European Journal of Pediatrics (2025) 184:337
https://doi.org/10.1007/s00431-025-06110-y

RESEARCH

Characteristics of lung sounds in early infants using automated analysis

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Received: 31 January 2025 / Revised: 3 March 2025 / Accepted: 24 March 2025

Abstract

A new lung sound analysis software program has been developed. It can automatically select a typical lung sound spectrogram and calculate lung sound parameters using machine learning programs. This study aimed to clarify lung sound characteristics in early infants using this program. Using the program, the characteristics of lung sounds in healthy 1- and 4-month-old infants were examined. The lung sounds were assessed in the supine position for 1-month-old infants and in both the sitting and supine positions for 4-month-old infants. We compared the characteristics of the infant lung sounds with those of healthy 3-year-old children. The lung sound parameters of the 1-month-old infants ($n = 58$) were affected by gender, height, and birth weight. However, those of the 4-month-old infants ($n = 50$) obtained in the sitting or supine position were not affected by these factors in the study. The lung sound parameters obtained in the sitting and supine positions were not significantly different, and they were not related to a history of wheezing or allergy. PAP_0 was higher for the 1-month-old infants than for the 4-month-old infants, and RPF_{50p} and RPF_{75p} were also higher for the 1-month-old infants than for the 4-month-old infants. The PAP_0, FAP_0, RPF_{50p}, RPF_{75p}, $A_{3a/AT}$, and $B_{4a/AT}$ of the 4-month-old infants were significantly higher than those of the 3-year-old children ($n = 80$).

Conclusion The new program confirmed the specificity of lung sound parameters in early infants. Further studies are needed to clarify why the specificity differs from that of 3-year-old children.

What is Known:
- *Lung sound analysis has been evaluated to some extent as safe and straightforward for estimating lung function in toddlers and older humans. However, it has not been applied to early infants.*

What is New:
- *A lung sound analysis method using new analysis software has clarified the characteristics of lung spectra in early infants. This technique may facilitate the early diagnosis and treatment of respiratory diseases in infants.*

Keywords Artificial intelligence · Chronic lung disease · Infant · Lung sound analysis

Communicated by: Peter de Winter

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Abbreviations

0 point	The maximum point of the breath sound spectrum extracted from parameter analysis
AI	Artificial intelligence
A_T	Total area under the curve of 100 Hz to the 0 point
AUC	Area under the curve
A_{3a}	Third area under the curve divided into 3 parts
A_{3a}/A_T	Ratio of high-pitched third area to total area
B_{4a}	Fourth area under the curve divided into 4 parts
B_{4a}/A_T	Ratio of high-pitched fourth area to total area
CLD	Chronic lung disease
COPD	Chronic obstructive lung disease

Published online: 13 May 2025

dBF_{50p}	DB at F_{50p}
dBF_{75p}	DB at F_{75p}
FAP_0	Analysis parameter of frequency at the 0 point
ML	Machine learning
PAP_0	Analysis parameter of power at the 0 point
RPF_{50p}	Ratio of power to (F_{99p}-F_{50p})[= dBF_{50p}/(F_{99p}-F_{50p})]
RPF_{75p}	Ratio of power to (F_{99p}-$F7_{5p}$)[= dBF_{75p}/(F_{99p}-F_{75p})

Introduction

Neonatal chronic lung disease (CLD) is a severe complication in infants with very low birth weight that can lead to respiratory dysfunction in the long term and growth and neurodevelopmental impairment [1, 2]. CLD and preterm birth are risk factors for the persistent decline in lung function and the onset of childhood asthma [3, 4]. For this reason, early follow-up monitoring incorporating the evaluation of respiratory function is required.

In recent years, airway diseases have been actively studied using lung sound analysis. Respiratory sound analysis can evaluate airway changes in infants [5], and it has been validated to be considerably safe and simple [6, 7]. Advances in artificial intelligence (AI) have markedly improved the technology that can extract information related to clinical diseases from respiratory sounds [8–12]. These technologies are expected to accurately detect respiratory diseases in real-time and facilitate early diagnosis. We recently reported on the clinical application of software [13] utilising machine learning (ML) algorithms to perform more accurate analysis of the lung sounds of children than current methods. The software program can automatically select the typical inspiratory sounds suitable for analysis from the lung sound spectrogram and calculate the lung sound parameters of these inspiratory sounds using ML algorithms.

This study aimed to compare the characteristics of the lung sounds of 1- and 4-month-old infants using the lung sound analysis software program.

Material and methods

Participants

The participants were infants who underwent a 1-month infant health checkup at our hospital and a 4-month infant health checkup in Isehara City, Kanagawa Prefecture, between April 1, 2024, and October 31, 2024. Their gestational ages were ≥ 37 weeks, and they weighed > 2500 g at birth. Infants who had respiratory symptoms on the day of the checkup or those with severe respiratory, circulatory, or neurological diseases were excluded. The parents or guardians of the 1-month-old infants were interviewed about pregnancy and delivery, and those of the 4-month-old infants were asked to complete a questionnaire (Supplementary Table) based on the ATS-DLD [14].

The data of eighty 3-year-old healthy children (boys: girls, 34: 46) without respiratory, circulatory, or neurological diseases who underwent an infant health check at age 3 in Isehara City between January 1, 2023, and March 31, 2024, were used for comparison. These data were used in our previous study [9 → 13].

Collection of lung sounds

Lung sounds were collected as described in previous reports [8, 9, 15]. Respiratory sounds were collected for > 10 s in a quiet room using a commercially available lung sound analysis system, LSA- 2020 (Kenz Medico Co., Saitama, Japan). A handheld microphone (BSS- 01, Kenz Medico Co., Saitama, Japan) was placed at the right second intercostal space along the midclavicular line. An acoustic amplifier unit was effective for analysing inspiratory sounds in the range of 100–2500 Hz. The recorded lung sounds were analysed according to the fast Fourier transform. The spectrum was obtained using a Hanning window, and the sampling frequency was 10,240 per second. The processing tap count was 2048, 1024, and 512 (default, 1024), and the frequency resolution was 10 Hz (when the tap count was 1024).

Lung sounds were assessed at rest in the supine position for 1-month-old infants and in the supine and sitting positions for 4-month-old infants to confirm their differences at rest in these positions. The lung sounds were assessed in the sitting position for the 3-year-old children.

Lung sound analysis using the new software

Lung sound analysis was performed according to a previous report [13]. The original lung sound analysis software program (Murata Manufacturing Co., Ltd., Version 1.6) can automatically (1) select the subject's typical inspiratory sounds suitable for the analysis from lung sound samples on the lung sound spectrogram and (2) analyse the lung sound parameters of the selected inspiratory sounds. The first 10 s of the acquired spectrogram image of each object are automatically selected, and each parameter is automatically calculated and then saved as individual data. To avoid crying sounds and external noises, the examiner can select the optimal 10 s to start the automatic analysis.

The selection of inspiratory sound samples mentioned above and the creation of an appropriate power spectrum for inspiratory sounds were automatically analysed using the ML algorithm [13]. The lung sound data were transformed into a spectrogram in an automatic procedure. From the spectrogram, multiple sound source components were extracted using non-negative matrix factorization (NMF), and the exact time when inspiration is relatively large was determined from each component. The power spectrum at the time was smoothed using Bayesian estimation [13]. Simultaneously, new lung sound parameters were calculated.

To calculate the new parameters using this software, the analytical base point (0 point) was calculated from the spectrum of the inhalation sounds of the participant [13]. The maximum frequency at the 0 point was calculated as FAP_0 (kHz) for convenience, and the basal lung sound power was calculated as PAP_0 (dBm). Other lung sound parameters were also determined using the 0 point in accordance with the previous lung sound analysis method [15]. The power (dBm) at half of the frequency from 100 Hz to the 0 point divided by the frequency at the same time (F_{50}) was designated as RPF_{50p}, and the power (dBm) at three-fourths of the frequency divided by the frequency at the same time (F_{75}) was designated as RPF_{75p}. Further, A_{3p} was defined as two-thirds of the frequency from 100 Hz to the 0 point, and A_{3a} was defined as the area from A_{3p} to the 0 point in the high-pitched region. A_{3a} was divided by the total area (A_T). B_{4p} and B_{4a}/A_T were calculated in the same manner [13].

Examination of the specificity of the lung sounds of the 1- and 4-month-old infants

For the 1-month-old infants, the correlations of each lung sound parameter calculated from the sample of each individual with gender, height, weight, respiratory rate, and birth weight were determined. Their respiratory rates were likely to fluctuate. They were measured within 6 to 10 s around the inhalation sound, and the number of breaths per minute was calculated.

In addition to these factors, correlations with the results of the ATS-DLD questionnaire regarding history of wheezing, diagnosis of asthma/asthmatic bronchitis, history of respiratory syncytial virus infection, and history of allergies were determined [14]. Furthermore, body position may affect the lung sound parameters of 4-month-old infants [16], and the influence of body position (sitting and supine) on lung sound parameters was examined. Changing position can induce infants to cry. Therefore, the decision to initially place the participant in the sitting or supine position was made based on the posture when entering the room (held by the mother or in a baby carriage).

Furthermore, the lung sound data of the 3-year-old children when they were younger were compared to examine the characteristics of the lung sounds of early infants.

Comparison with lung sounds of 3-year-old children

From the lung sound spectra of each 1-month-old infant (supine), 4-month-old infant (supine and sitting), and 3-year-old child (sitting), the median lung sound power for each frequency was calculated using the previous method [17]. The graphic data were compared.

Statistical analyses

The statistical analyses were conducted using SPSS software (IBM SPSS Statistics, Version 22 for Windows; IBM Corp., Armonk, N.Y., USA). Correlations were determined using Pearson's correlation coefficients. Mann–Whitney *U*-test was used to determine the difference between the two groups. The Wilcoxon signed-rank test was used to test the difference in measurements obtained at the sitting and supine positions for the same 4-month-old infant. *P*-values of < 0.05 denoted statistical significance.

Results

Participants

The lung sounds of 58 of 63 1-month-old infants (92%, median age 32 days, boys: girls, 32:26) were analysed (Table 1). The lung sounds of the remaining five (8%, boys: girls, 4:1) could not be analysed because they were crying during measurement.

Table 1 Characteristics of 1-month and 4-month-old infants

Characteristic	1 month ($n = 58$)	4 months ($n = 50$)	U	P
Sex (m:f)*	32:26	23:27	1313.0	0.33
Weight (g)	4105[§] (3165, 5610)	6750 (5270, 8600)	0.0	**< 0.001**
Height (cm)	52.5 (49.0, 56.5)	63.0 (57.5, 69.0)	0.0	**< 0.001**
Respiratory rate (/min)	59 (40, 102)	57[†] (31, 73)	680.5	**< 0.001**
Birth weight (g)	2963 (2500, 3935)	3100 (2528, 3985)	1329.5	0.57
Gestational age (weeks)	38.6 (37.6, 41.0)	39.7 (37.4, 41.6)	734.5	**0.003**

[*] *m:f* male:female, [§] median (minimum, maximum), [†] supine position. *U* and *P*-values were calculated using Mann–Whitney *U*-test

The lung sounds of 57 of 61 4-month-old infants were analysed (94%, median age 4 months 10 days, boys: girls, 27: 31). The sounds of the other four (7%) could not be analysed because they were crying during the assessment. The lung sounds were analysed in both the sitting and supine positions for 50 infants (88%, median age 4 months 11 days, boys: girls, 23: 27) (Table 1). Seven infants (12%) did not have their lung sounds recorded in both positions because the crying did not stop after changing positions. The assessment began in a sitting position for 46 of 50 participants (92%).

Characteristics of lung sounds in 1- and 4-month-old infants

Figure 1 shows typical lung sound spectrograms of 1- and 4-month-old infants and 3-year-old children. The inhalation sound in the lung sound spectrograms of these infants appeared as a vertically long rectangle. On the other hand, the shape for the 3-year-old children was triangular. For all cases in this study, the expiratory sound was not clearly visualised on the image.

The relationships between the lung sound parameters and sex, height, weight, birth weight, and respiratory rate were assessed for the 1-month-old infants. The girls had lower PAP_0 values ($P = 0.02$); PAP_0 is the basal lung sound power of the lung sound parameter. Height was also positively correlated with PAP_0 ($P = 0.03$) (Table 2). Similarly, birth weight was positively correlated with RPF_{75p} and B_{4a}/A_T ($P = 0.04$, $P = 0.04$, respectively).

For the 4-month-old infants, no correlations were found between the lung sound parameters and sex, height, weight, birth weight, or respiratory rate, except for RPF_{75p} and weight (Table 3). Furthermore, no correlations were found between any of the lung sound parameters and history of wheezing, diagnosis of asthma, RSV infection and allergic diseases, smoking, and use of domestic pets based on responses of the parents or guardians to a questionnaire interview (Supplementary Table; data not shown).

In examining the effects of posture in the 4-month-old infants, no clear differences were found between the lung sound parameters of the same infants assessed in the sitting and supine positions (Table 4).

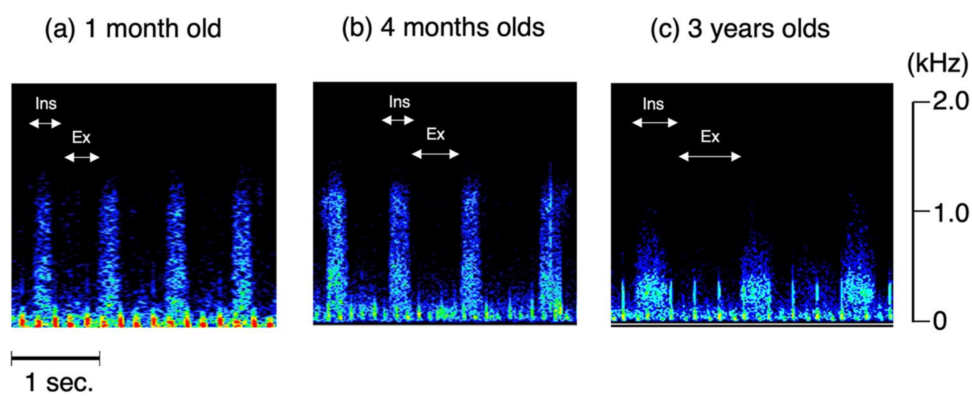

Fig. 1 Lung sound spectrograms of 1- and 4-month-old infants and 3-year-old children. **a** One-month-old infants. **b** Four-month-old infants. **c** Three-year-old children. The shapes of **a** and **b** are close to rectangles, while the shape of **c** is a triangle. Ex, expiration; Ins, inspiration

Table 2 Relationships between sex, height, weight, birth weight, and respiratory rate and each parameter in 1-month-old infants ($n = 58$, supine position)

Metric		Sex (m:f)*	Height (cm)	Weight (g)	Birth weight (g)	Respiratory rate (/min)
PAP_0	CC	− 0.312	0.283	0.131	0.080	0.227
	P	0.02	**0.03**	0.33	0.55	0.09
FAP_0	CC	0.064	− 0.076	− 0.015	− 0.214	− 0.013
	P	0.63	0.57	0.91	0.11	0.92
RPF_{50p}	CC	− 0.082	0.194	0.194	0.249	0.092
	P	0.54	0.15	0.14	0.06	0.49
RPF_{75p}	CC	− 0.159	0.132	0.235	0.275	− 0.168
	P	0.24	0.32	0.08	**0.04**	0.21
A_{3a}/A_T	CC	− 0.185	0.125	0.121	0.234	− 0.161
	P	0.17	0.35	0.36	0.08	0.23
B_{4a}/A_T	CC	− 0.203	0.201	0.189	0.268	− 0.080
	P	0.13	0.13	0.16	**0.04**	0.55

**m:f* male:female. Correlation coefficients (CC) were calculated by Pearson's correlation coefficient. Bold letter of *P*-value for CC shows a statistical significance

Table 3 Relationships between sex, height, weight, birth weight, and respiratory rate and each parameter in 4-month-old infants ($n = 50$)

Parameter		Sex (m:f)*	Height (cm)	Weight (g)	Birth weight (g)	Respiratory rate (/min)
Sitting position						
PAP_0	CC	−0.006	−0.165	−0.013	0.088	0.237
	P	0.97	0.31	0.94	0.55	0.10
FAP_0	CC	0.214	−0.117	−0.075	−0.112	0.085
	P	0.14	0.47	0.64	0.44	0.56
RPF_{50p}	CC	−0.005	0.163	0.289	0.136	−0.058
	P	0.97	0.32	0.06	0.35	0.69
RPF_{75p}	CC	0.072	0.145	0.318	0.178	−0.040
	P	0.62	0.37	0.04	0.22	0.78
A_{3a}/A_T	CC	0.116	0.067	0.172	0.042	0.042
	P	0.42	0.68	0.28	0.77	0.77
B_{4a}/A_T	CC	0.154	0.053	0.161	0.134	0.134
	P	0.29	0.75	0.31	0.35	0.35
Supine position						
PAP0	CC	0.020	0.145	0.182	0.097	−0.197
	P	0.89	0.37	0.25	0.51	0.17
FAP0	CC	−0.235	0.245	0.011	−0.032	0.020
	P	0.10	0.13	0.95	0.83	0.89
RPF50p	CC	0.075	−0.182	−0.014	0.080	0.149
	P	0.60	0.26	0.93	0.59	0.30
RPF75p	CC	−0.164	−0.121	0.180	0.108	−0.002
	P	0.26	0.46	0.25	0.46	0.99
A3a/AT	CC	−0.217	−0.101	0.161	0.026	−0.008
	P	0.13	0.54	0.31	0.86	0.96
B4a/AT	CC	−0.262	−0.074	0.155	0.014	−0.032
	P	0.07	0.65	0.33	0.92	0.83

**m:f* male:female. Correlations were determined using Pearson's correlation coefficients (CC). Bold letters of *P*-value for CC indicate statistical significance

Table 4 Comparison of lung sound parameters of 4-month-old infants obtained in the sitting and supine positions ($n = 50$)

	Supine position	Sitting position	*Z*	*P*
PAP_0	9.03 (4.10, 18.74)[§]	9.45 (5.53, 16.50)	− 1.781	0.08
FAP_0	1.72 (1.00, 2.15)	1.70 (1.14, 2.10)	− 0.693	0.49
RPF_{50p}	2.19 (0.88, 3.30)	2.18 (0.78, 3.98)	− 0.408	0.68
RPF_{75p}	3.20 (0.61, 4.78)	2.95 (0.67, 5.48)	− 0.516	0.61
A_{3a}/A_T	14.01 (4.45, 31.49)	12.60 (4.19, 27.85)	− 1.646	0.10
B_{4a}/A_T	7.16 (2.29, 20.79)	6.70 (1.85, 16.30)	− 1.627	0.10

[§]Median (minimum, maximum). *Z* and *P*-values were calculated by Wilcoxon signed-rank test

Comparison of lung sound parameters of 1- and 4-month-old infants and 3-year-old children

The PAP_0, RPF_{50p}, and RPF_{75p} of the 1-month-old infants (supine) were significantly higher than those of the 4-month-old infants (supine) ($P = 0.001$, $P < 0.001$, and $P = 0.03$, respectively). All parameters for the 4-month-old infants were higher than those for the 3-year-old children (all assessed in the sitting position) (Table 5). All parameters of the 1-month-old infants (supine) were higher than those of the 3-year-old children (sitting) (Table 5).

Comparison of lung sound spectra of the 1- and 4-month-old infants and 3-year-old children

To evaluate the lung sounds of 1- (supine) and 4-month-old infants (supine and sitting) and 3-year-old infants (sitting), we used a previous method [17] to calculate the median lung sound power (dBm) for each frequency measured at 10 Hz intervals from the lung sound spectrum data of each group of patients and created a graph (Fig. 2). In this figure, − 60 dBm was defined as 0 dB for ease of understanding.

The shapes of the lung sound spectra of 1- and 4-month-old infants were significantly different from those of the 3-year-old children. The lung sound

Table 5 Comparison of lung sound parameters for 1- and 4-month-old infants and 3-year-old children

Parameter	1 month (supine)	4 months (supine)	*U*	*P*	4 months (sitting)	3 years (sitting)	*U*	*P*
PAP_0	10.53[§] (6.08, 15.97)	9.03 (4.10, 18.74)	897.0	**0.001**	9.45 (5.53, 16.50)	8.45[†] (4.56, 15.58)	1241.0	**< 0.001**
FAP_0	1.74 (1.18, 2.24)	1.72 (1.00, 2.15)	1343.0	0.510	1.70 (1.14, 2.10)	1.52[†] (1.00, 2.48)	1274.0	**0.001**
RPF_{50p}	2.66 (1.25, 3.82)	2.19 (0.88, 3.30)	868.0	**< 0.001**	2.18 (0.78, 3.98)	1.60[†] (0.68, 4.11)	1280.5	**0.001**
RPF_{75p}	3.52 (1.15, 5.42)	3.20 (0.61, 4.78)	1085.0	**0.025**	2.95 (0.67, 5.48)	1.75[†] (0.51, 4.40)	880.0	**< 0.001**
A_{3a}/A_T	14.67 (5.10, 24.07)	14.01 (4.45, 31.49)	1217.0	0.151	12.60 (4.19, 27.85)	8.69[†] (1.61, 17.72)	978.0	**< 0.001**
B_{4a}/A_T	7.79 (1.68, 14.03)	7.16 (2.29, 20.79)	1183.0	0.100	6.70 (1.85, 16.30)	5.31[†] (0.17, 10.15)	1383.5	**0.003**

[§]Median (minimum, maximum). *U* and *P*-values were calculated by Mann–Whitney *U*-test. [†]$P < 0.001$ compared with data of 1-month-old infants. Bold letter of *P*-value for CC shows statistical significance

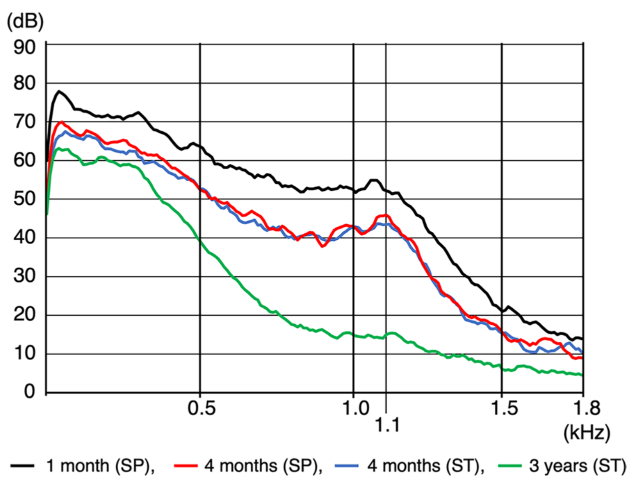

Fig. 2 Lung sound spectra of 1- and 4-month-old infants and 3-year-old children. Lung sound spectra of 1- and 4-month-old infants have almost the same shape, and the high-pitched area of inhaled sound is increased relative to that of 3-year-old children. Furthermore, lung sound spectra of 1- and 4-month-old infants show partial increase in the high-pitched area (around 1.1 kHz). ST, sitting position; SU, supine position

spectrum curve of the inhalation sounds of 1- and 4-month-old infants extended into the high-pitched area, and the lung sound power in the high-pitched area increased around 1.1 kHz. Furthermore, a steep attenuation was observed toward the high-pitched area (Fig. 2). This tendency was somewhat lower in the lung sound spectrum curves of 4-month-olds than for the 1-month-old infants. No difference was observed between the lung sound spectrum curves of the 4-month-old infants in the sitting and supine positions.

Discussion

In this study, we evaluated the lung sound characteristics of 1- and 4-month infants compared to those of 3-year-old children using automated analysis. PAP_0 was associated with sex and height, and RPF_{75p} and B_{4a}/A_T were associated with birth weight. Among the 1-month-old infants in our study, girls were significantly shorter and had greater weight than boys, suggesting that these results may be due to their smaller physique. Smaller physiques are thought to result in lower tidal volume and lower relative airflow [18], and PAP_0, which is the power of sound at the maximum frequency, was low. RPF_{75p} and B_{4a}/A_T, which indicate the volume of lung sounds in the high-pitched area, were also low. This study included only term infants, with relatively limited data on height, weight, and birth weight, which should be kept in mind even when examining age-matched cases.

The lung sound spectrograms of the 4-month-old infants born at term also showed a specific shape similar to those of 1-month-old infants (Fig. 2). On the other hand, lung sound analysis using new parameters showed no effect of various factors on the lung sound parameters. Each parameter settles at a certain value for the age group, which is related to the phenomenon of catching up in the infants [19]. This shows that the evaluation for 4-month-old infants should differ from that for 1-month-old infants. The ATS-DLD questionnaire was administered to 4-month-old children. However, the results were not as clear as those obtained for the 3-year-old children [13]. These were related to factors associated with the onset of lung sound parameters and asthma, which are wheezing or asthma diagnosis, history of RSV infection or allergic diseases, family smoking, or the presence of domestic pets. Four-month-old infants have few opportunities to contract infectious diseases and are also younger than the age at which allergic diseases typically develop [20].

In addition, the values of lung sound parameters did not change significantly depending on the body position (sitting or supine) in this study. These results may indicate that lung sound parameters can be compared across all ages in children. However, previous reports have suggested that changes in position can cause upper airway noise [21], and the effects of compression of the lungs by the thoracic and abdominal organs [22] may affect lung sounds. Therefore, it would be generally desirable to compare sounds obtained from patients in the same posture.

The lung sound spectra of 1- and 4-month-old infants showed no significant difference in the FAP_0 values. However, the 1-month-old infants had significantly higher PAP_0 values than the 4-month-old infants, suggesting an increase in the basic lung sound power with age. Furthermore, the high RPF_{50p} and RPF_{75p} values of the 1-month-old infants indicated an increase in the lung sound spectrum in the high-pitched area. The same observation was made when the lung sound parameters of the 4-month-old infants and 3-year-old children were compared: the younger infants had larger lung sound spectra in the high-pitched area. This was thought to be related to the fact that the inhalation sound spectra of the 1- and 4-month-old infants were tall and close to a rectangle, while those of the 3-year-old children were short and close to a triangle. The shape of the inhalation sound spectra of the 3-year-old infants was consistent with the shape of the lung sound spectrum of older infants reported in previous reports [15, 23].

One of the reasons for the difference in the lung sound spectrum between the early infants and children aged 3 years or older was thought to be the influence of the growth and development of the lungs and chest wall. The lungs act as a low-pass filter for lung sounds [24], and low sounds generated by breathing are easily transmitted, whereas high sounds above the filter cutoff frequency are gradually attenuated [25]. In early infants, the lungs and chest wall are immature and highly compliant, resulting in its diminished function as a low-pass filter. Furthermore, the chest wall is nearly three times as compliant as the lung during infancy, and the chest wall stiffness increases to the point that the chest wall and lung are nearly as equally compliant as during adulthood by the second year of life [26]. In the aforementioned comparison of gender differences of the 1-month-old infants, it was speculated that the power of lung sounds would be greater if the infant was larger in size. However, immaturity of the lungs and chest wall was considered to have a significant impact after comparing the groups with clear age differences.

This study has some limitations. First, the evaluation of lung sounds was obtained at only a single focal point. It was technically difficult to take lung sounds in the left lung areas due to interference from heart sounds for the subjects. Therefore, we could not obtain them at multiple lung areas like a comprehensive assessment of all lung areas by physical examination. Second, we were unable to directly examine the cause of the specific high-pitched sounds during inspiration in early infants. While it is speculated that turbulence not seen in older infants may be occurring in the airways of early infants, direct evaluation is thought to be difficult even with imaging techniques. It seems necessary to continue observations, taking into account the maturation and development of the airway and chest wall. Third, early infants not only have a high respiratory rate but also have unstable breathing volume and rhythm [27]. An analysis system that takes into account the respiratory physiology of early infants will be necessary.

Conclusion

The lung sound parameters obtained using the new analysis software program confirmed the specificity of lung sounds in early infants. The inhalation sound in the lung sound spectrograms of 1- and 4-month-old infants appeared as a vertically long rectangle and differed from those of 3-year-old children. The PAP_0, RPF_{50p}, and RPF_{75p} of the 1-month-old infants were significantly higher than those of the 4-month-old infants. All parameters for 1- and 4-month-old infants were significantly higher than those for 3-year-old children. Further studies are needed to clarify the mechanisms by which such differences are produced.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s00431-025-06110-y.

Acknowledgements We would like to thank the officials of Isehara City for their cooperation in the implementation of the questionnaires for infant health checkups. We would like to thank Editage for their assistance with English-language editing for this manuscript.

Author contributions Dr Yoshifumi Murayama, Prof Hiroyuki Mochizuki, and Prof Yoshiyuki Yamada conceptualized and designed the study, drafted the initial manuscript, and critically reviewed and revised the manuscript. Drs Hidetoshi Yano, Shigeki Ochiai, Mayumi Enseki, and Takashi Koike designed the data collection instruments, collected data, carried out the initial analyses, and critically reviewed and revised the manuscript. Prof Hiroyuki Furuya designed the data collection instruments, carried out the initial analyses, and critically reviewed and revised the manuscript. Prof Atsushi Uchiyama conceptualized and designed the study, coordinated and supervised data collection, and critically reviewed and revised the manuscript for important intellectual content. All authors approved the final manuscript as submitted and agree to be accountable for all aspects of the work.

Funding Open Access funding provided by Tokai University. This work was supported by JSPS KAKENHI Grant Number JP23 K02331.

Data availability No datasets were generated or analysed during the current study.

Declarations

Ethics approval This study was conducted in accordance with the Declaration of Helsinki, and the study protocol was approved by the institutional review board of Tokai University Hospital (No. 22R- 136, approval date: October 20, 2022, and No. 24R028 - 001H, approval date: July 26, 2024). For the 1-month-old infants, partial data were collected before the IRB approval date (July 26).

Consent to participate Written informed consent was obtained from the parents of participants in this study. These were retrospectively added as data of 1-month-old infants who participated in infant health checkups. For these cases, an opt-out was conducted for a period in the paediatric outpatient department of our hospital.

Competing interests The authors declare no competing interests.

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