

Wheeze Detection in the Pediatric Intensive Care Unit: Comparison Among Physician, Nurses, Respiratory Therapists, and a Computerized Respiratory Sound Monitor

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OBJECTIVE: To correlate wheeze detection in the pediatric intensive care unit among staff members (a physician, nurses, and respiratory therapists [RTs]) and digital recordings from a computerized respiratory sound monitor (PulmoTrack). **METHODS:** We prospectively studied 11 patients in the pediatric intensive care unit. A physician, nurses, and RTs auscultated the patients and recorded their opinions about the presence of wheeze at baseline and then every hour for 6 hours. The clinician auscultated while the PulmoTrack recorded the lung sounds. The data were analyzed by a technician trained in interpretation of acoustic data and by a panel of experts blinded to the source of the recorded data, who scored all tracks for the presence or absence of wheeze. The degree of correlation among the expert panel, the staff, and the PulmoTrack was evaluated with the Kappa coefficient and McNemar's test. The determinations of the expert panel were taken as the true state (accepted standard). **RESULTS:** The PulmoTrack and expert panel were in agreement on detection of wheeze during inspiration, expiration, and the whole breath cycle; in all cases the Kappa coefficients were 0.54, 0.42, and 0.50 respectively. The PulmoTrack was significantly more sensitive than the physician ($P = .002$), nurses ($P < .001$), or RTs ($P = .001$). However, the specificity of the PulmoTrack was not significantly different from that of the physician, nurses, or RTs. **CONCLUSIONS:** Between the physician, RTs, and nurses there was agreement about the presence of wheeze in critically ill patients in the pediatric intensive care unit. Compared to the objective acoustic measurements from the PulmoTrack, the intensive care unit staff was similar in their ability to detect the absence of wheeze. The PulmoTrack was better than the staff in detecting wheeze. *Key words:* wheeze, computerized respiratory sound monitor, PulmoTrack, pediatric intensive care unit, inter-rater agreement, auscultation. [Respir Care 2008;53(10):1304–1309. © 2008 Daedalus Enterprises]

Introduction

Wheezes are musical adventitious sounds that originate from the lungs.^{1,2} According to the Computerized Respi-

ratory Sound Analysis group, the dominant frequency of a wheeze is usually > 100 Hz, and the duration is > 100 ms.³ Wheezes are among the most common adventitious lung sounds heard in children with various airway diseases ad-

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mitted to the pediatric intensive care unit (PICU). The high noise level in the PICU may interfere with auscultation. In some PICUs the baseline noise is in the range 60–120 dB,⁴⁻⁷ which is substantially higher than that recommended by the World Health Organization (35 dB indoors, and 30 dB in a bedroom).

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PICU staff perform intermittent auscultation to detect wheeze. Their assessment provides clues to the presence of various airway disease states among intubated and non-intubated children. This assessment helps trigger appropriate therapeutic interventions in these children with rapidly changing lung conditions. However, the stethoscope has limitations. Auscultation is a subjective process, not easily quantifiable, and has a frequency response that attenuates lung sounds with frequency components above 120 Hz.^{8,9}

Given the noisy PICU environment and clinicians' different abilities to detect and quantify wheeze, a computerized respiratory sound monitor could provide continuous noninvasive wheeze assessment, independent of staff. Recently, advances in microelectronics have allowed improved sound amplification and filtering. The incorporation of this technology in a computerized respiratory sound monitor offers a consistent and high-fidelity automatic method for detecting and better characterizing adventitious and normal breath sounds.¹⁰⁻¹² A computerized respiratory sound monitor may provide early warning of clinically important changes in airway patency. A few studies have investigated the inter-rater agreement on wheeze detection in non-PICU environments,¹²⁻¹⁵ but little is currently known about inter-rater reliability in detecting wheeze in the PICU.

The aim of this study was to compare inter-rater agreement about wheeze detection in PICU patients. We compared auscultation findings from respiratory therapists (RTs), nurses, and a 3rd-year PICU fellow physician to the findings of an expert panel who listened to digital recordings of lung sounds acquired by a high-fidelity computerized respiratory sound monitor (PulmoTrack model 1010,

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Table 1. Subjects

Subject	Sex	Age (y)	Diagnosis	Intubated and Ventilated
1	Male	4	Asthma	Yes
2	Male	2	Asthma	No
3	Female	8	Pneumonia	Yes
4	Male	6	Asthma	No
5	Female	11	Asthma	No
6	Female	5	Pneumonia	No
7	Female	12	Asthma	No
8	Male	3	Asthma	No
9	Male	14	Spinal cord injury	Yes
10	Female	2	Asthma	No
11	Male	2	Asthma	No

Karmel Medical Acoustic Technologies, Yokneam Illit, Israel) at the same times that the clinicians auscultated.^{11,12,16,17} We also compared the RTs', nurses', physician's, and expert panel's findings to those of the PulmoTrack's wheeze-detection algorithm.

Methods

The work was carried out at MassGeneral Hospital *for* Children, Boston, Massachusetts, and the institutional review board approved the study.

Subjects

Informed consent was obtained from the patients' parents. The patients included were < 16 years old, had wheeze (due to asthma or other diseases), and were admitted to the PICU. Excluded were patients with wounds or lesions over the trachea or chest that prevented the placement of the contact acoustic sensors or adhesives, patients with known allergy to micropore adhesive tape, patients with defibrillators or pacemakers (which could interfere with the sounds detected by a computerized respiratory sound monitor), and patients in whom the study protocol would interfere with the patient's normal treatment protocol.

Eight of the 11 subjects had an admitting diagnosis of acute asthma, and 3 of the subjects were admitted for conditions other than asthma (Table 1). The 8 patients with asthma were enrolled in the order in which they were admitted to the PICU. The 3 nonasthmatic patients were enrolled at random, and placed in the study following the second, fourth, and sixth asthmatic patients. The resulting order of study subjects was 2 with asthma, 1 without asthma, 2 with asthma, 1 without asthma, and so on, ending with 2 with asthma.

Pediatric Intensive Care Unit

The study was performed in an 8-bed PICU, approximately 4,232 gross square feet, located on the 3rd floor of a 21-story building that is surrounded by 3 other patient-related buildings. Five of the 8 beds were in one large room that takes up approximately half of the PICU, in which curtains separate the beds from each other. These beds were in proximity to the nurses' station. Each subject was in one of these 5 beds during their hospital stay, and all measurements were done during daytime.

Computerized Respiratory Sound Monitor

Respiratory acoustic signals were recorded continuously by 5 phonopneumography piezoelectric contact sensors (PPG Sensors, Karmel Medical Acoustic Technologies, Yokneam Illit, Israel) applied over the trachea above the sternal notch, the right axilla, the left axilla, and both the left and right posterior lung bases. The sensors are coin-shaped piezoelectric elements that have a linear ± 3 -dB frequency response from 75 Hz to 2,000 Hz, a resonance at 2.7 kHz, a useable range that extends beyond 4 kHz, and a built-in passive ambient-noise-rejection capability. The sensors were attached to the chest with adhesive foam pads that further reduce ambient-noise interference and eliminate contact noise. All the sensors were connected to the PulmoTrack, which performs signal conditioning (amplification $\times 3,000$, and band-pass filtration of 80–4,000 Hz at 24 dB per octave) prior to analog-to-digital conversion (11,025 samples per second per channel). Two other signals were also tracked: ambient noise was recorded with an air-coupled microphone placed near the patient, and chest impedance was recorded to measure breathing activity (ie, respiratory rate, phase, and amplitude).^{11,12}

The PulmoTrack's wheeze-detection software uses a fast Fournier transform algorithm that was previously verified and has a sensitivity of 91% and a specificity of 89% in wheeze detection.^{8,11,18} The algorithm identifies continuous adventitious breath sounds in the frequency range 80–4,800 Hz in the tracheal channel and 80–2,400 Hz in the chest-wall channels. The system identifies and discards speech, crying, and other vocal-cord sounds.^{12,19,20}

An auditory audit of the data was performed to verify the detection accuracy. Sounds in the frequency range 150–850 Hz were classified as "asthmatic wheeze." The phase of respiration was determined by the changes in chest impedance recorded from the axilla sensors. All other continuous adventitious sounds outside that range were considered not asthmatic wheeze.¹²

The data were downloaded from the PulmoTrack and manually analyzed by a technician trained in the interpretation of acoustic data and who was blinded to the findings

of the RTs, nurses, and the physician (a 3rd-year PICU fellow). The sponsoring company's budgetary constraints disallowed analyzing all the data, so by random drawing we chose to analyze only the data from the right lung base. Wheeze rate was calculated as:

$$\text{Wheeze rate} = T_w/T_{\text{tot}}$$

where T_w is the breathing time with wheeze and T_{tot} is total breathing time.^{11,12,21}

As healthy children have a wheeze rate of $< 5\%$, calculated with the above formula,¹⁶ the PulmoTrack uses a wheeze rate of $> 10\%$ as the positive indication of wheeze.^{11,12}

Data Collection by Staff

Once the PulmoTrack was attached and functional, and the child was identified as breathing regularly, a physician (same physician with all patients), a PICU nurse, and a PICU RT (both different in all cases) independently auscultated for the presence or absence of wheeze at all 5 sensor sites while the PulmoTrack recorded the breath sounds.

The physician's, nurses', and RTs' auscultation findings were scored 0 (no wheeze) or 1 (wheeze present), and each finding was ascribed to the inspiratory phase, expiratory phase, or entire breath. The staff was blinded to the PulmoTrack's continuous sound monitoring. Immediately before and after auscultation at each sensor site, the auscultating clinician pressed a button on the PulmoTrack that time-marked the PulmoTrack's log file. The presence/absence of wheeze was evaluated by the physician, nurse, and RT at the start of the study and then on the hour for 6 hours.

Validation of Data by Expert Panel

The PulmoTrack's recordings were converted to a digital (WAV format) audio file and transferred to an audio compact disc, in which the assignment of a file to a particular audio track was randomized. One hundred time periods were randomly used to create acoustic data for the expert panel, which consisted of 2 pediatric pulmonologists, one RT, and one pediatric intensivist. Each panelist was a senior practitioner with > 10 years of clinical experience in his or her discipline. Each panelist was blinded to the other panelists, the staff, and the PulmoTrack. The panelists listened individually to each recorded track and scored it for the presence or absence of wheeze, and determined the respiratory phase of the wheeze (entire breath, inspiratory only, or expiratory only). If the panelist thought a recording could not be scored as above, due to artifacts, the panelist could decline to score the recording. A lung

sound was only considered a wheeze if ≥ 3 of the 4 panelists called it a wheeze; otherwise it was defined as a no-wheeze state.

Statistical Analysis

We used the Kappa coefficient to measure the agreement among the physician, nurses, and RTs. The Kappa coefficient was constructed with a confidence level of $\alpha = 0.05$. To calculate the sensitivity, specificity, and confidence interval for the presence/absence of wheeze we used the expert panel's findings as the standard. We used the exact McNemar test to compare the sensitivities and specificities between the PulmoTrack and each staff member, and to compare the proportion of wheeze detected by the PulmoTrack and the panel.

Results

Subjects

Table 1 describes the 11 subjects. The subjects' age range was 2–14 years. Five were female and 6 were male. Eight had asthma and were admitted with a primary diagnosis of asthma exacerbation, 2 were admitted for acute pneumonia, and one had acute respiratory failure secondary to spinal cord injury. Three were intubated for acute respiratory failure and received mechanical ventilation.

Data Analysis

The staff made 77 inspiratory-phase and 77 expiratory-phase observations. These observations were based on our protocol, in which the clinician examines the right lung base for the presence or absence of wheeze at the start of the study and then on the hour for 6 consecutive hours. Table 2 compares the initial wheeze detection by the staff. The physician detected marginally more wheezes than did the nurses or RTs. Table 3 shows close agreement among the staff in detecting wheeze (Kappa 0.75–0.76).

Validation of the PulmoTrack's Findings by the Panelists

All the panelists detected breath sounds in only 84 of the 100 breath-sound recordings. The PulmoTrack and the expert panel were similar in their ability to detect wheeze during inspiration, expiration, and both inspiration and expiration (Kappa coefficients 0.54, 0.42, and 0.49, respectively) (Table 4). The PulmoTrack had moderate agreement with the expert panel.

Table 2. Wheeze Detection by the Physician, Nurses, and RTs

	Percentage of Wheezes Detected		
	Both Phases (<i>n</i> = 154 observations)	Expiratory Phase (<i>n</i> = 77 observations)	Inspiratory Phase (<i>n</i> = 77 observations)
Physician	20	22	18
Nurses	16	18	13
RTs	16	16	16

RT = respiratory therapist

Table 3. Wheeze-Detection Agreement Between the Physician, Nurses, and RTs

Comparison	Kappa Coefficient	Confidence Interval (lower–upper)	<i>P</i> (McNemar test)
Physician vs nurses	0.76	0.62–0.89	.06
Physician vs RTs	0.76	0.62–0.89	.06
Nurses vs RTs	0.75	0.61–0.89	.99

RT = respiratory therapist

Comparison of PulmoTrack and Individual Staff Members

The sensitivities of the PulmoTrack, physician, nurses, and the RTs were 75%, 49%, 44%, and 41%, respectively, and the specificities were 76%, 80%, 89%, and 87%, respectively (Tables 5 and 6). There were significant differences between the sensitivity of the PulmoTrack and the physician ($P = .002$), nurses ($P < .001$), and RTs ($P = .001$). There was no significant difference between the specificity of the PulmoTrack and the physician ($P = .62$) or the RTs ($P = .18$). The nurses did better than the PulmoTrack ($P = .03$) in identifying a no-wheeze state.

Discussion

The physician (3rd-year PICU fellow), nurses, and RTs were similar in their ability to detect wheeze in the PICU. The physician and RTs were as accurate as the PulmoTrack in identifying the no-wheeze state. The PICU nurses were better than the PulmoTrack in recognizing the no-wheeze state. The PulmoTrack was better than the PICU staff in identifying wheeze.

Agreement among experienced clinicians about the presence of physical signs in the respiratory system is approximately midway between complete agreement and chance.^{22–24} To the best of our knowledge, our study is the first to compare inter-rater agreement among a physician, nurses, and RTs in a PICU. We found close agreement

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Table 4. Agreement Between the Expert Panel and the PulmoTrack

Respiratory Phase	Wheezes Detected by PulmoTrack (%)	Wheezes Detected by Panel (%)	<i>P</i> (McNemar test)	Kappa Coefficient	Confidence Interval (lower–upper)
Both phases	48	47	.99	0.49	0.31–0.68
Expiratory phase	57	57	.99	0.42	0.14–0.69
Inspiratory phase	38	36	.99	0.54	0.28–0.80

Table 5. Sensitivity

	Sensitivity (%)	Confidence Interval (lower–upper) (%)	<i>P</i> (McNemar test)
PulmoTrack	75	57.9–87.0	NA
Physician	49	32.4–65.2	.002
Nurses	44	27.8–60.4	< .001
RTs	41	25.6–57.9	.001

NA = not applicable
RT = respiratory therapist

Table 6. Specificity

	Specificity (%)	Confidence Interval (lower–upper) (%)	<i>P</i> (McNemar test)
PulmoTrack	76	60.5–87.1	NA
Physician	80	65.4–90.4	.62
Nurses	89	76.0–96.3	.03
RTs	87	73.2–95.0	.18

NA = not applicable
RT = respiratory therapist

among the staff members in detecting wheeze and no-wheeze conditions. This is similar to reports in non-PICU environments.^{12–15}

Computerized respiratory sound monitors have successfully detected and analyzed wheeze in diverse types of patients, including in children with asthma^{8,24–26} and cystic fibrosis,²⁷ in adults with asthma,²⁸ and in patients exposed to occupational hazards.²⁹ Those studies, which used different computer algorithms, found a wide range of sensitivity (approximately 50–80%). The PulmoTrack has also been used in more controlled environments. Bentur et al¹⁶ used the PulmoTrack in the homes of 12 children with mild or moderate asthma to monitor nocturnal wheeze before and during treatment. They found that PulmoTrack provided quantitative and noninvasive information about nocturnal wheeze in children. There was good correlation with conventional indices of asthma activity, and the PulmoTrack assisted in assessing treatment efficacy.¹⁶ Gross et al used the PulmoTrack in a sleep laboratory to evaluate lung sounds and study the interaction between sleep posi-

tion and bronchial obstructions in 20 patients.¹⁷ However, to the best of our knowledge, no previous data are available on the objective acoustic measurement of wheeze in critically ill children and comparison of such findings to professional evaluation.

The PICU environment is noisy,^{4,7} which can interfere with auscultation and the computerized respiratory sound monitor. Our results are similar to those of other studies in other environments. Trunsky et al³⁰ compared the auscultation abilities of medical personnel with and without the aid of automated breath-sound analysis. The automatic sound analyzer improved the detection rate of crackles (from 47% to 61%, *P* < .05) and expiratory wheeze (from 50% to 66%, *P* < .05) without affecting the specificity.³⁰ Pasterkamp et al^{24,31} compared the subjective assessment and computer analysis of wheeze. Recorded breath sounds from asthmatic patients were presented to 40 health professionals. There was a reasonable accord between the mean subjective wheeze scores and the computer-analyzed wheeze scores.^{24,31}

A limitation of our study was that the analysis was limited to the sounds from the right lung base. Further, our study had only 3 mechanically ventilated patients. Nevertheless, we believe that the 77 inspiratory and 77 expiratory assessments by the PICU staff and the 84 recordings assessed by the expert panel were sufficient to reasonably evaluate the performance of the PICU staff and the PulmoTrack.

The physician in our study was a 3rd-year PICU fellow, so we cannot extrapolate our findings to all PICU physicians.

Even though each PICU staff was blinded to the auscultation findings of the other staff, each was aware of his or her own previous findings, so after the first baseline auscultation the clinician had an opinion on whether the patient had a wheeze. This might have increased the agreement among the staff in various circumstances. We believe, though, that in real clinical situations, practitioners use sequential auscultations to make their clinical assessments. We also believe that 154 observations (77 during inspiration and 77 during expiration) at 5 different sites was sufficient to minimize that potential bias.

We did not measure the noise level in our PICU during the study period. It is possible that daily variations in noise level could impact study findings.

A computerized respiratory sound monitor is a “smart” stethoscope that records information very precisely, but has the same limitations as the stethoscope if used as the sole assessment tool. We did not take into account other factors that the RTs, nurses, and physicians would routinely consider when assessing the respiratory system, such as work of breathing, pulse rate, respiratory rate, and level of exhaustion. However, we believe our results have important clinical implications for the PICU environment.

Conclusions

There was agreement on wheeze detection in critically ill PICU patients among the physician, RTs, and nurses. Compared to an objective acoustic measurement, the PICU staff were similar in their ability to detect absence of wheeze. The PulmoTrack was better in the ability to detect wheeze. Therefore, given continuing advances in computer-based acoustic technology, computerized lung sound detectors and analyzers can expand and may supplement noninvasive diagnostic capabilities in the PICU. Further studies should address whether characterizing wheeze by intensity, pitch, or duration could improve detection of the degree of airway obstruction and have clinical implications.

REFERENCES

- Laënnec RTH. [De l'auscultation médiate ou traité du diagnostic de maladies des poumons et du coeur, fondé principalement sur ce nouveau moyen d'exploration]. *Article in French*. In 2 volumes. Brosson et Chaudé, Paris 1819. <http://gallica.bnf.fr/ark:/12148/bpt6k987580/f47.table>. Accessed August 6, 2008.
- Forgacs P. Crackles and wheezes. *Lancet* 1967;2(7508):203-205.
- Sovijärvi AR, Dalmasso F, Vanderschoot J, Malmberg LP, Righini G, Stoneman SAT. Definition of terms for applications of respiratory sounds. *Eur Respir Rev* 2000;10:597-610.
- Bailey E, Timmons S. Noise levels in PICU: an evaluative study. *Paediatr Nurs* 2005;17(10):22-26.
- Carvalho WB, Pedreira ML, de Aguiar MA. Noise level in a pediatric intensive care unit. *J Pediatr (Rio J)* 2005;81(6):495-498.
- Akhtar S, Weigle CG, Cheng EY, Toohill R, Berens RJ. Use of active noise cancellation devices in caregivers in the intensive care unit. *Crit Care Med* 2000;28(4):1157-1160.
- Morrison WE, Haas EC, Shaffner DH, Garrett ES, Fackler JC. Noise, stress, and annoyance in a pediatric intensive care unit. *Crit Care Med* 2003;31(1):113-119.
- Earis JE, Sovijärvi AR, Vanderschoot J. European Respiratory Society Task Force Report. Computerized respiratory sound analysis: recommended standards for term and techniques. *Eur Respir Rev* 2000;10:585-649.
- Abella M, Formolo J, Penny DG. Comparison of acoustic properties of six popular stethoscopes. *J Acoust Soc Am* 1992;91(4 Pt 1):2224-2228.
- Earis JE, Cheatham BMJ. Current methods used for computerized respiratory sound analysis. *Eur Respir Rev* 2000;10:586-590.
- Bentur L, Beck R, Berkowitz D, Hasanin J, Berger I, Elias N, Gavriely N. Adenosine bronchial provocation with computerized wheeze detection in young infants with prolonged cough: correlation with long-term follow-up. *Chest* 2004;126(4):1060-1065.
- Levy ML, Godfrey S, Irving CS, Sheikh A, Hanekom W, Bush A, Lachman P. Wheeze detection: recordings vs assessment of physician and parent. *J Asthma* 2004;41(8):845-853.
- Stevens MW, Gorelick MH, Schultz T. Interrater agreement in the clinical evaluation of acute pediatric asthma. *Asthma* 2003;40(3):311-315.
- Gorelick MH, Stevens MW, Schultz TR. Comparability of acute asthma severity assessments by parents and respiratory therapists. *Arch Pediatr Adolesc Med* 2002;156(12):1199-1202.
- Angelilli ML, Thomas R. Inter-rater evaluation of a clinical scoring system in children with asthma. *Ann Allergy Asthma Immunol* 2002;88(2):209-214.
- Bentur L, Beck R, Shinawi M, Naveh T, Gavriely N. Wheeze monitoring in children for assessment of nocturnal asthma and response to therapy. *Eur Respir J* 2003;21(4):621-627.
- Gross V, Reinke C, Penzel T, Becker HF, Vogelmeier CF. [Dependence of nocturnal bronchial obstruction on sleep position]. *Article in German*. *Biomed Tech (Berl)* 2002;47(Suppl 1 Pt 2):863-865.
- Gavriely N. *Breath sounds methodology*. Boca Raton: CRC Press; 1995:55-97.
- Beck R, Dickson U, Montgomery MD, Mitchell I. Histamine challenge in young children using computerized lung sounds analysis. *Chest* 1992;102(3):759-763.
- Pasterkamp H, Consunji-Araneta R, Oh Y, Holbrow J. Chest surface mapping of lung sounds during methacholine challenge. *Pediatr Pulmonol* 1997;23(1):21-30.
- Sanchez I, Avital A, Wong I, Tal A, Pasterkamp H. Acoustic vs. spirometric assessment of bronchial responsiveness to methacholine in children. *Pediatr Pulmonol* 1993;15(1):28-35.
- Smyllie HC, Blendis LM, Armitage P. Observer disagreement in physical signs of the respiratory system. *Lancet* 1965;2(7409):412-413.
- Godfrey S, Edwards RH, Campbell EJ, Armitage P, Oppenheimer EA. Repeatability of physical signs in airways obstruction. *Thorax* 1969;24(1):4-9.
- Pasterkamp H, Wiebicke W, Fenton R. Subjective assessment vs. computer analysis of wheezing in asthma. *Chest* 1987;91(3):376-381.
- Lim S, Gavriely N, Irving CS, et al. Quantitative documentation of wheezes in asthma clinics using an automatic wheeze quantification device (abstract). *Eur Respir J* 1999;14 (Suppl):147.
- Mikami R, Murao M, Cugell DW, Chretien J, Cole P, Meier-Sydow J, et al. International symposium on lung sounds. Synopsis of proceedings. *Chest* 1987;92(2):342-345.
- Sanchez I, Powell RE, Pasterkamp H. Wheezing and airflow obstruction during methacholine challenge in children with cystic fibrosis and in normal children. *Am Rev Respir Dis* 1993;147(3):705-709.
- Baughman RP, Loudon RG. Lung sound analysis for continuous evaluation of airflow obstruction in asthma. *Chest* 1985;88(3):364-368.
- Bohadana AB, Massin N, Teculescu D, Peslin R. Tracheal wheezes during methacholine airway challenge (MAC) in workers exposed to occupational hazards. *Respir Med* 1994;88(8):581-587.
- Trunsky H, Budinger GRS, Jain M, Corbridge T. The use of phonopneumography improves the accuracy of stethoscopic examination of intensive care patients (abstract). *Am J Respir Crit Care Med* 1998;A135.
- Pasterkamp H, Kraman SE, Wodicka GR. Respiratory sounds: advances beyond the stethoscope. *Am J Respir Crit Care Med* 1997;156(3):974-987.