FULL PAPER

Internal Medicine

Three-legged radiographic view for evaluating cranioventral lung region in standing calves with bovine respiratory disease

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ABSTRACT. This study proposed a novel radiographic positioning in order to image the cranioventral lung region using a portable X-ray unit and digital radiography system. In the novel position, calves were restrained in a chute and a unilateral forelimb was pulled cranially with the contralateral forelimb tied to the chute; the forelimbs were then spread cranio-caudally as in a scissor position (Three-legged view: TL view). In a preliminary study, we applied the TL view for imaging of 14 clinically healthy calves. In a clinical study, accuracy in detecting cranioventral lung lesions was compared between the standard standing view and the TL view for 19 calves, which were culled from herd; the results of postmortem examination were used as gold standard. Seven evaluators independently interpreted the images. The median (range) number of trials and the time for obtaining optimal position were 2 (1–7) and 263 sec (105–488), respectively in 14 healthy calves. Calves thicker than approximately 40 cm were not considered candidates for TL view in this setting because of difficulty in restraint and the low output of the portable X-ray unit. The TL view improved the detection of consolidation in the cranioventral lung region, compared with the standard view. The TL view was considered an optional view when the cranioventral lung region was an area of interest, because this view was relatively easy to perform and required a small number of personnel, even for large calves.

KEY WORDS: calf, cranioventral thorax, novel view, pneumonia, portable radiography

Bovine respiratory disease (BRD) is one of the most common causes of losses in the dairy industry; it is associated with increased costs of rearing, impaired growth, and reduced milk production [8, 16]. Accurate clinical diagnosis is difficult because of a lack of gold standard diagnostic tests [24]. The clinical diagnosis is typically based on clinical signs such as depression, anorexia, abnormal breathing, nasal discharge, coughing, and increased rectal temperature; and several scoring systems have been developed, based on the severity of clinical signs [1, 10, 24]. The limitations of these diagnostic methods include their subjective nature for grading the severity of clinical signs, as well as the lack of both sensitivity and specificity in detecting lung lesions [1, 11]. Lung auscultation is also subjective and skill-dependent, and a previous study reported poor sensitivity of lung auscultation for detection of lung lesions [3].

Thoracic radiography is valuable in the diagnosis of diseases of the respiratory tract, and radiographs can be obtained of calves in the standing or recumbent position [5]. Although BRD often affects the cranial aspect of the right cranial lung lobe [6], it is technically inevitable that opacity of the shoulders and forelimbs overlaps the region of the cranial aspect of the right cranial lung lobe in standing calves [13]. Therefore, optimal radiographic examination of the cranial thorax of calves requires placing calves in lateral recumbency with the forelimbs pulled cranially [5, 14]. However, placing calves in lateral recumbency for prolonged periods of time can contribute to the onset of atelectasis of the lung in the dependent hemithorax, and therefore, alternate-side images are sometimes added to the examination protocol [7]. One study reported another radiographic method for imaging the cranial thorax of calves: holding calves up with the forelimbs pulled cranially [22]. Although these radiographic methods are useful

Fig. 1. The novel radiographic view (Three-legged view: TL view) was obtained by pulling a unilateral forelimb cranially with the calf in a standing position. The contralateral forelimb and the hindlimbs were tied to a chute using flat braids.

objective tools to predict the presence of pulmonary lesions, including in the cranial aspect of the right cranial lung lobe, they require a considerable amount of time and labor, and appear to be applicable to small calves alone.

During routine radiographic examination of the thorax, we found that the cranioventral lung region can be evaluated more easily when the forelimbs are in a scissor position, compared with when they are aligned, resulting from reduced overlap between the forelimbs and the cranioventral lung region. We hypothesized that thoracic radiographs obtained by pulling the unilateral forelimb cranially in standing calves would show the cranial thorax, even in large calves. Thus, the present study investigated the use of this novel radiographic view for depicting the cranial thorax of calves for the clinical diagnosis of BRD. We conducted a preliminary study using healthy calves and a prospective clinical study using culled calves that were presented for pathological appraisal.

MATERIALS AND METHODS

Preliminary study

Fourteen clinically healthy Holstein calves under 9 months of age were enrolled in this study. The calves were restrained with a head halter in a chute, to which the flat panel detector (FPD; CALNEO C 1417s, Fuji Film Co., Ltd., Tokyo, Japan) was attached. Radiographs of the cranioventral thorax were obtained with the calf's unilateral forelimb pulled cranially; the contralateral forelimb and, if necessary, the hindlimbs were tied to a chute using flat braids (Three-legged radiographic view: TL view) (Fig. 1). When the unilateral forelimb is pulled cranially, the contralateral forelimb (pivoting forelimb) slides caudally as in a scissor position, bearing the weight of the calf; therefore, there is reduced overlapping of the opacity of the forelimbs on the cranioventral lung region. The forelimb opposite to the FPD was pulled to prevent the calf from kicking the FPD. The forelimb was pulled as cranially as possible; when the elbow of the pivoting forelimb overlapped the fifth sternebra or xiphoid process (or sixth rib), the images were considered optimal positioning images (Fig. 2B). The pulled forelimb was released after each exposure, and the trials were repeated until an optimal positioning image was obtained. The numbers of trials and the time required for obtaining optimal positioning images from the start of the radiographic examination were recorded.

Clinical study

This prospective study was completed between Jun 5, 2017 and December 21, 2017. Holstein calves culled and presented for pathological appraisal at the Animal Teaching Hospital, Obihiro University of Agriculture and Veterinary Medicine, were enrolled in the study. Inclusion criteria were as follows: (1) body thickness at the level of the last rib ≤40 cm and (2) sufficient stability to be restrained for radiographic examination. Respiratory scores (RS) were determined in accordance with a standard respiratory scoring system [10, 16]. RS is the sum of points from four categories of clinical signs, including increased rectal temperature, cough, nasal discharge, and ocular discharge or ear drop; increasing values represent progressive severity. Calves with RS >4 were considered sick [10]. For each calf, latero-lateral horizontal radiographs of the cranioventral part of the thorax were imaged twice with two different views. First, the standard cranioventral view was obtained with the calf standing. Second, the same area was radiographed using the TL view. The exposure index (EI) of each image was recorded; the EI was developed by the International Electrotechnical Commission in 2008, and is designed to generate a linear relationship between the index value and detector exposure [4]. The number of trials and the time required to obtain optimal positioning images from the start of the radiographic examination were also recorded. All calves were euthanized under deep barbiturate anesthesia, unless they died spontaneously. Clinical and pathological examination procedures used in this study were approved by the Institutional Animal Care and Use Committee at the Obihiro University of Agriculture and Veterinary Medicine (Permit number: 29–38). Postmortem examination was performed within 2 weeks after radiographic examination. Gross lung lesions, such as dark red and firm lung tissue representing consolidation or atelectasis of right and left cranial lobes, were recorded.
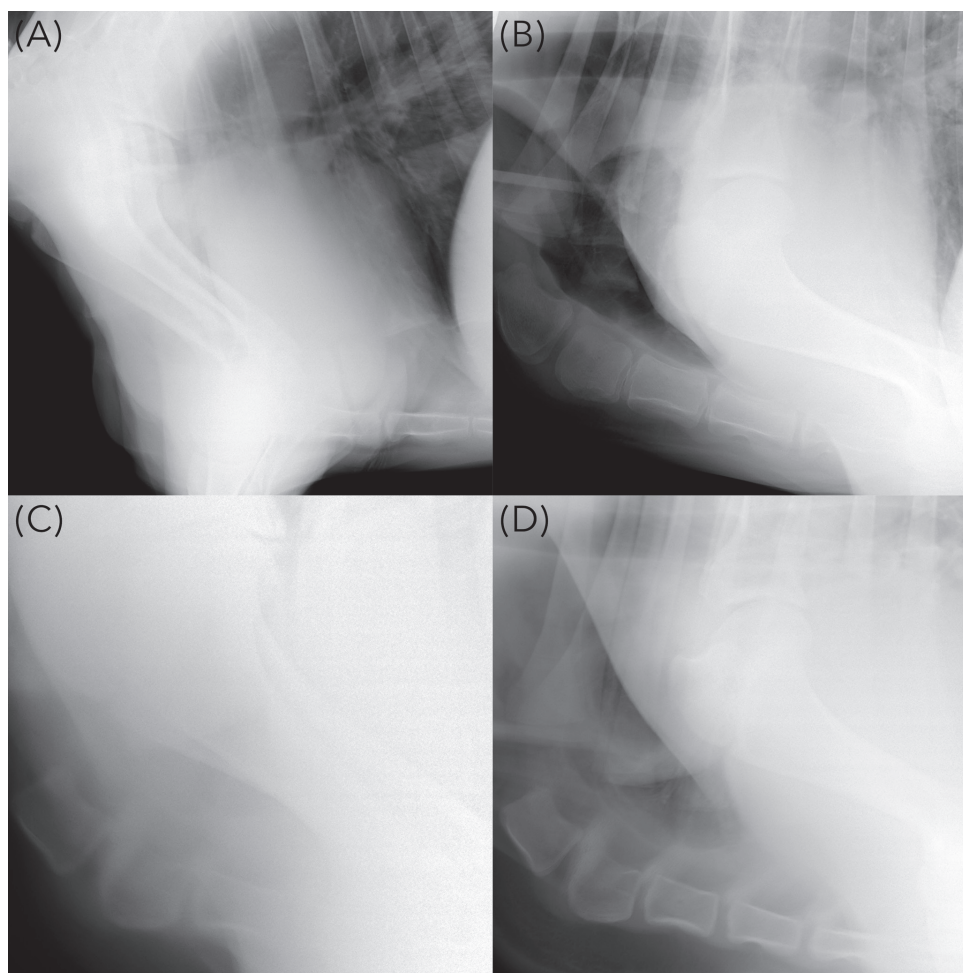
Fig. 2. Typical radiographic images of standard view (A, C) and TL view (B, D) of calves no. 1−6 (A, B) and no. 1–3 (C, D). Calf no. 1–3 was larger than calf no. 1−6, and the image contrast was reduced due to X-ray attenuation and scattered radiation; however, the visibility of the cranioventral lung area was obviously superior in the TL view image, compared with the standard view image.

The radiographs were independently interpreted using OsiriX (Pixmeo, Gengeva, Switzerland) by seven experienced clinical veterinarians who were blinded to the results of postmortem examination. A training phase preceded the image evaluation process. Standard cranioventral view images were displayed in random order; then, TL view images were displayed in random order. The evaluators were allowed to use processing tools, such as the window and level settings or magnification, as in standard clinical procedures. The images were scored by using a five-point confidence scale—pneumonia was: 1 (definitely absent), 2 (probably absent), 3 (uncertain), 4 (probably present), and 5 (definitely present). Pneumonia was considered present if consolidation, such as air bronchograms or border effacement of adjacent cardiac silhouette, could be viewed in the cranioventral lung regions [7].

The radiographic scores were compared with the findings of the results of postmortem examination by use of receiver operating characteristic (ROC) analysis. The empirical ROC curves were obtained using ROCFIT software (a web-based calculator for ROC curves; Baltimore: Johns Hopkins University [updated March 19, 2014; cited]. Available from: http://www.rad.jhmi.edu/ jeng/javarad/roc/JROCFITi.html). Areas under the ROC curves (AUC) were determined for all evaluators and each radiographic view. Comparisons of mean AUCs between the two radiographic view images were performed using paired t-tests. $P<0.05$ was considered statistically significant. The intraclass correlation coefficient (ICC) was used to evaluate interobserver agreement. The following ICC interpretation scale was used: 0 to 0.20, slight; 0.21 to 0.40, fair; 0.41 to 0.60, moderate; 0.61 to 0.80, substantial; 0.80 to 1.00, (almost) perfect [23].

In this study, all radiographic examinations were performed by a radiologist (G.S.) and a technician, using a portable X-ray unit (PORTA 380HF, JOB, Hyogo, Japan); the exposure factors and source-to-image-receptor distance were set to 80 kV, 2.0 mAs (15 mA and 0.13 sec), and 100 cm, respectively, in all experiments.

RESULTS

For the preliminary study, age, body thickness, number of trials, time required for radiographic study, and whether optimal

Table 1. Profile, the number and the time required for radiographic examination, and whether optimal positioning was achieved in 14 calves in preliminary study

Calf no.	Age (days)	Body thickness (cm)	The no. of trials	The time required (sec)	Optimal position[a]
1–1	255	43	1	185	+
1–2	208	42	1	105	+
1–3	226	40	3	357	+
1–4	160	36	1	241	+
1–5	217	40	2	353	+
1–6	88	35	2	190	+
1–7	120	36	7	488	+
1–8	120	36	2	196	+
1–9	132	34	1	344	+
1–10	155	40	1	285	+
1–11	160	41	1	165	+
1–12	164	42	3	380	+
1–13	106	39	3	352	+
1–14	148	37	2	142	+

a) Whether optimal positioning images were obtained.

Table 2. Profile, clinical and necropsy findings, EI value of each views, whether optimal positioning was achieved and interval between radiographic and postmortem examination of 19 calves in clinical study

Calf	Age (days)	Body thickness (cm)	Reason of culling	EI Strandard view	EI TL view	Optimal position[a]	RS	Interval (days)	Gross lung lesion[b]
2–1	15	17	atresia ani	503	571	+	4	0	-
2–2	103	26	poor growth	405	477	+	3	5	+
2–3	84	24	heart murmur	364	571	+	1	3	-
2–4	17	17	heart murmur	541	708	+	3	10	-
2–5	44	18	opisthotonus	647	721	+	1	4	+
2–6	155	30	poor growth	224	259	+	2	0	+
2–7	167	34	poor growth	268	428	+	2	1	+
2–8	69	26	heart murmur	468	444	+	1	12	+
2–9	5	20	atresia ani	391	521	-	2	2	+
2–10	64	21	poor growth	444	624	+	2	3	-
2–11	133	27	poor growth	398	647	+	2	3	-
2–12	182	33	poor growth	133	321	+	1	10	-
2–13	202	39	heart murmur	72	109	+	2	1	-
2–14	112	24	hermaphroditism	364	512	+	2	4	-
2–15	29	20	heart murmur	428	377	+	2	1	+
2–16	56	25	testicular swelling	288	245	+	1	7	+
2–17	264	27	poor growth	304	521	+	0	2	+
2–18	240	40	hyena disease	79	119	+	1	1	-
2–19	100	21	poor growth	384	550	+	5	1	+

a) Whether optimal positioning images were obtained. b) Gross lung lesions in right and/or left cranial lung lobes. EI, exposure index; TL view, three-legged view; RS, respiratory score.

positioning was achieved are summarized in Table 1 for the 14 calves. The median (range) number of trials and the time required for obtaining optimal positioning images were 2 (1–7) and 263 sec (105–488), respectively. Because we used a digital radiography system, we could retake radiographs quickly. Optimal positioning images were achieved in all calves. However, in large calves (approximately thicker than 40 cm), image contrast was reduced because of X-ray absorption by thick soft tissue (Fig. 2D); indeed, obtaining optimal positioning was difficult when the calf resisted restraint. Therefore, calves thicker than 40 cm were excluded from the clinical study.

For the clinical study, 19 calves met the inclusion criteria. Age, body thickness, reason for culling, EI of each view image, whether optimal positioning was achieved, RS, interval between radiographic and postmortem examination, and presence of gross lung lesions in the right and/or left cranial lung lobes are shown in Table 2 for the 19 calves. The median (range) age, RS, and interval between radiographic and postmortem examinations were 100 days (5–264), 2 (0–5), and 3 days (0–12), respectively. Only one calf with RS >4 was considered to have clinical respiratory disease, based on the scoring system. Ten of the 19 calves had gross lung lesions in the right and/or left cranial lung lobes. An optimal positioning image was not achieved in one calf (no. 2–9),
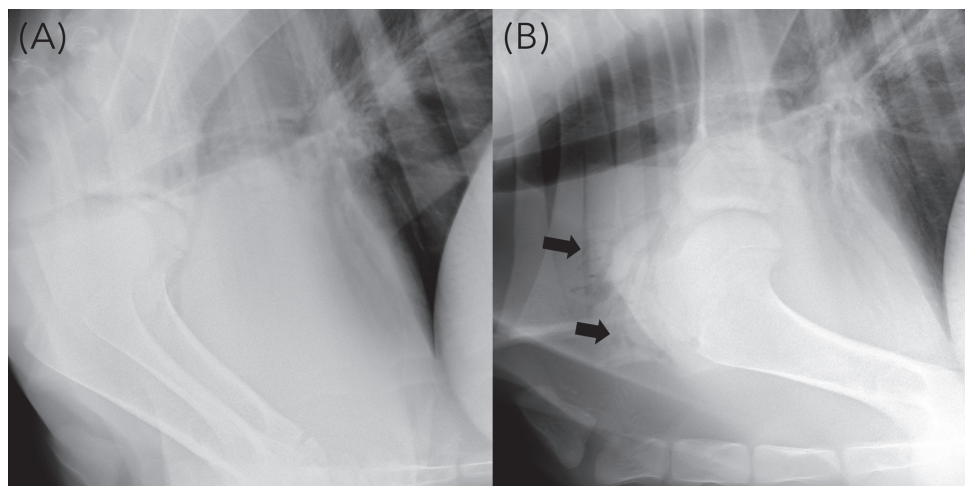
Fig. 3. Radiographic images of standard view (A) and TL view (B) of calf no. 2−19, which exhibited gross lung lesion. Air bronchograms were clearly detectable by using the TL view (B: arrows).
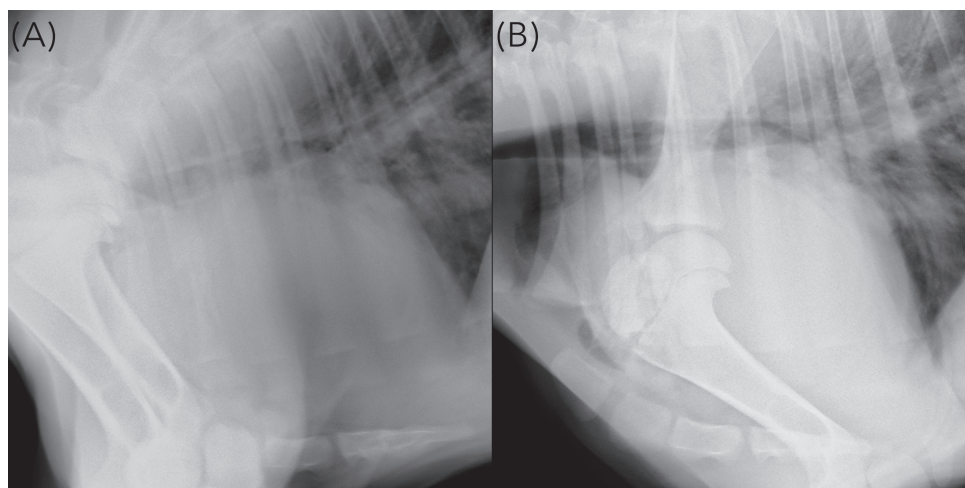

Fig. 4. Radiographic images of each view of calf no. 2−9. It was impossible to pull a forelimb fully because the calf experienced difficulty in standing with three legs. In the resultant image, a part of the forelimb opacity overlapped the cranioventral lung region (B). However, the pneumonic lesion remained easier to detect by using the TL view, compared with the standard view (A).

which was 5-day-old female with atresia ani and heart murmur.

Typical radiographic images of each view of a calf with gross lung lesion are shown in Fig. 3. The TL view image shows the cranioventral lung region more clearly, compared with the standard view images. Because one calf (calf no. 2–9) grew too weak to maintain the TL view position, it was difficult to fully pull a forelimb; thus, a part of the opacity of the pivoting forelimb overlapped the cranioventral lung lesion in the resultant image (Fig. 4).

For all images evaluated in this study, substantial agreement was found among the seven evaluators (ICC, 0.66: 95% confidential interval, 0.54–0.77); therefore, it was judged that there were no significant differences among the scores of the evaluators. AUCs of all evaluators with the two views are summarized in Table 3. AUCs of the TL view were higher than those of the standard view for all evaluators; this difference was statistically significant (P=0.001).

Table 3. Area under the ROC curves for each radiographic view

Evaluator	Standard view	TL view
1	0.744	0.861
2	0.622	0.950
3	0.661	0.894
4	0.706	0.867
5	0.783	0.850
6	0.733	0.917
7	0.606	0.850
Mean	0.694	0.884[a]

a) Significantly different by the paired *t*-test (P<0.05).

DISCUSSION

In this study, we proposed a novel radiographic view for evaluation of the cranioventral lung region of calves. Because pneumonic changes are typically located in this region, it is very important to image this area [6, 22]. However, it requires considerable labor and time to examine this region, because calves must be placed in lateral recumbency with forelimbs pulled cranially [7, 14]. A previous study described another radiological technique, in which calves were held up with forelimbs pulled cranially [22]. This technique appeared to be applicable only to small calves; indeed, only 4–6-week-old calves were examined in that study. In large calves or cattle, cranioventral lung regions have been examined with patients standing, and the sensitivity of radiography for detecting lung lesions in this area is inferior to that for other parts of the lung lobes [13]. Similarly, in our preliminary study, image contrast was reduced from attenuation of X-rays by thick soft tissue and considerable scattered radiation in large calves (approximately thicker than 40 cm). The X-ray unit used in this study had a maximum available tube setting of 80 kV and 15 mA; exposure times longer than 0.13 sec seemed to result in susceptibility to respiratory motion artifacts. Recently, it was revealed that low ratio grids or scatter correction processing improve the image quality of portable thoracic radiography in calves [20, 21]. Therefore, if a more powerful portable X-ray unit with a low ratio grid or scatter correction processing had been used, the image quality would have been improved. Considering both the reduced image contrast and difficulty of positioning, calves ≤40 cm are candidates for TL view, although it was apparent that the cranioventral lung area was more clearly shown by using TL view compared with the standard view even in calves >40 cm. The number of trials and the time required for obtaining optimal positioning images in this study were considered to be acceptable if a digital radiography system was used. In the clinical study, the TL view significantly improved the detection of lung lesions in the cranioventral areas, compared with the standard view; moreover, we could examine these areas in calves up to 264 days old. In addition, it required only two personnel to complete radiographic examinations. Although the full benefit of the TL view was not realized in one calf (no. 2–9), the detection of lung lesions appeared to be easier with the TL view than with the standard one. Radiographic assessment of the heart is more difficult in TL view than in standard one, because the opacity of the pivoting forelimb overlaps the heart silhouette (Figs. 2–4). If a heart disease is suspected to coexist with BRD, obtaining both TL and standard views are recommended.

Recently, thoracic ultrasonography (US) has been reported as a valuable tool to monitor pneumonic lesions [3, 9]. Thoracic US is accurately correlated with macroscopic findings in BRD patients [15, 17]. However, thoracic US does not routinely extend cranially beyond the 3rd intercostal space [3, 17], because the 1st and 2nd intercostal spaces, located medial to the forelimbs, are impossible to examine with transducers. Although one study reported that a linear rectal transducer can be inserted between the forelimb and the cranial thoracic body wall [15], that study included only calves <12 weeks of age. The authors of that study mentioned that it might be impossible to examine this area when the forelimb musculature increases as the calves mature. Thus, it is unclear whether the cranial aspect of the right cranial lung lobe can be assessed by US for calves older than 12 weeks of age. In this study, 10 of the 19 calves were older than 12 weeks of age. Of these 10 calves, five had gross lung lesions in the right and/or left cranial lung lobes. These findings indicate that this novel radiography position enables evaluation of cranioventral lung areas in large calves. Although US could be applicable for calves with the TL view position, additional time is required for scanning, compared with taking radiographs; as a result, the burden for both calves and personnel would be increased when using US. Thoracic US accurately detects lung lesions in calves with subclinical disease [3, 9]. Because nine of the 10 calves with gross lung lesions in this study did not appear clinically sick based on the RS, radiography with the TL view can also be considered sufficiently sensitive to detect subclinical lung lesions.

In digital radiography, underexposure results in images with grainy appearance caused by image noise; EI can be used to judge whether incident doses are excessive or insufficient [19]. In one study using a human thoracic phantom, EI values ≥250 were considered to be within the diagnostic range [18]. In the present study, 4/19 images of standard view and 3/19 images of TL view had EI values <250. Although the diagnostic reference range of the EI value for thoracic radiography in calves is yet to be established, all images in this study were considered to be of diagnostic quality with respect to the detection of pneumonic changes. Because of the low output of portable X-ray units, it has been speculated that only small calves are candidates for potable thoracic radiography [2]. The results of this study indicate the potential for portable X-ray units to be used in thoracic radiography in large calves with digital radiography. Indeed, the overall image quality of canine thoracic radiography, using digital radiography, did not deteriorate, even if it was made at a half-exposure dose [12]; however, EI values of the images were not described in that study.

The absence of the comparison of diagnostic ability between images obtained with the novel radiographic view and with the lateral recumbency technique is a limitation. It is inevitable in the TL view that a small part of the opacity of a forelimb musculature overlaps with the cranioventral lung region; therefore, the lateral recumbency technique may be more appropriate for evaluating that area. Because the TL view is relatively easy to perform, is not time-consuming, and does not require many personnel, it may be considered as an optional view when the cranioventral lung region is the area of interest. The interval between radiographic and postmortem examinations is another limitation. The pneumonic lesion may have progressed in this interval. Finally, the sample size was relatively small. Increasing the number of patients would have increased statistical power in this study.

In conclusion, this study proposed a novel radiographic view for thoracic radiography in calves. This radiographic view allows better observation of the cranioventral lung region, compared with the standard view; moreover, the novel view is easier to perform, compared with the lateral recumbency technique, even in large calves. Thus, this radiographic view may be suitable as a screening radiographic view when BRD is suspected in calves.

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