NINTH INTERNATIONAL CONFERENCE

ON LUNG SOUNDS

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UNIVERSITY OF CINCINNATI MEDICAL CENTER
SHRINERS' BURNS INSTITUTE
CINCINNATI, OHIO

PRESENTED BY

INTERNATIONAL LUNG SOUNDS ASSOCIATION

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Ninth International Conference on Lung Sounds

Cincinnati, Ohio

Program

Thursday, September 20, 1984

Registration -- 8:30 AM

Welcome - Dr. Martin Goldberg, Chairman ---------------------- 9:00 AM
Department of Internal Medicine
University of Cincinnati Medical Center

Opening Remarks - Dr. Robert G. Loudon ---------------------- 9:05 AM

Keynote Address - Dr. Shoji Kudoh ---------------------------- 9:15 AM

Session A - Dr. Masashi Mori, Chairman ---------------- 9:30 - 11:30 AM

A Review of Signal Processing Methods Applicable ----- 11:30 - 12:30 PM
to Analysis of Lung Sounds - Dr. Robert Berkovitz
Guest Lecturer

Lunch --- 12:30 - 1:45 PM

Session B - Dr. David Cugell, Chairman --------------- 1:45 - 3:40 PM

Debate: Relationship among lung sounds, ventilation 3:40 - 4:20 PM
and flow - Dr. Y. Ploysongsang and
Dr. Steven S. Kraman

Moderator: Dr. David Cugell

Cocktails and Buffet -- 7:00 PM

Friday, September 21, 1984

Session C - Dr. William Waring, Chairman -------------- 9:00 - 11:00 AM

Business Meeting -- 11:00 - 11:30 AM

Photograph --- 11:30 - 12:00 PM

Lunch -- 12:00 - 1:15 PM

Session D: Dr. Sadamu Ishikawa and
Dr. Riichiro Mikami, Chairmen ------------ 1:15 - 3:35 PM

Cracklefest --- 3:35 - 4:00 PM

Summary - Dr. Steven S. Kraman ----------------------- 4:00 - 4:30 PM

SESSION A:
DR. MASASHI MORI, CHAIRMAN

9:30 - 9:50 AM	Effect of pleural effusion on sound transmission of the canine chest wall	M. Yonemaru T. Abe H. Kobayashi T. Kawashiro T. Yokoyama
9:50 -10:10 AM	Production mechanisms of fine crackles in excised normal canine lung	M. Munakata Y. Homma M. Matsuzaki H. Ogasawara H. Kusaka K. Tanimura Y. Kawakami
10:10 -10:30 AM	Experimental study of the mechanism of producing crackles	T. Abe M. Yonemaru H. Kobayashi T. Kawashiro T. Yokoyama
10:30 -10:45 AM	Coffee Break	
10:45 -11:30 AM	Bullar Revisited: A Centennial Retrospect	R. Loudon
11:30 -12:30 PM	A Review of signal processing methods applicable to analysis of lung sounds	R. Berkovitz
12:30 - 1:45 PM	Lunch	

Effect of pleural effusion on sound transmission of the canine chest wall

Authors: M. Yonemaru, T. Abe, H. Kobayashi, T. Kawashiro, T. Yokoyama

To evaluate the effect of pleural effusion on sound transmission of the chest wall, eleven dogs were studied in the supine position. After the dogs were sacrificed, the pure sound ranging from 100 to 1000 Hz was introduced at the tracheostoma and detected by microphones placed on the chest wall. The amplitude of the sound wave was measured at the tracheostoma and on the lateral as well as on the anterolateral wall of the right chest. The sound transmissibility from the tracheostoma to the chest wall was calculated before and after injecting saline into the pleural space.

On the lateral wall, introduction of the saline decreased the sound transmissibility at lower frequency span below 300 Hz. At 100 Hz, reduction in the sound transmission of 3.7 ± 3.7, 6.6 ± 4.9 and 10.0 ± 5.7 dB occurred, respectively, by the introduced saline of 5, 10 and 15 ml/kg/hemithorax. On the anterolateral wall, introduction of the saline increased the sound transmissibility above 500 Hz. Its increase showed the highest values, 5-9 dB, around 650 Hz.

Production mechanisms of fine crackles in excised normal canine lung

Authors: M. Munakata, Y. Homma, M. Matsuzaki, H. Ogasawara, H.Kusaka, K. Tanimura, Y. Kawakami

The production mechanism of crackles is believed to be closely related to airway closing and opening phenomenon. But there is no direct evidence which confirms this relationship. We studied physiological conditions when fine crackles are generated, using excised normal canine lung lobe ventilated in an airtight box.

Respiratory flow (V), transpulmonary pressure (Ptp), alveolar pressure (Palv) and generated crackles were recorded simultaneously. Palv was measured by pleural capsule method developed by Sasaki et al (J Appl Physiol 1980; 48:982). In this method, the pleural surface was multipunctured by a small needle (0.8mm OD, 2 mm long) and Palv was directly measured as the inside pressure of the capsule (15 mm OD, 5 mm depth) glued on the punctured surface. Crackles were picked up from the inside of the capsule by an electron condenser microphone (SONY ECM150). We measured all parameters in various inspiratory and expiratory Ptp, and the following investigations were made: 1) relationship between Palv and beginning of crackle generation, and 2) the precedent condition of inspiratory and expiratory Ptp when crackles were generated.

Inspiratory fine crackles were produced in normal dog lung under certain conditions. At initial phase of inspiration, Palv changed parallel to the box pressure, then changed direction and returned to zero gradually. Crackles were produced from this turning point in pressure which may show the beginning of airway opening. When the inspiratory Ptp was kept constant (15-20 cmH2O), crackles were produced at the expiratory Ptp under -1 to 2 cmH2O and increased in number with the decrease of expiratory Ptp. When the expiratory Ptp was kept constant (-10 cmH2O), crackles were produced at the inspiratory Ptp over 4 to 6 cmH2O and increased in number with the increase of the inspiratory Ptp.

These results agree with the previous knowledge of pressure changes about the airway closing and opening phenomenon, and suggest that fine crackles in normal canine lung are produced by airway opening phenomenon.

<u>Experimental study of the mechanism of producing crackles</u>

Authors: T. Abe, M. Yonemaru, H. Kobayashi, T. Kawashiro,
T. Yokoyama

The mechanism of experimentally induced crackles was investigated by analyzing the polarity of the initial deflection. The crackles were studied during spontaneous ventilation on five anesthetized dogs, by introducing contrast medium into the right upper bronchi through a catheter. The crackles thus produced were recorded at the tracheostoma and on the right chest wall using electret condenser microphones.

The initial deflection of crackles recorded at the tracheostoma and on the chest wall over the right lower lobe was negative on inspiration and positive on expiration. In contrast, the initial deflection of most crackles recorded over the right upper lobe was positive on inspiration and negative on expiration.

Our findings suggested that the crackles investigated in this study were produced by the sudden disappearance of the pressure difference across the obstruction in the airway.

Bullar Revisited: A Centennial Retrospect

Author: R. G. Loudon, M.B.,Ch.B.

In 1884 the experiments performed by Mr. Bullar to determine the site of origin of respiratory sounds were described to the Royal Society by Dr. Lauder Brunton. They are reported in the Proceedings of that august body. The report describes the various theories then current, and a sequence of experiments on animal lungs designed to choose among these theories. The questions asked, the experimental design, and the results obtained are described clearly and briefly. The equipment and methods used are described in sufficient detail to allow an effort to duplicate the study. The results are presented in descriptive rather than numerical terms; Mr. Bullar had no microphone, no tape recorder, no analog-to-digital converter, and no spectrum analyzer. But we may regard this investigation as the forerunner of a type of approach which now, one hundred years later, is again attracting attention.

SESSION B
DR. DAVID CUGELL, CHAIRMAN

1:45 - 2:05 PM	Thoracic and abdominal volume changes in wind instrument players	D. Cugell
2:05 - 2:25 PM	The speed of the sound through the lung, true or imaginary?	M. Mori N. Honda T. Hisada H. Kino S. Koike K. Kinoshita
2:25 - 2:45 PM	Acoustic theory of lung sound transmission	A. Majumder
2:45 - 3:00 PM	Coffee Break	
3:00 - 3:20 PM	Spectral matrices of respiratory sounds	C. Druzgalski A. Wilson
3:20 - 3:40 PM	Further validation of the vortex theory of breath sound generation	J. Patterson J. Seiner J. Hardin J. Levasseur J. Manning P. Kudirka J. York
3:40 - 4:20 PM	Debate: Relationships among lung sounds, ventilation, and flow Moderator: Dr. D. Cugell	Y. Ploysongsang S. Kraman

Thoracic and abdominal volume changes in wind instrument players

Author: D. Cugell

Instruction of novice instrumentalists on proper breathing technique is highly empiric, and includes such physiologically meaningless phrases as, "support the tone with the diaphragm"! Precise control of expiratory flow and oral pressures is a highly refined skill that is acquired by all competent wind instrumentalists. Although the expiratory flows and intrathoracic pressures that are employed while playing have been well described, such measurements neither distinguish the skilled from the unskilled performer, nor assist teachers in their instructional tasks.

Flow is generated by a coordinated contraction of the muscles of the chest wall and of the abdomen. The interaction of the muscles of these two compartments and their contribution to the specific airflow requirements of wind instrumentalists was measured in a group of young professional brass players. A large plastic funnel, pneumotachograph, and microphone were fitted to the horn of the instrument, and respiratory impedence plethysmographs were placed around the thorax and abdomen. Performers were asked to play a brief chorus repeatedly with visual monitoring of either sound level or airflow to assure a consistent, repetitive performance. There was often marked variability in the pattern of abdominal and thoracic volume change while playing. In addition, distinct pattern differences were noted between the trumpet, trombone, french horn, and tuba. For example, consistent end-inspiratory and end-expiratory lung volumes were observed in the trombone player, whereas considerable variations in these volumes were noted in both the french horn and tuba players. Pianissimo passages on the trumpet concluded with a rapid expiratory maneuver prior to the succeeding inspiratory gasp. The tuba player maintained constant tonus of the abdominal muscles whereas a synchronous contraction of both chest wall and abdominal muscles was observed in the other brass instrument players. The extent to which the observed results represent different instrumental requirements, differences between performers, or different degrees of performance skill are under investigation.

The speed of the sound through the lung, true or imaginary?

Authors: M. Mori, N. Honda, T. Hisada, H. Kino, S. Koike, K. Kinoshita

The speed and the transmission path of the sound through the human lung have been studied by various investigators. By measuring the transit time of the sound signal between two different sites and comparing the results before and after the inhalation of helium-oxygen mixture, Kraman suggested that the sound traveled predominantly through the lung parenchyma, while Jacob, who had done similar measurements, concluded that the sound did travel through the airways.

An airway model was made of plastic tubes and blocks. Impulse signals were given at the one end, and the output signals were recorded at the other ends of the model. The transit times ranged from 0.26 to 2.2 ms and the apparent speed of sound (the length of the path divided by the transit time) was about 180 to 150 m/s, which was about a half of the speed of sound in the air. Our conclusion is that most of the time delay we observed is due to the phase shift caused by the geometrical structure of the airway model which behaves as a low-pass filter. Our observation supports Jacobs conclusion.

Acoustic theory of lung sound transmission

Author: A. K. Majumder

The acoustics of lung sound transmission from a particular plane wave source to the chest surface have been investigated for normal human subjects and for patients with respiratory diseases. The mechanism of sound transmission is considered in two parts: 1) within the lung airways and tissues, and 2) through the chest wall

The characteristics of sound propagation through the lung and chest wall are described by electrical equivalent and one-dimensional wave theory on transmission line. The terminal admittances and sound pressures of the airway network and chest wall have been calculated using a computer program and correlating these results with geometrical and mechanical properties of the airways and breath sounds. Also the transmission factor of the lung and chest wall have been calculated and it shows the chest wall is a low-pass filter characteristic. There is about a 12 dB fall in acoustical intensity per octave up to 600 Hz and 20 dB/Oct above 600 Hz for normal subjects.

Spectral matrices of respiratory sounds

Authors: C. Druzgalski, A. Wilson

Most methods of spectral analysis of signals including respiratory sounds involve continuous determination of spectral characteristics on random or semi-random segments of data. Due to the relatively low rate of change of the respiratory airflow and/or volume signals, there are limitations in precise triggering. Thus, a large variability exists in correspondence of a specific respiratory phase and a window of respiratory sound signals subject to spectral analysis. This limitation leads to the lack of a well-established and generally accepted quantitative interrelationship between absolute or relative magnitude values of specific frequency components of lung sounds and their correlation with levels of ventilation and pathologic conditions.

The system developed was used for precise and repetitive determination of a time window within the respiratory cycle and to assess the variability of spectral characteristics. Spectral summation and selective spectral averaging allow noise extraction in the spectral analysis and derivation of spectral characteristics free of artifacts. Spectral matrices which are used to represent these characteristics include multi-dimensional analysis and representation of the spectral amplitude versus frequency versus location versus respiratory phase for given diagnostic or therapeutic conditions. The real values of the amplitude at specific frequencies were used to conduct statistical evaluation of lung sounds characteristics. Further, the statistical analysis conducted showed that averaging of as low number of spectra as three, allows extraction of noise and an emphasis of spectral characteristics attributed solely to lung sounds.

Accumulated experimental data and results obtained validate this approach to the spectral analysis of lung sounds. This method allows one to enhance capabilities of differentiation of lung sounds. A conceptual approach to spectral analysis and examples of results will be discussed.

Further validation of the vortex theory of breath sound generation

Authors: J. Patterson, J.M. Seiner, J.C. Hardin, J.E. Levasseur, J.C. Manning, P.V. Kudirka, J.A. York

Definitive proof of intra-airway vortex orbiting as the mechanism of breath sound production was provided by stroboscopic and acoustic studies of a precisely-machined 4.76/4.0/4.0 mm (parent/daughter/daughter) Plexiglas bifurcation. When "expiratory" vortices were visualized with kerosene vapor in the airstream under He/Ne laser light, the vortex motion appeared to cease when the stroboscope was triggered by the fundamental tone of the bifurcation at a given airflow. When the stroboscope was slightly out of synchronization, the vortex could be made to orbit slowly clockwise or counterclockwise, depending on the stroboscope setting. Thus, there was a 1:1 correspondence between the fundamental tone and the vortex orbital frequency.

Three precisely machined bufurcations (one 4.6/4.0/4.0; and two 4.0/3.4/3.4 mm) were studied separately, and also joined as sequential orders. Even though the two small bifurcations were machined with the same program, the ranges of Reynolds numbers over which tones were produced, although overlapping, were not identical, a finding that emphasizes the sensitivity of the sound spectra to small anatomical differences. The responses of human farfield breath sound spectra to inhalation of a single cigarette are in keeping with this finding. The 3 bifurcations joined as a simulated bronchial tree showed a lower range of tones than the spectra of the individual components. This fact suggests that presentation to a bifurcation of an airflow input already containing rotating air masses (vortices) facilitates the formation of tones, as compared with a flow input with rectilinear streamlines.

SESSION C
DR. WILLIAM WARING, CHAIRMAN

9:00 - 9:20 AM	Frequency spectra of newborn infants' vesicular lung sounds	J. Kanga S. Kraman
9:20 - 9:40 AM	Comparative lung sound analysis: Adults, term infants and premature infants	S. Kraman J. Kanga
9:40 -10:00 AM	Frequency variations of breath sounds produced during maximal forced expirations	G. Charbonneau M. Meslier J. Racineux M. Sudraud E. Tuchais
10:00 -10:20 AM	Coffee Break	
10:20 -10:40 AM	Acoustic transmission of the respiratory system	S. Kudoh A. Shibuya N. Shioya R. Mikami
10:40 -11:00 AM	Site to site variation in crackle measurements	F. Davidson R. Murphy, Jr.
11:00 -11:30 AM	Business Meeting	
11:30 -12:00 PM	Photograph	
12:00 - 1:15 PM	Lunch	

Frequency spectra of newborn infants' vesicular lung sounds

Authors: J.F. Kanga, S.S. Kraman

Examination of the infant chest reveals lung sounds that are different to the ear from those of adults. To characterize this subjective difference, we compared the lung sounds of 10 full term infants, 7 premature infants and 8 adults. All subjects were free of cardiorespiratory disease and the adults were non-smokers. Lung sounds were recorded from locations over the right and left upper and lower lobes during the middle of inspiration, using miniature, air coupled, electret microphones fastened to the skin with double-sided adhesive tape rings. Frequency analysis was by fast fourier transform (FFT). We averaged the spectra derived from two breaths at each of the four locations from all subjects in each group. All subjects were studied using the same procedures and equipment so that observed differences in frequency could not be attributed to variations in technique. Our analyses revealed that, at all four locations, the spectral components of the term infants' lung sounds above 300-400 Hz were greater in amplitude than the adults. Below 300-400 Hz, the lower frequencies of the adults predominated. The differences were statistically significant at all four locations. The spectra of the premature infants' lung sounds showed a further shift toward the higher frequencies compared with the term infants.

These findings support the impression that the lung sounds of infants contain more high frequency components than those of adults. The reasons for this are probably that, in infants, the filtering properties of the lung are different from those of the adult lung, and that the sound traverses less lung tissue between the generating airways and the chest wall.

<u>Comparative lung sound analysis: Adults, term infants and premature infants.</u>

Authors: S.S. Kraman and J.F. Kanga

Vesicular lung sounds are presumed to originate in larger airways where turbulent airflow exists. Several investigators, however, have failed to find a source above the main carina and others have demonstrated that the sound is a regional phenomenon. Nonetheless, the precise sites have never been demonstrated. Because it is easy to identify sound production in the trachea, we studied the inspiratory vesicular lung sounds of healthy adults, term (mean weight 3.5 Kg) and premature newborn infants (mean weight 1.38 Kg) to see whether, in these small lungs and airways, the source of sound would be detectable in the trachea. We reasoned that, should a tracheal origin be present in infants, it would imply that the mechanism producing the sound was a relatively large airway phenomenon, as is generally believed.

We placed microphones on the chest wall first over the base of each lung and then over each apex and used coherence analysis to detect central (tracheal) sound production. LOWER LOBES: For the adults, no central airway component could be identified. For the term infants, a coherence peak of 0.75 occurred at 281 Hz. For the premature infants, a broader coherence peak of 0.90 at 281 Hz was noted. UPPER LOBES: No coherence at any frequency.

These findings confirm the absence of a tracheal source of lower lobe lung sound in adults and demonstrate such a source in infants. The diameter of the trachea of the newborn infant, and the airflow within it, are similar to those of the adult segmental bronchus. Our data, therefore, suggest that the source of the lung sound heard on the chest in adults originates in the vicinity of the segmental airways. Subsequent analyses of adult lung sounds recorded over adjacent segments and subsegments yielded coherence plots similar to those of the infants when recorded over opposite lungs, thereby supporting our conclusion.

We conclude that the inspiratory vesicular lung sound of adults originates in airways at or near the segmental bronchi. The mechanism is probably turbulence produced within those airways or convected there from central airways.

Frequency variations of breath sounds produced during maximal forced expirations

Authors: G. Charbonneau, N. Meslier, J.L. Racineux, M. Sudraud, E. Tuchais

For 8 normal subjects, we recorded lung sounds, and flow rates. The subjects performed 3 forced expirations. The sound was recorded at the trachea using an electret condenser microphone put in a probe. Lung volumes and flow rates are recorded at the mouth using a pneumotachograph. Signals were recorded on an FM magnetic tape recorder and then digitized at 5120 Hz. A time window 1024 samples (0.2 s) wide is stepped across the samples with a step size of 128 samples. For each position of the window, the frequency spectrum is computed using a Fast Fourier Transform (FFT). For each shifted frequency spectrum, we compute vs. time the mean frequency and the mean amplitude over the range 60-1260 Hz. This gives two time-varying functions MF (t), MA (t) and corresponding values of the flow rate v (t). We pay special attention to the possible existence of wheeze as well as to its time appearance. When a wheeze is present, it always corresponds in time and duration to a significant reduction in the MA curve. In many cases, at the time where the wheeze takes place, the flow rate is maximum and starts to decrease, however the wheeze occurs sometimes somewhat later. Those observations will be discussed in terms of ways of wheeze production.

Acoustic transmission of the respiratory system

Authors: S. Kudoh, A. Shibuya, N. Shioya, R. Mikami

Characteristics of acoustic transmission of the respiratory system were studied in seven healthy volunteers using white noise introduced into the oral cavity. Rapid attenuation was seen with increasing frequency at a rate of 40 db/dec (12 dB/oct), and the cutoff frequency was approximately 300 Hz at the apex and 150 Hz at the base of the chest. These results agreed well with those of our previous report using sinusoidal sound waves.

The attenuation rate and/or the cutoff frequency were varied in the patients with pulmonary diseases.

Phase characteristics of the healthy respiratory system analyzed by tone burst will also be discussed.

<u>Site to site variation in crackle measurements</u>

Authors: F. Davidson, R.L.H. Murphy, Jr.

Crackles may be heard at many sites over the chest in patients with a variety of illnesses. While specific crackle waveform measurements have been made in certain categories of illness, little information exists as to the variability of such measurements at different chest sites. Auscultatory crackles were studied by time expanded waveform analysis at six sites in both lateral decubitus positions in a patient with congestive heart failure and a patient with diffuse pulmonary fibrosis. To see how variable crackles were at different sites in the same patient, and to compare crackles at the same site in two different diseases (CHF versus pulmonary fibrosis) measurements were made of IDW, 2CD, number of zero crossings, number of crackles per breath (density) and timing of crackles during the breath (early, mid, late, pan). The magnitude of the variation in these parameters will be presented.

SESSION D
DRS. SADAMU ISHIKAWA AND RIICHIRO MIKAMI, CHAIRMEN

1:15 - 1:35 PM	Do experienced physicians hear lung sounds more correctly than young fledgling physicians?	M. Matsuzaki K. Tanimura H. Kusaka M. Inoue M. Munakata H. Ogasawara Y. Homma Y. Kawakami
1:35 - 1:55 PM	Auscultatory percussion of emphysema	S. Ishikawa S. Doss B. Upadhyay L. Kenny K. MacDonnell
1:55 - 2:15 PM	Continuous adventitious sounds in lung cancer	N. Shioya S. Kudoh A. Shibuya R. Mikami
2:15 - 2:35 PM	Quantifiable differences in the crackles (rales) of interstitial fibrosis and obstructive lung disease	R. Murphy, Jr. E. DelBono F. Davidson P. Betancourt M. Bermann
2:35 - 2:50 PM	Coffee Break	
2:50 - 3:10 PM	Laryngeal sound and respiratory muscle sound display in the assessment of sleep apnea	B. Phillips S. Kraman
3:10 - 3:30 PM	The use of lung sounds analysis for continuous evaluation of airflow obstruction in nocturnal asthma	R. Baughman R. Loudon
3:30 - 4:00 PM	Cracklefest	
4:00 - 4:30 PM	Summary	S. Kraman

Do experienced physicians hear lung sounds more correctly than young fledgling physicians?

Authors: M. Matsuzaki, K. Tanimura, H. Kusaka, M. Inoue, M. Munakata, H. Ogasawara, Y. Homma, Y. Kawakami

It has been pointed out that observer variability in interpreting lung sounds is great, especially for the quality of crackles and wheezes. The ATS recommended to classify crackles (whezes) by IDW (dominant frequency). The purpose of this report is to test whether these objective criteria fit with auscultatory diagnosis and whether clinical experience actually improves the auscultation ability.

We chose six experienced pulmonary internists working for 5 years or more for "trained group (TR)" and twelve fresh doctors, who had worked for only three months as qualified doctors without any special education on lung sounds, for "untrained group (UN)". After a short time guidance for lung sound interpretation according to the ATS criteria, they listened to 21 kinds of crackling sounds and 11 kinds of wheezing sounds that are stored in our lung sound library tapes through a speaker for about 30 seconds per case to judge the qualities of these rales (fine crackle or coarse crackle? wheeze or rhonchus?). Then we examined the observer variability and the rates of correct response between TR and UN. Interrelationships between these objective lung sound indexes and subjective response were also discussed.

1) Standard deviation agreement index (%max) of crackle test was 87.4% for TR and 67.1% for UN, and that of wheeze test was 92.3% for TR and 84.3% for UN.

2) TR responded more correctly than UN did in crackle test (113/126 vs 202/252 $p<0.05$) but not in wheeze test (61/66 vs. 114/132).

3) Some "incredible" false responses were found even in TR. This indicates the need for objective description of auscultatory findings.

Auscultatory percussion of emphysema

Authors: S. Ishikawa, S. Doss, B. Upadhyay, L. Kenny, K.F. MacDonnell

At the constant levels of lung volume the subjects were asked to hold their breath and the right side of the chest wall, on the level of the nipple, was percussed mechanically by the same investigator (SD). The input sound signal was recorded next to the site of percussion. The transmitted output sound signal was recorded simultaneously at the opposite side of the chest wall using an electronic stethoscope.

The lung sound is also recorded during quiet breathing at the central and peripheral airways. The recordings were then transcribed onto photographic paper at the speed of 100 mm/sec and 800 mm/sec. Sound intensity was measured manually from the tracing. Waveform analysis was performed in both input and output sound signals.

Standard pulmonary function tests were performed. In healthy subjects with normal stature the input to output signal ratio remained remarkably narrow range and it was 2.0 ± 0.2 at FRC.

In subjects with increased muscle bulk and subcutaneous fat tissue in the chest wall, input to output signal ratio was high.

The louder the input signal, the louder the output signal was observed to be.

In patients with a moderate degree of emphysema, input to output signal ratio was high and correlated with the degree of hyperinflation (RV/TLC).

In patients who have advanced emphysema with minimal muscle mass and minimal subcutaneous fat, the input sound became "tympanic" and the input to output signal ratio approached 1.

Continuous adventitious sounds in lung cancer

Authors: N. Shioya, S. Kudoh, A. Shibuya, R. Mikami.

Adventitious lung sounds were studied in patients with lung cancer. Continuous sounds were heard in 30 cases of 150 patients of lung cancer. Seven cases were excluded because of previous asthmatic history. Incomplete occlusion was seen bronchoscopically at the trachea, main bronchus and/or lobar bronchus in all 23 cases. Acetylcholine inhalation test revealed normal airway reactivity. These sounds did not disappear by the treatment with bronchodilator or corticosteroid.

On auscultation, these sounds were classified into inspiratory stridor, low-pitched rhonchi and high-pitched wheezes with prolonged expiration. According to the findings of phonopneumogram using a sound spectrograph, the fundamental frequencies of these sounds were ranged from 80 Hz to 300 Hz, which were lower than those of wheezes in asthmatic patients as we had previously reported. Although fixed monophonic wheeze was seen in many cases as described by Forgacs, random monophonic wheezes were also seen in some cases.

Quantifiable differences in the crackles (rales) of interstitial fibrosis and obstructive lung disease

Authors: R.L.H. Murphy, E.A. DelBono, F.F. Davidson,
P.E. Betancourt, M.M. Bermann

We studied the waveform characteristics of crackles in patients with interstitial fibrosis (IF) and chronic obstructive lung disease (COPD) to determine whether quantifiable differences were present that would assist in distinguishing these conditions. Crackle waveforms were examined on time intensity plots with an expanded time axis using a stethograph (STG). The time between the first and second crossings of the baseline by individual crackles, (the initial deflection width or IDW) averaged .65 ± .15 for the IF patients, significantly lower than the 1.02 ± .26 for the COPD patients. The time for the crackle to complete two cycles (two cycle duration or two CD) was shorter in IF averaging 4.93 ± .81 as compared to 5.75 ± 1.16 in COPD. The number of times the crackle waveform crossed the baseline was 4.3 ± 1.0 in IF and 5.6 ± 2.1 in COPD. The number of crackles in each breath and the number of chest wall sites positive was greater for IF than COPD. Objectively verifiable differences exist between the crackles of patients with IF and COPD.

Laryngeal sound and respiratory muscle sound display in the assessment of sleep apnea

Authors: B.A. Phillips, S.S.Kraman

The presence of respiratory effort during apnea is used to classify sleep apnea as obstructive, central or mixed. Respiratory effort has been assessed in a number of ways, including the use of esophageal balloons, magnetometers, pneumographs and respiratory inductance plethysmography (RIP). These methods are all expensive and/or cumbersome.

Acoustic methods of assessing airflow have been developed and used by several investigators. We have begun to use similar methods to detect muscle effort as well. Contracting muscle produces sound of approximately 25 Hz and the intensity of this sound is proportional to the strength of muscle contraction (Oster & Jaffe, Biophys J 1980; 30:119-128). We have developed a system that uses a microphone placed on the upper abdomen to detect and display muscle sound to be used as an index of muscle contraction during sleep studies. Besides low-pass filtering, no signal processing is used and the raw wave-form is displayed on the polygraph. We have included this system and a laryngeal microphone (to detect airflow) to study all of the patients referred to the sleep lab at the University of Kentucky since March 1984. The tracheal and muscle sound signals were displayed on polygraph paper together with traditional airflow and oxymetric data and RIP wave-forms.

Compared with RIP, we found that the muscle sound display was as effective for qualitative assessment of muscle activity, but was much more convenient, comfortable and inexpensive. We conclude from this preliminary study that the simultaneous display of laryngeal and muscle sound may be a clinically useful, simple and inexpensive method to screen for and classify sleep apnea.

The use of lung sounds analysis for continuous evaluation of airflow obstruction in nocturnal asthma

Authors: R. P. Baughman, R. G. Loudon

By recording and analyzing lung sounds from patients with asthma, we have shown a relationship between the duration of wheezing present during the respiratory cycle and the level of airflow obstruction. This provides a continuous method of evaluating airflow obstruction without disturbing the patient. The sound signal from a microphone attached to the chest wall was recorded. Two hundred and fifty millisecond segments of the sound signal were analyzed using the fast fourier transform (FFT) technique. Segments with frequency characteristics associated with wheezes, peaks in the 150-1000 Hz frequency range, were counted. A five minute sample was analyzed by randomly selecting 50 segments and analyzing each segment for the presence of a wheeze. This process estimated the proportion of time in which wheezing was present, which correlated with the FEV1 in 60 observations of 12 patients ($r = 0.89$, $p<0.001$).

We measured the amount of wheezing present during the night in stable, wheezy asthmatics. Eight studies were performed on 5 subjects. The amount of wheezing present from midnight to 12:30 AM was compared to that present from 4 AM to 4:30 AM and more wheezing and therefore more obstruction was found at 4 AM ($p<0.05$), consistent with previous observations by others. Our method permits a detailed description of fluctuations in airflow obstruction, without the patient's sleep pattern being disturbed. One subject, who was studied three times, had the same pattern of three episodes of increasing obstruction that spontaneously improved. Our technique allows us to study the effect of circadian rhythm and sleep stage on bronchomotor tone, without disturbing the patient.

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