers using, respectively, an acoustic stethoscope, electronic stethoscope, and an electronic stethoscope which filtered out noise below 800 Hz, examined each subject. Anterior and posterior sites were listened to on the right and left during tidal breathing and slow deep breathing after expiring to residual volume (RV). The results of auscultation are presented in Table 1.

Table 1

Percent Positive Crackles in 79 Nursing Students

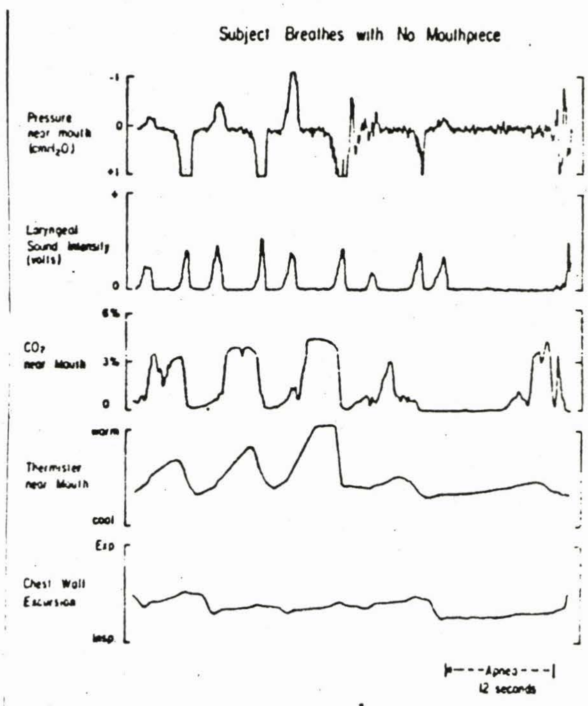
| Type of Stethoscope | Tidal Breathing | | | | Deep Breathing $\overline{P}$ Expiring to RV | | | |
|---|---|---|---|---|---|---|---|---|
| | L Ant | L Post | R Ant | R Post | L Ant | L Post | R Ant | R Post |
| Acoustic | 1 | 0 | 3 | 0 | 27 | 8 | 60 | 10 |
| Electronic | 1 | 0 | 0 | 0 | 52 | 11 | 84 | 16 |
| Filtered | 0 | 0 | 1 | 0 | 65 | 13 | 92 | 18 |

Crackles were rare during tidal breathing in the subjects we examined. After expiring to RV, however, crackles were heard at the R anterior base 92% of the time with the filtered stethoscope, 84% with the electronic stethoscope, and 60% with the acoustic stethoscope. We conclude that with the use of sensitive equipment and/or special breathing maneuvers, crackles are present in normal subjects, a finding consistent with the theory that crackles are caused by airway opening.

# USE OF LARYNGEAL SOUND RECORDINGS TO MONITOR APNEA

P. E. Krumpe
J. M. Cummiskey

Laryngeal sounds are produced by air flow across the glottis. We have found that apnea (cessation of air flow for periods exceeding 10 seconds) can be identified by the cessation of laryngeal sounds during continuous monitoring. We recorded laryngeal sounds using a microphone coupled to a stethoscope head taped to the subject's lateral neck. This signal was amplified, integrated and rectified using commercially available equipment. Artefacts seen in laryngeal sound recordings are caused by extraneous sound and can be easily distinguished from apnea. Laryngeal sound continuous monitoring is non-invasive and directly reflects air flow, in contrast to other methods for apnea detection such as mouth pressure, mouth temperature, end tidal gas analysis and thoracic movement detectors (Figure 1). This method is useful for detection of sleep apnea syndromes and could be adapted to design an apnea alarm system.




Work supported by VA Funding

# MONITORING OF SECRETION SOUNDS

R. G. Loudon

One of the most frequently conducted procedures in an intensive care unit is the suctioning of secretions from the airways via an orotracheal or tracheostomy tube. The need for suctioning may be indicated in various ways. Welling up of secretions into the tube, coughing spasms, or signs of distress on the part of the patient suggest that suctioning has been left rather late. On the other hand, excessive suctioning will disturb or distress the patient and traumatize his airways unnecessarily. Auscultation of the chest at intervals gives a better indication of accumulation of secretions, but is intermittent and usually irregular. A continuous monitoring system which gave an early and graduated indication of the presence of secretions in the airways would provide obvious advantages for the management of intubated patients.

We have used small microphones for continuous monitoring of secretion sounds. The most practical and effective location for microphone placement proved to be the removable plastic cap which seals the suction port in the tracheostomy tube connector. As the microphone is attached to the outside surface of the plastic cap it is not in direct contact with the respired gases; the plastic is thin enough to transmit the desired sound frequencies well. An arbitrary scale for secretion sound intensity has been developed and used to measure the time course for individual patients of reaccumulation of secretions after suctioning.

Sounds sensed by the microphone are available in real time for observation by nursing, respiratory therapy or medical staff, either as an audible or a visible display locally, and could readily be made available at a central station. Recording the sound signal allowed subsequent analysis to determine the time course of reaccumulation of secretions following suctioning. The clinical significance of the reappearance of secretion sounds can be assessed by comparison off-line with simultaneous measurements of heart rate and arterial oxygen saturation measured by ear oximeter.

Session D

Chairman: David Cugell

| | | |
|---|---|---|
| 1:20 pm | Lung Sound Nomenclature | D. Cugell |
| 1:40 pm | Teaching Pulmonary Auscultation in Edinburgh | A. G. Leitch |
| 2:00 pm | A Clinical Assessment of Respiratory Sound Characteristics Under Varying Conditions of Gas Density | R. Donnerberg<br>C. Druzgalski |
| 2:20 pm | Breath Sounds in Emphysema and Lung Fibrosis - Deviations from the Normal Spectral Curves | N. Gavriely<br>Y. Palti |
| 2:40 pm | Analogous Characteristics of Thoracic, Laryngeal, and Oral Respiratory Sounds | C. Druzgalski<br>A. Wilson<br>R. Donnerberg |
| 3:00 pm | Comparison of Wheezes Over the Trachea and on the Chest Wall | Y. Takezawa<br>F. Shirai<br>S. Sawaki<br>R. Mikami<br>S. Kudoh<br>A. Shibuya<br>I. Ono |
| 3:20 pm | Identification of Wheezes by Graphical Representation | S. Ishikawa<br>S. Holford<br>R. Murphy, Jr. |
| 3:40 pm | Detection of Pulmonary Abnormalities in Asbestos Workers by Lung Sound Analysis | R. Murphy, Jr. |
| 4:00 pm | Cracklefest | |
| 4:30 pm | Summary | M. Turner-Warwick |

# TEACHING PULMONARY AUSCULTATION IN EDINBURGH

A. G. Leitch
R. A. Wilkie
A. Morgan

Ninety-four Final Year medical students were entered in a study designed to assess their auscultatory ability and to see if this could be improved by listening once to a teaching tape on lung sounds. All students listened to four different chest sites and recorded their findings on a standard form. Fifty students recorded their findings before, and 44 their findings after listening to the teaching tape. The lung sounds at each site were also tape recorded with an electronic stethoscope for subsequent playback and discussion. There were no significant differences between the groups in their ability to correctly assess lung sounds. The percentages of students correctly interpreting the following four different aspects of lung sounds were as follows:

| | Before Tape | After Tape |
|---|---|---|
| Breath sound type | 59 | 60 |
| Breath sound intensity | 45 | 47 |
| Added sound type | 54 | 52 |
| Added sound timing | 51 | 47 |

In spite of our failure to detect any improvement in performance after one tape session 76% of the students found the teaching tape useful or very useful, and a similar percentage suggested that teaching of this kind should continue.

# A CLINICAL ASSESSMENT OF RESPIRATORY SOUND CHARACTERISTICS UNDER VARYING CONDITIONS OF GAS DENSITY

R. L. Donnerberg
C. K. Druzgalski

It is widely accepted that changes in a gas density affect dynamic performance of the respiratory system. Specifically, the presence of obstruction in upper respiratory airways results in a gas density dependent value of respiratory resistance, while resistance attributed to peripheral airways is independent of gas density. The characteristics of respiratory sounds such as intensity and frequency correlate well with the rate of respiratory airflow. Furthermore, the character of respiratory airflow such as turbulent or laminar which is typical for upper and peripheral airways, respectively, affect the composition of respiratory sounds.

For these reasons conducted studies considered dependence of respiratory sounds characteristics such as intensity and frequency in subjects breathing with a gas of varying density. Studied subjects were breathing for 10-15 minutes through a two-way valve with air and 50% helium, 50% $O_2$, and 80% He, 20% $O_2$ gas mixtures, respectively. Respiratory sounds were recorded over the right upper and right lower lung field as well as over the trachea. The sound signals together with respiratory airflow signals obtained using a standard pneumotachygraph were stored on a magnetic tape.

A study of sound data included auscultatory observations and spectral analysis of thoracic and laryngeal sounds. Experimental data have shown a decrease in sound intensity in the presence of gas of lower density. It was accompanied by a frequency shift into higher frequency region.

Application of gas mixtures of varying density allow differentiation of different types of resistance and possible separation of respiratory sound generation which can be attributed to the upper and peripheral respiratory airways, respectively.

# BREATH SOUNDS IN EMPHYSEMA AND LUNG FIBROSIS - DEVIATIONS FROM THE NORMAL SPECTRAL CURVES

N. Gavriely
Y. Palti

Breath sounds recorded from patients suffering from emphysema and lung fibrosis were measured by an FFT based frequency domain analysis method. In both the characteristic exponential pattern of the power spectra of normal thoracic sounds as well as the wide band pattern of tracheal sounds were preserved. However, the values of the parameters used to characterize the spectral curves of the thoracic breath sounds, e.g. the slope, in dB/oct, and the maximal frequency, in Hz, deviated from the normal range. As compared with the normal, the values of the slopes at the different locations were increased by 15-30% in emphysematic patients and decreased by 30-40% in lung fibrosis. The maximal frequencies were normal or slightly reduced in emphysema and increased (30-50%) in lung fibrosis.

We conclude that breath sounds in emphysema and lung fibrosis may be characterized by the same parameters used to characterize normal breath sounds. These parameters may be used to distinguish between the conditions. We further conclude that the basic mechanisms of sound generation and transmission are not altered in emphysema and fibrosis. However, the actual values of the parameters of the transfer function of the lung are related to its morphology.

# ANALOGOUS CHARACTERISTICS OF THORACIC, LARYNGEAL, AND ORAL RESPIRATORY SOUNDS

C. K. Druzgalski
A. F. Wilson
R. L. Donnerberg

Numerous auscultatory techniques involve an analysis of acoustic events recorded in various locations over the thorax as well as the mouth and on some occasions over the trachea. Oral respiratory sounds are often recorded and analyzed because of their relative high intensity, although there is a general agreement that they do not precisely reflect dynamic characteristics of the lung due to their distortion in upper respiratory tract. Respiratory sounds recorded over the thorax represent the state of peripheral airways due to the proximity of sound source. However, diagnostically useful information can be lost due to low S/N ratio.

The objective of this investigation was to develop an algorithm and determine interrelationships characterized by the intensity and frequency distribution of thoracic, laryngeal, and oral respiratory sounds. For this reason we have recorded respiratory sounds over the right upper and right lower lung fields over the trachea and at the mouth under constant conditions of articulators. Respiratory phase and flow rates were monitored using a bellows type pneumotachograph placed around the subject's chest.

Comparative and differential characteristics including frequency spectra of respiratory sounds were determined. Spectral energy distribution showed the presence of frequency correlates between thoracic, oral, and laryngeal sounds particularly in low frequency range while determined at low respiratory airflow rates. Furthermore, the dynamic change of thoracic sounds was 3-4 times or more lower due to the damping effect of the chest wall.

It is anticipated that these studies will provide an additional insight into auscultatory diagnosis by the determination of factors affecting respiratory sound distribution and their interdependence.

Supported by NIH Grant HL24613

# COMPARISON OF WHEEZES OVER THE TRACHEA AND ON THE CHEST WALL

Y. Takezawa
F. Shirai
S. Sawaki
R. Mikami
S. Kudoh
A. Shibuya
I. Ono

For the purpose of clarifying the transbronchial transmission of wheeze in asthmatic patients, characteristics of wheeze simultaneously recorded on different areas were studied.

Microphones were attached to the anterior chest wall over the major bronchi on both sides and to the anterior portion of the neck over the trachea. Air flow was also recorded. Wheezes from each area were analyzed by a sound spectrograph or a spectrum analyzer, and were compared with each other. The results were as follows:

1) Wheezes over the trachea were identical with those detected on the chest wall of either side, in terms of timing and the fundamental frequency.

2) High component of overtones over 1,000 Hz were more clearly detected over the trachea than on the chest wall.

Wheezes over the trachea could be regarded as the synthesized sounds by those from both lungs. The neck was considered to be an important area for auscultation in asthmatic patients.

## IDENTIFICATION OF WHEEZES BY GRAPHICAL REPRESENTATION

S. Ishikawa
S. Holford
R. Murphy

To study the correlation between chest auscultation and graphic representation of lung sounds in patients with asthma, 60 recordings were made from 10 patients in a clinically stable state. Three observers listened to these recordings for the presence of continuous adventitious sounds (wheezes). All observers agreed that wheezes were present in 27 recordings; average observer agreement was 81%. The same observers examined time expanded waveform analyses made at a paper speed of 800 mm/sec for the presence of undulating sinusoidal deflections which replaced the normal lung sound waveform pattern (waveform wheezes). All observers agreed that waveform wheezes were present in 31 recordings. Average observer agreement was 81%. The observers then examined waveforms of these same recordings while simultaneously listening to the tape recordings. All observers agreed that wheezing was present in 40 recordings; average observer agreement was 95%. Of the 47 sound recordings on which all observers agreed that wheezing could be heard, 38 corresponding waveforms were interpreted by all observers as showing waveform wheezes.

We conclude that there is a close correlation between auditory perception and the presence of waveform wheezes by time expanded waveform analysis. Simultaneous viewing of waveform tracings while listening for continuous adventitious sounds appears to reduce observer variability.

Supported in part by Grant HL23318 from the National Heart, Lung and Blood Institute

# DETECTION OF PULMONARY ABNORMALITIES IN ASBESTOS WORKERS BY LUNG SOUND ANALYSIS

R. Murphy, Jr.
S. Holford
E. Del Bono

As crackles (rales) are regarded as a characteristic finding in interstitial fibrosis due to asbestos exposure, we sought objective methods of crackle detection applicable for efficient use in surveys of industrial populations. From over 1,000 recordings of workers in industries using asbestos, we selected 28 workers with probable "asbestosis" based on 1) UICC radiographic findings of irregular opacifications (1/2 or greater) and 2) vital capacity and/or diffusing capacity less than 80% of predicted. Twenty of these workers had basilar crackles on clinical auscultation. Lung sound recordings from these 28 workers were randomly interspersed with recordings from 28 student nurses with no history of significant lung disease. Two of these nurses had crackles on clinical auscultation. Observers examined these recordings by:

1) listening for crackles
2) examination of time-expanded wave-forms (TEW) made from these recordings
3) examination of wave forms while simultaneously listening to the recordings
4) listening to the tape recordings after electronic filtering of the sounds had been performed with an 800 Hz high-pass filter (Stethographics Model #180).

The observers were asked to classify each example as having crackles and therefore consistent with "asbestosis" or as normal. Results are summarized in the following table:

Range of Classification Success with Multiple Observers

| Lung Sound Analysis Method | Range (No. correct out of 28) | |
|---|---|---|
| | "Asbestotic" | Normal |
| Tape playback | 14-19 | 23-27 |
| TEW readings without listening | 14-16 | 26-27 |
| TEW readings with simultaneous listening | 16-21 | 21-28 |
| Filtered lung sound analysis | 21-26 | 22-27 |

The above data was obtained from analysis of only one breath at one site (the right lower lobe posteriorly). The filtered lung sound analysis was also done at two additional sites, left lower lobe posteriorly and the right middle lobe. This reduced the number of false positives from 6 to 1. Unfortunately it also reduced the number of two positives to eighteen. However, time expansion of the false positives show tracings with high frequency artefacts or relatively few crackles as compared to true positives. The sensitivity of filtered lung sound analysis appears to be satisfactory for industrial screening purposes and can be rapidly performed with relatively simple instrumentation. Specificity is satisfactory when time-expanded wave-form analysis of the filtered sound is performed.

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Will Bishop
Department of Medicine
St. Thomas Hospital
Medical School
London SE1 7EH England

Leslie Capel
The London Chest Hospital
Bonner Road
London E29JX England

David Cugell
Northwestern Univ. Med School
Ward Memorial Building
303 E. Chicago Avenue
Chicago, Illinois 60611

Frank Davidson
Pulmonary Service
Lemuel Shattuck Hospital
170 Morton Street
Boston, Mass 02130

C. Forbes Dewey
Mass Institute of Technology
Department of Mechanical Eng
77 Massachusetts Avenue
Cambridge, Mass 02139

Roy L. Donnerberg
Division of Pulmonary Disease
N-325 Means Hall
466 W. Tenth Avenue
Columbus, Ohio 43210

Christopher Druzgalski
Dept of Electrical Engineering
California State University
Long Beach, California 90840

Jeffrey J. Fredberg
Cambridge Collaborative
238 Main Street
Cambridge, Mass 02142

Noam Gavriely
Department of Physiology
Faculty of Medicine
Technion
Israel Institute of Technology
12 Haalia Street
Haifa, Israel

James B. Grotberg
Department of Engineering Sciences
and Applied Mathematics, Northwestern Univ
Evanston, Illinois 60201

Peter Holst
Wellington Clinical School of Medicine
Wellington Hospital
University or Ortago
Wellington, New Zealand

Norinari Honda
The Second Dept of Internal Medicine
University of Tokyo
7-3-1 Hongo, Bunkyo-ku
Tokyo, 113 Japan

Yukihiko Honma
First Department of Internal Medicine
School of Medicine
Hokkaido University
N-15, W-7, Sapporo 060 Japan

Sadamu Ishikawa
Lemuel Shattuck Hospital
Pulmonary Section
170 Morton Street
Jamaica Plain, Mass 02130

Kojiro Kinoshita
Mitsui Memorial Hospital
Department of Radiology
1 Kanda-Izumi-cho
Chiyoda-ku, Tokyo, Japan

Steve Kraman
Veterans Administration Hospital
CDD (111-H)
Lexington, Kentucky 40507

Peter E. Krumpe
Pulmonary Medicine Section
Martinez VA Hospital
150 Muir Road
Martinez, California

Shoji Kudoh
The Third Department of Internal Medicine
Faculty of Medicine
University of Tokyo
Hongo, Bunkyo-ku, Tokyo 113 Japan

Enora Kunica
Lemuel Shattuck Hospital
Pulmonary Section
170 Morton Street
Jamaica Plain, Mass 02130

A. Gordon Leitch
Brewster House
Pollock Halls
18 Holyrood Park Road
Edinburgh, Scotland

Robert G. Loudon
Department of Internal Medicine
Pulmonary Disease Division
Room 7510 Medical Science Bldg.
Cincinnati, Ohio 45267

Shigeto Manabe
Department of Pediatrics
The First Hospital of
Nippon Medical School
Iidabashi 3-5-5, Chiyoda-ku
Tokyo, 102 Japan

Michiyuki Matsuzaki
First Department of Internal Medicine
School of Medicine
Hokkaido University
N-15, W-7, Sapporo 060 Japan

Riichiro Mikami
The Second Department of Internal Med
Nara Medical University
840 Shijo, Kashiwara
Nara 634 Japan

Yoshitsugu Minami
First Department of Internal Med
School of Medicine
Hokkaido University
N-15, W-7, Sapporo 060 Japan

Masashi Mori
The Second Dept of Internal Med
University of Tokyo
7-3-1 Hongo, Bunkyo-ku
Tokyo, 113 Japan

Hajime Morinari
Department of Resp Dis
Tokyo Post and Tele-communication Hosp
Tokyo Teishin Hospital
Fujimi 2-14-11, Chiyoda-ku, Tokyo, Japan

Mitsuru Munakata
First Department of Internal Medicine
School of Medicine
Hokkaido University
N-15, W-7, Sapporo 060 Japan

Raymond L.H. Murphy, Jr.
Lemuel Shattuck Hospital
Pulmonary Section
170 Morton Street
Jamaica Plain, Mass 02130

Hideki Ogasawara
First Department of Internal Medicine
School of Medicine
Hokkaido University
N-15, W-7, Sapporo 060 Japan

John L. Patterson, Jr.
Box 282
Medical College of Virginia
Richmond, Virginia

Y. Ploy-Song-Sang
Department of Internal Medicine
Pulmonary Disease Division
Room 7510 Medical Science Bldg.
Cincinnati, Ohio 45267

B. McA Sayers
Department of Medicine
St. Thomas Hospital
Medical School
London SE1 7EH England

Atsuo Shibuya
System Engineering Laboratory
Research Institute for Polymers
and Textiles
Higashi 1-1-4, Yatabe
Tsukuba-gun
Ibaragi, 305 Japan

Fumio Shirai
The Second Department of Internal Med
Nara Medical University
840 Shijo, Kashiwara
Nara 634 Japan

Yuichi Takezawa
The Second Department of Internal Med
Nara Medical University
840 Shijo
Kashiwara, Nara 634 Japan

Agrégé Tuchais
Center Hospitalier et
Universitarie D'Angers
Angers, Cedex, France

Margaret Turner-Warwick
Cardiothoracic Institute
Brompton Hospital, Fulham Road
London Sw3 6hp, England

Peter Workum
Lemuel Shattuck Hospital
Pulmonary Section
170 Morton Street
Jamaica Plain, Mass 02130

Peter Wright
Department of Medicine
St. Thomas Hospital
Medical School
London SE1 7EH England

Paul Forgacs
5, Oakway
Bromley
Kent BR2 OLJ England

Philip Hugh-Jones
Chest Unit, Department of Medicine
King's College Hospital Medical School
Denmark Hill
London SE5 8RX
England