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Ultrasonography of the cranial part of the thorax is a quick and sensitive technique to detect lung consolidation in veal calves

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Abstract

Background: In the veal calf industry, bovine respiratory disease is the main cause of morbidity and mortality. Lung ultrasonography (LUS) is an accurate technique to diagnose bronchopneumonia in calves. Due to the economic constraints faced by the industry, a screening technique able to rapidly examine large numbers of calves is required.

Objective: To determine if lung ultrasonography focusing on the cranial part of the thorax (1st to 2nd intercostal space (ICS) on the right and 2nd to 3rd on the left) and/or on the middle part of the thorax (3rd to 5th ICS on the right and 4th to 5th on the left) (alternative techniques) are rapid screening techniques as sensitive as LUS of the entire lung (reference technique) to identify calves with lung consolidation lesions.

Methods: Data on 300 veal calves aged 33.1 ± 8.0 days and weighing on average 67.5 ± 4.0 kg at LUS from two farms were analysed. Systematic LUS of the entire lung was performed on all calves and a lung consolidation score was given to different parts of the thorax. Agreements between the alternative and the reference techniques were measured by Cohen's κ, McNemar's test and weighted κ.

Results: Agreement between LUS focusing on the cranial + middle part or on the cranial part only of the thorax and the reference technique were almost perfect with a cutoff of 1 cm. The relative sensitivity of these two alternative techniques was high (> 93%).

Conclusion: Lung ultrasonography of the cranial + middle part or on the cranial part only of the thorax are quick and sensitive techniques to identify veal calves with lung consolidation lesions shortly after arrival at the facility.

KEYWORDS
bovine, bovine respiratory disease, diagnostic imaging, infectious disease, pneumonia

1 | INTRODUCTION

Bovine respiratory disease (BRD) is one of the main health issues encountered in both the dairy and beef cattle industries, and leads to important economic losses (Peel, 2020). The term BRD encompasses mainly bronchopneumonia in cattle caused by an array of infectious agents and environmental factors resulting in pulmonary lesions (Taylor et al., 2010). Lung lesions associated with bronchopneumonia are usually characterised by various degrees of lung consolidation (Ollivett et al., 2015; Rabeling et al., 1998).

Lung consolidation is the main ultrasonographic finding associated with negative health and production outcomes in many studies. Dairy heifers with lung consolidation lesions have been found to have a higher risk of dying (Adams & Buczinski, 2016), decreased average daily gain (ADG) (Cramer & Ollivett, 2019) and decreased first-lactation milk production (Dunn et al., 2018) and are more likely to be culled prematurely (Adams & Buczinski, 2016; Teixeira & McArt, 2017). In feedlot cattle, consolidation lesions were associated with a higher risk of relapse after treatment of bronchopneumonia and a lower ADG (Timsit et al., 2019). In the veal calf industry, respiratory diseases are the main cause of morbidity and mortality, particularly during the first weeks after animals arrive at fattening facilities, and are the main indication for antimicrobial use (Fertner et al., 2016; Lava et al., 2016; Pardon et al., 2012; Pardon et al., 2012). Lung ultrasonography (LUS) could be a useful tool for the early diagnosis of bronchopneumonia in veal calves, which could help target antibiotic treatments and adapt management measures. However, due to the economic constraints faced by the industry, coupled with the large number of animals that enter veal calf farms in batches over short periods of time, a rapid screening technique is required.

Lung ultrasonography is a more sensitive technique than clinical scoring or lung auscultation to detect bronchopneumonia in calves (Buczinski et al., 2014; Buczinski et al., 2015; Cramer et al., 2019; Pardon et al., 2019; Rabeling et al., 1998). Moreover, inter-observer agreement of LUS has been estimated to be good between practitioners for the diagnosis of most lung lesions and pleural lesions, particularly for lung consolidation lesions, even when the operator has only moderate experience (Buczinski et al., 2018; Buczinski et al., 2013).

In calves, lung lesions occur first in the cranial lobes due to airborne bacterial infection before extending to the more caudal lobes (Dagleish et al., 2010). This preferential location of consolidation lesions in the cranioventral part of lungs is often reported in LUS studies (Ollivett & Buczinski, 2016; Ollivett et al., 2015), but there is a lack of data on the distribution of affected lung lobes. The objective of the study is to compare alternative ultrasonographic techniques focusing on different parts of the thorax (cranial + middle, cranial, middle) versus the reference technique. Our hypothesis was that LUS focusing on the cranial + middle part of the thorax is a rapid screening technique that is as sensitive as LUS of the entire lung to identify veal calves with lung consolidation lesions 1 or 2 weeks after arrival at the fattening unit.

2 | MATERIALS AND METHODS

2.1 | Study design

Lesion scores of 300 lung ultrasonography findings recorded during health monitoring from two batches of 140 and 160 white veal calves, located respectively on farm 1 and farm 2, were retrospectively included in the analysis. Lung ultrasonography was performed 14 and 6 days after the arrival of the animals on farm 1 and farm 2, respectively.

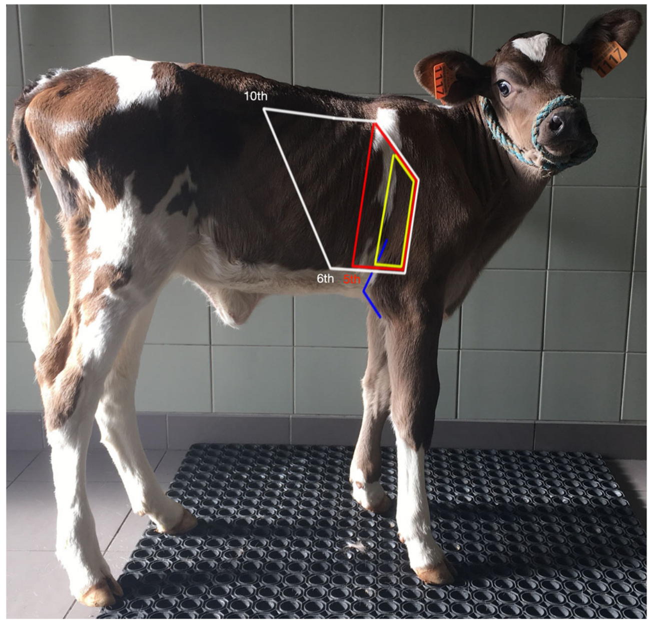

FIGURE 1 Clipping areas for the right thorax. In white: clipping area for LUS of the entire thorax done on all the calves in our study. For information: clipping area needed for LUS of the cranial + middle part of the thorax was delimited by the red line and clipping area need for an examination of the cranial part was delimited by the yellow line. In blue: point of the elbow

All calves involved in this study were cared for according to the 'Good practices guidelines in cattle, beef calves, sheep and goats' in compliance with French regulations (https://agriculture.gouv.fr/sites/minagri/files/documents/pdf/gph__bovins_veaux_ovins_caprins_20145952_0001_p000_cle0f3116.pdf).

2.2 | Lung ultrasonographic examination procedures

Lung ultrasonography was performed by two experienced practitioners (NM and VH), present together on both farms, using an Easi-Scan:Go Curve device (IMV-imaging, France) with an 8.5 MHz broadband curved linear probe (an 8 cm scan depth) and a wireless head-mounted viewing device. Each operator examined randomly half of the calves included in the study and used the same technique. The whole lung field was clipped on each side for every calf (represented in white in Figure 1) and sprayed with 70% isopropyl alcohol before applying the probe. All LUS were performed on standing calves with minimal restraint. All calves were housed in individual boxes allowing easy access to either side of the thorax (Figure 2). Both the right and left sides of the thorax were scanned by holding the probe parallel to the ribs, beginning from the 10th intercostal space (ICS) to the 1st ICS on the right side, and to the 2nd on the left side (Ollivett et al., 2015). For the first four and three ICS respectively on the right side and the left side, the probe was placed under the triceps brachii muscle between the thorax and the forelimb (Figure 3).

FIGURE 2 Lung ultrasonography was performed on standing calves with minimal restraint. All calves were housed in individual boxes allowing easy access to either side of the thorax

FIGURE 3 The probe was held vertically and placed under the triceps brachii muscle between the thorax and the forelimb and was then moved cranially to reach the first ICS

2.3 | Lung ultrasonographic scoring

Each side of the thorax was divided into two parts on farm 1 [a cranial + middle part (1st to 5th ICS on the right and 2nd to 5th ICS on the left) and a caudal part (6th to 10th ICS)] and in three parts on farm 2 [a cranial part (1st to 2nd ICS on the right and 2nd to 3rd on the left), a middle part (3rd to 5th ICS on the right and 4th to 5th on the left) and a caudal part (6th to 10th ICS)] (Figure 4). Each part was individually scored with a four-point graduated scale corresponding to the maximal extension of the lung consolidation lesions observed with regard to depth extension or dorsoventral extension: score 0 corresponded to no lung consolidation or lung consolidation less than 1 cm of extension; score 1 corresponded to lung consolidation from 1 to 3 cm; score 2 corresponded to lung consolidation from 3 to 5 cm and score 3 corresponded to lung consolidation more than 5 cm of extension. A superficial extension at the surface of more than 1 cm but less than 1 cm in depth was scored as 0 in order to avoid any misclassification with pleural thickening, pleural irregularity, or both (Buczinski et al., 2014). The extension of lung consolidation lesions was directly counted using the grid on the viewing device (Figure 5).

2.4 | Reference technique versus alternative techniques

Lung ultrasonography of all parts on both sides of the thorax was considered as the reference test to identify calves with lung consolidation lesions. The ultrasound lesion score (ULS) with the reference test ULS_{Ref} was the highest score observed among the four different parts examined on farm 1 (the right cranial + middle part, the right caudal part, the left cranial + middle part and the left caudal part) or the six different parts examined on farm 2 (the right cranial part, the right middle part, the right caudal part, the left cranial part, the left middle part and the left caudal part).

Three main alternative techniques to identify calves with lung consolidation lesions were compared with LUS of all parts on both sides of the thorax:

- *Alternative technique 1*: LUS of the cranial + middle part of the thorax (ULS_{CM}), evaluated on both farms. On farm 1, ULS_{CM} was the highest score observed among the two cranial + middle parts of the thorax (right and left). On farm 2, where the cranial + middle part was divided into a cranial part and a middle part (Figure 4), ULS_{CM} was the highest score observed among the right and left cranial parts and the right and left middle parts.
- *Alternative technique 2*: LUS of the cranial part of the thorax only (ULS_C).
- *Alternative technique 3*: LUS of the middle part of the thorax only (ULS_M).

These last two evaluations (alternative techniques 2 and 3) were done only with farm 2 data. The ULS_C was the highest score observed among the right and left cranial parts and ULS_M was the highest score observed among the right and left middle parts.

2.5 | Statistical analysis

The characteristics of the calves included in the study were described according to breed, sex, age and weight at LUS. The weight at LUS

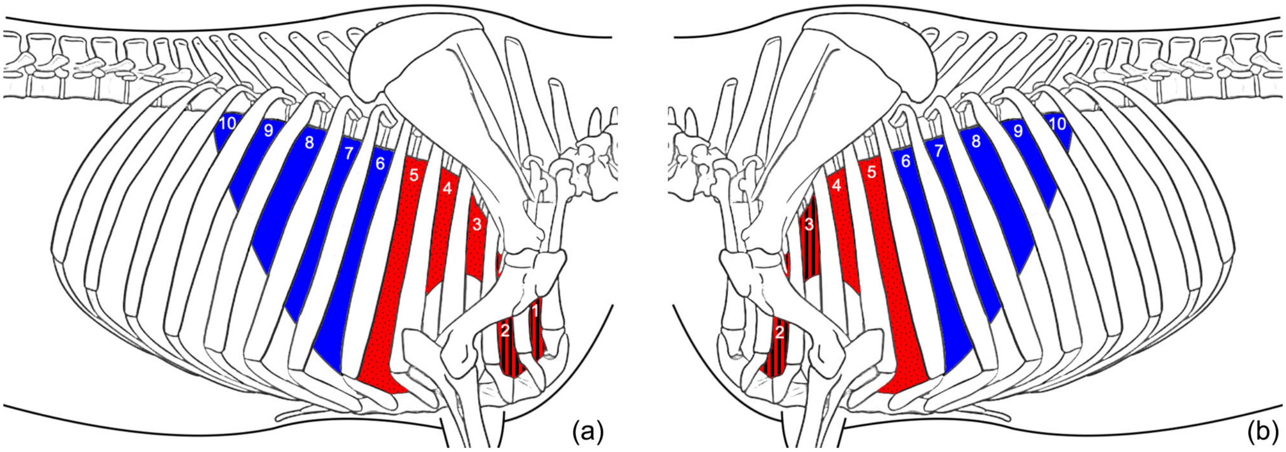

FIGURE 4 Landmarks of the different lung ultrasonographic parts used in the right (a) and the left (b) hemithorax. Intercostal spaces are labelled by numbers. The cranial + middle part of the right thorax (1st to 5th ICS corresponding to the right cranial lobe and the right middle lobe) and the cranial + middle part of left thorax (2nd to 5th ICS corresponding to the left cranial lobe) are in red. The caudal parts of the right and left thorax (6th to 10th ICS corresponding to the caudal lobes) are in blue. The red hatched parts (corresponding to the cranial part of the right thorax and the left thorax; i.e. the cranial part of the right cranial lobe and the cranial part of the left cranial lobe, respectively) and the red dotted parts (corresponding to the middle part of the right thorax and the left thorax; i.e. the caudal part of the right cranial lobe plus the right middle lobe and the caudal part of the left cranial lobe, respectively) correspond to the additional subdivisions used on farm 2

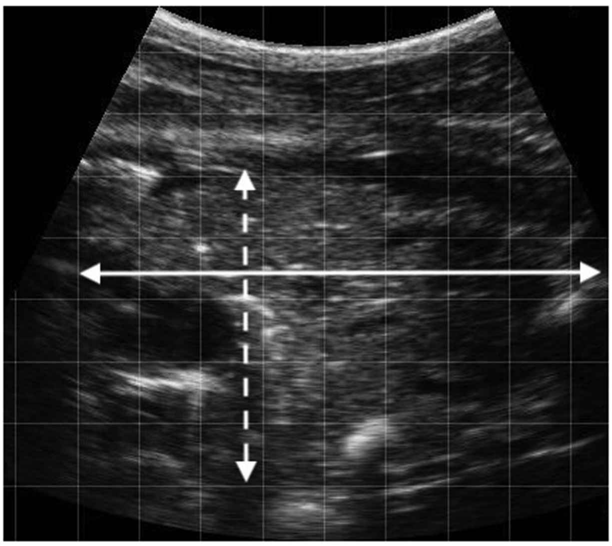

FIGURE 5 Ultrasonographic image of a consolidated lung in a veal calf scored 3: dorsoventral extension of 8.5 cm (continuous line), depth extension of 5 cm (dotted line). Image orientation: left = dorsal, right = ventral, top = superficial, bottom = deep. Each square of the grid is 1 cm^2. 8.5 MHz curved

was calculated with the weight at introduction measured individually with a balance by technicians and the individual average daily gain. The distribution of lung consolidation lesions was described according to the score (i.e. extension of lesion) and the location (cranial, middle or caudal).

To assess the performance of ultrasonography to identify calves with consolidation lesions when focusing ultrasonography on specific parts, the degree of agreement between the alternative techniques and the reference test was measured by Cohen's κ for the three different lesion extension cutoffs: 1 cm (no lesion or <1 cm vs. ≥1 cm); 3 cm (no lesion or <3 cm vs. ≥3 cm); and 5 cm (no lesion or < 5 cm vs. ≥5 cm). κ was defined as:

$$\kappa = \frac{P_O - P_E}{1 - P_E},$$

where P_0 was the observed agreement and P_E the chance agreement. The 95% confidence interval (CI) of κ was estimated by:

$$\kappa \pm 1.96\sqrt{\frac{P_O\,(1 - P_0)}{n(1 - P_E)^2}},$$

where n was the total number of calves. The Cohen's κ agreement was considered poor if $\kappa < 0$; slight if $0 \le \kappa \le 0.20$; fair if $0.21 \le \kappa \le 0.40$; moderate if $0.41 \le \kappa \le 0.60$; substantial if $0.61 \le \kappa \le 0.80$ and almost perfect if $\kappa > 0.80$ (Landis & Koch, 1977). A technique was considered perfect if the lower bound of the 95% confidence interval (CI) was greater than 0.80.

Cohen's κ is influenced by prevalence and by table asymmetry, which can lead to the κ paradox (low κ despite high raw percentage of agreement). Therefore, a McNemar's test was performed to evaluate the discrepancy between the reference technique and the alternative technique in marginal proportions.

The relative sensitivity (Se) of each technique was calculated for each farm as:

$$\text{Se} = \frac{\text{True positive}}{\text{True positive + False negative}}$$

TABLE 1 Descriptive statistics of the calves included in the study

Variable		Farm 1 ($n = 140$)	Farm 2 ($n = 160$)	Total ($n = 300$)
Breed	Holstein	131 (93.6)	1 (0.6)	132 (44.0)
	Crossbred[†]	9 (6.4)	152 (95.0)	161 (53.7)
	Normande	0	3 (1.9)	3 (1.0)
	Montbeliarde	0	2 (1.3)	2 (0.7)
	Bleue du Nord	0	2 (1.3)	2 (0.7)
Sex	Male	140 (100)	159 (99.4)	299 (99.7)
	Female	0	1 (0.6)	1 (0.3)
Age in days at ultrasonographic examination (mean ± SD)		37.1 ± 6.6	29.6 ± 7.5	33.1 ± 8.0
Weight in kg at ultrasonographic examination (mean ± SD)[‡]		68.6 ± 4.4	66.6 ± 3.4	67.5 ± 4.0

Note: Percentages are indicated in parentheses.
[†]Almost all crossbred calves were Holstein × Belgian Blue.
[‡]Calculated with the weight at introduction measured individually with a balance by technicians and the individual average daily gain.

The 95% CI of relative sensitivity was estimated by:

$$\mathrm{Se} \pm 1.96\sqrt{\frac{\mathrm{Se}\,(1-\mathrm{Se})}{n}},$$

where n was the total number of calves.

In addition, inter-test agreements between scores attributed with the reference technique and the two alternative techniques were assessed using the weighted κ (κ_W).

The symmetry of consolidation lesion distribution between the right and left sides of the thorax and the performances of different unilateral ultrasonography techniques were described and discussed in Supporting Information 1.

All analyses were carried out using the κ function of the R software 'vcd' package (R Foundation for Statistical Computing, Vienna, Austria, http://www.R-project.org).

3 | RESULTS

The descriptive statistics of the calves included in this study are summarised in Table 1. Lung consolidation lesions were identified in 119 out of 300 calves (39.7%): 58 calves (19.3%) had a ULS_{Ref} 1, 26 calves (8.7%) had a ULS_{Ref} 2 and 35 calves (11.7%) had a ULS_{Ref} 3. Prevalence of calves with lung consolidation lesions was 52.1% and 28.8% on farm 1 and on farm 2, respectively.

Among the 119 affected calves, 95 calves (79.8%) had lesions located in the cranial + middle part of the thorax, 1 calf (0.8%) had lesions located in the caudal part of the thorax and 23 calves (19.3%) had lesions located both in the cranial + middle part and the caudal part of the thorax. Among these 23 calves, the score of the cranial + middle part of the thorax was always equal to or higher than the score of the caudal part of the thorax.

For every alternative technique focusing on specific parts of ultrasonography examination of the thorax to identify calves with lung consolidation lesions, Cohen's κ values on agreement with the reference test are summarised in Table 2. The main result was that the Cohen's κ values on agreement between LUS focusing on the cranial + middle part of the thorax (ULS_{CM}) or LUS focusing on the cranial part of the thorax (ULS_{C}) and LUS of the entire thorax (ULS_{Ref}) were almost perfect (0.99; 95% CI: 0.98–1 and 0.95; 95% CI: 0.90–1 respectively) with a cutoff of 1 cm. However, the Cohen's κ value on agreement between LUS focusing on the middle part of the thorax (ULS_{M}) and LUS of the entire thorax (ULS_{Ref}) was slight (0.12; 95% CI: 0.01–0.23) with a cutoff of 1 cm.

The McNemar's test substantiated these observations: no difference was observed between ULS_{Ref} and ULS_{CM} or ULS_{C} (McNemar's; $p > 0.05$). A significant discrepancy was observed between ULS_{Ref} and ULS_{M} (McNemar's; $p < 0.05$) that suggested the presence of the κ paradox: the Cohen's κ value was therefore under-estimated and should be different from the agreement percentage.

Table 3 summarises the relative sensitivity of each technique on the two farms. The relative sensitivity of LUS focusing on the cranial + middle part of the thorax with a cutoff of 1 cm was high, 100% and 98% respectively on farm 1 and farm 2 and the relative sensitivity of LUS focusing only on the cranial part of the thorax with a cutoff of 1 cm was high (93%) on farm 2. The relative sensitivity varied according to the cut-off.

The agreement between scores attributed with the reference technique and the alternative technique focused on the cranial + middle part of the thorax (ULS_{CM}), calculated using K_W, was almost perfect (0.99, 95% CI: 0.98–1) (Table 4). The weighted κ coefficient was 0.96 (95% CI: 0.91–1) for the second alternative technique focusing on the cranial part of the thorax only (ULS_{C}), also indicating an almost perfect agreement (Table 5) whereas the weighted κ coefficient was 0.11 (95% CI: 0.00–0.22) for the third alternative technique focusing on the middle part of the thorax only (ULS_{M}), indicating a slight agreement (Table 6).

TABLE 2 Cohen's κ agreement between alternative techniques and the reference test to identify calves with lung consolidation lesions in 300 veal calves at the beginning of the fattening period from two veal calf facilities

Parts of lungs examined	Cutoff ≥ 1 cm					Cutoff ≥ 3 cm					Cutoff ≥ 5 cm				
	Calves with lung consolidation lesions	Calves without lung consolidation lesions	κ	95% CI Lower	95% CI Upper	Calves with lung consolidation lesions	Calves without lung consolidation lesions	κ	95% CI Lower	95% CI Upper	Calves with lung consolidation lesions	Calves without lung consolidation lesions	κ	95% CI Lower	95% CI Upper
Reference: both sides, all parts, calves from farms 1 and 2 (ULS_{Ref})	119	181				61	239				35	265			
Bilateral ultrasonography															
Alternative technique 1: Right cranial + middle part (1st to 5th ICS) and left cranial + middle part (2nd to 5th ICS) (ULS_{CM})	118	182	0.99	0.98	1.00	60	240	0.99	0.97	1.00	35	265	1.00	1.00	1.00
Unilateral ultrasonography															
Right cranial + middle part and the right caudal part (1st to 10th ICS)	95	205	0.83	0.76	0.89	51	249	0.89	0.82	0.96	29	271	0.90	0.81	0.98
Left cranial + middle part and the left caudal part (2nd to 10th ICS)	81	219	0.72	0.64	0.80	43	257	0.79	0.70	0.88	24	276	0.79	0.68	0.91
Right cranial + middle part (1st to 5th ICS)	94	206	0.82	0.75	0.89	50	250	0.88	0.81	0.95	29	271	0.90	0.81	0.98
Left cranial + middle part (2nd to 5th ICS)	81	219	0.72	0.64	0.80	43	257	0.79	0.70	0.88	24	276	0.79	0.68	0.91
Reference: both sides, all parts, calves from farm 2 (ULS_{Ref})	46	114				21	139				13	147			
Bilateral ultrasonography															
Alternative technique 2: Right cranial part (1st to 2nd ICS) and left cranial part (2nd to 3rd ICS) (ULS_C)	43	117	0.95	0.90	1.00	19	141	0.94	0.86	1.00	13	147	1.00	1.00	1.00
Alternative technique 3: Right middle part (3rd to 5th ICS) and left middle part (4th to 5th ICS) (ULS_M)	4	156	0.12	0.01	0.23	2	158	0.15	0	0.35	0	160	0	0	0
Unilateral ultrasonography															
Right cranial part (1st to 2nd ICS)	35	125	0.82	0.72	0.92	18	142	0.91	0.81	1.00	13	147	1.00	1.00	1.00
Left cranial part (2nd to 3rd ICS)	27	133	0.67	0.54	0.80	13	147	0.74	0.57	0.91	7	153	0.68	0.45	0.92

TABLE 3 Relative sensitivity of each technique to identify calves with lung consolidation lesions in 300 veal calves at the beginning of the fattening period from two veal calf facilities

	Cutoff ≥ 1 cm						Cutoff ≥ 3 cm						Cutoff ≥ 5 cm					
	Relative sensitivity	95% CI		Relative sensitivity	95% CI		Relative sensitivity	95% CI		Relative sensitivity	95% CI		Relative sensitivity	95% CI		Relative sensitivity	95% CI	
Parts of lungs examined	Farm 1	Lower	Upper	Farm 2	Lower	Upper	Farm 1	Lower	Upper	Farm 2	Lower	Upper	Farm 1	Lower	Upper	Farm 2	Lower	Upper
Reference: both sides, all parts, calves from farms 1 and 2 (ULS$_{Ref}$)																		
Bilateral ultrasonography																		
Alternative technique 1: Right cranial + middle part (1st to 5th ICS) and left cranial + middle part (2nd to 5th ICS) (ULS$_{CM}$)	1	1	1	0.98	0.97	0.99	1	1	1	0.95	0.94	0.97	1	1	1	1	1	1
Unilateral ultrasonography																		
Right cranial + middle part and the right caudal part (1st to 10th ICS)	0.77	0.73	0.80	0.85	0.82	0.88	0.78	0.74	0.81	0.95	0.94	0.97	0.73	0.69	0.76	1	1	1
Left cranial + middle part and the left caudal part (2nd to 10th ICS)	0.73	0.69	0.76	0.61	0.57	0.65	0.73	0.69	0.76	0.67	0.63	0.70	0.76	0.73	0.80	0.68	0.65	0.72
Right cranial + middle part (1st to 5th ICS)	0.77	0.73	0.80	0.83	0.80	0.86	0.78	0.74	0.81	0.90	0.88	0.93	0.73	0.69	0.76	1	1	1
Left cranial + middle part (2nd to 5th ICS)	0.73	0.69	0.76	0.61	0.57	0.65	0.73	0.69	0.76	0.67	0.63	0.70	0.76	0.73	0.80	0.68	0.65	0.72
Reference: both sides, all parts, calves from farm 2 (ULS$_{Ref}$)																		
Bilateral ultrasonography																		
Alternative technique 2: Right cranial part (1st to 2nd ICS) and left cranial part (2nd to 3rd ICS) (ULS$_C$)				0.93	0.92	0.95				0.90	0.88	0.93				1	1	1
Alternative technique 3: Right middle part (3rd to 5th ICS) and left middle part (4th to 5th ICS) (ULS$_M$)				0.09	0.06	0.11				0.10	0.07	0.12				0	0	0
Unilateral ultrasonography																		
Right cranial part (1st to 2nd ICS)				0.76	0.73	0.79				0.86	0.83	0.88				1	1	1
Left cranial part (2nd to 3rd ICS)				0.59	0.55	0.63				0.62	0.58	0.66				0.54	0.50	0.58

TABLE 4 Contingency table and weighted κ (κ_W) value for comparison between ultrasound lesion score with the focused LUS (cranial + middle part of the thorax on both sides) and ultrasound lesion score with the reference technique (all parts on both sides of the thorax) performed on farms 1 and 2

Reference technique: LUS of all parts on both sides of the thorax	Alternative technique: LUS focused on the cranial + middle part of the thorax				Number of calves	κ_W
	0	1	2	3		
0	181	0	0	0	181	0.99 (95% CI = 0.98–1)
1	0	58	0	0	58	
2	1	0	25	0	26	
3	0	0	0	35	35	
Number of calves	182	58	25	35	300	

TABLE 5 Contingency table and weighted κ (κ_W) value for comparison between ultrasound lesion score with the focused LUS (cranial part of the thorax on both sides) and ultrasound lesion score with the reference technique (all parts on both sides of the thorax) performed on farm 2

Reference technique: LUS of all parts on both sides of the thorax	Alternative technique: LUS focused on the cranial part of the thorax				Number of calves	K_W
	0	1	2	3		
0	114	0	0	0	114	0.96 (95% CI = 0.91–1)
1	1	24	0	0	25	
2	2	0	6	0	8	
3	0	0	0	13	13	
Number of calves	117	24	6	13	160	

TABLE 6 Contingency table and weighted κ (κ_W) value for comparison between ultrasound lesion score with the focused LUS (middle part of the thorax on both sides) and ultrasound lesion score with the reference technique (all parts on both sides of the thorax) performed on farm 2

Reference technique: LUS of all parts on both sides of the thorax	Alternative technique: LUS focused on the middle part of the thorax				Number of calves	κ_W
	0	1	2	3		
0	114	0	0	0	114	0.11 (95% CI = 0.00–0.22)
1	23	2	0	0	25	
2	7	0	1	0	8	
3	12	0	1	0	13	
Number of calves	156	2	2	0	160	

4 | DISCUSSION

Focusing ultrasonographic examination on the cranial + middle part of the thorax is a quick and sensitive technique to identify veal calves with lung consolidation at 1 or 2 weeks after arrival in the fattening unit. By examining only the right cranial + middle part and the left cranial + middle part (i.e. the cranial lobes on both sides of the thorax and the right middle lobe), the Cohen's κ value on agreement with the reference technique is almost perfect (0.99; 95% CI: 0.98–1) and the relative sensitivity is high. On farm 2, a more precise scoring of the cranial + middle part of the thorax was performed by scoring the cranial part of the cranial lobe and the caudal part of the cranial lobe (plus the middle lobe for the right side) independently. When examining only the cranial part of the cranial lobes on both sides, the Cohen's κ value on agreement with the reference technique remains almost perfect (0.95; 95% CI: 0.90–1) and the relative sensitivity is 93% (95% CI: 92–95%) with a cutoff of 1 cm. As recently reported, focused LUS is a sensitive technique to detect calves with consolidation lesions when examining a large number of animals (Pravettoni et al., 2021). Indeed, LUS focusing on the caudal part of the cranial lobe of the left lung, on the middle lobe of the right lung and on the caudal part of the cranial lobe of the right lung had a relative sensitivity of 81.6% to detect calves with pneumonia (i.e. with lung consolidation lesion at least 1 cm deep) and the agreement between the focused technique and the LUS of the whole thorax was substantial (Pravettoni et al., 2021).

In young calves, consolidation lesions due to bronchopneumonia occur preferentially in the cranial part of the lungs (Dagleish et al., 2010). Indeed, in our study, in 99.2% of affected calves, lesions were located in the right or left cranial lung lobes or in the right middle lung lobe. Although rarely observed by the authors in calves with bronchopneumonia, pulmonary lesions in the caudal part of the lungs without abnormalities in the cranial part of the lungs had already been described in older calves (Ollivett & Buczinski, 2016). In our study, only one calf had a lesion in a caudal lobe without lesions in the more cranial lobes, in accordance with previous reports (Ollivett & Buczinski, 2016; Ollivett et al., 2015). However, only a few recent studies have focused on the cranial part of the cranial lung lobes (Adams & Buczinski, 2016; Cramer & Ollivett, 2019; Ollivett et al., 2015; Teixeira et al., 2017). In many studies, operators only examined the right 2nd or left 3rd to the 10th ICS, (Teixeira & McArt, 2017) the 3rd to the 11th or 12th ICS, (Berman et al., 2019; Jung & Bostedt, 2004; Reinhold et al., 2002) the 4th and 5th ICS, (Pravettoni et al., 2021) the 4th to the 6th, 8th, 11th or 12th ICS (Buczinski et al., 2014; Buczinski et al., 2013; Rabeling et al., 1998; Timsit et al., 2019). Lung ultrasonography examination of the first intercostal spaces is possible in young calves and is informative. The ultrasound probe can be placed under the triceps brachii muscle to examine the 1st to the 3rd ICS; in older calves, forelimb musculature limits this access (Ollivett et al., 2015; Timsit et al., 2019).

We found that to maximise the sensitivity of detection of lung lesions in young calves, ultrasonography of the lung should always begin from the 1st ICS on the right side of the thorax and from the 2nd ICS on the left side of the thorax. A study by Berman et al. demonstrated that adding LUS of the right cranial part of the lung did not lead to an increase in sensitivity to detect lesions of active pneumonia (defined as the presence of lung lesions with active inflammation) (Berman et al., 2019). However, in our study, no distinction was made between lesions of active pneumonia and lesions of non-active pneumonia. The prevalence of lung consolidation lesions (≥1 cm) was 39.7% in our sample of veal calves, whereas this prevalence was 23.9% in the Berman et al. study (Berman et al., 2019). This difference in prevalence could be explained by a longer time period between the arrival of calves on farms and the ultrasonographic examinations. A longitudinal study found that in veal calf systems, the incidence of morbidity due to BRD begins immediately after arrival and increases gradually to reach a peak at week 3 (Pardon et al., 2012). In our study, LUS was performed 14 days and 6 days after the arrival of calves on farm 1 and farm 2, respectively, whereas in the study of Berman et al. (2019) LUS was performed upon arrival. A herd effect also could explain differences in prevalence of lung consolidation lesions between farms.

In our study, only consolidation lesions were investigated. Currently, it is not possible to distinguish active lung lesions requiring a treatment from non-active lesions (i.e., sequelae of a previous bronchopneumonia) for which treatment would not be beneficial (Buczinski & Pardon, 2020). Before considering any treatment, other criteria such as medical history or clinical examination still need to be taken into account in addition to LUS. However, detection of calves with consolidation lesions after arrival at the facility could be an interesting tool to implement a strategy of segregation of calves at risk of negative production outcome or calves requiring closer medical monitoring. Another potential use of this screening tool would be to determine the cut-off of lung consolidations prevalence to decide whether or not to treat a batch metaphylactically with antibiotics.

It was reported that the thymus could be confused with consolidation lesions of the lung, that is why the left cranial part of the thorax was often not included in the lung ultrasonography to avoid false-positive case (Ollivett & Buczinski, 2016). However, with some experience, it is possible to distinguish between them thanks to the different ultrasonic appearance of these structures. Indeed, the thymus is a well-delimited, hypoechoic and homogenous structure, whereas lung consolidation lesion is an irregular hypoechogenic and heterogeneous zone with disseminated hyperechoic dot-shaped structures (corresponding to residual air or gas produced by bacteria) and anechoic dot-shaped or tubular structures (corresponding to vessels or fluid in the bronchi) (Flöck, 2004; Kurosawa et al., 2011).

We decided to score lung consolidation lesions according to the maximal extension between depth extension and dorsoventral extension of lesions. This scoring avoids subdividing each cranial, middle or caudal part into a ventral, a median or a caudal part and scoring it individually. This scoring seems to be more representative of the extension and the severity of lesions even if depth extension and dorsoventral extension are probably correlated, but this was not investigated in our study. Further studies are needed to investigate the association between ultrasound lesion score and different outcomes using our scoring scale.

Thoracic ultrasonography of the whole thorax required around 6–7 min per calf in our study including calf handling and restraint, clipping, examination and data recording. This duration was not measured for every calf but estimated from the time spent by the 2 operators on the farms to examine all 300 calves. This duration was approximative and overestimated because breaks between LUS sessions were included. The duration of the LUS of the entire thorax in our study is in agreement with the duration previously reported in other studies: 5 min for 2nd or 3rd to 9th or 10th ICS LUS (Teixeira & McArt, 2017), 7–9 min for 4th to 11th ICS LUS (Buczinski et al., 2013). By reducing the clipping area (Figure 1) and the examination area (Figure 4), alternative techniques are faster than the reference technique. However, the cranial + middle part of the thorax is the more difficult area to ultrasound (Ollivett et al., 2015; Timsit et al., 2019). Lung ultrasonography of the cranial + middle part of the thorax and LUS of the cranial part of the thorax only take around 3–4 and 2–3 min respectively. These two durations were estimated by carrying out a series of LUS examinations on another farm including calf handling and restraint, clipping, examination and data recording. The authors prefer to clip the thorax before LUS examination considering it has the advantage of improving probe contact and saving time afterwards for the LUS itself. However, this step was not performed in most of the recent studies because it is time consuming and seems not to impact the ability to identify ultrasonography lesions (Buczinski et al., 2014; Buczinski et al., 2013; Dunn et al., 2018; Ollivett et al., 2015; Pravettoni et al., 2021; Teixeira & McArt, 2017; Timsit et al., 2019). If it is preferred not to clip the calves, the alternative techniques are even faster.

5 | CONCLUSION

In conclusion, young veal calves with lung consolidation lesions could be rapidly identified shortly after arrival at the facility by focusing the ultrasonography examination on the cranial + middle part of the thorax. Moreover, a more targeted LUS examination of the cranial part of the thorax only offers a good balance between sensitivity and convenience.

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AUTHOR CONTRIBUTIONS

Nicolas Masset: Conceptualization, Formal analysis, Funding acquisition, Investigation, Methodology, Validation, Writing - original draft, Writing - review & editing; Sébastien ASSIE: Formal analysis, Validation, Writing - review & editing; Nicolas Herman: Formal analysis, Validation, Writing - review & editing; Thibault Jozan: Conceptualization, Funding acquisition; Vincent Herry: Conceptualization, Formal analysis, Funding acquisition, Investigation, Methodology, Validation, Writing - original draft, Writing - review & editing.

CONFLICT OF INTEREST

This study was funded by MSD. One author (TJ) is an employee of MSD, a pharmaceutical company. No reference to products marketed by MSD could inappropriately influence or bias the content of the paper.

OFF-LABEL ANTIMICROBIAL DECLARATION

The authors declare no off-label use in compliance with European legislation.

INSTITUTIONAL ANIMAL CARE AND USE COMMITTEE (IACUC) OR OTHER APPROVAL DECLARATION

Authors declare no IACUC or other approval was needed. This study was carried out on commercial veal calf farms, so on 'private lands'. On the basis of an accurate description of the study's objectives and its design, the landowners (the farmers) gave permission to conduct the study on their farms. With the exception of this informed consent of each farmer and his/her permission to conduct the study on his/her farm and on his/her animals, no other specific permission was required according to local regulations. This field study did not involve endangered or protected species and was limited only to non-invasive procedures (i.e. clipping and thoracic ultrasonography). No calves were sacrificed for the purposes of the study.

HUMAN ETHICS APPROVAL DECLARATION

Authors declare human ethics approval was not needed for this study.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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SUPPORTING INFORMATION

Additional supporting information may be found in the online version of the article at the publisher's website.

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