Comparison of the Lung Sound Frequency Spectra of Infants and Adults

Jamshed F. Kanga, MD, and Steve S. Kraman, MD

Summary. Auscultation of the infant chest reveals lung sounds that seem different from those of adults. To characterize this subjective difference, we compared the phonopneumographic median frequencies of lung sounds of seven full-term and six premature infants with those of seven adults free of cardiopulmonary disease. The median frequencies over the upper lobes for the adults, term infants, and premature infants were 282 ± 63(SD) Hz, 383 ± 80 Hz, and 483 ± 86 Hz, respectively. At this location the differences among the three groups were significant ($p < 0.01$). Over the lower lobes, the median frequencies for the adults, term infants, and premature infants were 243 ± 56 Hz, 386 ± 76 Hz, and 390 ± 63 Hz, respectively. Here the difference between the adults and both groups of infants was significant ($p < 0.01$), but that between the term and premature infants was not. We conclude that the normal lung sounds of newborn infants contain higher-frequency components than those of adults. We postulate that this difference is the result of less filtering of the lung sound in infants. This difference should be considered when lung sounds of infants are described or assessed for the presence of abnormalities. (*Key words:* phonopneumography; median frequencies of lung sounds in full-term, premature infants versus adults; clinically used breathing maneuvers.) *Pediatr Pulmonol 1986; 2:292–295.*

Since the invention of the stethoscope by Laennec,[1] auscultation has played an important role in the diagnosis of chest diseases. Phonopneumography, the recording, display, and analysis of breath sounds, has been used to define lung sounds in objective and quantifiable terms. There have been several studies using phonopneumography in adults,[2-7] but little is known about lung sound analysis in children, especially infants.

Scarpelli has stated that, on auscultation of the infant chest, the lung sound quality seems to differ from that in the adult, as the sound appears to be produced closer to the listening ear.[8] Recently, Pasterkamp et al.[9] analyzed the frequency spectra of lung sounds of newborn infants and compared their results with those reported in the literature for older children and adults. They did not find any difference in the mean peak frequencies and frequency range between the infants and adults. This finding was contrary to our own subjective experience, so we undertook this clinical study to compare lung sound frequency spectra under normal conditions of auscultation.

From the Departments of Pediatrics and Medicine, University of Kentucky Medical Center and Veterans Administration Medical Center, Lexington, Kentucky.

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Address correspondence and reprint requests to Dr. Kanga, Assistant Professor of Pediatrics, University of Kentucky School of Medicine, 800 Rose Street, Lexington, KY 40536.

Methods

We studied three groups of subjects: (1) seven term infants with a mean weight of 3.1 kg, a gestational age range of 37 to 40 weeks (mean 39.5 weeks) at their second to fourth day of life (mean 2.6 days); (2) six premature infants (table 1) with a mean weight of 1.33 kg, gestational age range of 27 to 33 weeks (mean 31 weeks), and chronologic age ranging from 3 to 13 days (mean 8.3 days); and (3) seven nonsmoking adults (mean age 33 years). All subjects were free of cardiopulmonary disease at the time of the recording. The premature infants had normal chest roentgenograms and were breathing room air at the time of the recording. Most of these very low birth weight infants had required supplemental oxygen for mild hyaline membrane disease at birth; they were studied either in their incubators or under radiant warmers in the neonatal intensive care unit. The term infants were studied while rooming with their mothers in the maternity ward. The adults were studied in the pulmonary function laboratory. The same equipment was used on all subjects.

Breathing Maneuvers

During quiet, tidal breathing, none of the subjects produced lung sounds that were loud enough to be clearly heard above the background cardiovascular and muscle noise. Therefore, the adult lung sounds were recorded during deep, submaximal inspirations similar to those normally elicited during a clinical examination of the chest. To obtain similar lung sound amplitude for the infants, we recorded for as long as necessary until the infant spontaneously sighed or otherwise took deep breaths that resulted in clearly audible lung sounds. This occurred frequently in the term infants but often after 10 or more minutes in the premature infants. Our criteria for acceptable lung sounds were that they be clearly obvious to the ear and that they exceed the background noise (displayed on the oscilloscope screen) by at least two times prior to filtering.

Recording and Measurement

The lung sounds were recorded by using miniature air-coupled electret condenser microphones that were fastened to the chest with double-sided adhesive rings. Recording sites were over the right and left upper and lower lobes. Upper lobe locations were on the upper anterior chest wall, corresponding to segment number 2 according to the classification of Boyden.[10] Lower lobe locations were on the lower posterior chest wall (segment number 9[10]). Recordings from the left and right sides were performed simultaneously. The quality of the recordings was monitored by listening through headphones.

The lung sounds were recorded on a stereo cassette tape deck (Sharpe model RT 3388A) at the bedside. The lung sounds thus recorded were later passed to an FM tape recorder (Hewlett-Packard model 3964A) at a tape speed of 3 3/4 inches per second. From this tape, the sounds, identified by ear and by display on an oscilloscope screen, were digitized at 5000 Hz by a 14-bit digitizer (Data 6000, Data Precision Corp.) after filtering between 100 and 1200 Hz (to minimize low-frequency cardiovascular and muscle artifacts and to avoid aliasing corruption). The length of the sampled segments was 0.1024 second (512 digitized points at 5000 Hz digitizing rate). The digitized records were examined to identify the inspiratory lung sounds, and the power spectrum was determined by a 512-point fast Fourier transformation (FFT). The median frequency was determined by calculating the mid-power point of the spectral components after discarding all points below 100 Hz and above 1200 Hz. Two clearly identifiable, artifact-free, inspiratory lung sounds were so analyzed at

table 1—Gestational Age, Chronologic Age, and Weight of Premature Infants at the time of Lung Sound Recording

Subject	Gestational Age (weeks)	Chronologic Age (days)	Weight (kg)
1	27	11	0.83
2	29	9	1.38
3	31	3	1.30
4	33	7	1.53
5	33	13	1.52
6	33	7	1.42

each of the four locations in each subject. The median frequencies of the sounds at the upper and lower lobes were assembled within each of the three groups and compared by one-way analysis of variance (ANOVA). Differences within groups were examined using Gabriel's Sum of Squares Simultaneous Test Procedure.

Results

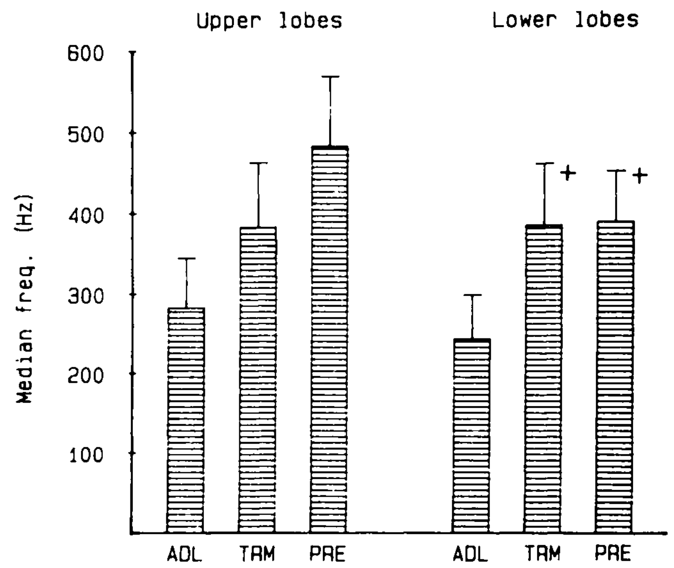
The results are shown graphically in figure 1. Over the upper lobes the median frequencies for the adults, term infants, and premature infants were 282 ± 63 Hz, 383 ± 80 Hz, and 483 ± 86 Hz, respectively. At this recording location the differences between the median frequencies were significant ($p < 0.01$). Over the lower lobes the median frequencies for the adults, term infants, and premature infants were 243 ± 56 Hz, 386 ± 76 Hz, and 390 ± 63 Hz, respectively. There was a significant difference ($p < 0.01$) in the median frequencies between the adults and both groups of infants, but not in those between the term and premature infants.

The differences between the frequency spectra of the three study groups are evident in figure 2, which shows the grouped spectra. The relative dominance of high-frequency lung sound components in the infants is apparent.

A low-frequency hum was apparent between breaths of those premature infants who were in incubators during recording. This sound was eliminated prior to frequency analysis by post-recording filtering of sounds below 100 Hz.

Discussion

In the present study we demonstrate a significant difference between the frequency spectra and median frequencies of lung sounds of infants and adults. Our findings differ from those of Pasterkamp et al.,[9] who found that the mean peak frequencies and frequency ranges of the lung sounds of 14 newborn infants were not



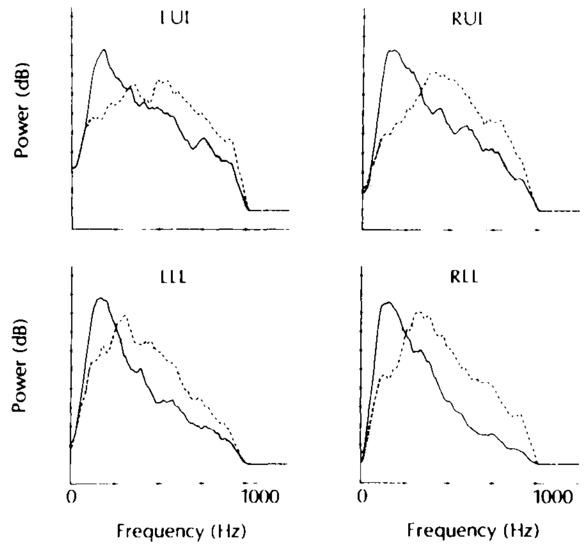


figure 1 (*left*)—The median frequency ± SD of the lung sounds of adults (ADL), term infants (TRM), and premature infants (PRE) over the upper and lower lobes. (+ No difference between these groups. All other groups significantly different— $p < 0.01$.)

figure 2 (*right*)—Mean frequency spectra of the inspiratory lung sound of adults, term infants, and premature infants at the four recording locations. Each spectral plot is the smoothed, mean FFT of one inspiratory sound from each of the subjects. The spectra have been normalized with respect to total spectral energy (area under each curve) to facilitate comparison among the groups. Each vertical tick mark is approximately 10 dB. The tendency toward a broader frequency spectrum for the infant sounds is apparent. (——— adults, · · · · · · term infants, ------ premature infants; LUL = left upper lobe; LLL = left lower lobe; RUL = right upper lobe; RLL = right lower lobe.)

different from those of normal adults. The frequency spectral data of our study cannot be directly compared with those of Pasterkamp et al. because they reported peak frequencies (the frequency at which maximum amplitude occurs), whereas we compared the median frequencies. Although the peak frequency is a commonly reported parameter of lung sound, it is easily affected by spurious or random peaks that may occur in the spectrum. Also, in cases in which a large amount of low-frequency sound is present and a high-pass filter is used, the peak frequency may simply represent the "shoulder" of the filter rather than the true spectrum, as was the case in the present study. The median frequency weighs the total frequency components of the spectrum and is, therefore, less likely to be affected by spurious peaks. For these reasons, the median frequency may better represent the lung frequency spectra and give more consistent and reliable results than the peak frequency.

Another difference between our study and that of Pasterkamp et al. is that they compared their findings with adult normal values described in the literature.[4,11,12] As techniques for lung sound recording and signal processing are not standardized, comparison of results from different laboratories may not be appropriate. In our investigation the adult subjects were studied as much as possible, by the same techniques and equipment used to study the infants.

Although our data show a clear difference between lung sounds of adults and infants, we are not sure of the reason for this. We postulate that it may result from the different thicknesses of the lung parenchyma and/or chest wall through which the sound travels. Lung tissue is thought to attenuate high-frequency sound passing through it.[13,14] In the small infants, the distance traversed is shorter, so that the high-frequency components of the lung sound may be filtered less than in the larger, term infants and in the adults. The different chest wall thickness may exert an additional effect, but we are unaware of previous work that would confirm this. It is also possible that, unlike adult lung sounds,[15] the infant's lung sounds are partly generated in the trachea.

There are other possible explanations for the differences observed between the adult and infant lung sounds. In addition to size, there are structural differences between the two. The number of alveoli increases tenfold from birth to adulthood.[16] It is conceivable that the immature lung has sound transmission and/or production characteristics that change with lung maturation. Work with excised lungs may be needed to explore this hypothesis. Contracting muscle produces sounds with a peak frequency of 25 to 30 Hz[15,17]; therefore, such low-frequency sounds arising from skeletal or cardiac muscles may be another factor contributing to the lower median frequency in the adult subjects. Larger muscle activity and muscle mass in the adult subjects may have contributed some low-frequency sound, in spite of the attenuation of frequencies below 100 Hz. Respiratory muscle sounds have not been studied in infants; therefore, we cannot postulate on their potential contribution to the frequency spectra. Cardiovascular sounds overlap with lung sounds at frequencies below 100 Hz, as was recently shown,[18] and with the technique used, we were unable to sample breath sounds free of cardiac sounds. Because heart sounds are well heard all over the infant chest, a component of cardiovascular sound must have been included in our analysis and could have lowered the median frequency. This effect, however, would decrease rather than increase the differences among the groups studied. We know of no way to exclude this possibility.

Finally, in our study the adult subjects were asked to perform deep submaximal inspirations, whereas the infants were recorded during spontaneous sighing inspirations, which may or may not have been equivalent to the respirations recorded in the adults. Nevertheless, these are the types of maneuvers used clinically to assess lung sounds. There is no reason to believe that differences in depth or rate of breathing would change the frequency distribution of the lung sounds, although further investigation is needed to verify this assumption.

In conclusion, because conventional pulmonary function tests are difficult to perform in infants, there is great need to develop other simple, noninvasive methods of assessing lung function. With further research, phonopneumography may prove a valuable aid in the diagnosis and management of lung diseases in infancy and childhood. Characterization of the frequency spectra of normal lung sounds is the first step toward the study of lung sounds in diseased states. In our study, we have found the median frequency of normal lung sounds to differ between adults and infants. This difference should be considered before undertaking studies of lung sounds in infants with pulmonary diseases.

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References

1. Laennec RTH, De l'Auscultation Mediate. Paris: Brosson & Chaude, 1819.
2. Weiss EB, Carlson CJ. Recording of breath sounds. Am Rev Respir Dis 1972; 105:835–839.
3. Banaszak EF, Kory RC, Snider GL. Phonopneumography. Am Rev Respir Dis 1973; 107:449–455.
4. Hallgren RC, Huang SM, McMahon SM, Shockey TP. Breath sounds: Development of a system for measurement and analysis. J Clin Eng 1982; 7:135–141.
5. Urquhart RB, McGhee J, Macleod JES, Banham SW, Moran F. The diagnostic value of pulmonary sounds: A preliminary study by computer-aided analysis. Comput. Biol. Med., 1981; 11:129–139.
6. Gavriely N, Palti Y, Alroy G. Spectral characteristics of normal breath sounds. J Appl Physiol 1981; 50:307–314.
7. Wooten FT, Waring WW, Wegmann MJ, Anderson WF, Conley JD. Method for respiratory sound analysis. Med Instrum 1978; 12:254–257.
8. Scarpelli EM. Examination of the lung. Pulmonary disease of the fetus, newborn and child. Philadelphia: Lea & Febiger, 1978: 11.
9. Pasterkamp H, Fenton R, Leahy F, Chernick V. Spectral analysis of breath sounds in normal newborn infants. Med Instrum 1983; 17:355–357.
10. Boyden EA. Segmental anatomy of the lungs. New York: McGraw Hill, 1955.
11. Schreiber JR, Anderson WF, Wegmann MJ, Waring WW. Frequency analysis of breath sounds by phonopneumography. Med Instrum 1981; 15:331–334.
12. Chowdhury SK, Majumder AK. Digital spectrum analysis of respiratory sound. IEEE. Trans Biomed Eng 1981; 28:784–788.
13. Rice DA. Sound speed in pulmonary parenchyma. J Appl Physiol 1983; 54:304–308.
14. Hannon RR, Lyman RS. Studies on pulmonary acoustics II. The transmission of tracheal sounds through freshly exenterated sheep's lung. Am Rev Tuberc 1929; 19:360–375.
15. Kraman SS. Vesicular (normal) lung sounds: How are they made, where do they come from, and what do they mean? Semin Respir Med 1985; 6:183–191.
17. Dunhill MH. Postnatal growth of the lung. Thorax 1962; 17:329–333.
18. Oster GV, Jaffe JS. Low frequency sounds from sustained contraction of human skeletal muscle. Biophys J 1980; 30:119–127.
18. Pasterkamp H, Fenton R, Tal A, Chernick V. Interference of cardiovascular sounds and phonopneumography in children. Am Rev Respir Dis 1985; 131:61–64.