The Relationship between Normal Lung Sounds, Age, and Gender

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Auscultation is one of the most important noninvasive and feasible methods for the detection of lung diseases. Systematic changes in breathing sounds with increasing age are of diagnostic importance. To investigate these changes, we recorded lung sounds taken from four locations in the posterior thorax of 162 subjects, together with airflow. The data were analyzed according to age, sex, and smoking habit. In order to describe the power spectrum of the lung sounds, we calculated mean and median frequency, frequency with the highest power, and a ratio (Q) of relative power of the two frequency bands of 330 to 600 Hz and 60 to 330 Hz. Linear regression analysis was used as a measurement of age-dependence of these variables. Significant differences in Q were found in men versus women ($p < 0.05$), but not in smokers versus nonsmokers. Within the groups, a small but significant correlation existed between Q and age ($r^2 \leqslant 0.1$, $p < 0.05$). For both men and women, a slight increase of the relative power in the frequency band of 330 to 600 Hz was recorded with increasing age. However, on the basis of large individual variations, these small changes ($\Delta Q \sim 5\%$, $SD(Q) \geqslant \pm 5\%$) have no clinical significance and need not to be considered in the automatic detection of lung diseases by analyzing lung sounds.

Auscultation of the lung is an important and simple diagnostic method (1). It gives direct information about the structure and function of the lung that cannot be obtained with any other simple and noninvasive method (2–6). Several pathologic changes in the lung, which produce characteristic sounds, can be detected more readily by auscultation than by radiography because of the convenience and availability of the stethoscope (1). Some lung diseases (e.g., pneumonia) can be recognized by experienced clinicians before a radiographic finding is available. For this reason, it is necessary to learn and understand the "language" of lung sounds.

The only reliable and quantitative method for an objective assessment of lung sounds is a digital recording with subsequent frequency analysis. Usually, a Fast Fourier Transformation (FFT) is used to calculate a power spectrum (7). To characterize the frequency spectrum, earlier studies have used the following parameters: median frequency (8, 9), selected frequency with the highest power (9), quantile frequencies (8), and the power of frequency bands (7, 10). In subjects with healthy lungs, the frequency range of the vesicular breathing sounds extends to 1,000 Hz, whereas the majority of the power within this range is found between 60 Hz and 600 Hz (7, 11). Other sounds, such as wheezing or stridor, can sometimes appear at frequencies above 2,000 Hz (7). The normal classification of lung sounds in frequency bands involves low (100 to 300 Hz)-, middle (300 to 600 Hz)-, and high (600 to 1,200 Hz)-frequency bands (10). In the range of lower frequencies (< 100 Hz), heart and muscle sounds overlap; this range must therefore be filtered out for the assessment of lung sounds (2).

Because the tracheal sounds correlate with body height (8) and airflow (12–14), and because the amplitude of normal breathing sounds is also airflow-dependent (15–17), a correct comparison of different breathing-sound spectra requires a similar airflow (18, 19).

Changes in lung function with age have long been well known and studied (20); among these are the age dependence of airway closure (21) and or the loss of pulmonary elasticity (21, 22). The frequency spectrum of lung sounds below 300 Hz in infants and children is also age dependent (18). In adults, an age dependence of lung sounds has been assumed (7), but exact investigations of this topic have not yet been done. Should an age-dependence exist, it must be considered during diagnostic auscultation.

We developed a digital method of analyzing breathing sounds, and evaluated this method in a prospective study of volunteers to test whether an age-dependence of lung sounds could be found.

METHODS

Subjects

A total of 162 subjects, aged 20 to 80 yr and with healthy lungs, were investigated. They were recruited from our hospital. Patients with lung diseases (based on their history, auscultation, radiographic findings, and lung function tests) were excluded. Smokers ($n = 67$) as well as nonsmokers ($n = 95$) and both males ($n = 83$) and females ($n = 79$) were selected. The distribution of subject age was homogeneous (Table 1). The subjects were classified as nonsmokers if they had not smoked for more than 5 yr and if the number of pack-years smoked was not more than five. Written informed consent was obtained from each subject.

Measuring Methods

Because no standard procedure for the recording of lung sounds had previously been available, we will describe our procedures in detail.

Our system allows continuous recording of a maximum of five signal sources with a scanning rate of 5,512 Hz for each source (23). The recording of lung sounds was done with four air coupled microphones (ECM77; Sony, Inc., Tokyo, Japan), that proved to be useful for recording normal lung sounds (24). A half-sphere coupling chamber between the skin surface and the microphone was used. The size and form of the microphone coupler are of great importance, owing to their influence on the transmission of lung sounds (25, 26). With increasing depth of the coupler cavity, the high-frequency response of the transmission diminishes.

However, the main interest in our study was focused on frequencies below 600 Hz, and our coupler depth of 6 mm was therefore sufficient. The couplers and the microphones were tested and calibrated at the German national institute for science and technology (Physikalisch Technische Bundesanstalt) in Brunswick, Germany. There were only marginal differences in the measuring spectra of the microphones.

In order to investigate whether there were differences in sounds at different locations, we recorded the breathing sounds in four positions

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TABLE 1

DISTRIBUTION OF SUBJECTS' AGES

Age (*yr*)	Male (*n = 73*)	Female (*n = 62*)
20–29	16	14
30–39	16	16
40–49	16	16
50–59	17	13
60–69	10	12
> 70	8	8

on the posterior chest (3rd intercostal spaces in the left and right paravertebral positions, and 7th intercostal spaces of the midscapular line on the left and right sides). The microphone couplers were secured with double-sided tape in fixed positions on the subjects' backs.

Airflow was measured with a pneumotachograph (Model 974010; Siemens, Munich, Germany) equipped with a pressure-sensor (Model 160PC; Honeywell-Microswitch, Minneapolis, MN) and amplifier (Model TP-MF-01-48-B; GEPAmbH-Munich, Germany) and was simultaneously displayed on a computer monitor. It was possible to control the subjects' airflow by means of marked lines on the monitor. The controlled breathing needed for this was practiced with every subject before data recording. The subjects were instructed to attain but not to exceed a certain flow value (1.7 L/s) if possible, which resulted in the airflow being approximately the same in all records. Thus, the requirements for a comparison of frequency spectra were met.

By using standardized breathing, we assumed that the influence of sounds emanating from the mouth or pneumotachograph tube were the same for all volunteers, and would show no changes with age. Because of the long distance from the mouth to the microphones on the subjects' backs, the sounds generated at the mouth or pneumotachograph could be neglected during lung-sound analysis.

To reduce the influence of heart and muscle sounds, as well as noise, and to prevent aliasing, we bandpass-filtered all sound signals (TP-MF-01-48b), using a bandpass of 60 to 2,100 Hz (48dB/octave; Butterworth). We also analogously amplified the sound signals from the microphones to provide an acoustic on-line control.

All signals were digitized at 5,512 Hz with 12-bit resolution (ADC; Sorcus M4/486, Heidelberg, Germany) for computerized frequency analysis.

Evaluation

For the evaluation of individual recordings, we used the established technique of FFT with overlapping windows (2, 7, 27–29). All numerical calculations were done with the version MATLAB 5.2 program package (which includes a signal-processing toolbox) (The MathWorks, Inc., Natick, MA).

As the first step in our analysis of lung sounds, we identified artifacts such as rubbing sounds of the microphone cable or overmodulation of the amplifier, and removed them with help from spectrogram overview FFT. Four consecutive inspirations and expirations were then chosen from every recording. By comparing the individual microphone signals, we calculated the power spectrum at maximal flow (PS_{mf}) for the instantaneous times of maximal flow values in the respiratory cycle. Next, we applied an FFT with a window of 0.1 s. With this technique, the resolution of the frequency values amounts to 11 Hz. The controlled breathing described earlier leads to a plateau area of flow values near their maximum values, ensuring a more constant flow within the window of 0.1 s. The values of PS_{mf} were averaged over the four breathing cycles. The amplitude of PS_{mf} (relative power) was interpreted as a probable distribution of frequencies (the sum of the absolute values was normalized to 1). Using this method, it is possible to compare the distribution of frequencies from different recordings regardless of the loudness of lung sounds.

For the characterization of frequency spectra, we used the following parameters (Figure 1): median frequency (Fmedian), mean frequency (Fmean), frequency with the highest power (Fmax), and quantile frequencies (F2, F20, F80, F98). Additionally, we created a new descriptive parameter to characterize the frequency spectrum, as subsequently described.

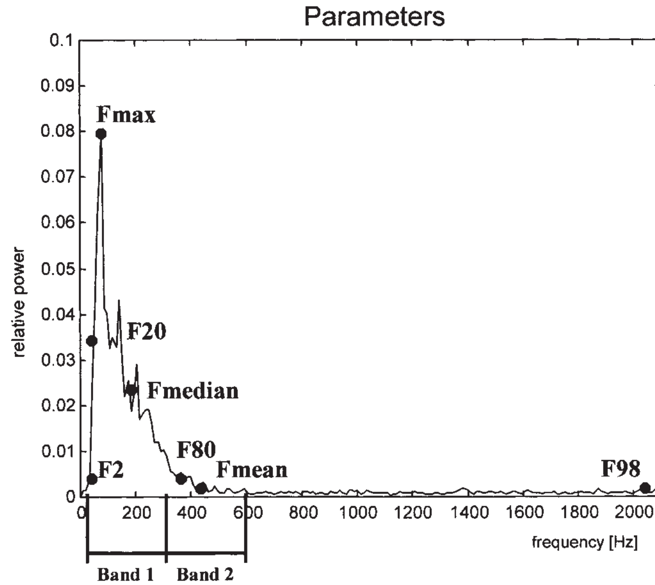

Figure 1. Parameters for spectral-analysis shown at PS_{mf}.

The majority of lung sounds are found within the frequency band of 60 to 600 Hz. We separated this area into two bands of the same size and calculated the ratio (Q) of these two frequency bands as follows:

$$Q = \frac{\text{rel.Power(330 to 600 Hz)}}{\text{rel.Power(60 to 330 Hz)}} \cdot 100\%$$

The ratio Q provides information about an eventual change in the frequency range between 60 and 600 Hz. It does not take into consideration noise components of higher frequencies (> 600 Hz), and is therefore suitable for describing changes in lung sounds in the area of interest.

Within the study subject groups, values were averaged and values of SD were calculated. The square of Pearson's product-moment coefficient of correlation (r^2) and the respective p values for the individual parameters versus age were then calculated. Student's *t* test was used to check group differences. All statistical calculations were made by using SPSS for Windows 8.0 (SPSS, Inc., Chicago, IL). A value of $p < 0.05$ was taken to be statistically significant.

RESULTS

The breathing sounds of 162 subjects (83 males; age = 47.0 ± 15.7 yr [mean ± SD]; height = 1.78 ± 0.08 m; body mass index [BMI] = 26.4 ± 4.5; and 79 females; age = 46.6 ± 16.3 yr; height = 1.65 ± 0.07 m; BMI = 24.6 ± 4.3) with healthy lungs were recorded and separated according to sex and smoking habit. In comparing individual groups, no significant differences were noted with regard to smoking habit. However, the lung sounds of males and females showed significant differences in Q, and were therefore evaluated separately (Table 2).

Significant differences were also seen between inspiration and expiration. With respect to this comparison, it must be noted that high-frequency noise components have a greater influence on quiet breathing sounds during expiration. The average frequency values (Fmean) for inspiration were increased, although PS_{mf} was shifted to lower frequencies. This is clearly illustrated by a decrease in Q and a reduction in Fmax (Table 2).

No significant changes with age were found in F2, F20, F80, F98, or Fmax. At all four recording sites, there was significant correlation between Q and age ($p < 0.05$) for both men and women, and for both inspiration and expiration. The extent of the correlation was only slight ($r^2 \leqslant 0.1$). The values of the lin-

TABLE 2

COMPARISON OF PARAMETERS CALCULATED FOR MALE AND FEMALE SUBJECTS FROM RECORDINGS OF THE FOUR MICROPHONE POSITIONS USED IN THE STUDY*

	Microphone at 3rd Intercostal Space on Left Side			Microphone at 7th Intercostal Space on Left Side		
	Male (*n* = 73)	Female (*n* = 62)	*t*-Test	Male (*n* = 71)	Female (*n* = 70)	*t*-Test
Med I	193.5 ± 32.8 Hz	210.5 ± 41.2 Hz	n.s.	198.0 ± 32.5 Hz	211.3 ± 33.5 Hz	$p < 0.05$
Mean I	411.3 ± 101.5 Hz	384.7 ± 79.9 Hz	n.s.	373.4 ± 88.0 Hz	330.4 ± 58.4 Hz	n.s.
Max I	103.0 ± 34.9 Hz	113.8 ± 55.2 Hz	n.s.	109.2 ± 29.1 Hz	118.7 ± 41.6 Hz	n.s.
QI	15.5 ± 5.6%	22.4 ± 10.9%	$p < 0.05$	18.6 ± 7.7%	23.9 ± 8.4%	$p < 0.05$
Med E	192.9 ± 54.4 Hz	199.3 ± 63.5 Hz	n.s.	187.9 ± 32.5 Hz	194.7 ± 62.4 Hz	n.s.
Mean E	503.1 ± 140.8 Hz	481.3 ± 125.0 Hz	n.s.	482.3 ± 137.5 Hz	453.2 ± 131.5 Hz	n.s.
Max E	92.9 ± 24.3 Hz	93.4 ± 24.3 Hz	n.s.	86.4 ± 19.4 Hz	89.2 ± 24.4 Hz	n.s.
QE	12.4 ± 5.2%	15.8 ± 7.4%	$p < 0.05$	13.3 ± 5.7%	16.5 ± 6.4%	$p < 0.05$
	Microphone at 3rd Intercostal Space on Right Side			**Microphone at 7th Intercostal Space on Right Side**		
	Male (*n* = 73)	Female (*n* = 68)	*t*-Test	Male (*n* = 75)	Female (*n* = 70)	*t*-Test
Med I	201.3 ± 38.4 Hz	205.5 ± 37.0 Hz	n.s.	172.2 ± 24.1 Hz	191.7 ± 88.2 Hz	n.s.
Mean I	435.5 ± 122.3 Hz	384.6 ± 100.6 Hz	$p < 0.05$	313.1 ± 66.5 Hz	290.6 ± 104.9 Hz	n.s.
Max I	104.3 ± 32.3 Hz	107.4 ± 38.4 Hz	n.s.	108.2 ± 31.1 Hz	107.6 ± 34.4 Hz	n.s.
QI	15.7 ± 5.9%	20.0 ± 8.8%	$p < 0.05$	13.1 ± 5.2%	16.6 ± 6.8%	$p < 0.05$
Med E	205.8 ± 57.3 Hz	205.0 ± 68.7 Hz	n.s.	154.0 ± 29.7 Hz	156.7 ± 29.5 Hz	n.s.
Mean E	483.5 ± 143.8	439.2 ± 140.1 Hz	n.s.	387.5 ± 99.0 Hz	361.0 ± 98.7 Hz	n.s.
Max E	109.3 ± 38.0 Hz	107.1 ± 40.8 Hz	n.s.	88.7 ± 21.7 Hz	87.5 ± 21.3 Hz	n.s.
QE	14.0 ± 7.1%	17.1 ± 7.4%	$p < 0.05$	10.6 ± 4.1%	12.3 ± 4.6%	$p < 0.05$

Definition of abbreviations: E = expiration; I = inspiration; Max = frequency with highest power; Mean = mean frequency; Med = median frequency; n.s. = not significant; Q = ratio of 330- to 600-Hz frequency band to 60- to 330-Hz frequency band.
* Without artifacts.

ear regression equation (Y = ax + b) for the correlation are given in Table 3. In Figure 2, the dependence on age of Q for one recording site is seen (linear regression of age versus Q for the 7th intercostal space on the left side). This position represents vesicular breathing. The large individual variations are easily recognized because of the wide scattering of values. The increases in the linear regression (y = ax + b) are small ($a \sim 0.1$, $\Delta Q \sim 5\%$; Table 3) in relation to the standard deviations of Q for the various age groups (STD[Q] $\geqslant \pm 5\%$).

With regard to anthropometric parameters, we found a small correlation between BMI and lung sounds ($r^2 < 0.2$) only for some recording sites. Height, body weight, and BMI were only weakly correlated with age ($r^2 \leqslant 0.1$) in our volunteer groups.

DISCUSSION

The nomenclature of lung sounds is not yet internationally standardized (30). Earlier studies tried to characterize an average normal sound spectrum for healthy subjects, as previously described in one such study (11). A project of the European Union (Computerized Respiratory Sound Analysis [CORSA]) is developing a standardized measuring and evaluation method for lung sounds (31, 32). However, standardized description and evaluation methods for normal lung sounds do not currently exist, and the descriptive parameters of the frequency spectrum used in our study must therefore still be tested. We investigated for changes with age in the distribution of frequencies of lung sounds, and not in their loudness. Referring to the description of the frequency spectrum shown in Figure 1, the quantile frequencies (F2, F20, F80, F98), the average values (Fmean), and the frequency component with the maximum amplitude (Fmax) are not ideal. The quantile frequencies and Fmean represent only the minority of lung-sound power (Figure 1). Fmax depends mainly on the cutoff frequency of the high-pass filter, and shows only minimal changes in the different measurements. A better parameter is the Q for both the 60

TABLE 3

COMPUTED PARAMETERS* FOR LINEAR REGRESSION (y = ax + b) BETWEEN AGE AND RATIO Q OF 330- TO 600-Hz FREQUENCY BAND TO 60- TO 330-Hz FREQUENCY BAND FROM RECORDINGS AT FOUR MICROPHONE POSITIONS

	Microphone at 3rd Intercostal Space on Left			Microphone at 7th Intercostal Space on Left			Microphone at 3rd Intercostal Space on Right			Microphone at 7th Intercostal Space on Right		
	Parameter	Male (*n* = 73)	Female (*n* = 62)	Parameter	Male (*n* = 71)	Female (*n* = 70)	Parameter	Male (*n* = 73)	Female (*n* = 68)	Parameter	Male (*n* = 75)	Female (*n* = 70)
Q Inspiration	r^2	0.06	0.07	r^2	0.06	0.11	r^2	0.08	0.13	r^2	0.06	0.13
	b	11.39	14.12	b	13.16	15.71	b	10.74	11.13	b	9.45	9.4
	a	0.09	0.18	a	0.13	0.18	a	0.11	0.17	a	0.09	0.16
Q Expiration	r^2	0.09	0.05	r^2	0.07	0.09	r^2	0.06	0.06	r^2	0.07	0.07
	b	7.83	11.31	b	8.85	11.01	b	9.80	11.50	b	7.55	8.70
	a	0.10	0.10	a	0.10	0.12	a	0.09	0.12	a	0.07	0.08

Definition of abbreviations: Q = ratio of 330- to 600-Hz frequency band to 60- to 330-Hz frequency band; r^2 = square of Pearson product-moment coefficient of correlation.
* Described in the text.

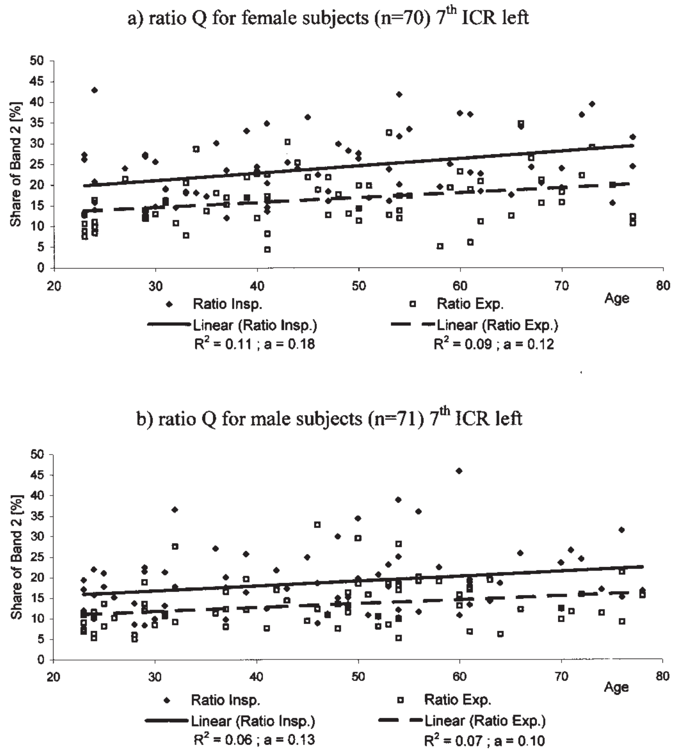

Figure 2. Linear regression (y = ax + b) for age dependence of Q, for male and female subjects for the 7th intercostal space on the left side (meanings of symbols are described in the figure).

to 330 Hz and 330 to 600 Hz frequency bands, where the majority of breathing sounds are found. Q provides a means of identifying changes in energy in that region of the acoustic spectrum in which there is significant energy, without regard to the band of frequencies with minimal power. Additionally, the frequency band between 300 and 600 Hz is important for automatic identification of bronchial breathing (33), a frequent auscultatory finding in patients with pneumonia. Should changes appear in this frequency band, they would have to be calculated as correction factors in the assessment of pneumonia.

In other studies (11, 18, 34), the breath-sound spectrum has been applied as double logarithmic. In one study, a twin-shared linear fit was computed (11). In such studies, the slopes of the linear regression equations are used as descriptive parameters. Our results are basically comparable to the results of these studies.

In investigations of lung sounds of healthy subjects, differences in the frequency spectra of vesicular breath sounds of men and women were found (11). We also found a larger proportion of higher frequencies in women than in men. This difference was significant in our study. Like Gavriely and colleagues (11), we did not find a significant difference between smokers and nonsmokers.

The normal frequency spectra of inspiration and expiration are different and must be considered as individual characteristics. Similar findings have been made by other research groups (10, 11, 18). A different mechanism for the origin of lung sounds has been considered as a probable cause of this difference (11, 34).

Muscle sounds can overlap with the spectral region of breathing sounds at lower frequencies (7). If there are changes in muscle sounds with age, this could have influenced our results. For a minimization of these effects, we used a high-pass filter of 60 Hz, as have other groups (2).

Lung sounds in different lung locations are not identical (10, 11, 34, 35). For this reason, we recorded the lung sounds at four different sites. In our measurements, we identified only small differences in lung sounds between these four auscultation sites (Table 2).

A small change in lung-sound spectra with age was observed at all four auscultation sites. A negligible displacement of the frequency pattern to higher values occurred. This is illustrated by a significant correlation between Q and age. The dependence on age was of the same magnitude for both men and women. A possible cause for the correlation between lung sounds and age could be the change in tissue structure with age, which also leads to a change in lung function (20–22).

At some locations we found only a slight correlation between BMI and Q ($r^2 < 0.2$, data not shown). The correlation between age and BMI was also weak for our volunteer groups ($r^2 \leqslant 0.1$); therefore, the influence of BMI on the age dependence of lung sounds can be neglected.

It is well known that normal lung sounds show interpersonal variations. In addition to this, it has to be taken into account that both a same-day variability and a between-day variability exist in lung sounds (36). On the basis of these large variations, the changes with age were seen only with investigation of a larger number of subjects.

Changes in breathing sounds in pathologic processes have long been known and studied. These changes are much more pronounced, with the result that slight age-dependent changes can be neglected in the automatic detection of lung diseases. "Electronic auscultation" could be introduced as a routine clinical technique for the objective diagnosis of lung diseases and their progress, without consideration of the age of the patient.

With respect to the investigation of breathing sounds, computer supported analyses have contributed to understanding of the origin and transmission of different acute signals of the respiratory system, as well as to the understanding of their clinical importance (7). On the other hand, the subjective perception of lung sounds and their interpretation by experienced physicians will continue. The purpose of computer-supported analysis of breathing sounds is their objective understanding and archiving. Because the sensitivity of human hearing is reduced, particularly in the lower frequency ranges, an objective electronic recording for recognizing deviations within these ranges could be helpful. Since the procedure for doing this is not costly, invasive, or particularly intensive, it would be suitable as an examination method for high-risk groups such as pneumonia patients. A daily or even more frequent analysis of lung-sound spectra could help to identify patients with incipient pneumonia before the appearance of any radiologic abnormality.

In conclusion, we found age-determined changes of lung sounds do exist. A negligible displacement of the frequency pattern to higher values occurred with progressive age. This was of the same magnitude for both men and women. However, these changes are too small to be clinically relevant. Consequently, there is no need to consider a patient's age during automated lung auscultation.

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