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Department of Community Medicine

# ILSA 2017 in Tromsø

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ISBN:

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## History of ILSA conferences

In October 1976, the First International Conference on Lung Sounds was held in Boston, MA. The objectives of this conference were defined as follows:

*"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".*

ILSA conferences have been arranged every year since then, driven by research interest among medical doctors, engineers and researchers from other relevant fields, together with the fast development of technology for recording and analyzing lung sounds.

| No. | Date | Place | Local Organizer(s) |
|---|---|---|---|
| 1 | October, 1976 | Boston, MA | Raymond L.H. Murphy, Jr. |
| 2 | September, 1977 | Cincinnati, OH | Robert Loudon |
| 3 | September, 1978 | New Orleans, LA | William Waring |
| 4 | September, 1979 | Chicago, IL | David Cugell |
| 5 | September, 1980 | London, England | Leslie Capel & Paul Forgacs |
| 6 | October, 1981 | Boston, MA | Raymond L.H. Murphy, Jr. |
| 7 | October, 1982 | Martinez, CA | Peter Krumpe |
| 8 | September, 1983 | Baltimore, MD | Wilmot Ball |
| 9 | September, 1984 | Cincinnati, OH | Robert Loudon |
| 10 | September, 1985 | Tokyo, Japan | Riichiro Mikami |
| 11 | September, 1986 | Lexington, KY | Steve S. Kraman |
| 12 | September, 1987 | Paris, France | Gerard Charbonneau |
| 13 | September, 1988 | Chicago, IL | David Cugell |
| 14 | September, 1989 | Winnipeg, Canada | Hans Pasterkamp |
| 15 | October, 1990 | New Orleans, LA | David Rice |
| 16 | September, 1991 | Veruno, Italy | Filiberto Dalmasso |

| | | | |
|---|---|---|---|
| 17 | August, 1992 | Helsinki, Finland | Anssi Sovijarvi |
| 18 | August, 1993 | Alberta, Canada | Raphael Beck |
| 19 | September, 1994 | Haifa, Israel | Noam Gavriely |
| 20 | October, 1995 | Long Beach, CA | Christopher Druzgalski |
| 21 | September, 1996 | Chester, England | John Earis |
| 22 | October, 1997 | Tokyo, Japan | Masashi Mori |
| 23 | October, 1998 | Boston, MA | Sadamu Ishikawa |
| 24 | October, 1999 | Marburg, Germany | Peter von Wichert |
| 25 | September, 2000 | Chicago, IL | David Cugell |
| 26 | September, 2001 | Berlin, Germany | Hans Pasterkamp |
| 27 | September, 2002 | Helsinki, Finland | Anssi Sovijarvi |
| 28 | September, 2003 | Cancun, Mexico | Sonia Charleston, Ramon Gonzales Camerena & Tomas Aljama Corrales |
| 29 | September, 2004 | Glasgow, Scotland | Ken Anderson & John Earis |
| 30 | September, 2005 | Boston, MA | Raymond L.H. Murphy, Jr. |
| 31 | September, 2006 | Halkidiki, Greece | Leontios Hadjileontiadis |
| 32 | November, 2007 | Tokyo, Japan | Shoji Kudoh |
| 33 | October, 2008 | Boston, MA | Sadamu Ishikawa & Raymond L.H. Murphy,Jr. |
| 34 | September, 2009 | Haifa, Israel | Noam Gavriely |
| 35 | October, 2010 | Toledo, Ohio | Dan E. Olson |
| 36 | September, 2011 | Manchester, England | Ashley Woodcock |
| 37 | October, 2012 | Mayo Clinic, MN | Rasanen Jukka |
| 38 | November, 2013 | Kyoto, Japan | Yukio Nagasaka |
| 39 | October, 2014 | Boston, MA | Sadamu Ishikawa |
| 40 | September, 2015 | Saint-Petersburg, Russia | Alexander Dyachenko |
| 41 | October, 2016 | Tokyo, Japan | Masato Takase & Shoji Kudoh |
| 42 | September, 2017 | Tromsø, Norway | Hasse Melbye |

# The 42nd ILSA conference in Tromsø

The usefulness of lung auscultation is changing. It depends on how well practitioners understand the generation of sounds. It also depends on their knowledge on how lung sounds are associated with lung and heart diseases, as well as with other factors such as ageing and smoking habits. In clinical practice, practitioners need to give sufficient attention to lung auscultation, and they should use the same terminology, or at least understand each other's use of terms. Technological innovations lead to an extended use of lung auscultation. Continuous monitoring of lung sounds is now possible, and computers can extract more information from the complex lung sounds than human hearing is capable of. Learning how to carry out lung auscultation and to interpret the sounds are essential skills in the education of doctors and other health professionals. Thus, new computer based learning tools for the study of recorded sounds will be helpful.

In this conference there will be focus on all these determinants for efficient lung auscultation. In addition to free oral presentations, we have three symposia: on computerized analysis based on machine learning, on diagnostics, and on learning lung sounds, including the psychology of hearing. The symposia include extended presentations from invited speakers.

The 42nd conference is the first in history arranged by a research unit for general practice. Primary care doctors are probably the group of health professionals that put the greatest emphasis on lung auscultation in their clinical work. Many patients with chest symptoms consult without a known diagnosis, and several studies have shown that general practitioners pay attention to crackles and wheezes when making decisions, for instance when antibiotics are prescribed to coughing patients. In hospital, the diagnosis of lung diseases is more strongly influenced by technologies such as radiography and blood gas analysis. Since lung auscultation holds a strong position in the work of primary care doctors, I think it is just timely, that the 42nd ILSA conference is hosted by General Practice Research Unit in Tromsø. I hope all participants will find presentations of importance, and that the stay in Tromsø will be enjoyable.

*Hasse Melbye, conference president (hasse.melbye@uit.no)*

Professor at General Practice Research Unit, Department of Community Medicine, Faculty of Health Sciences, UIT The Arctic University of Norway

## Prevalence and associations of crackles and wheezes in a general adult population - the Tromsø 7 study

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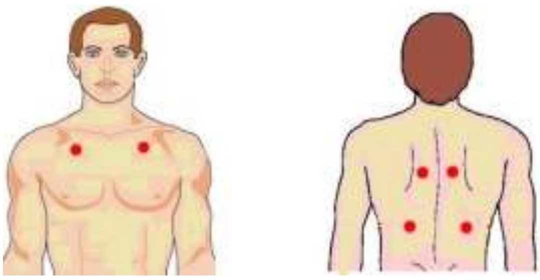
**Background:** The stethoscope is a medical tool that is broadly available, cheap, and easy to use. However, there is a lack of epidemiological data about abnormal lung sounds in relation to chronic heart and lung diseases.

**Aims:** To explore the prevalence of crackles and wheezes in a general population and detect explanatory factors

**Methods**: We recorded respiratory sounds from a random sample of 4,033 participants from the Tromsø 7 study (n=21,083), using a microphone set in a stethoscope tube. We obtained recordings from six locations on the chest (figure). The participants were 40 to 84 years old. In addition, we obtained information on symptoms, self-reported disease and clinical tests. Four observers classified the recordings independently, and several rounds of classification were carried out to optimize reliability. Chi-square tests were used to explore associations.



**Results**: We found adventitious sounds in 28% (n=1131) of the individuals, of which 13% (n=532) presented with crackles and 18% (n=729) with wheezes. In about 71.6% (crackles) and 73.25 (wheezes) of the individuals, the positive finding was present in only one of the six locations. The prevalence of adventitious sounds was evenly distributed across the six chest locations except for inspiratory crackles that were more frequent in the bases of the lungs. Daily cough ($p <.001$) and Modified Medical Research Council (mMRC) score >2 ($p <0.001$) were associated with inspiratory crackles. Present (but not past) smoking was associated with both crackles ($p <0.001$) and wheezes ($p <0.01$). Self-reported heart attack ($p <0.01$), COPD ($p <0.001$) and rheumatoid arthritis ($p <0.001$) were also associated with crackles.

**Conclusions**: The presence of adventitious lung sounds was common in our sample. We found an association of positive findings with respiratory symptoms, smoking status and self-reported disease. Further analyses will explore the relationship between crackles and wheezes with defined diagnostic categories for heart and lung diseases.

## Reliability and validity of computerised respiratory sounds in COPD

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**Background:** Respiratory sounds (RS) are the outcome most related to the movement of air within the tracheobronchial tree. Their characteristics are promising to easily reflect lung function in patients with chronic obstructive pulmonary disease (COPD). However, RS measurement properties, namely reliability and validity, have been poorly tested.
Aims: This study assessed the between-days reliability and validity of RS in patients with COPD.

**Methods:** 50 patients (36♂, 67.3±9.3y, FEV1 49.5±19.7% predicted) with stable COPD were recruited. Lung function (FEV1% predicted) was recorded with a spirometer (MicroLab 3535, CareFusion). RS at anterior and posterior right/left chest were simultaneously recorded for 20s, using air-coupled electret microphones (C417 PP, AKG), in 2 sessions conducted 5-7 days apart. Adventitious (no. of crackles and wheeze occupation rate–%wh) and normal (median frequency–F50 and maximum intensity–Imax) RS were processed using validated algorithms. Between-days reliability was calculated with intraclass correlation coefficient (ICC1,2). Construct validity, against FEV1% predicted, was explored with Spearman's coefficient.

**Results:** During inspiration, no. of crackles and %wh showed excellent (ICC>0.75) and moderate-to-good (ICC>0.4) reliability at anterior and posterior chest ($p<0.05$). F50 and Imax showed moderate-to-good (ICC>0.4 and ICC>0.6, respectively) reliability at anterior and posterior right chest ($p<0.05$). During expiration, %wh, F50 and Imax were only reliable at anterior chest (ICC>0.5, ICC>0.4 and ICC>0.6, respectively; $p<0.05$). No. of crackles were not reliable. Significant ($p<0.05$) low-to-moderate ($0.3<r_s<0.7$) correlations between FEV1% predicted and RS were found for inspiratory and expiratory no. of crackles at anterior left and posterior chest, inspiratory F50 at anterior left chest and inspiratory and expiratory Imax at anterior chest.

**Conclusion:** Inspiratory no. of crackles, recorded at posterior chest, and Imax, recorded at anterior chest, seem to be the most reliable and valid RS parameters to reflect lung function in patients with COPD.

## Monitoring of nocturnal respiratory symptoms in COPD patients by using LEOSound lung sound monitor

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**Background and aim:** Chronic obstructive pulmonary disease (COPD) is one of most common causes of death worldwide. Typical respiratory symptoms are breathlessness, chronic cough and wheezing. Especially for night time symptoms there is a lack of awareness, which can lead to disturbed sleep and impaired daytime performance. COPD is also showing a high coincidence with obstructive sleep apnea (overlap-syndrome), which is also associated with acoustic symptoms snoring and apnea. By using objective lung sound monitoring our aim was to investigate the ability of LEOSound to monitor nocturnal respiratory symptoms like cough, respiratory rate and wheezing.

**Methods:** All recordings were performed by using LEOSound (Löwenstein Medical GmbH & Co. KG, Germany). LEOSound is an objective lung sound monitoring device, which contains algorithms to automatically detect coughing and wheezing.

**Results:** Our dataset contains recordings of 48 patients with stable COPD. Of these patients, 18 are classified into COPD stage II, 19 into COPD stage III and 11 into COPD stage IV. Most patients were male (63%) and had a mean age of 67.1 ± 7.6 years and mean packyears of 43.9 ± 20.6.

The validation of cough and wheezing detection were performed for all 48 patients. The automated detection of cough shows a sensitivity of over 95 % and a specificity of over 80 %. Sensitivity and specificity for wheezing detection above 90 %. The automated detection of respiratory rate has a root mean square error (RMSE) ≤ 2 breaths per minute.

**Conclusion:** LEOSound lung sound monitor is able to record and detect cough and wheezing with high sensitivity and specificity. As a certified medical device, it offers an opportunity to record nocturnal respiratory symptoms in COPD-Patients. Other respiratory symptoms like snoring and apnea were also be recorded by using LEOSound and will be automatically detected soon.

## Lung sounds intensity: is there a difference between spontaneous and target airflow?

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**Background:** Lung sounds intensity (LSI) is a non-invasive measure to assess respiratory system that has a linear relationship with airflow. Clinicians often assess LSI asking subjects to breathe deeply with open mouth, while researchers have been using target airflows. For clinical practice, however, it would be easier to rely on lung sounds acquired without airflow measurements.

**Aims:** This study assessed if LSI was different when acquired with subjects breathing spontaneously and at a target airflow.

**Methods:** A total of 1020 recordings from 85 adults aged 40 or over were used. Lung sounds were recorded consecutively at 6 chest locations (right and left: upper posterior, lower posterior, upper anterior) using a stethoscope with a microphone in the tube. Recordings were first performed at spontaneous deep breathing and then at a target airflow of 1.5L/s. Breathing phases were manually annotated and inspiratory and expiratory LSI in the 100–2000Hz band were determined.

**Results:** LSI at a target airflow was found to be significantly higher than at spontaneous airflow both during inspiration (mean differences (MD) from 1.8 to 3.7dB; $p<0.001$) and expiration (MD from 1.5 to 3.2dB; $p<0.001$) at all locations. In inspiration, differences between right and left were only seen at upper posterior chest at spontaneous airflow ($p=0.016$) and at lower posterior chest at target airflow ($p=0.030$). In expiration, however, differences were seen at all locations both at spontaneous and target flows ($p<0.034$).

| Breathing phase | Location | Right | | Left | |
|---|---|---|---|---|---|
| | | Spontaneous | Target | Spontaneous | Target |
| Inspiration | Upper anterior | 20.9±2.5 | 24.3±3.0 | 20.6±2.6 | 24.3±3.3 |
| | Upper posterior | 19.5±2.1 | 21.3±2.6 | 18.9±2.0 | 21.7±2.8 |
| | Lower posterior | 20.2±2.5 | 23.3±2.6 | 20.6±2.5 | 23.8±2.7 |
| Expiration | Upper anterior | 18.9±2.0 | 22.1±2.9 | 18.0±2.1 | 20.8±2.7 |
| | Upper posterior | 18.0±2.4 | 19.6±2.7 | 17.1±2.0 | 19.1±2.5 |
| | Lower posterior | 16.5±2.1 | 18.6±2.2 | 17±2.0 | 19.6±2.6 |

Table 1. LSI at spontaneous and target airflow (dB) (n=85).

**Conclusion:** LSI was higher at a target airflow of 1.5L/s than at spontaneous airflow. Despite differences in LSI were minor, its clinical significance is still unknown. This knowledge gap should direct future research.

## The influence of adventitious sounds and artifacts on the frequency and intensity of normal respiratory sounds

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[2]University of Manitoba.

**Background and aim:** Normal respiratory sounds (NRS) constitute a non-invasive way to assess lung function as they are generated by the airflow in the respiratory tract. Studies have been characterizing NRS using two main approaches: i) analyzing the complete sound file or ii) analyzing the sound file after excluding adventitious sounds/artifacts. The use of distinct approaches make comparisons between studies difficult, however, it is not known if characteristics of NRS differ significantly between the two approaches.
Therefore, this study aimed to compare the differences in the spectral characteristics of NRS between the two approaches.

**Methods:** A total of 1020 recordings from 85 adults aged 40 or over were recorded. Lung sounds were recorded consecutively at 6 chest locations (right and left: upper posterior, lower posterior, upper anterior) using a stethoscope with a microphone in the tube. Recordings were first performed at spontaneous deep breathing and then at a target airflow of 1.5L/s. Breathing phases were manually annotated in all recordings, and then the two strategies to analyze the spectral characteristics of NRS in the 100–2000Hz band were applied. In strategy 1, without further analysis, the quartile frequencies (F25, F50 and F75) and mean intensity (Imean) were determined. In strategy 2, the quartile frequencies and mean intensity were determined after excluding adventitious respiratory sounds (crackles/wheezes) and artifacts detected with algorithms. Paired t-tests were used to analyze differences between the two strategies.

Table 1. Normal respiratory sounds at spontaneous and target airflows using two different strategies.

| | **Inspiration** | | | | **Expiration** | | | |
|---|---|---|---|---|---|---|---|---|
| | Strategy 1 Mean (SD) | Strategy 2 Mean (SD) | Mean difference | p-value | Strategy 1 Mean (SD) | Strategy 2 Mean (SD) | Mean difference | p-value |
| Spontaneous airflow (n=510) | | | | | | | | |
| F25 (Hz) | 166.9±16.0 | 166.5±15.9 | 0.39 | <.001 | 158.2±17.5 | 157.2±18.3 | 0.93 | <.001 |
| F50 (Hz) | 367.0±35.6 | 365.7±35.5 | 1.32 | <.001 | 354.6±39.8 | 351.5±41.5 | 3.05 | <.001 |
| F75 (Hz) | 664.5±44.5 | 662.2±44.9 | 2.28 | <.001 | 656.5±46.5 | 651.8±50.8 | 4.73 | <.001 |
| Imean (dB) | 20.1±2.5 | 20.0±2.5 | 0.14 | <.001 | 17.6±2.3 | 17.3±2.4 | 0.33 | <.001 |
| Target airflow (n=510) | | | | | | | | |
| F25 (Hz) | 179.5±16.5 | 179.2±16.6 | 0.31 | .001 | 169.6±18.8 | 168.7±19.1 | 0.94 | <.001 |
| F50 (Hz) | 391.6±35.0 | 390.6±35.2 | 1.02 | <.001 | 376.3±40.7 | 373.9±41.1 | 2.40 | <.001 |
| F75 (Hz) | 690.3±43.3 | 688.7±43.3 | 1.62 | <.001 | 677.1±44.6 | 673.1±44.3 | 4.03 | <.001 |
| Imean (dB) | 23.1±3.1 | 23.0±3.1 | 0.14 | <.001 | 20.0±2.9 | 19.6±2.9 | 0.35 | <.001 |

**Conclusion:** Spectral characteristics are different between the two approaches, with frequency and intensity parameters achieving slightly higher values when using the first strategy. Future research should explore if these differences are clinically relevant or not.

# Using machine learning to provide automatic image annotation for wildlife camera traps in the Arctic

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**Summary**

The arctic tundra is considered the terrestrial biome expected to be most impacted by climate change, with temperatures projected to increase as much as 10 °C by the turn of the century. The Climate-ecological Observatory for Arctic Tundra (COAT) project monitors the climate and eco-systems using several sensor types. We report on results from projects that automate image annotations from two of the camera traps used by COAT: an artificial tunnel under the snow for capturing information about small mammals, and an open-air camera trap using bait that captures information of a range of larger sized birds and mammals. These traps currently produce over two million pictures per year.

We have developed and trained several Convolutional Neural Network (CNN) models to automate annotation of images from these camera traps. Results show that we get a high accuracy: 97.84% for tunnel traps, and 94.1% for bait traps. This exceeds previous state of the art in animal identification on camera trap images, and is at a level where we can already relieve experts from manual annotation of images.

**Introduction**

The arctic tundra is expected to be more challenged by climate change than any other terrestrial biome, with models projecting an average temperature increase in the Arctic as large as 10 °C by the turn of the century [1]. The Climate-ecological Observatory for Arctic Tundra (COAT) [1] [2] is a long-term research initiative for real time detection, documentation and understanding of climate impacts on terrestrial arctic ecosystems. COAT is a collaboration of several Norwegian research institutions under the umbrella of FRAM - High North Centre for Climate and Environment. The study areas include the bioclimatic extremes of the terrestrial Arctic, the low-arctic coast of the Norwegian mainland and the high-arctic Svalbard archipelago.

COAT uses several types of sensors for observations, including satellites, snow observations, meteorological observations, camera traps, and microphones. Manual annotation and analytics of images from the camera traps is by now already a demanding and time consuming task, and this burden will further increase as more traps are deployed.

This paper reports on results from using machine learning techniques on two separate sets of camera trap images: camera traps used in small mammal tunnels underneath the snow and baited camera traps above the snow. These traps are expected to capture more than two million pictures per year with the current and near future set of cameras.

**Small mammal camera traps**

*Figure 1: Image of a tundra vole from one of the COAT camera traps under the snow.*

One of the camera traps used is an artificial tunnel (see Figure 1) with a motion sensitive camera that records mammals that run through all year round [3]. These traps give brand new information on a whole community of different species (shrews, voles, lemming, least weasel and ermine) during the long arctic winter, since the traps become part of tunnel systems used by mammals in the winter. The resulting image sequences can be used to analyze animal population and community dynamics. Correct species identification is however essential for this purpose. An advantage in this regard is that the images are similar with respect to background and distance to the animal.

We trained three different Convolutional Neural Network (CNN) models and used them to predict and label images (see [4] for more details). To train the models, we had to manually annotate a dataset selected from 74,429 unlabeled camera trap images. The images were pre-processed to accommodate the algorithms we used, and to remove unnecessary information that could influence training, such as the black borders displaying image metadata.

Results show that we achieve 97.84% accuracy, 97.81% precision and 93.45% recall on a dataset with 10000 camera trap images and 11 classes. This exceeds previous state of the art in animal identification on camera trap images [5] [6] [7].

*Figure 2: Image from one of the COAT open-air camera traps showing a golden eagle.*

**Open-air baited camera traps**

These camera traps take images every five minutes, both day and night, overlooking an area with bait on the ground. Automatic annotation of these images is a harder problem than for the tunnel traps described above, as there will be more variation in weather, area around the camera, types of animals and distances to the animals in the image. Many images contain animals that are far away from the bait, making them hard to see, even by human experts. Images with animal presence will usually contain several different species, making the problem significantly harder than with single animal images. Furthermore, accumulating snow covers the bait, which partially obstructs the view of animals digging down to the bait, as seen in **Feil! Fant ikke referansekilden.**.

*Figure 3: Image from baited trap with a partially obstructed red fox surrounded by two hooded crows and one raven.*

This project created a system that use three different CNN methods (Faster Region-based CNN, Single Shot Multibox Detector and You Only Look Once v2) for training and annotation, and compared the results of each method. See [8] for more details about the system.

Results from the project show that we can detect and classify animals in the images with 94.1% accuracy at 21 frames per second, exceeding the performance of previous work. Reindeer is the most challenging species to detect, as they are frequently far away from the camera. Many of the other animal classes had an accuracy close to 100%.

**Conclusions**

The promising results from these projects show that we are close to automating the annotation of images from the camera traps. We have not yet done a study that compares the accuracy of the automatic annotation systems to human experts that are currently annotating the images. We expect that the automatic system is close to the accuracy level of experts, as it is easy to make subtle mistakes in the software they are currently using, and humans are prone to make mistakes in tiresome and repetitive work.

We believe that the results are promising and expect that further improvements to automatic annotation of images will provide the means for scaling up the number of camera traps. This will enable observations with more spatial resolution and of larger geographic areas without the limitations currently introduced by limited human resources.

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# A New Computerized Approach for Lung Sounds Analysis Using Sound Signature

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**Background:**Obstructive Lung disease is a condition where the lung airways change their shape (e.g. become narrow). These changes are associated with changes in the sounds generated within the lung during breathing. Listening to these sounds is limited by the low sensitivity of the human auditory system and the inability of the stethoscope to transfer low energy sounds.

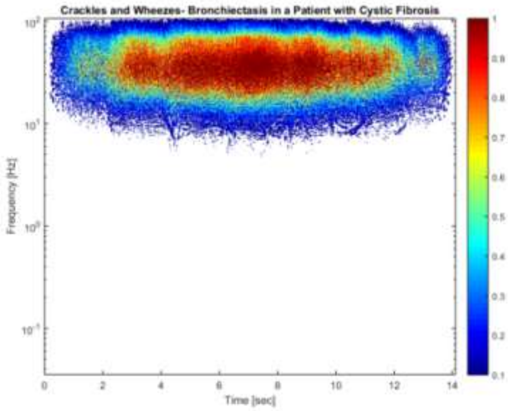


*Fig.1: Intensity Map of Sound Signature*

**Aim:** Suggesting a new approach to allow computerized analysis in order to overcome these obstacles.

**Methods:** The new method is based on Discrete Time-Frequency Distribution. It is based on Fourier transform applied to autocorrelation type function of the semi-periodical lung sound. The concept starts by sampling wide frequency lung sounds (from infra sound to audible range), identifying the active breathing periods, convert the data into its Sound Signature using the above transform, and displaying the Sound Signature (display formats are shown in the Figures).

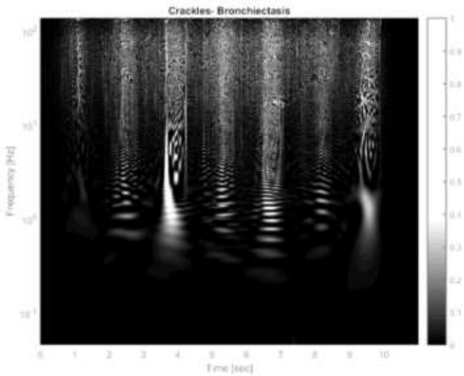


*Fig.2: Gray Scale of Sound Signature*

**Results:** Using this transform, we show, in this presentation, that among the properties of the proposed transform, one can find: time shift and modulation preservation, representation of time-frequency energy distribution, and very high time-frequency resolution (limited by Heisenberg Uncertainty Principle). The new approach does not suffer from distortion of the outcome shape, while other methods, using windowing, deform the time-frequency representation (mainly by a way of low pass filtering effect). Examples of such transforms include: spectrograms, Wavelet, or Short-Time Fourier Transform. In this presentation, the Sound Signature is demonstrated on few Sound Signature examples of different pathological lung sounds, in addition examples of the Sound Signature display are presented.

**Conclusion:** By using the Sound Signature the lung sounds are converted from an acoustic signal into a HD digitized image. This method allows computerized classification of lung sounds using image processing classification techniques.

**Acknowledgment:** The autors wishes to thank Prof. Noam Gavriely for his helpful review, comments and suggestions.

# Use Wide Range Sound Signature in Computerized Classification of Lung Diseases

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**Background:** Computerized classification of chest sounds is a challenging task. However, using advanced processing technologies facilitates a clinically usable medical device. Our method integrates the following: wide range pickup detector (Infrasound and audible sound), converting the data into Sound Signature images, and applying image classification Big Data algorithms.

**Aim:** The scope of this project is to evaluate the feasibility of implementing computerized classification to wide range lung Sound Signature.

**Methods:** The computerized pickup unit contain the following steps: Capturing data from the wide band pickup unit, segmentation of the breathing sequence, Sound Signature transform and displaying the data. We asked medical students to use the pickup device during regular operation of the pulmonary clinics in a few medical centers. A group of 42 volunteers participated in the study. For each volunteer we measure the lung sounds at 14 points located: six on the front chest, six on the back, and two on the chest sides. The group was divided into three: 19 Healthy volunteers, 13 COPD patients, and 10 IPF patients.

**Results:** The healthy Sound Signature vs. the COPD and the IPF can be separated by their patterns, as seen in the figures below:
Out of the 42 volunteers we measure, 79% of the healthy volunteers had the same Sound Signature for healthy lung sound as shown on Fig. 1, 77% of the COPD patients and 70% of the IPF patients had the corresponding Sound Signature as Presented in Fig.1.

**Conclusions:** The use of Infrasound as part of the lung Sound Signature enhances the classification of chest sounds and may facilitate the calculation of probability-of-existence of certain disease and screening lung conditions.

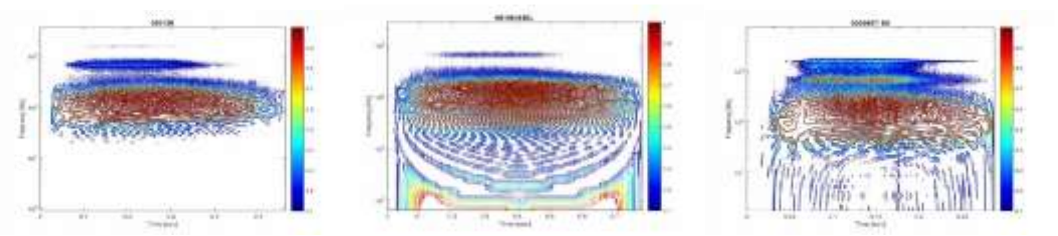

*Fig. 1: Example of three Sound Signatures. Left – Healthy, Center – patient with COPD, Right – Patient with IPF.*

**Acknowledgment -** The autors wishes to thank Prof. Noam Gavriely for his helpful review, comments and suggestions.

## Detection of Wheezes and Breathing Phases Using Deep Convolutional Neural Networks

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**Introduction:** Detection and interpretation of lung sounds is difficult, so inexperienced health personnel classify lung sounds differently [1]. Integrating an automatic system for detection and classifying lung sounds into digital stethoscopes could help interpret lung sounds. Previous approaches for detection of wheezes have used small datasets and machine learning methods such as Gaussian mixture models [2], artificial neural networks [3] and support vector machine [4].

We use a variant of artificial neural networks called deep learning. The recent improvements in deep learning algorithms, data availability, and computational power have allowed deep learning to be used in fields such as self-driving cars, image analysis, and speech recognition. Also, in medical fields, large image datasets have been used to train deep learning models to automatically classify symptoms and diseases [5]. However, to our knowledge, deep learning for classification has not been applied to lung sounds.

**Methods:** Deep learning typically requires a bigger dataset than most other machine learning approaches. The Tromsø Study 7 has collected a large lung sound dataset of which we use 8784 unique recordings of lung sounds. We have developed deep learning algorithms and trained them using this dataset. The algorithms detect wheezes and breathing phases in lung sounds. We have used the algorithm to build a lung sound classification service that can be used by various applications such as a web based lung auscultation learning tool for students.

Our approach uses state-of-the-art deep convolutional neural networks (ConvNets), to automatically detect breathing phases and wheezes in lung sound recordings. Using ConvNets, we can utilize large datasets without manual feature engineering. Related work has shown that deep ConvNets can outperform previous methods for acoustic recognition on tasks such as speech recognition and acoustic event detection.

We evaluate our wheeze detection system using recall and precision. We also calculate the mean class precision and recall across both classes. For the breathing phase detection system, we use mean average precision (mAP). This metric is often used to evaluate results from a document retrieval system, but also for object detection systems.

*Table 1: Wheeze detection.*

| Class | Precision (%) | Recall (%) |
|---|---|---|
| Normal | 79 | 98 |
| Wheeze | 96 | 73 |
| Mean class | 89 | 85,5 |

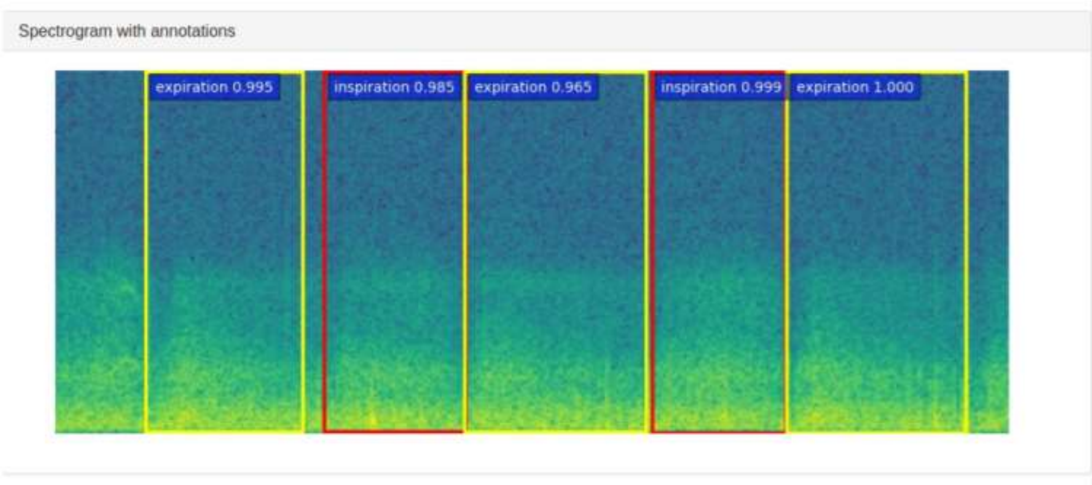
*Table 2: Breathing phase detection.*

| Class | AP (%) |
|---|---|
| Inspiration | 89 |
| Expiration | 88 |
| mAP | 88 |

**Results:** Our results (Table 1 and Table 2) show that we have successfully implemented wheeze detection with wheeze recall (sensitivity) of 73%, and normal recall (specificity) of 98%. We have also implemented a breathing phase detection with an average precision of 89% for the inspiration phase and 88% for the expiration phase.

*Figure 1. Screenshot from our lung auscultation prototype used to detect wheezes.*

*Figure 4. Screenshot from our lung auscultation prototype used to detect breathing phases.*




**Conclusion and future work:** Our approach successfully detects wheezes and breathing phases. Further research is necessary to determine how we can integrate our approach into commercial applications such as a learning tool, a digital stethoscope or a home monitoring deviceEncouraged by these results, we have started a company Medsensio AS, which have received initial funding from the Research Council of Norway. Our main goal will be to use novel methods and developments in computer science for medical data analysis. We will start by using our approach in a lung auscultation teaching tool and integration with smart stethoscopes.

We are currently investigating the clinical and research aspects of lung sounds, such as how lung sounds are used for early screening and the relationship with diseases such as COPD and asthma. Furthermore, we plan to validate our approach on other datasets recorded in different environments and with different equipment.

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## Machine Learning Based Crackle Detection

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**Background**: In recent years, many innovative solutions for recording and viewing sounds from an electronic stethoscope have become available. However, to fully utilize such smart stethoscopes, there is a need for an automated approach for detecting abnormal lung sounds.

**Aim**: To create an algorithm for automated detection of crackles in lung sound recordings.

**Methods**: We developed a machine learning based approach for detecting crackles in lung sounds recorded using a stethoscope with a microphone in the tube in the 7th Tromsø Study (a health survey). We trained and evaluated the machine learning model using 209 files with crackles classified by experts. We use features extracted from small windows in audio files. We evaluated several feature extraction methods and classifiers.

**Results**: We got the best performance using four features from the time domain and one from the spectrum domain, classified by a SVM with a Radial Basis Function Kernel. With this approach, we obtained a precision of 86% and recall of 84% for classifying a crackle in a window. This is more accurate than found in human classifiers in studies of health personnel. The classifier is very fast.

**Conclusion:** Our approach detects and visualizes individual crackles in recorded audio files. It is accurate, fast, and has low computational resource requirements. The approach is therefore well suited for development of tools that can help health personnel to detect and understand the implication of crackles. Further research is necessary to demonstrate the use of such tools in the clinical setting.

# Comparison of Various Machine Learning Algorithms on Adventitious Pulmonary Sound Classification

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**Background:** Time, location and frequency of adventitious pulmonary sounds may help to track signs of different pulmonary diseases. In literature, various techniques are proposed to classify pulmonary sounds using machine learning algorithms.

**Aim:** In this study, using various machine learning algorithms pulmonary sounds are classified into normal vs. adventitious groups. Moreover, continuous pulmonary sounds are further classified into mono/polyphonic wheeze types.

**Methods:** Non-dyadic wavelet transform is used to extract raw features from pulmonary sounds by comparing Fourier transform and dyadic discrete wavelet transform methods. Machine learning algorithms such as k Nearest Neighbour, naive Bayes and support vector machines are used to compare classifier's performances.

**Results**: The experimental results showed that non-dyadic wavelet transform performs better classification accuracies when compared to Fourier based methods with 5–10 % higher correct classification rates both in normal-adventitious and wheeze type classification problems. Support vector machine classifier with radial basis function performs the best correct classification rates when raw features are fed into the classifiers. Performance of various parameters are provided to demonstrate optimum parameter set also.

**Conclusion**: Wavelet based technique provides better time frequency resolution than Fourier transform and dyadic discrete wavelet transform methods, however in case of wheeze type classification an adaptive wavelet based method is needed. Support vector machine classifier when compared to other classifiers provides better results.

**Acknowledgements:** The work is supported by Boˇgaziçi University Research Fund under grant number 16A02D2. The work of S. Ulukaya is supported by the Ph.D. scholarship (2211) from Turkish Scientific Technical Research Council (TUBITAK).

## Cardiac Response to Respiration in Deep Inspiration followed by Breath Holding

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**Background:** Heart rate becomes slower on inspiration. When one takes deeper breathe, as more negative pressure is generated within the chest which leads to more blood returning to left ventricle, then a larger volume of blood must be pumped out, hence a delay of heart beats on inspiration. We have been studying this phenomenon for past 4 years and reported at annual ILSA meetings on healthy nonsmoking subjects, smokers, and patients with COPD.

**Methods:** This year we investigated Effects of Breath Holdings in 10 Healthy Nonsmoking Individuals when they come to my office for routine visit with no acute respiratory illnesses. We used 2 channel ECG and lung sounds simultaneously recording ECG and tracheal sounds at sitting position.

**Results:** 2 QRS intervals became 41 msec on Deep Inspiration comparing to Expiration Period of 30 msec. average of all 10 subjects , mean heart rate reduction from 76 to 59 /min.

While deep inspiration followed by breath holding, heart rate reduction occurred comparing to expiration period. After change of 2QRS intervals following deep inspiration (became longer, slowing heart rate ) the 2 QRS intervals remained essentially the same during breath holding period.

**Conclusion:** We conclude that deep inspiration with breath holding is more advantageous for slowing heart beat comparing to just deep inspiration.

## Auscultatory phenomena in patients with partially controlled bronchial asthma with intrapulmonary auscultation

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**Background:** One of the most common chronic diseases is bronchial asthma, and in recent years, the incidence of it is only increasing. This represents a serious medico-social and economic problem, especially against the backdrop of untimely and inadequate diagnosis of the disease.

**Materials and methods:** During the traditional bronchoscopy (Karl Storz Tele Pack X) is performed simultaneously with video bronchoscope intrapulmonary registration acoustic phenomena specifically designed to work with the bronchoscope microphone. Simultaneously recording lung sounds produced by the electronic stethoscope (3M Littmann Electronic Stethoscope 3200) for further analysis and comparison data

**Results:** By recording in 20 patients with partially controlled asthma (GINA 2014). The main characteristics, which evaluated abnormal noises were a range of received frequencies and duration of which depend on the sensitivity of the sensor and the proximity to the site of occurrence of wheezing. This was traced frequency correlation on the cause of wheezing. Thus, the average duration of wheezing during intrapulmonary auscultation was about 250 ms, the prevailing average rate of wheezing 400 Hz, the bass - 200 Hz ($p < 0,05$). Frequency range wheezing - 80-1600 Hz ($p < 0,05$). The highest rate was observed in the presence of mucus and, especially, the spasm, which were recorded using the received video and flutter to give more bass version of wheezing. When registering the sounds on the body surface average duration was 100 ms, the prevailing average frequency - 150 Hz, and the range was only 350-950 Hz ($p < 0,05$). A clear correlation when it was received.

**Conclusion:** Intra-pulmonary auscultation can improve the quality of the diagnostic process by obtaining a wider range of diagnostic information, will help to better understand the nature of pathological processes occurring in the lower respiratory tract and will positively affect the effectiveness of examination and treatment of the patient.

## Lung sounds of patients with interstitial pneumonia in left and right lateral decubitus position - Effect of gravity on lung sounds

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**Background:** We reported that lung sounds of interstitial pneumonia (IP) were influenced by body position, and lung sound intensity (LSI) was greater in the dependent position. As most of the sound power comprised of crackles, this observation means that crackles in IP is louder in the dependent lung. We also found that LSI was not symmetrical; LSI was greater on the left than on the right and postural changes of LSI were greater on the right than on the left. This study aims to clarify the effects of lung position on LSI, i.e., dependent side or upside, when the subjects are in right and left lateral decubitus positions.

**Methods:** We recorded lung sounds on both the right and the left lung bases in left and right lateral decubitus position in seventeen patients with IP. Lung sounds were recorded for ten seconds by sound spectrometer, LSA2012 (Kenz-Medico). We averaged the sound intensity of whole ten seconds and compared the averaged LSI in the two lateral decubitus positions.

**Results:** In left lateral decubitus position, LSI on the left lung (dependent lung) was significantly greater than that on the right lung (upside lung). In right lateral decubitus position, there was no significant difference in LSI between the left lung (upside lung) and the right lung (dependent lung). The postural change of LSI between upside and dependent side was greater on the right lung than on the left lung.

**Conclusions:** The LSI of IP, i.e., loudness of the crackles was greater when the lung was in the dependent side than in the upside. The postural change of LSI was greater on the right lung than the left lung.

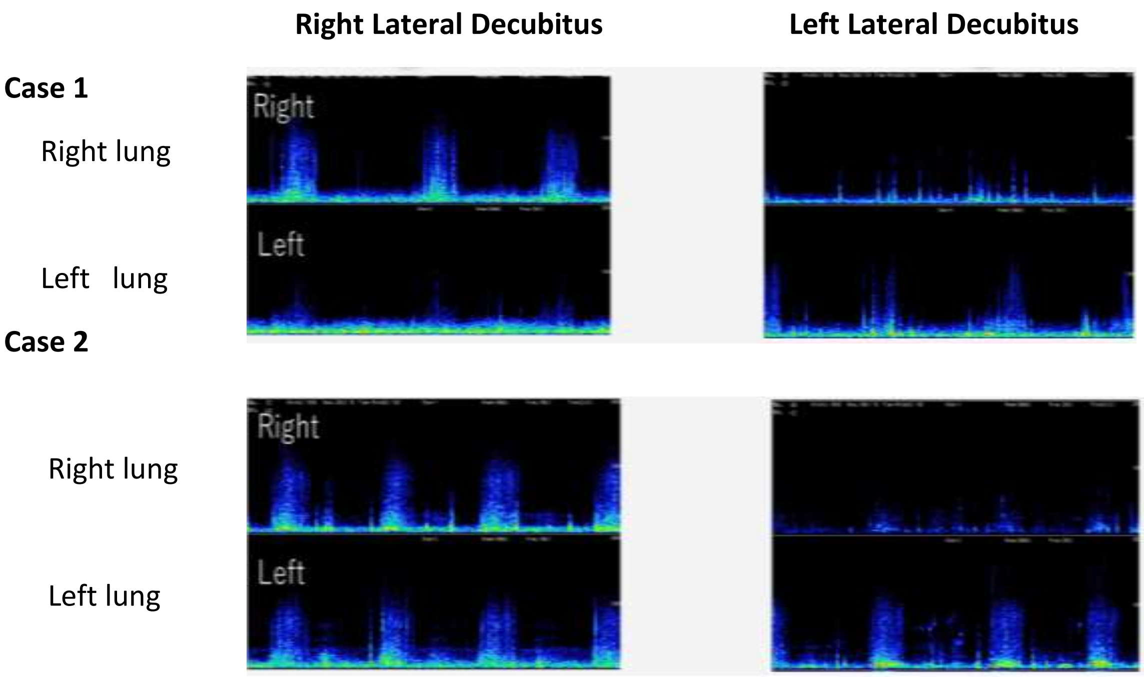


*Figure: Sound spectrogram of two cases with IP. The lung sounds were recorded on bilateral lung bases in right lateral and left lateral decubitus position.*

The crackles are recognized as bunch of light blue vertical lines. In both cases, crackles are more prominent in the dependent side than in the upside.

In case 1, crackles in upside lung disappear. In case 2, attenuation of crackles in left lung is slight in the right lateral decubitus position.

*Table: The lung sound intensity (dBm) in each frequency range*

| Body position | Sound frequency | Right lung Mean (SD) | Left lung Mean (SD) |
|---|---|---|---|
| Right Lateral Decubitus | Low | 5.0 (10.7) | 8.1 (10.2) |
| | Middle | -13.5 (12.8) | -11.2 (11.6) |
| | High | -24.8 (12.2) | -26.5 (14.0) |
| Left Lateral Decubitus | Low | -4.9 (11.9) | 13.5 (8.6) |
| | Middle | -25.3 (10.5) | -3.7 (9.3) |
| | High | -39.7 (10.0) | -16.0 (11.7) |

# Comparing lung sounds intensity between sitting, supine and prone position in patients with interstitial pneumonia

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**Background:** Auscultation of patients with stable interstitial pneumonia (IP) are usually done in the sitting position, whereas in critically ill conditions, patients often lie in the supine position. Last year we reported that lung sounds of IP were influenced by body position in eight patients with IP. Most of the sound power was comprised of crackles. These findings suggest that the loudness of crackles in IP was influenced by body position. This year, we tried to assure these observations by increasing the number of the subjects.

**Methods:** We analyzed lung sounds of seventeen patients with IP by a sound spectrometer, LSA2012 (Kenz-Medico). Two acoustic sensors were placed on the left and the right lung bases. The lung sounds were recorded in sitting, supine and prone positions. We recorded the lung sounds for ten seconds and averaged sound intensity of whole recorded sounds. We measured the lung sound intensity (LSI) of three frequency ranges, low (L: 200-390Hz), middle (M: 400-790Hz), and high (H: 800-1600Hz), and compared the averaged LSI of each frequency ranges in each body positions.

**Results :** The LSI was greater on the left than the right in all body positions. The difference of LSI between the left and the right lung was the greatest in prone and the smallest in supine position, although there were some individual variations as shown in the figure. There were significant postural changes of LSI on the right but not on the left. Statistically significant difference was observed between prone and supine, and prone and sitting position on the right. However, no significant postural change of LSI was observed on the left. (Table)

**Conclusions**: LSI of IP was greater on the left than on the right, suggesting that the loudness of crackles were louder on the left than on the right in all body positions. The postural changes of LSI were significant on the right but not on the left. These observations should be considered in auscultation and the lung sound study of IP.

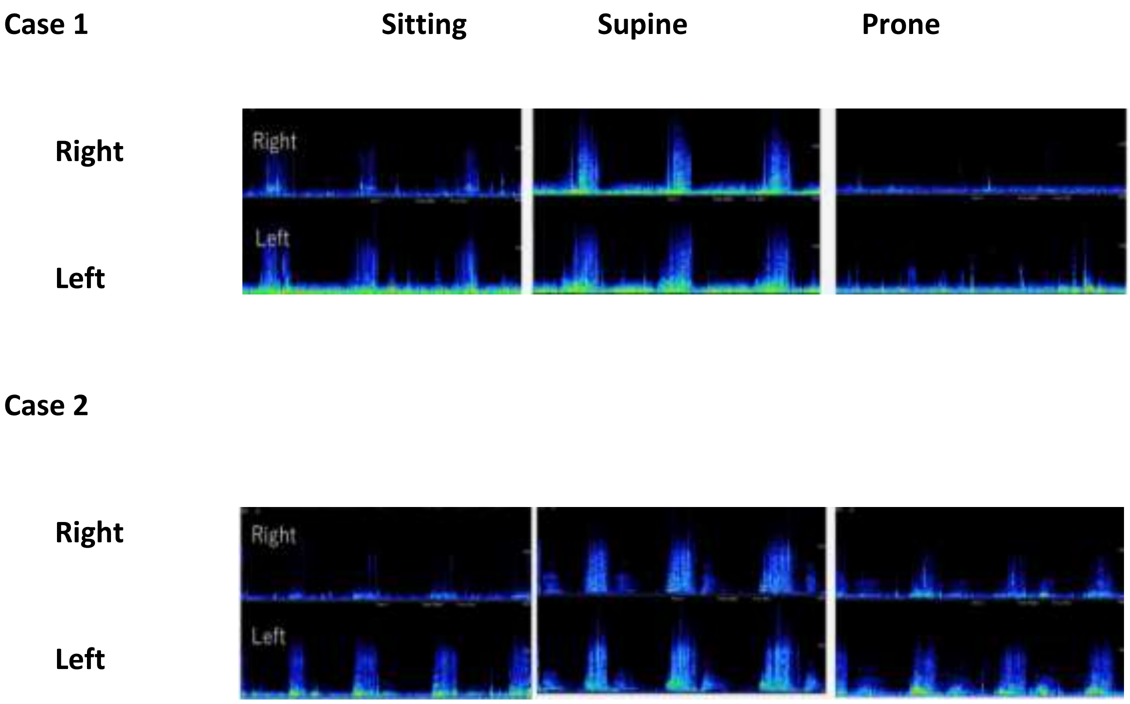


*Figure. Sound-specrogram of two cases of IP.*

In both cases, crackles are more prominent in supine position. The lung sounds are more loud on the left than on the right. The effects of body position on LSI are greater in case 1 than in case 2. The differences of LSI between the right and the left are greater in case 2 than in case 1.

| Body position | Sound frequency | Right lung Mean (SD) | Left lung Mean (SD) |
|---|---|---|---|
| Sitting | Low | 1.0 (8.5) | 8.3 (9.1) |
| | Middle | -16.9 (9.0) | -9.7 (14.0) |
| | High | -26.2 (9.4) | -19.5 (16.3) |
| Supine | Low | 1.3 (9.4) | 6.5 (12.8) |
| | Middle | -11.2 (9.4) | -7.2 (12.1) |
| | High | -24.4 (10.4) | -18.3 (13.7) |
| Prone | Low | -4.6 (10.3) | 9.1 (9.1) |
| | Middle | -24.2 (13.3) | -10.6 (12.0) |
| | High | -37.6 (13.3) | -23.8 (13.9) |

*Table. The lung sound intensity (dBm) in each frequency range*

## Lung sound changes associated with pneumothorax

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Pneumothorax (PTX) is an abnormal accumulation of air in the plural space that can be life threatening.

**Purpose**: The purpose of the study is to investigate the changes in lung sounds associated with the occurrence of pneumothorax.

**Methods:** Patients undergoing video assisted thoracic surgery (VATS) participated in the study after informed consent. Subjects were sedated and mechanically ventilated then one lung was collapsed as a normal part of the surgical procedures. Sounds were recorded at chest surface with an electronic stethoscope placed at the mid axillary line at the level of the $5^{th}$ intercostal space while subjects were in the decubitus position. Measurements were repeated for the control and pneumothorax states in each patient.

**Results and conclusions:** A drop in the acoustic energy with PTX was observed over the affected hemithorax. This drop may be because the collapsed lung and airways interfered with sound transmission in the affected side and/or due to diverting airflow and acoustic energy to the unaffected side. These results suggest that a simple acoustic method may be used to distinguish PTX from the control state.

## Crackles and Rhonchi with Postural Dependence in a 9-year-old Girl with Severe Mycoplasmal Pneumonia

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**Background:** *Mycoplasma pneumoniae* (Mp) is the most common cause of pneumonia in school age children. In general, there are few physical signs such as crackles and wheezes, despite general symptoms and problems with the respiratory system. Usually, mycoplasmal pneumonia is successfully treated with macrolides or tetracyclines. However, there are a few unusual cases which do not respond to these antibiotics and require the systemic use of corticosteroids.

**Case:** A 9-year-old girl was admitted to our hospital for high fever and cough lasting seven days. She had been taking clarithromycin (CAM) since the 3rd day of the illness, but symptoms did not improve. On physical examination, some crackles were noticed, and a chest X-ray revealed bilateral diffuse patchy infiltrates. Her SpO2 was 95% breathing room air and oxygen was administered through a nasal cannula. Mycoplasmal pneumonia was suspected, and intravenous sulbactam/ampicillin and oral minocycline were administered. However, her symptom worsened, and crackles and rhonchi increased dramatically. The recordings of the lung sounds confirmed coarse crackles and expiratory rhonchi which increased markedly on the dependent side of lateral decubitus position. On the 4th day of admission, prednisolone 1mg/kg/day was introduced, and the symptoms dramatically improved thereafter. The diagnosis of a mycoplasmal pneumonia was confirmed with the increased serum antibody titer (20480x) for Mp.

**Conclusion:** Postural dependence of crackles was said to be a characteristic of the fine crackles. However, as shown in this case, coarse crackles could have the similar characteristic in some occasion.

## Rumbling rhonchi in bronchial asthma: Their relation to airway inflammation

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**Introduction:** The rumbling rhonchi are low-pitched continuous rales and imply retained secretion in bronchi, implying presence of airway inflammation. ($35^{th}$ ILSA2010, $41^{st}$ ILSA 2016, Allergol Int. 2012; 61:353 ) We examined parameters of airway inflammation in rather stable asthmatic patients, with or without rumbling rhonchi.

**Methods:** We examined pulmonary function, FENO (Fraction of exhaled nitric oxide) and peripheral blood eosinophils as parameters of airway inflammation in 148 non-smoking stable asthmatic patients (Age: 63 ± 16, M/F: 59/79) when they had no acute symptoms. Non-smoking subjects included 43 ex-smokers and 105 never smokers. Ex-smokers were involved in this study when they did not smoke for more than three years.

The loudness of the rumbling rhonchi was classified into three grades, Grade 0 (no rumbling rhonchi), Grade 1 (present, but faintly audible) and Grade 2 (present and loudly audible). There were 47 patients (10 ex-smokers and 37 never smokers) in Grade 0, 61 patients (16 ex-smokers and 45 never smokers) in Grade 1 and 40 patients (17 ex-smokers and 23 never smokers) in Grade 2.

**Results:** FENO was significantly higher in Grade 2 than in Grade 0 ($p<0.01$) and Grade 1 ($p<0.03$). There was no significant difference of FENO between Grade 0 and Grade 1 ($p=0.23$). There was no significant difference of pulmonary function among Grade 0, Grade 1 and Grade 2. There was no significant difference of pulmonary function among Grade 0, Grade 1 and Grade 2, although peripheral blood eosinophil appeared to be higher in Grade 2.

**Conclusions:** We conclude that rumbling rhonchi suggest airway inflammation as shown in increase of FENO. However, presence of rumbling rhonchi did not suggest decreased pulmonary function nor eosinophilia in the peripheral blood.

*Table: FENO, %FEV1/FVC and peripheral blood eosinophil (number and percentage) with the grade of rumbling rhonchi*

| Rumble Grade | FENO (mean +/-SD) | %FEV1/FVC (mean +/-SD) | Eosinophils /cmm (mean +/-SD) | Eosinophils (%) (mean +/-SD) |
|---|---|---|---|---|
| 0 (no) N=47 | 23.4 +/- 32.7 | 73.5 +/- 29.1 | 227 +/- 479 | 3.6 +/- 6.4 |
| 1 (faint) N=71 | 30.1 +/- 31.8) | 79.8 +/- 11.1 | 199 +/- 157.2 | 3.7 +/- 2.8 |
| 2 (loud) N=40 | 55.4 +/- 67.9 | 73.7 +/- 11.4 | 509 +/- 961 | 5.9 +/- 8.6 |

## Rumbling rhonchi and bronchial inflammation in patients with bronchial asthma

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**Introduction:** The rumbling rhonchi have non-sinusoidal wave in their time-expanded wave form and imply retained secretion in bronchi, thus supposed to reflect an aspect of airway inflammation. ($35^{th}$ ILSA2010, Allergol Int. 2012; 61:353 ) As there have been no previous studies on the clinical implication of presence of rumbling rhonchi in patients with bronchial asthma, we examined pulmonary function and FENO (fraction of expired nitric oxide) as parameters of airway inflammation in rather stable asthmatic patients, with or without rumbling rhonchi.

**Methods:**We studied eighty cases of non-smoking adult asthmatics (Age: 62.9 ± 15.62, M/F: 36/31) when they had no acute symptoms. All of the ex-smokers involved in this study quitted smoking for more than three years. After careful auscultation of the lung, the patients were examined pulmonary function and FENO (fraction of expired nitric oxide). The loudness of the rumbling rhonchi was classified into three grades, Grade 0 (no rumbling rhonchi), Grade 1 (present, but faintly audible) and Grade 2 (present and loudly audible). These grades were determined by the loudness of the rumbling rhonchi irrespective of their extent.

**Results:**There were 18 patients (three ex-smokers and 15 never smokers) in Grade 0, 37 patients (11 ex-smokers and 26 never smokers) in Grade 1 and 25 patients (11 ex-smokers and 14 never smokers) in Grade 2. Inspiratory or expiratory short wheezes were heard in seven patients in Grade 0, three patients in Grade 1 and two patients in Grade 2. These wheezes were heard in small area, less than one quarter of anterior or posterior chest.

FENO was significantly higher in Grade 2 than in Grade 0 ($p<0.05$) and Grade 1 ($p<0.05$). There was no significant difference of FENO between Grade 0 and Grade 1 ($p=0.23$). There was no significant difference of pulmonary function among Grade 0, Grade 1 and Grade 2. (Table)

**Conclusions:** Rumbling rhonchi reflected airway inflammation as shown in increase of FENO. However, the grade of rumbling rhonchi did not correlate with the pulmonary functions or presence of short wheezes.

Rumbling rhonchi were heard more often in patients who had history of smoking in the past. Thus, the presence of rumbling rhonchi was assumed to reflect eosinophilic airway inflammation and also chronic airway inflammation caused by smoking of more than years ago.

*Table*

| Rumbling rhonchi | FENO (ppb) | FEV1/FVC (%) | FEF75*/predFEF75 (%) |
|---|---|---|---|
| Grade 0 (n=18) | 23.6 ± 12.78 | 69.8 ± 12.50 | 53.9 ± 28.52 |
| Grade 1 (n=37) | 32.2 ± 19.20 | 78.1 ± 12.27 | 81.6 ± 47.43 |
| Grade 2 (n=25) | 63.3 ± 93.09 | 72.4 ± 24.29 | 62.0 ± 36.64 |

*FEF75: expiratory flow rate at 75% of FVC (forced vital capacity).

# Lung sounds of a patient with bronchiolitis obliterans: comparison with pulmonary emphysema

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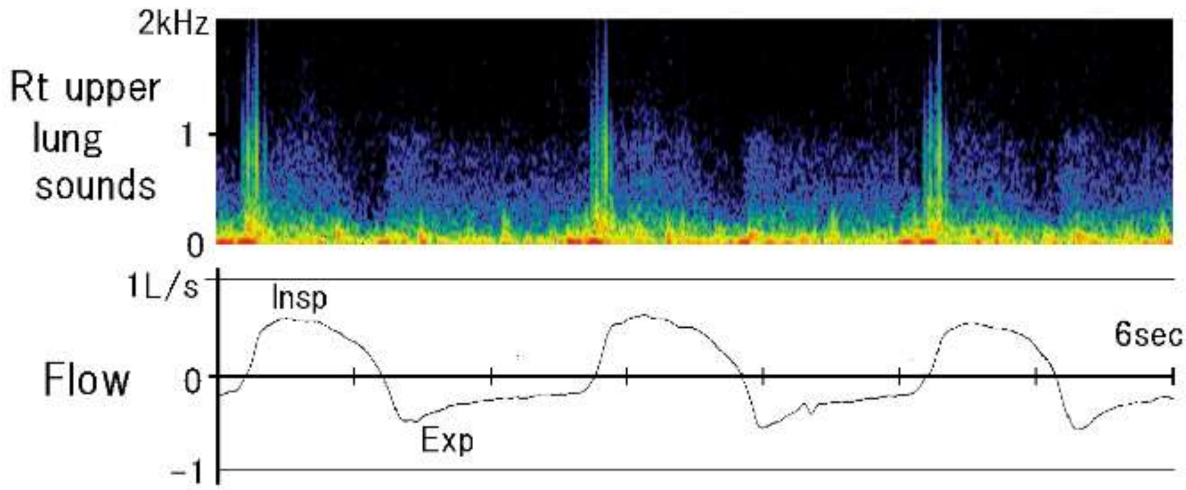
***Background:*** We have reported enhanced high frequency component in lung sounds of pulmonary emphysema (PE) (Ishimatsu: Intern Med 2015; 54:1183-1191). Both PE and bronchiolitis obliterans (BO) exhibit severe airflow obstruction, while underlying morphological changes are quite different between them. Thus, comparison of lung sounds between PE and BO may be important to understand the mechanisms for lung sound characteristics of obstructive lung diseases.

***Methods:*** Subjects were a BO patient (Case report by Nishihara: Chest 2017; 151(3): e57-e62), 20 COPD patients, and 20 normal subjects. Tracheal sounds and lung sounds at six sites (R&L-upper, R&L-middle, R&L-lower) were analyzed using FFT. Sonogram and power spectra were compared.

***Results***

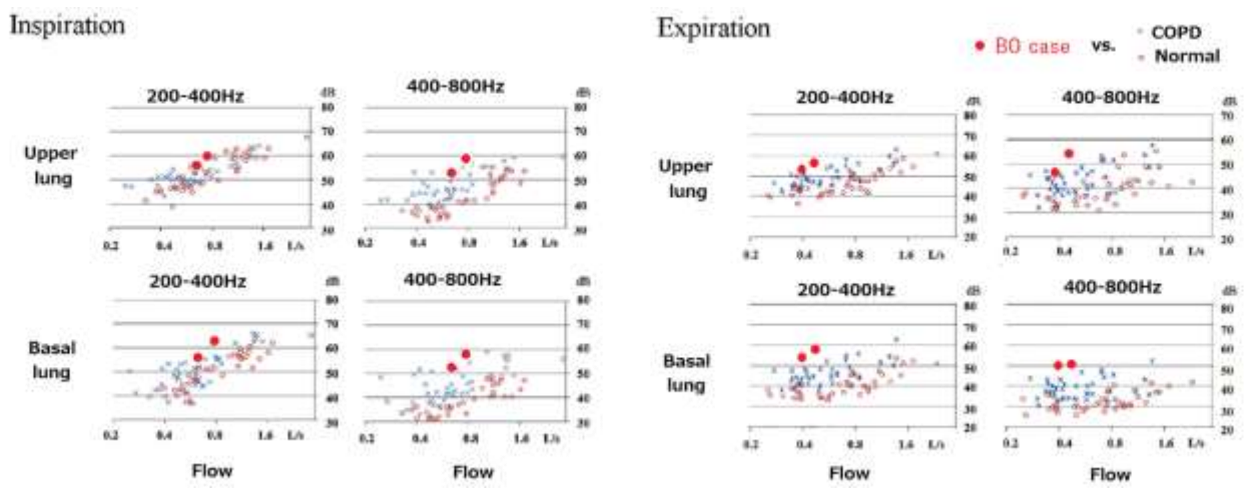
1.Adventitious sounds:

In the BO case, coarse crackles were found at the very beginning of inspiration (Fig) over all the lung fields. In the PE cases, crackles were identified in 13 out of 20 cases, only at lung bases, and not confined to the beginning of inspiration.



2. Basic breath sounds: Both BO and PE cases had greater breath sound intensity at a given airflow in both inspiratory and expiratory phases as compared with normal subjects (Fig).

Coherence analyses indicated that the origin of basic breath sounds in the BO case was located at a peripheral region not only for inspiratory but also expiratory phase, which was different from PE cases.




***Conclusion:*** Patients with airway obstruction often exhibit breath sounds with enhanced high frequency components. The mechanism underlying this phenomenon may be different between airway diseases and parenchymal diseases.

# Sub-classification of wheezes and crackles is not helpful when lung auscultation is used for detecting decreased lung function in adults

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**Background:** Pulmonary auscultation is frequently a part of physical examination during health screening, with crackles and wheezes regarded as valuable, but not very specific, signs of lung disease. In the Tromsø study (2015-16) we had the opportunity to record lung sounds in a random sub-sample of 21,083 adults aged 40 years or older. The aim of the present analysis is to describe the associations between adventitious lung sounds and reduced lung function as measured by spirometry and pulse oximetry, and to assess whether subcategories of crackles and wheezes differ in their value to detect reduced lung function.

**Methods:** 15 seconds of lung sounds were recorded at 6 positions on the chest in 4,033 participants. The participants were asked to breathe deeply with an open mouth. The recordings were classified for the presence of crackles or wheezes (including rhonchi) by two independent observers. Cases of disagreement were discussed with a third observer, and agreement was obtained by consensus. All recordings with crackles or wheezes thus classified underwent a second evaluation by two pairs of observers. Again, crackles and wheezes were classified as present or absent, with an additional class of "uncertain". It was also possible to classify the recordings as normal. Crackles (present or uncertain) were further sub-classified as single or multiple and as coarse or fine. Wheezes were sub-classified as short, ordinary or long, and into wheezes or rhonchi, where musical low-pitched wheezes were to be classified as wheezes. When both observers in a pair classified a recording as normal or felt that the presence of crackles or wheezes was uncertain, the final classification was "normal". When both observers in a pair classified crackles or wheezes to be present, or one felt the sound was present and the other was uncertain, the sound was classified as present. When one observer found a recording normal and the other felt that crackles or wheezes were present, the recording was discussed between all four observers. If at least three out of the four observers found crackles or wheezes to be present, this was accepted as the final classification. Spirometry was carried out according to ATS/ERS guidelines using Vmax Encore spirometer. Global Lung Function Initiative reference values were used. Oxygen saturation was measured with Onyx II pulse oximeter, and the highest $SpO_2$ after three measurements was used. $FEV_1/FVC$ less than the lower limit of normal (LLN), $FEV_1\% \leq 70$ predicted, and $SpO_2 \leq 95\%$ were used as outcome variables. We also had information on smoking habit, and the participants answered the Modified Medical Research Council (mMRC) questionnaire on shortness of breath (score 0-4).

**Results:** Among the 4,033 participants with lung sounds recorded, the median age was 65 years (range 40-84), and 53.5% were women. Spirometry was available from 3,799, and pulse oximetry from 3,872 participants. Crackles were found in 532 participants (13.2%),

with purely inspiratory crackles in 495. Wheezes were found in 729 (18.1%). FEV1/FVC less than LLN was found in 10.2%, FEV1% ≤70 in 5.2% and SpO2 ≤ 95% in 4.7%. Crackles were significantly associated with all three outcome variables, and most strongly with decreased oxygen saturation (OR=2.7). Wheezes were only associated with the spirometric outcomes, and most strongly with FEV1% ≤70 (OR=1.7). Current and previous smoking and shortness of breath (mMRC ≥2) were stronger predictors of all outcome variables, with ORs between 2.3 to 7.3 (current smoking for FEV1% ≤70). Sub-classification of inspiratory crackles showed a somewhat higher OR of multiple vs. single crackles regarding decreased oxygen saturation (figure 1) but the difference was not statistically significant. Even less difference was found between fine and coarse crackles. For wheezes (inspiratory or expiratory) there was a somewhat higher OR of ordinary and long vs. short wheezes regarding FEV1 % ≤70 (figure 2), but the difference was not statistically significant. Even less difference was found between wheezes and rhonchi. There was very low agreement between the observers for all sub-classifications (figure 1 and 2).

**Conclusion:** Crackles and wheezes are significant predictors of reduced lung function in the general population, but weaker predictors than smoking habit and shortness of breath. Subcategories of crackles and wheezes were not significantly stronger predictors of reduced lung function. Since the agreement between observers on subcategories is very low, it is recommendable to not pay attention to sub-classifying when using lung auscultation as a tool in population screening of adults.

**Fig 1. Odds ratio of inspiratory crackles, including sub-categories, for SpO2≤95%**

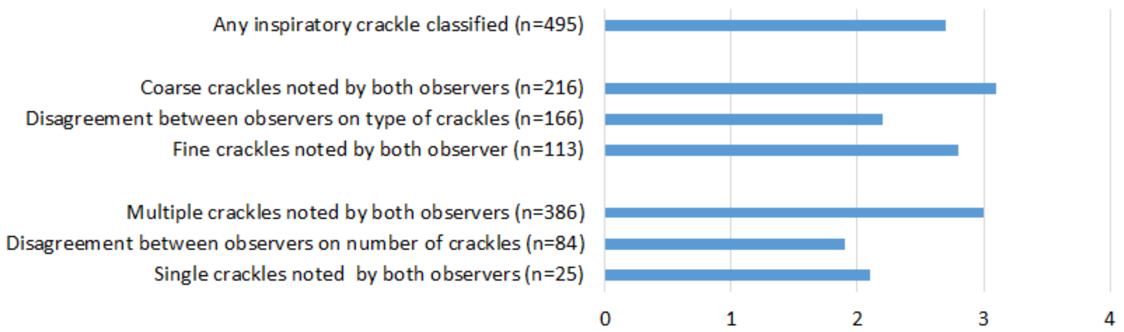
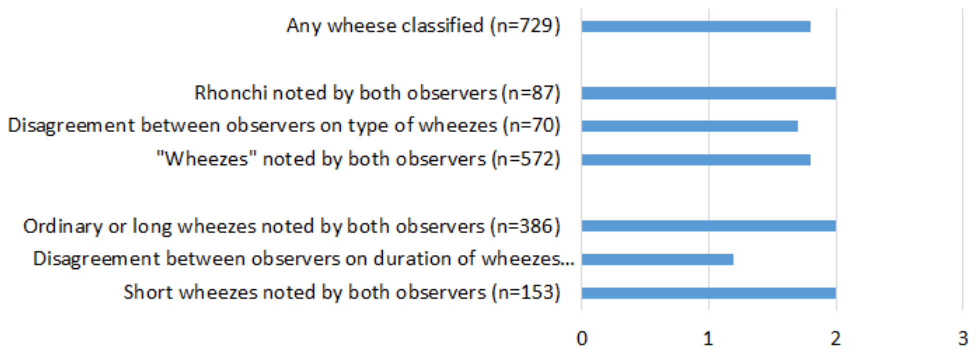



**Fig 2. Odds ratio for wheezes, including sub-categories, for FEV1% predicted ≤70**



## Can normal respiratory sounds differentiate COPD grades?

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**Background:** Normal respiratory sounds (NRS) are a reliable and useful marker for the diagnosis and monitoring of chronic obstructive pulmonary disease (COPD) and are valuable for early detecting pathological events through the course of the disease. However, little is yet known about its characteristics in different severity grades of the disease.

**Aims:** This study explored the characteristics of NRS across COPD grades. Methods: 66 patients with COPD were recruited from routine pulmonology appointments. Lung function data was used to categorize patients according to GOLD severity classification into two groups, either mild-to-moderate (n=30; 64.9±13.7yrs; 60%♂; FEV1 72±18% pred) or severe-to-very-severe (n=36; 67.5±7.5yrs; 75%♂; FEV1 33±11% pred) grades. NRS were recorded with a microphone for 20 seconds on the posterior left chest, at spontaneous airflow. NRS frequency and intensity were analyzed with validated algorithms within the 100-300 Hz band. Mann–Whitney U tests were used.

**Results:** The groups were homogeneous in terms of age and gender. No significant differences were found between the two groups in NRS during both inspiration and expiration in the median frequency and mean intensity (Table 1).

**Conclusion:** NRS seem to be similar between different COPD severity grades in stable patients. Further studies with larger samples are needed to enhance our understanding on the respiratory acoustics during the course of COPD.

**Table 1. Frequency (Hz) and mean intensity (dB), posterior left chest, 100-300 Hz, by disease severity (n=66)**

| | Inspiration | | | Expiration | | |
|---|---|---|---|---|---|---|
| | GOLD 1 and 2 (n=30) | GOLD 3 and 4 (n=36) | p-value | GOLD 1 and 2 (n=30) | GOLD 3 and 4 (n=36) | p-value |
| **F25** | 36.2 [26.2 - 40.0] | 34.0 [25.6 – 37.7] | p=0.776 | 25.4 [21.3 - 33.4] | 26.9 [21.7 – 36.0] | p=0.333 |
| **F50** | 80.4 [60.9 - 85.5] | 76.3 [57.9 – 85.2] | p=0.285 | 58.5 [48.4 – 77.6] | 61.0 [52.0 – 80.0] | p=0.285 |
| **F75** | 130.3 [109.1 – 139.0] | 125.3 [104.3 – 137.8] | p=0.842 | 105.6 [88.1 – 129.2] | 109.4 [93.5 – 131.5] | p=0.341 |
| **Mean intensity** | 16.1 [9.9 – 25.9] | 17.7 [11.2 – 32.7] | p=0.455 | 9.3 [7.2 – 19.2] | 13.2 [8.7 – 23.8] | p=0.094 |

# Is Auscultation Still Useful or is it Just Nostalgia?

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Not surprisingly, I have an opinion on this matter. In fact, I believe that auscultation of the chest is not only as important as it ever was, but is more important now than in the past. The reason for this is simply that we can now do so much more for diseases that are discovered during the history and physical examination. This makes rapid diagnosis more critical than it has ever been. For example, if in the 1850s, a middle-age man suddenly complained of indigestion, whether it was truly indigestion or a myocardial infarction hardly mattered as there was little that could realistically be done for him at the time. He would either recover or not. Now, he would be rushed to an emergency room where something as simple as listening to his chest and discovering extrasystoles or a new mitral regurgitation murmur would point the physicians in the right direction and (following an ECG) he would be in the Cath Lab within 90 minutes. Distinguishing heartburn from a heart attack is of critical importance.

Similar arguments can be made for pneumonia. Before the antibiotic era, a physician could only apply a leach or two and hope for the best. About 1 in 3 patients died. Once penicillin was developed and shown to be remarkably effective, correct diagnosis became important. Complaints of cough, myalgias and chills can suggest several conditions but careful auscultation revealing localized bronchial breath sounds or even something as subtle as localized crackles can point to a lung infection. It is true that these findings are not unequivocal and do require confirmatory imaging. Also, normal auscultation (like a normal history) never completely rules out a lung infection. However, virtually nothing else is as quick, easy, practically without cost and immediately available as auscultation. A rapid diagnosis of pneumonia with prompt initiation of treatment has been shown to improve outcome. Speed and availability matter!

### A true story

Mr. Smith was a gentleman in his mid 50s who had a history of asthma in childhood and had begun coughing and noting shortness of breath within the past year. He went to his primary care physician who, based on the symptoms and the past history, diagnosed asthma. He began to treat him with a variety of bronchodilators and inhaled steroids and subsequently continued such treatment over the next few years. Mr. Smith's symptoms were somewhat variable but, in general, followed a downward course. Spirometry was performed and revealed a reduced vital capacity but no obstruction. In the progress notes written by his primary care physician, auscultation of the chest was always described as "clear." Finally, after seven years of trying to treat this man's asthma without success, the physician referred him to a pulmonologist for an evaluation. At the first encounter, the pulmonologist concluded that this gentleman had far advanced pulmonary fibrosis (IPF) and referred him immediately to a transplant center. As Mr. Smith was so severely ill, he was listed quickly for transplant without having time to address his morbid obesity and deconditioning which would've been ideal. He did receive a double lung transplant. However, he suffered from multiple postoperative complications and remained in the hospital for several weeks until his death.

Mr. Smith suffered from a progressive and incurable lung disease. Although there are currently medications available that treat IPF, they are only effective in slowing the progression of the disease. By the time that Mr. Smith was eventually diagnosed, it was far too late to consider anything other than a transplant and even that was unlikely to succeed. However, had he been correctly diagnosed at an earlier stage, there would have been time to initiate one of the medications, start pulmonary rehabilitation and weight-loss regimens that might have made him a much better candidate for a lung transplant and increased his chances for several more years of life. This would have made a difference to him and to his family. His primary care physician either did not hear or did not realize the significance of inspiratory crackles that Mr. Smith must have had at the very least later in his disease course.

**Another true story**

A 40 year-old woman was referred to me because of a chronic cough that had persisted for two years. I have seen dozens of patients like this and determining the cause can sometimes be difficult and lengthy. During my initial examination, chest auscultation revealed profuse but faint fine crackles at both posterior bases but was otherwise unremarkable. Usually, a workup for a chronic cough starts with tests to evaluate for gastroesophageal reflux disease, Upper airway cough syndrome (UACS) or asthma.[1] Chest films or CT scans are rarely indicated. However, as crackles are unusual in this scenario, I ordered a high-resolution chest CT scan. The scan revealed diffuse reticulations and traction bronchiectasis. The pattern was not typical of idiopathic pulmonary fibrosis so the next step was a surgical biopsy that revealed chronic hypersensitivity pneumonitis (HP). HP is a rare condition but when present, often causes chronic cough. Had I not detected and recognized fine crackles and understood the implications of their presence, months might have been lost looking for common causes of a cough that were not there.

**What about portable ultrasound?**

ultrasound technology has been evolving rapidly and is being used in more and more situations. Some have argued that ultrasound will soon supplant the stethoscope for all physical examination screening and this will mark the end of auscultation.[2,3] I will argue against this notion using nothing more than my brain! For purposes of this discussion, I will accept that portable ultrasound will soon rival the stethoscope in size, portability and price and that all medical students will be adequately trained in its use. What then could ultrasound detect that auscultation could not, assuming equally skilled use? Conversely, what could auscultation reveal that ultrasound could not? I've made a table that shows my personal estimates of the comparative effectiveness of auscultation vs. a hypothetical, immediately available ultrasound device in the hands of an adequately trained physician.

| Condition | Portable Ultrasound | Auscultation |
|---|---|---|
| Pericardial effusions | +++ | <+ |
| Pleural effusions | +++ | +¶ |
| Heart valve dysfunction | +++ | ++ |
| Arrhythmia | +++ | +++ |
| Heart failure (cardiomegaly) | +++ | + |
| Heart failure (pulmonary edema) | ++ | +++ |
| Cardiac thrombus or tumor | +++ | - |
| Esophageal intubation | - | ++ |
| Mainstem bronchus intubation | - | ++ |
| Tracheal stenosis or malacia | - | ++ |
| Asthma, COPD (wheeze) | - | +++ |
| Asthma, COPD (rhoncus) | - | +++ |
| COPD (diminished lung sounds) | - | ++ |
| COPD (Coarse crackles) | - | ++ |
| Pulm. fibrosis, CHF (fine crackles) | - | ++ |
| Pneumonia (bronch. BS, crackles) | ++* | ++** |

¶++ if percussion used also    *Increased lung density    **Crackles, bronchial breath sounds

I'm sure that almost any clinician could take issue with some or most of my ratings. But is there anyone who could place positives under ultrasound in all the categories? It seems obvious to me that both modalities have strengths and weaknesses and ultrasound will never do all that auscultation does. Cardiologists could probably manage well with just ultrasound and many of the commentators who predict the death of the stethoscope talk only about how effective ultrasound is as a diagnostic tool for examining the heart. But pulmonologists, ER physicians, critical care specialists and primary care physicians care about lungs too and ultrasound is of very limited use in the respiratory system. Ultrasound applied to the body surface does not penetrate air-filled organs and abnormalities in lung parenchyma and airways are completely invisible to ultrasound. But listen in the audible sound range and these same abnormalities make noises or fail to make expected normal sounds and two centuries of experience have taught us how to interpret these findings. It strikes me as almost magical! Medical students soon should be trained in both auscultation and ultrasound. I fully expect that dual-capable instruments incorporating an electronic stethoscope and portable ultrasound (perhaps using a smart phone as a display) and in various designer colors will be available in the near future. I hope I'm around long enough to hang one of those beauties around my neck.


1. http://emedicine.medscape.com/article/1048560-overview Accessed June 12, 2017
2. http://www.medpagetoday.com/cardiology/arrhythmias/55688 Accessed April 29, 2017
3. https://consumer.healthday.com/diseases-and-conditions-information-37/misc-diseases-and-conditions-news-203/is-the-stethoscope-living-on-borrowed-time-684172.html Accessed April 29, 2017

## Psychoacoustics of auscultation

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Laennec's stethoscope brought chest sounds to the attention of a much greater audience than direct auscultation had done before. His device underwent refinements over the course of the next two centuries, initially to improve its portability but later also to enhance the perception of sounds of interest, particularly in the low frequency range of heart sounds. Harvey Fletcher, who first presented the increased pressure levels required to perceive sound at low frequencies by equal loudness contours, stated that "*as machines we may describe (our ears) in the same terms that apply to devices we ourselves construct... But to understand the mechanism of the ear is by no means to understand the act of hearing, for we have not heard until the brain has perceived the message sent by the auditory nerve*" (in Speech and Hearing, 1929).
Psychoacoustics is a field of recognition science within psychology. Much as the study of respiratory sounds has drawn researchers from several disciplines, including physics, acoustics, electronic and computer engineering, physiology and medicine, psychoacoustics has involved these areas. However, studies of respiratory sounds that have brought researchers together, e.g. at meetings of the International Lung Sounds Association, have rarely touched on the psychoacoustics of auscultation. This review addresses relevant areas of hearing range and threshold, the characteristics of chest sounds, the masking effects of simultaneous and non-simultaneous sounds, the influence of selective hearing, and the multisensory contributions during auscultation.

**Hearing range and threshold:** Normal (basic) lung sounds are of low intensity during quiet breathing. Their greatest sound spectral power is in a frequency range where the perception of equal loudness requires relatively higher sound pressure levels. Respiratory effort and related changes in the sound generating air flows but also the individual anatomy as well as dynamic changes in regional ventilation and airway characteristics determine basic lung sound intensity. The perception of puerile breathing, i.e. the characteristic of basic respiratory sounds in young children and also in asthma first described by Laennec, can be explained by a relative reduction in sound spectral power at low frequencies. In asthma, this is often accompanied by an increase of sound spectral power at higher frequencies, even in the absence of wheeze. Psychologically, a decrease in lung sound intensity at low frequencies is often visualized as "reduced air entry" although this cannot explain the phenomenon in most cases of acute asthma.

**Characteristics of chest sounds:** Respiratory and cardiovascular sounds have the principle attributes of loudness (related to amplitude), pitch (related to frequency), duration (in relation to the respiratory phase or the cardiac cycle), and timbre (an attribute that allows to distinguish between sounds of the same perceptual loudness, pitch and duration). The latter attribute is well recognized in cardiac auscultation, e.g. in the characterization of murmurs by their harshness, a term that is not recognized in the current formal classification of respiratory sounds. Physicians as well as caregivers of children with obstructive airway diseases are aware of "rattles, ruttles and rhonchi", low pitched adventitious sounds that are often included under "wheezing" although their sound waveforms, their perception, and their relevance regarding underlying diseases and their prognoses, may be substantially different from wheezing.

**Masking effects:** Low intensity sounds can become inaudible in the presence of louder masking noises. An example is the increasing difficulty of recognizing brief rapidly dampened sound deflections, e.g. crackles, within random sound waves of increasing amplitude, i.e. basic lung sounds at increasing air flows. Masking effects on a sound (maskee) can also occur after an acoustic stimulus (masker). The duration of this effect depends on the duration and intensity of the masker and the relative frequency of masker and maskee. Clinically, this is of relevance during auscultation in noisy environments, including the inadvisable practice of listening through clothing.

**Selective hearing:** Much in our processing of acoustic signals has to do with anticipation. In speech perception, familiarity with the language is obviously of critical importance. In healthy and particularly in younger individuals, the threshold of hearing is lowest in the frequency range of speech sounds. The ability to focus on and successfully process a speech signal in a noisy environment is known as the "cocktail party effect". The intelligibility of interrupted speech depends on the interruption rate, where older and hearing-impaired subjects have most difficulties at more frequent interruptions. No studies of interobserver agreement on respiratory sounds exist from Laennec's time, but it is quite possible that he and his students understood more of the "language of the lungs" than contemporary users of the stethoscope.

**Multisensory contributions:** In contrast to hearing recorded audio signals of respiratory sounds, auscultation in a clinical setting provides the listener with simultaneous information from visual signals, e.g. of respiratory effort and related signs of changing respiratory resistance, of chest deformities, and of sources of potential masking noises. Basic respiratory sounds during expiration in a healthy subject at rest will be audible during only the first part of the respiratory phase while the true length of expiration until the following breath is apparent on visual inspection. Prolonged expiration in asthma is therefore, at least in part, a psychoacoustic phenomenon, based on the longer audibility of respiratory sound, particularly in the presence of wheezing.
Audio engineers are expected to have a thorough understanding of psychoacoustics. Further advances in the study and teaching of respiratory sounds will also benefit from deeper insights in this area.

## Teaching and learning pulmonary auscultation – the Computerized Lung Auscultation – Sound Software (CLASS)

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**Background:** Respiratory sounds (RS) are directly related to movement of air, changes within the lung tissue and position of secretions within the tracheobronchial tree, which make them valuable indicators of respiratory health. Respiratory sounds acquired through auscultation are nearly universally available, inexpensive, non-invasive and comfortable (no need to tolerate a facemask or seal around a mouthpiece), cost-effective, can be repeated as often as necessary and require minimal patient co-operation. Nevertheless, the mastering of auscultation requires complex acoustic skills to distinguish between different types of RS with similar frequencies, intensities and timings. Currently, health students are taught these skills by repeatedly listening to recordings of typical RS and visualizing their waveforms. However, these methods offer limited interaction and provide students with a narrow representativeness and usefulness of RS. Due to the subjectivity associated with the auscultation and inadequate training, the mastering of pulmonary auscultation has been decreasing and therefore, innovative teaching/learning methods to contribute for the detection/discrimination and interpretation of RS are warranted. The new era of Computer-assisted learning tools offer an exciting opportunity for self-directed learning and problem-solving, providing students with complementary activities on a computer, related with the material being taught. Such tools show great potential to be used in the teaching of pulmonary auscultation, as they would allow students to interact with a diversity of RS recorded in clinical environments, from patients with different conditions and ages, and test the knowledge acquired. However, few Computer-assisted learning tools have been developed for this purpose and they do not integrate simultaneously all the required features to enhance health students' skills on pulmonary auscultation, i.e., record, storage, playback and analysis of RS, knowledge testing and tutorials about RS.

**Aim:** Thus, Computerized Lung Auscultation – Sound Software (CLASS), developed for enhancing the teaching/learning of pulmonary auscultation to health professionals, will be presented.

**Method:** CLASS is open-source and was designed using a User-Centred Design process. This process facilitates users' workflow throughout the application as it supports their current

habits and behaviours, instead of requiring them to adapt to the application. It was developed to record, store and annotate RS in a single application and includes interactive tutorials and exercises to test the acquired knowledge. CLASS was assessed during its design process by identifying the problems that different users (medical doctors, physiotherapists, respiratory researchers and students) had when interacting with the application and the required improvements were performed throughout. Moreover, CLASS usability has been assessed by 8 physiotherapy students using computer screens recordings, think aloud reports and facial expressions according to the international standards for software validation. Time spent in each task, frequency of messages and facial expressions, number of clicks and problems reported have been counted and improvements integrated.

**Results:** CLASS is organized in five tabbed document interfaces: main, patients, recordings, annotations and tutorials. The “main” tab is where the information about the user and general statistics about the use of CLASS can be inserted, edited and analysed. In the “patients” tab, information about patients’ characteristics, session and recordings can be inserted, edited and analysed. The “recordings” tab allows to record (with a digital stethoscope or microphone), store and analyse RS of a selected patient and session. The “annotations” tab is where the different RS and breathing phases can be displayed, played back, annotated and analysed; and exercises, with distinct levels of complexity, can be solved based on gold standard files previously annotated by a panel of experts. Finally, the “tutorials” tab displays the definitions, acoustic properties and clinical interpretation of all types of RS.

**Conclusion:** CLASS is an innovative CALT and is available with all the required features for learning and consolidating pulmonary auscultation skills. It allows recording, storage, playback and analyses of RS files, practice of RS exercises, and further knowledge consolidation using the available tutorials. CLASS is simple to use and can be easily incorporated in academic activities. Moreover, since it was developed on open source components, it can be installed in individuals’ personal computers, so it can be taken to clinical or any other environments, enabling the learning process to be extended and consolidated outside academia.

## Improved classification of lung sounds by medical students when spectrograms are displayed

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**Background:** Visual representation of sound with spectrograms is an attractive option to reduce variation when classifying respiratory sounds. The technology is commercially available.

**Aims:** To explore the impact of spectrograms on inter-observer agreement when classifying wheezes and crackles.

**Methods**: We used 30 recordings of respiratory sounds classified by four experienced lung sound researchers on a majority rule basis. The sample contained 15 normal recordings and 15 with wheezes or crackles. We produced spectrograms of the recordings using Adobe Audition 5.0 (Adobe Systems. San Jose, CA, USA). In a classroom, the students were shown examples of wheezes and crackles in spectrograms. Then we played the 30 recordings in a random order twice, first without the spectrogram, then with live spectrograms displayed. Twenty-three fourth year medical students at the faculty of medicine at UiT the Arctic University of Norway classified the sounds using an on-line questionnaire (Questback AS, Oslo, Norway). We asked them to classify the sounds as normal/abnormal. If abnormal, they had to further specify whether the recording contained wheezes, crackles or other sounds. We calculated kappa values for the agreement between each student and the expert classification with and without display of spectrograms, we also calculated Fleiss kappa for the 23 observers with and without the spectrograms. We used Hotelling's $T^2$ to explore statistically significant differences. We used the statistical software "R", version 3.2.1 and the package "multiagree".

**Results**: When classifying wheezes, 15/23 students (1 with $p<.05$) had a positive change in k, and 16/23 (5 with $p<.05$) when classifying crackles. All the statistically significant changes were in the direction of improved kappa values (.343 - .763). Fleiss kappa values were k=.555 and k=.511 (p=.63) for wheezes with and without spectrogram, respectively. For crackles, these values were k=.403 and k=.223 (p=<0.01) in the same order. When leaving out the five significant improvers, the Fleiss kappa values were k=.381 and k=.229 (p=0.01) in the same order.

**Conclusions**: We found a statistically significant improvement in the agreement when classifying crackles using spectrograms. We observed no significant differences for wheezes.

## Making an illustrated lung auscultation guide book for nurses: are these illustrations appropriate?

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**Purpose:** Recently, many textbooks and guidebooks on the auscultation of the lung are published in Japan. Most of these books do not use illustration to explain why lung sounds are generated. There are still some uncertainty why these lung sounds are generated, but simple schematic illustration will help our understanding of lung sounds. It will be needed to promote our common concepts for mechanism of lung sound generation.

**Methods:** We published a brief guidebook of auscultation of the lung which includes schematic illustration of lung sound generation. The illustrations in our guidebook (Figures) are shown in this presentation and will be discussed. As the real mechanisms of lung sound generation are still uncertain, the appropriateness of these illustrations should be discussed by the members of ILSA. Critical review and comments will be appreciated.

**Results:** Some examples of the figures are shown. Figure 1: Possible explanation of why inspiratory breath sounds are louder than expiratory breath sounds. Figure 2: Possible explanation of why frequency of wheezes in bronchial asthma fluctuates.

These figures show the possible mechanism of why these lung sounds are generated. It would be preferable if basic agreement on the illustrated mechanisms of lung sound generation will be discussed and shared by members of ILSA.

**Discussion:** There have been many published studies on the mechanisms of the lung sound generation. However, these results are difficult to understand for clinical personnel including physicians, nurses and physiotherapists. Simple schematic illustrations may help understanding the clinical implications of the lung sounds, and thus promote the daily use of the lung sound auscultation.

**Conclusions:** We propose schematic illustrations of lung sounds generation. The appropriateness of these schematic illustrations needs discussion to share our common understanding of lung sound generation.

**Figures**

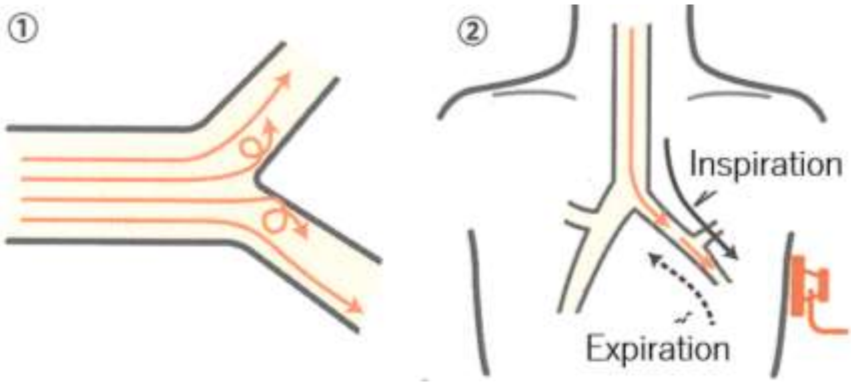


*Figure 1: Possible explanation of why inspiratory breath sounds are louder than expiratory breath sounds.*

1. Inspiratory air flow hit the bifurcated bronchial wall and makes more airflow turbulence than inspiratory airflow.
2. Inspiratory airflow directs stethoscope while expiratory airflow directs opposite.

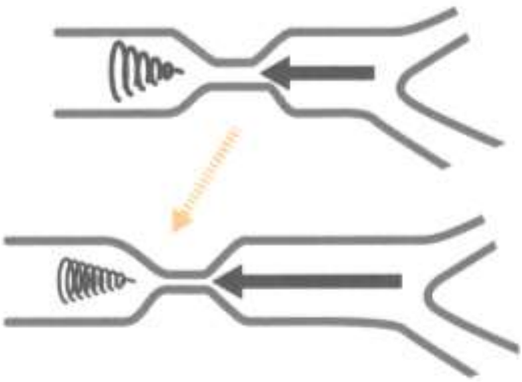

*Figure 2: Possible explanation of why frequency of wheezes in bronchial asthma fluctuates.*

During the expiration, the size of bronchial lumen fluctuates while the narrowest site of the bronchus (choke point) moves.  These changes of the bronchial lumen result in the fluctuation of the speed of vortex shedding and frequency of wheezing.

## Live Demonstration of an Advanced Pulmonary Auscultation Simulator

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Continuing a multi-year research plan for the United States Department of Defense, we are researching the development of an advanced auscultation simulator [1] that will provide for a dynamic examination with varying acoustic output based upon listening location [2], respiratory effort & phase. The simulator will be delivered online through web browsers and support a novel pedagogical approach [3]. We employ synthetic lung & breath sounds with a clean acoustic profile so that numerous sounds can be mixed without degradation. [4].

The prototype is composed of an authoring module and a client module. We demonstrate the following capabilities of the authoring module: Respiratory loop & I:E ratio settings, selection & temporal placement of synthetic lung sound elements, layering of synthetic lung sounds, anatomic placement & acoustic listening pattern determination, and association of clinical exam elements with clinical correlation.

The client module is shown and the following are demonstrated: Clinical examination over anatomy to demonstrate changes in vesicular sounds from back, to sternum to tracheal area, various auscultation exams depicting pathologies (pneumonia, congestive heart failure, asthma, interstitial pulmonary fibrosis), clinical recognition of lung sounds with corrective feedback, and metering of exam technique for listening locations with sufficient exertion & length. Additionally, the client demonstrates use as a review tool with the ability to isolate individual sound elements.

The demonstrated design follows a cognitive task analysis of expert examinations and employs the cognitive & clinical recognition steps with a virtual mentor to provide real-time feedback to pulmonary auscultation novices.

The next stage of research will be to design and eventually conduct human research studies to determine 1) physician impressions of synthetic lung sounds for recognition and fidelity [5], 2) the assessment accuracy of the simulator versus expert assessment, and 3) the training effect of the simulator for lung sound classification [6] and clinical correlation [7].

It is hoped that these new methods for detailed assessment and individually accessible lung sound elements complexed with the proper international classification will results in improved competency & greater clinical emphasis on auscultation skills.

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## Pulmonary Rehabilitation effects on computerized respiratory sounds of patients with AECOPD

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**Background:** Pulmonary rehabilitation (PR) is fundamental for the management of patients with stable chronic obstructive pulmonary disease (COPD). However, its role during acute exacerbations (AECOPD) is controversial, mainly due to the lack of sensitivity of the measures used to assess changes in the respiratory system. Computerized respiratory sounds can overcome this problem as they are closely related to movement of air within the tracheobronchial tree, hence having more sensitivity to detect small changes.

**Aim:** To assess the effects of a community-based PR program on computerized respiratory sounds of patients with AECOPD.

**Methods:** 10 patients (70±8years, FEV1 46±15%predicted) with AECOPD were recruited at the emergency department and treated with standard medication plus a 3-week (2*/week) community-based PR program (i.e., breathing control and airway clearance techniques, thoracic mobility and expansion exercises, exercise training and psychoeducational support). Computerized respiratory sounds were acquired at posterior chest within 48h of the emergency episode (Pre) and following PR (Post). Adventitious respiratory sounds, i.e., wheezes and crackles, were analysed with previous validated algorithms. Differences between Pre/Post PR were explored with Wilcoxon-sign rank tests.

**Results:** After PR, patients presented significantly less inspiratory (Pre: 1.4 [0-5.2] vs Post: 0 [0-2.6], p=0.016) and expiratory crackles (Pre: 1.2 [0-21.2] vs Post: 0 [0-2], p=0.004), and expiratory wheezes occupation rate (Pre: 20.6 [0-82.9] vs Post: 0 [0-26.1], p=0.004) (Fig. 1).

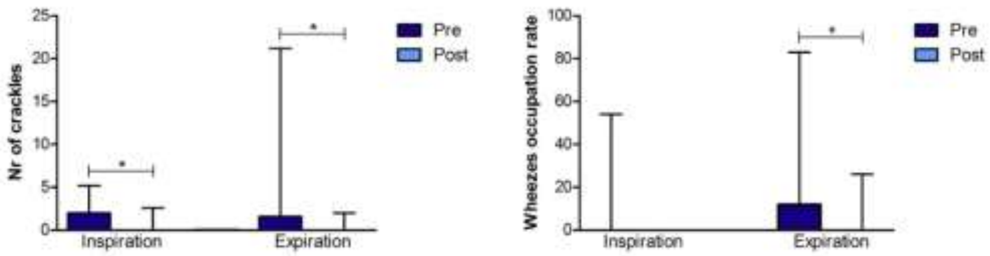


Fig. 1: a) Number of crackles Pre/Post PR, per respiratory phase; b) Wheezes occupation rate Pre/Post PR, per respiratory phase.

**Conclusion:** Crackles and wheezes are related with increased bronchial obstruction, thus their reduction seems to indicate that PR was effective in improving the respiratory system function. Ineffective management of AECOPD is associated with further lung function decline and higher risk of exacerbations. Therefore, PR might be an important strategy for the management of AECOPD. More studies are needed to verify these findings.

# New features of 10-19 kHz sound propagation through human lungs

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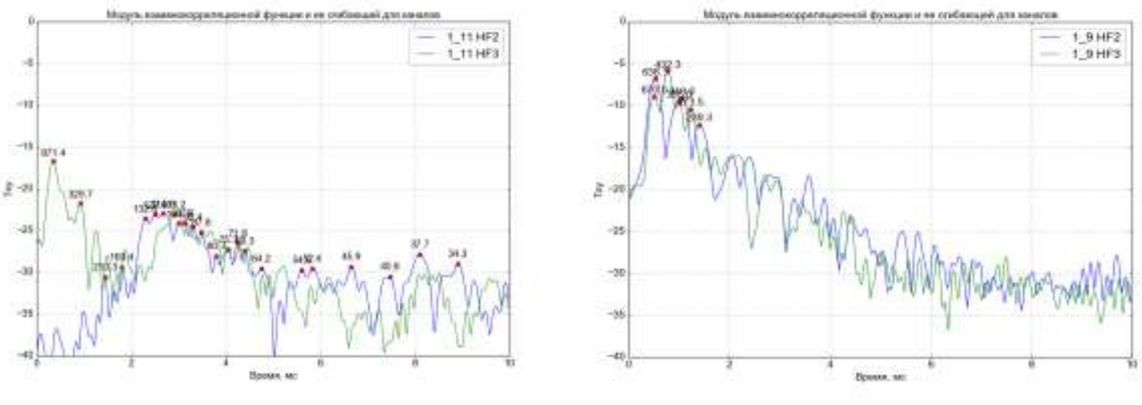
**Background**: The phenomenon of 10-40 kHz sound transmission through human lungs with speed of about 1000 m/s was revealed by Rueter et al., 2010. While Korenbaum et al., 2014, using signal compression technique for transmission sounding of lungs, found low- and high-speed sound propagation components in the frequency range of 10-19 kHz.

**Objective**: A more detailed study of the characteristics of the sound transmission of complex signals in human lungs in the frequency range of 10-19 kHz.

**Method**: The 14-channel apparatus (Korenbaum et al., 2014) was provided with new accelerometer sensors having a resonance frequency near 35 kHz, which made possible a linear performance in the frequency range of 10-19 kHz. Chirp signals 10-19 kHz (6 min) were emitted into human thorax (4 positions) by small shaker. A convolution of emitted and received signals technique was used. Sound propagation in human lungs was studied for opposite chest positions of shaker (ch. 1) and sensors (chs. 9-12) in 4 volunteers.

**Results**: The possibility of decomposition of received signals into high- and low- speed arrivals (Korenbaum et al., 2014) is verified in independent sample of subjects. The existence of low- speed arrivals with propagation velocities of 150-50 m/s, which amplitude and/or velocity is inversely dependent on an air-filling of lungs (inspiration/exhalation breath retardations) has been revealed (fig. 1a). These arrivals may be treated as the result of propagation of a sound wave through the lung parenchyma mainly. On the contrary, the amplitudes of high-speed arrivals with velocities of 150-1000 m/s are enhanced with a decrease in air-filling of the lungs during breath retardation during exhalation (fig. 1a). Thus the high-speed arrivals may be connected to the dominant sound wave propagation through high-density tissues of thorax.




a) b)

Fig. 1. Transmission diagrams $T_{xy}$, dB on Time delay, ms – a) norm, b) reduced air-filling; blue – inspiration, green – exhalation, red dots – identified arrivals with their velocities.

Four variants of the ratio of the amplitudes of high- and low-speed arrivals and their changes depending on an air-filling of lungs (inspiration/exhalation) have been found. One of the them (fig. 1b) is characterized by the predominance of amplitudes of high-speed arrivals, both during inspiration and exhalation, which may be acoustically interpreted as a local reduction in air- filling and ventilation of lung parenchyma. It is seen only in one elderly patient with a long-term course of hormone-dependent asthma, but not in 3 other young healthy individuals.

**Conclusions**: The results seem to be promising for the development of high-resolution transmission acoustic imaging of lungs.

**Acknowledgement:** The study is supported by the RFBR grant 16-08-00075-a and the scholarship of the President of Russian Federation for graduate students and young scientists.

# DIFFERENCES IN WAVEFORMS AND POWER SPECTRA OF CHEST WALL PERCUSSION SOUNDS OBTAINED BY VARIOUS SENSORS

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**Background:** Various sensors are employed for registration of lung sounds and chest wall percussion sounds. The most widespread ones are different electronic stethoscopes with microphones. Other heavy sensors, light accelerometers and built-in microphone of a smartphone are used as well. It's important to estimate effect of sensor choice on recorded waveforms and power spectra of sounds.

**Aims:** To compare waveforms and power spectra of percussion taping obtained by 1) different sensors fixed on the same place of the right back chest wall and 2) the same sensors fixed over and under diaphragm projection on the right back chest wall.

**Methods:** A group of 10 normal male volunteers participated in the study. Manual or apparatus taps were applied to the right back chest wall and percussion vibrations of the chest wall were registered 4.3 – 4.4 cm apart by virtue of: 1) Jabes stethoscope, 2) accelerometer, 3) one or two of 10 different smartphone models.

**Results**: All used sensors provided well reproducible tapping recordings. Waveforms and power spectra of tapping registered on the same place of the chest wall of the same test subject by different sensors varied considerably. Waveforms and spectra of a few pairs of sundry models of smartphones fixed over and under diaphragm projection varied much between smartphones and places of fixation. Power spectra and waveforms of accelerometer signal revealed maximums at frequencies about expected frequencies of resonance of the oscillator comprised by accelerometer mass and viscoelasticity of chest wall soft tissues.

**Conclusion:** Reproducibility of waveforms and spectra of registered percussion sounds is good. Differences of waveforms and spectra between sensors including various smartphones suggest standardization of sensor.

**Acknowledgments:** The study was supported in part by the Russian Foundation for Basic Research (RFBR) project no. 15-01-06246 and by Program IV.7.1 of the Russian Academy of Sciences (RAS) Presidium.

## Using cough epochs to describe nocturnal cough in COPD patients

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**Background and aim:** Chronic cough is very common in patients suffering from chronic obstructive pulmonary disease (COPD). Several ways of quantifying cough have been published in recent years. The ERS defines a cough epoch as at least two consecutive cough events with a maximum distance of two seconds. Although in practice cough mostly occurs in epochs most of the studies focus on cough frequency quantified by counting expulsive phases. The aim of this study was to describe frequency, severity and characteristics of nocturnal cough in COPD patients, by using cough epochs.

**Methods:** We investigated 10 patients of each COPD stage II-IV for two consecutive nights by using objective lung sound monitoring. 11 patients reported ongoing smoking, while 19 patients quit smoking. All automatically detected cough events were manually validated and assigned to cough epochs. A classification in productive or non-productive was also done manually. Epochs containing at least one productive cough, were classified as productive.

**Results:** We found cough epochs in 29 of 30 patients. 75.3 ± 23.3 % of all cough events occurred in cough epochs. Most of the cough epochs were found in patients with COPD III with a median number of 6.5 productive and 8.5 normal cough epochs. Active smokers had significantly more productive cough (60.9 %) than non-smokers (24.4 %) ($p = 0.0033$). Most of the cough events were non-productive and patients showed similar distribution of cough epochs in both nights.

**Conclusion:** In our dataset productive cough was primarily caused by persistent smoking. With the high amount of cough events occurring in cough epochs, these cough epochs might be a promising way of quantifying cough. Especially in diseases with increased mucus production, productive cough epochs should be considered in the assessment and description of cough distribution throughout the night. This will soon be done automatically.

## Investigation of pre- and postoperative lung sounds of patients who underwent general thoracic surgery

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**Background:** In the field of sound analysis, some low-priced software and simple voice recorders developed for music began to be available recently. Although it is difficult to calibrate these devices scientifically, they are fit to clinical use. We have auscultated, recorded, and analyzed the lung sounds of pre- and postoperative patients for 10 years.

**Aims:** In general thoracic surgery, it is important to find complications, for example postoperative bronchial stump fistula and retention of bronchial discharge, without delay. We have been trying to detect these disorders by analyzing the lung sounds.

**Materials:** The sounds of more than 100 patients undergone general thoracic surgery were analyzed.

**Methods:** Lung sounds were recorded in voice recorder, Linear PCM Recorder D50® [Sony, Inc. Japan], through the bilateral chest wall using a pair of hand-made stethoscopes consisting of hard gum and electret condenser microphone AT9903®[Audio-Technica, Inc. Japan]. Recorded sounds were analyzed by Adobe Audition CC®. It could easily demonstrate sound spectrogram, time-base waveform pattern, and power spectrum of the two-channel sounds.

**Results:** Postoperatively most of the patients, who had not have abnormal sounds preoperatively, generally did not produce adventitious sounds excluding sounds generated by mouth. Sleeve lobectomy, which consisted of resection and anastomosis of stem bronchus, produced rhonchi during both inspiration and expiration in the early postoperative course, but these rhonchi disappeared gradually. These rhonchi were supposed to be produced by retention of bronchial discharge around the anastomotic site. Postoperative bronchial fistula, which was a severe complication, generated rhonchi during expiration. These rhonchi were supposed to be produced by the gradient between intrabronchial and intrapleural pressures during expiration.

**Conclusion:** Lung sound analysis in general thoracic surgery provided useful information of postoperative complications.

## National survey on the perception of respiratory sounds among Greek doctors (preliminary report)

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**Background and aim**: There are considerable differences in the perception of lung sounds among clinicians. We aimed to explore the reliance and trust in stethoscope in a sample of Greek doctors.

**Methods**: We constructed an electronic form that contained 5 samples of recorded adventitious lung sounds, namely, fine crackles, coarse crackles, wheezing, pleural rub, and crackles plus squawk. No clinical information or videos were given. The form was sent to 300 clinicians, mostly pediatricians, who were asked to characterize each recorded sound according to his/her own perception. Participants did not choose from predefined choices but prompted to use their own words for the description of each sound. We summarized the answers in 15 categories according to the Greek established terminology and the semantics of each term. Participants were also asked to answer how much they trusted stethoscopic findings and score their importance in the diagnostic procedure in comparison with clinical history and chest x-ray (cxr).

**Results**: In this first phase of the survey we received 51 completed questionnaires. Forty-eight (95.5%) reported that they trust stethoscopic findings very much. Regarding the diagnostic procedure the highest importance score (220) was given to stethoscopic findings, whereas clinical history and cxr were scored with 218 and 190 (99% and 86% of the highest score), respectively. In the recognition of adventitious sounds a correct answer was given by the majority of participants for fine and coarse crackles, and wheeze (83%, 85%, and 89%, respectively) but a variety of terms were used. Pleural rub, and the combination of crackles with squawk were recognized by 3 (5.8%) and 3 (5.8%), respectively.

**Conclusion:** Clinicians seem to rely on and trust stethoscope in everyday practice. Their skills in recognising adventitious sounds are quite good for the most common, but they use a confusing variety of terminology.