

Preliminary study of a support system for noninvasive pneumonia detection using breath sound analysis in calves

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Abstract

Pneumonia in calves is caused by a complex association between host, pathogen, and environmental factors, and it is challenging to detect the subclinical stages. Therefore, it is crucial to accurately and rapidly identify calves with pneumonia on farms to provide appropriate treatment in a timely manner. In the present study, we focused on the frequency components of lung sounds to distinguish calves with and without pneumonia, without the need for veterinary expertise. In addition, we evaluated the pathogenesis of pneumonia by clarifying the relationship between the frequency components of lung sounds and lung ultrasound findings in calves. Although further case accumulation is needed, the findings of the present study suggest that the frequency component analysis of lung sounds determined using auscultation may be a useful tool for detecting respiratory abnormalities and that the mean power frequency value of the lung sounds auscultated at the fifth intercostal space may aid in understanding the pathogenesis of interstitial pneumonia.

Keywords: calves, lung sounds, sound analysis

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Introduction

Diseases in livestock reduce productivity, and therefore, it is essential to enable their early detection and treatment. However, livestock are unlikely to show symptoms in the early stages of the disease (Buczinski *et al.*, 2014), and by the time farmers detect the symptoms, the disease is already advanced, resulting in delayed treatment (Leruste *et al.*, 2012). If farmers can detect diseases at an early stage, they and veterinarians can respond quickly. Many cattle suffer from respiratory diseases on farms and these diseases have a significant negative effect on productivity. Lung lesions are associated with reduced growth in beef cattle (Bryant *et al.*, 1999) and weight gain in dairy calves (Waltner-Toews and Martin, 1986). Pneumonia accounts for a large proportion of respiratory diseases in cattle (Curtis *et al.*, 1986), and in calves, pneumonia is a complex disease (known as bovine respiratory disease complex) caused by the interplay of host, pathogen, and environmental factors (Griffin *et al.*, 2010). While it has been reported that calves that contract respiratory disease within the first 3 months of life have a 2.5 times higher risk of death than those that do not (Waltner-Toews and Martin, 1986), it is challenging to detect respiratory disease at the subclinical stage in calves (Leruste *et al.*, 2012; White and Renter, 2009). Therefore, for efficient cattle production, it is crucial to identify calves with pneumonia early and accurately on farms and provide appropriate treatment immediately.

The sounds obtained through auscultation include respiratory sounds and adventitious noises. Differences in the compositions of these sounds are reflected in their frequency components (Reichert *et al.*, 2008). Respiratory sounds, also known as lung sounds, are generated by turbulence and eddy currents in the trachea, bronchi, and alveoli (Pasterkamp *et al.*, 1997). Abnormal or adventitious lung sounds often overlap with normal breathing sounds and are typically classified into one of three categories: intermittent adventitious sounds, continuous adventitious sounds, or pleural friction sounds. Each of these sounds is associated with a specific pathological condition. Intermittent adventitious sounds are brief, typically lasting 25 ms or less, and are further categorized into fine crackles, characterized by prominent high-frequency components, or coarse crackles, characterized by lower-frequency components. Continuous adventitious sounds, defined as those lasting 250 ms or more, include wheezes characterized by high-frequency components; rhonchi, which have low-frequency components; and friction rubs, which also exhibit prominent high-frequency characteristics. These classifications aid in the identification of specific respiratory abnormalities (Bahoura and Lu, 2006).

In the present study, we focused on the frequency components of lung sounds to distinguish between calves with and without early-stage pneumonia in a farm without veterinary expertise. In addition, we evaluated the pathogenesis by determining the relationship between the frequency components of lung sounds and lung ultrasound findings in calves.

Materials and Methods

Ten calves, including Holstein and Holstein-Japanese Black crossbreeds, aged 1-6 months, were used in this study. All calves were referred to the Obihiro University Veterinary Medical Center for diagnosis and treatment of pneumonia. The animals were housed in the same stall on a farm with wood shavings used as bedding. Ethical review and approval for animal use were waived for this study because this was a case report and all examinations and treatments were performed on the patient. Informed consent was obtained from all the owners who participated in this study. All experimental procedures involving animals were conducted in accordance with the Committee of Care and Use of Experimental Animals of the Graduate School of Bioagricultural Sciences, Nagoya University (approval number: 2018031366).

Ultrasound imaging (LOGIQ e; GE Healthcare Japan, Tokyo, Japan) and auscultation using an electronic stethoscope (Bresco; Ad Soar Co., Ltd., Kawasaki, Japan) were performed on both the left and right lung fields, and examinations were conducted from the 4th to 8th intercostal spaces (ICS) along a line from the shoulder joint to the transverse process of the 13th thoracic vertebra (Figure 1A).

Pneumonia scoring by ultrasonography was performed based on the following criteria: 0 indicated the presence of only multiple reverberation artifacts; 1 indicated slightly hyperechoic areas limited to the lung surface; 2 indicated the presence of a comet-tail sign, characterized by an abnormal, vertically oriented artifact extending deep into the lung field; and 3 indicated a comet-tail sign accompanied by clear visualization of the pulmonary interstitium and the presence of a speckled, heterogeneous, hyperechoic area (Figure 1B), suggestive of pus accumulation.

Calves with scores of 0 or 1 on both the right and left ICS were assigned to the healthy group (group H), whereas those with a score of 2 or 3 were assigned to the pneumonia group (group P).

Auscultation sounds were recorded for 30 s using an IC recorder (PCM-A10; Sony Corporation, Tokyo, Japan) in the WAV file format. The sound files were converted from stereo to mono format using audio editing software (Audacity®; Audacity Team, <https://audacityteam.org/>). A 10-second segment of continuous sound with minimal noise was extracted. The extracted audio files were decomposed into sine waves of various wavelengths using the fast Fourier transform. The amplitude of the sine wave obtained from the Fourier transform was used as the power of the frequency and the power spectrum was calculated. From the power spectrum, the mean power frequency (MPF), an index of change in the frequency components, was calculated for the frequency range of 0 to 2,000 Hz and compared between the groups. The formula used to calculate the MPF was as follows:

$$MPF = \frac{\sum_{i=0}^{2000} F(i) \cdot A(i)}{\sum_{i=0}^{2000} A(i)},$$

where $F(i)$ and $A(i)$ indicate the frequency and amplitude at variable i , respectively. The MPF values of the lung sound data were compared using Welch's

t-test for all ICSs and each ICS. Correlation analysis was also performed between the pneumonia score and the MPF. Sounds editing and analysis were conducted using R software version 4.3.2 ([http://www.R-](http://www.R-project.org/)

project.org/) with the “tuneR” and “stats” packages. Statistical significance was defined as a $P < 0.05$, while P -values between 0.05 and 0.1 were considered to suggest a trend.

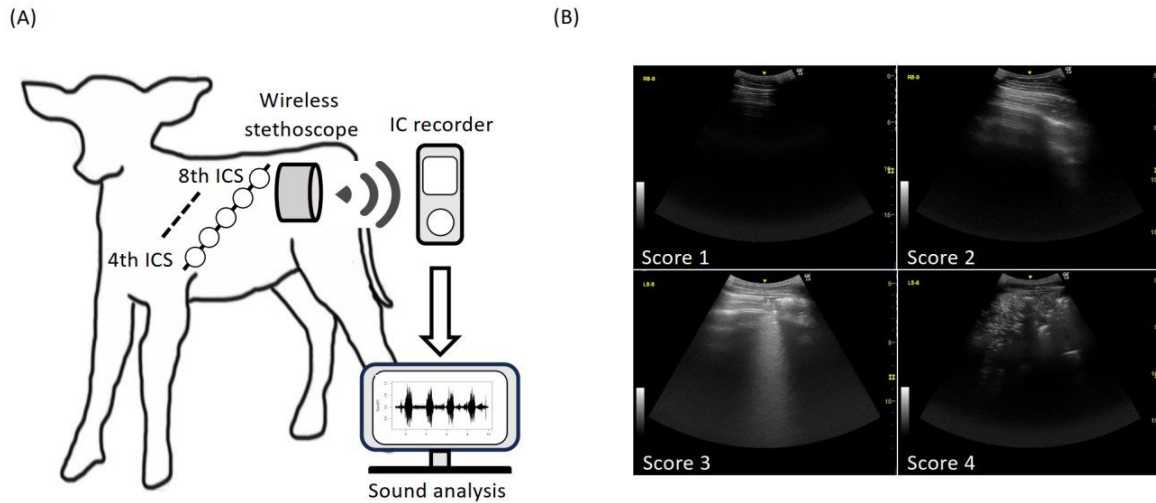


Figure 1 Ultrasound imaging and auscultation using an electronic stethoscope in both left and right lung fields (A). Examinations were conducted from the 4th to the 8th intercostal spaces (ICSs) along a line extending from the shoulder joint to the transverse process of the 13th thoracic vertebra. Pneumonia scoring by ultrasonography (B): A score of 0 indicates the presence of only multiple reverberation artifacts. A score of 1 indicates slightly hyperechoic areas limited to the lung surface. A score of 2 indicates the presence of a comet tail sign, characterized by an abnormal, vertically oriented artifact extending deep into the lung field. A score of 3 indicates a comet-tail sign accompanied by clear visualization of the pulmonary interstitium and the presence of a speckled, heterogeneous, hyperechoic area.

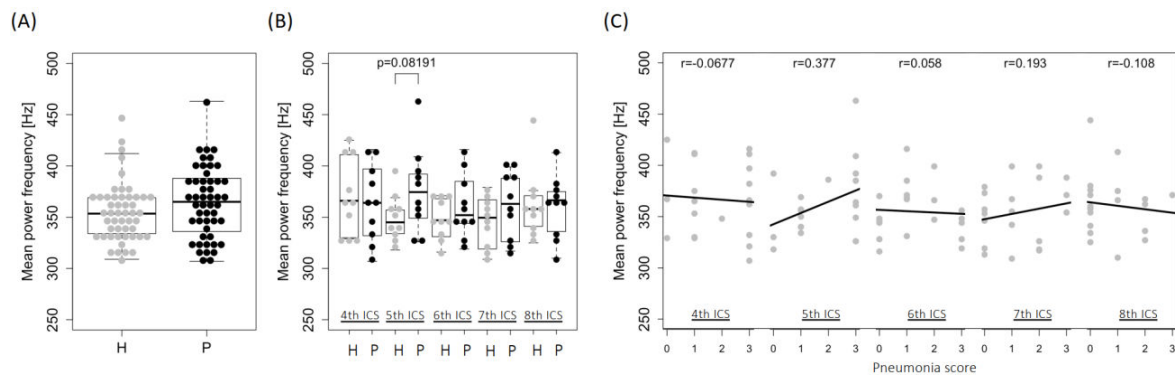


Figure 2 Mean power frequency (MPF) values from the 4th to the 8th intercostal spaces (ICSs) in the healthy group (H) and pneumonia group (P) (A). MPF values in groups H and P at each ICS (B) and the correlation coefficients between the pneumonia score and MPF at each ICS (C).

Results and Discussion

The MPF value from the 4th to the 8th ICS was 355.0 ± 4.0 Hz (mean $\pm$ standard deviation) in group H and 364.7 ± 4.8 Hz in group P (Figure 2A). There were no significant differences between MPF values between groups (Welch's t -test; $P = 0.12$). The MPF values in group H and P were 369.6 ± 16.2 Hz and 364.2 ± 16.8 Hz, respectively, at the 4th ICS; 348.6 ± 9.5 Hz and 376.1 ± 18.4 Hz, respectively, at the 5th ICS; 348.9 ± 8.8 Hz and 360.8 ± 13.8 Hz, respectively, at the 6th ICS; 345.8 ± 11.2 Hz and 361.5 ± 14.6 Hz, respectively, at 7th ICS; and 362.1 ± 14.7 Hz and 360.7 ± 13.2 Hz, respectively, at the 8th ICS (Figure 2B). There were no significant differences in MPF values between the 4th, 6th, 7th, and 8th ICSs. However, the MPF value at the 5th ICS tended

to be higher in group P than in group H (Welch's t -test; $P < 0.1$). A higher MPF value was observed at the 5th ICS in calves with pneumonia, suggesting that the lung sounds of calves with pneumonia may have a greater proportion of high-frequency components than those of healthy calves. This high-frequency component indicates the presence of torsional sounds during auscultation. A characteristic feature of torsional sounds is that they contain higher-frequency components than lung sounds produced by normal breathing (Munakata *et al.*, 1991). Torsional sounds occur when fibrotic alveolar tissue loses its elasticity and expands with breathing, and they are typically detected using auscultation in humans with pneumonia (Nath and Capel, 1980).

The correlation coefficients between the pneumonia score and MPF were 0.068, 0.377, 0.058, 0.194, and 0.108 for the 4th, 5th, 6th, 7th, and 8th ICSs, respectively (Figure 2C). A weak positive correlation was observed only for the 5th ICS ($P < 0.1$). The correlation between pneumonia scores and MPF values in both the right and left ICSs, as well as the comparison of MPF values between group H and group P, suggested that bilateral auscultation at the 5th ICS may be optimal for frequency component analysis and may contribute to understanding the pathophysiology of pneumonia in calves. Bovine lungs are divided by the mediastinum, and the anatomical structures of the left and right lungs differ. The right lung includes a branching tracheal bronchus, whereas the left lung lobe is significantly smaller than the right (Mansour *et al.*, 2023). However, no differences in the auscultation sounds between the right and left lung lobes were observed between the 5th and 8th ICSs in the present study. In cattle, the general auscultation area is located caudal to the elbow (Buczinski *et al.*, 2014), which is positioned caudally to the branching tracheal bronchus. The 5th ICS is adjacent to the caudal portion of the cranial or middle lobes of both lungs. Therefore, abnormalities detected in this area may reflect pathological changes in the cranial regions of the lungs. Further investigations focusing on more cranial areas are required. In conclusion, calves with pneumonia may exhibit increased MPF values at the 5th ICS, suggesting that this site is valuable for evaluating the underlying pathophysiology.

The findings of the present study suggested that the frequency component analysis of lung sounds using auscultation may be a useful tool for detecting respiratory abnormalities. In Holstein or crossbred (Holstein × Japanese Black) calves aged 1-6 months, the MPF value of lung sounds auscultated at the 5th ICS may aid in understanding the pathogenesis of interstitial pneumonia. In this study, interstitial pneumonia was confirmed in experimental animals using pathological autopsy and ultrasonographic imaging. In cases of bovine interstitial pneumonia, changes in the alveolar tissue that may not be as audible as torsion sounds through conventional auscultation can potentially be detected as high-frequency components using frequency analysis. However, the sample size in this study was limited, and further case accumulation and studies with larger cohorts are needed to validate the reliability and diagnostic thresholds of this lung sound analysis. Nevertheless, these findings have clinical relevance and may contribute to reducing economic losses for livestock producers by facilitating early identification and an understanding of the pathogenesis of pneumonia.

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