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Growth of preweaned, group-housed dairy calves diagnosed with respiratory disease using clinical respiratory scoring and thoracic ultrasound—A cohort study

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ABSTRACT

The objectives of this cohort study were to identify a cut point on a previously described 6-level ultrasound score (USS6) at which average daily gain (ADG) is affected and to determine whether there is any additional benefit of using a clinical respiratory score. Calves from a commercial herd in Ohio were enrolled at entry to an automated calf feeder barn at (mean \pm standard deviation) 21 ± 6 d of age ($n = 308$). Calves that survived until 50 d ($n = 233$) were included in the analyses. Twice-weekly health exams included a clinical respiratory score (CRS), USS6 (0–5, based on lung mass involved), and body weight. For the CRS, the nose, eyes, ears, cough, and rectal temperature were assigned a score (0–3), and calves were considered positive (CRS+) when at least 2 areas scored ≥ 2 . For analysis, USS6 and CRS status were based on a calf's first bovine respiratory disease event identified during the study period. The first multivariable linear model was fit to determine whether USS6 was associated with ADG and controlled for CRS. We detected no difference in ADG among calves with USS6 scores of 2, 3, 4, and 5. Based on this finding, we proposed a simplified 2-level ultrasound score (USS2; without lung consolidation or with lung consolidation ≥ 1 cm²). A second multivariable model was fit to assess the association between USS2 and ADG; this model controlled for CRS, birth weight category, breed, and cohort. Calves with lung consolidation ($n = 169$) had lower ADG than calves without lung consolidation ($n = 64$; 0.73 vs. 0.85 kg/d, respectively). Calves that were CRS+ ($n = 61$) had lower ADG than calves that were CRS– ($n = 172$; 0.74 vs. 0.84 kg/d, respectively). Although CRS did not

affect the relationship between USS2 and ADG, both CRS and USS2 are necessary to explain variation in ADG. We simplified USS6 and proposed USS2 based on how lung consolidation affected ADG. A simplified 2-level ultrasound score may be more practical for veterinarians to identify calves that may be at risk for poor growth. The effect on ADG was similar between calves with lung consolidation and calves identified as CRS+. Therefore, both thoracic ultrasonography and CRS should be used to identify calves with all types of respiratory disease that affect growth. However, this study represents calves in group housing from 21 to 50 d of age on 1 farm with high disease incidence. We encourage studies that investigate the effects of lung consolidation and CRS on ADG in different management systems.

Key words: automated calf feeder, average daily gain, bovine, pneumonia

INTRODUCTION

As reported by dairy producers, bovine respiratory disease (BRD) accounts for approximately 23% of heifer deaths during the preweaning period (USDA, 2010). Other short-term consequences of preweaning BRD include increased treatment costs (Van Donkersgoed et al., 2007) and reduced growth (Virtala et al., 1996). The long-term effects of preweaning BRD include decreased survival to first calving (Adams and Buczinski, 2016; Teixeira et al., 2017) and decreased milk production (Dunn et al., 2018).

Early life growth is of interest to dairy producers because of the long-term associations between preweaning growth and first-lactation milk production (Moallem et al., 2010; Soberon et al., 2012). In a New York study, BRD was associated with a 0.07 kg/d reduction in ADG during the first month of life (Virtala et al., 1996). Another study reported that calves treated for BRD had lower ADG between 2 and 3 mo, 3 and 6 mo, and 6 and 9 mo of age (0.17, 0.07, and 0.04 kg/d, respectively)

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compared with healthy calves (Stanton et al., 2012). In contrast, a recent study that used the Wisconsin calf clinical respiratory scoring system (CRS; McGuirk, 2008) to detect sick calves did not find an association between CRS status and ADG (Heins et al., 2014).

The variable effect of BRD on calf growth might be due to different BRD definitions among studies (Ollivett, 2014). For example, Virtala et al. (1996) defined pneumonia as calves with inducible cough, abnormal auscultation of respiratory tract, evidence of body temperature $>39.5^{\circ}\text{C}$, depression, and lack of involvement of other body systems that could contribute to a fever. In contrast, other studies did not describe the screening methods or the definition of BRD at all (Waltner-Toews et al., 1986; Sivula et al., 1996). Furthermore, a limitation of studies that rely on clinical diagnoses is that both producers (compared with postmortem examination) and the CRS (compared with ultrasonographic lung lesions) lack sensitivity for the identification of pneumonia (Sivula et al., 1996; Buczinski et al., 2015). Recently, thoracic ultrasonography (TUS) was validated as an accurate (Ollivett and Buczinski, 2016), rapid, on-farm diagnostic tool to identify lung consolidation associated with BRD in preweaned dairy calves (Buczinski et al., 2013, 2014; Ollivett, 2014). Buczinski et al. (2015) reported Bayesian estimates for TUS sensitivity (79.4%, 95% CI: 66.4–90.9) and specificity (93.9%; 95%CI: 88.0–97.6). Sensitivity and specificity refer to the proportion of calves with and without pneumonia, respectively, that are correctly identified by TUS. Within-herd prevalence of subclinical pneumonia can range from 23 to 67% (Ollivett and Buczinski, 2016), which represents a large source of unidentified disease. Thoracic ultrasonography, which can detect pneumonia regardless of clinical status (Buczinski et al., 2014; Ollivett et al., 2015), might improve our ability to accurately assess the impact of BRD on calf growth and assist with early management decisions.

Early disease detection can be achieved through systematic scoring, including CRS and TUS; however, this can be time consuming and labor intensive. Because TUS has superior sensitivity and specificity compared with CRS (Buczinski et al., 2015), the use of TUS only may be more expedient and accurate for the detection of BRD. A 6-level TUS score (USS6) ranging from 0 to 5 based on the mass of lung tissue involved has been proposed (Ollivett and Buczinski, 2016). However, it is unknown which levels of USS6 affect calf performance, and a simplified version may be more practical for veterinarians interested in identifying calves at risk for poor ADG. Therefore, the objectives of this cohort study were to identify a cut point on a previously described 6-level ultrasound score at which ADG

is affected and to determine whether there is any added benefit of using a clinical respiratory score.

MATERIALS AND METHODS

Data collection for this cohort study took place in Ohio between February and August 2016 on a dairy cattle facility that raised heifer and bull calves and freshened only primiparous heifers. The Institutional Animal Care and Use Committee at the University of Wisconsin-Madison (A005049-A03) approved this study.

Animal Management Before Study Enrollment

Calves were separated from the dam within 30 min of birth and received 4 L of pasteurized maternal colostrum within 3 h of birth. If adequate quality maternal colostrum (Brix $\geq 22\%$) was unavailable, calves were given colostrum replacer or a combination of colostrum replacer and pasteurized maternal colostrum. Farm staff recorded birth weight and calving ease score for all calves. The calving ease score ranged from 1 to 5 (1 = no assistance, 2 = minor assistance, 3 = hard pull, 4 = mechanical assistance and hard pull, 5 = surgical delivery). Calves were housed in 2 identical barns that contained straw-bedded individual pens for approximately 3 wk before entering an automated calf feeder barn (ACFB). Calves were fed 5 L of whole milk or milk replacer twice daily by bucket when housed individually, depending on the available supply of whole milk.

During the pre-enrollment phase of the study, calves were monitored daily and all treatments were recorded by farm staff on paper treatment records. Farm staff defined a diarrhea event before enrollment as extremely watery feces during at least 2 consecutive feedings. Prior to enrollment, farm staff treated calves for a respiratory event when they presented with labored breathing, cough, and droopy ear. During the pre-enrollment phase of the study, research staff collected jugular venous blood from 3- to 5-d-old calves using a 20-gauge \times 1-inch Vacutainer needle and glass tube without anticoagulant (BD Vacutainer Precision Glide, Becton, Dickinson, and Co., Franklin Lakes, NJ) to measure serum total protein (STP) as an indicator of passive transfer of maternal antibodies. Blood tubes were stored on ice for up to 2 h and then centrifuged at $3,000 \times g$ for 20 min at 20°C . Serum total protein was measured using a digital refractometer (Misco PA202, Solon, OH). The STP values were stored in the farm management software and collected digitally at the end of the study.

Enrollment and Animal Management

Enrollment for this study occurred from February to July 2016. Calves were formally enrolled into the study upon entry to the ACFB at approximately 21 d of age. Calves were eligible for study enrollment if they entered the ACFB by 30 d of age and remained in the ACFB until the end of follow-up, which was 50 d of age. The study period was defined as the time a calf was enrolled until 50 d of age. The ACFB had 2 identical sides with 4 pens on each side for a total of 8 pens; each pen measured 3.4 m × 18.3 m. Pens were bedded with straw from February to March and a combination of shavings and sand from April through August. The ACFB was naturally ventilated with curtain sidewalls and supplemental positive-pressure tube ventilation. Calves had nose-to-nose contact between pens.

Four automated calf feeders (Lely Calm calf feeder, Lely North America, Pella, IA) served the 8 pens with 1 nipple provided per pen ($n = 13 \pm 3$ calves per pen). Calves had ad libitum milk access until 40 d of age; then, from 41 to 46 d of age, calves were stepped up from 8 to 9.7 L/d, and from 47 to 56 d of age, calves were stepped down from 9.7 to 9 L/d. The age of the calf was entered into the automated feeding program to ensure calves were on the correct feeding stage based on their age. Whole milk from early lactation cows, purified using UV light (UVPure calf milk purifier, GEA Group Aktiengesellschaft, Düsseldorf, Germany), was the predominant source of liquid feed in the ACFB. The farm chose to supplement this whole milk with milk replacer (32 g of milk replacer per 1 L of whole milk). Specifically, from February to April, calves were supplemented with medicated 22:20 milk replacer that contained neomycin sulfate and oxytetracycline, each at 1,600 g/t (Renaissance Nutrition Inc., Roaring Spring, PA). Medicated milk replacer was added because the farm experienced a period of very high morbidity and mortality before the study. The farm used a milk replacer with antibiotics until their nutritionist advised them to stop. From May through August, the farm supplemented calves with a 22:20 milk replacer (Renaissance Nutrition Inc.) that contained Celmanax (Arm & Hammer Animal Nutrition, Princeton, NJ).

Clinical Scoring System, Ultrasonographic Data Collection, and Weighing During Study Period

Research staff performed health examinations on enrolled calves twice weekly until 50 d of age. Calves were scored on Mondays and Thursdays (pens 1–4) or Tuesdays and Fridays (pens 5–8). Health examinations were recorded using the Wisconsin Calf Health Scorer

app (<https://www.vetmed.wisc.edu/dms/fapm/apps/chs.htm>) and included a CRS (Lago et al., 2006; McGuirk, 2008), USS6 (Ollivett and Buczinski, 2016), and fecal, navel, and joint scores (McGuirk, 2008). Briefly, the CRS assigned 0 (normal) to 3 (severely abnormal) points for each of the following categories: nasal discharge, eye discharge, ear position, cough, and rectal temperature. Calves were considered positive for clinical respiratory disease (CRS+) when 2 categories with a score of ≥ 2 were observed (McGuirk and Peek, 2014). One experienced researcher (MCC) trained 2 research staff members on how to properly score calves using the CRS before the study. Inter-observer agreement (kappa score) among the 3 observers for CRS status (CRS+ vs. CRS-) was determined before the study ($\kappa = 0.6$) and halfway through the study ($\kappa = 0.7$).

For the USS6, a portable linear rectal ultrasound set at a depth of 9 cm, frequency of 6.2 MHz, and gain of 23 dB (near 13 dB; far 36 dB; Ibex Pro, E.I. Medical, Loveland, CO) was used. Approximately 150 mL of 70% isopropyl alcohol was applied to the hair as a transducing agent. One researcher (MCC) performed all USS6 exams. The left and right lungs were scanned in a systematic manner using a technique previously described in dairy calves (Ollivett et al., 2015; Ollivett and Buczinski, 2016). Briefly, the USS6 exam began on the right side of the calf dorsally at the level of the scapula in the right sixth intercostal space (ICS) and moved cranially to the right first ICS. This allowed for examination of the right middle, caudal aspect of the right cranial lung lobe and cranial aspect of the right cranial lung lobe (Ollivett and Buczinski, 2016). On the left side of the calf, the USS6 exam began dorsally at the level of the scapula in the left sixth ICS and moved cranially to the left second ICS. This allowed for examination of the caudal aspect of the left cranial lung lobe and cranial aspect of the left cranial lung lobe (Ollivett and Buczinski, 2016). Within each ICS, the probe was held parallel to the ribs and scanned ventrally until specific ultrasonographic anatomical landmarks were identified before moving cranially into the next ICS as described previously (Ollivett and Buczinski, 2016). Normal lung was characterized by observation of a hyperechoic line with reverberation artifact, indicative of the normal pleural interface (Blond and Buczinski, 2009). Consolidated lung appeared hypoechoic and lacked both the hyperechoic line of the pleural surface and reverberation artifact. For the USS6, 5 lung lobes in total were examined and considered separate lung lobes for the scoring system (Ollivett and Buczinski, 2016). The USS6 ranged from 0 to 5 (0 = normal or < 1 cm² consolidation; 1 = diffuse comet tails; 2 = lobular pneumonia: consolidation ≥ 1 cm²; 3 = lobar

Table 1. Classifications used for defining lung consolidation at the first bovine respiratory disease (BRD) event in 233 preweaned dairy calves¹ observed between 21 and 50 d of age

Ultrasound score and level	Definition	Proportion of calves [% (no./no.)]
USS6 ²		
0	Normal or <1 cm ² consolidation	27 (64/233)
1	Diffuse comet tails	0
2	Lobular pneumonia: consolidation ≥1 cm ²	31 (73/233)
3	Lobar pneumonia, 1 entire lung lobe consolidated	29 (68/233)
4	Lobar pneumonia, 2 entire lung lobes consolidated	8 (19/233)
5	Lobar pneumonia, ≥3 entire lung lobes consolidated	4 (9/233)
USS2 ³		
0	Normal or consolidation <1 cm ²	27 (64/233)
1	Consolidation ≥1 cm ²	73 (169/233)

¹Calves that were not identified with lung consolidation were assigned a score of 0 (n = 64).

²Six-level thoracic ultrasound score (Ollivett and Buczinski, 2016); refers to ultrasound score at a calf's first BRD event.

³Two-level thoracic ultrasound score; cut point determined from analysis testing the association between USS6 and ADG. Categories that were statistically ($P > 0.10$) and biologically similar were collapsed.

pneumonia, 1 entire lung lobe consolidated; 4 = lobar pneumonia, 2 entire lung lobes consolidated; 5 = lobar pneumonia, ≥3 entire lung lobes consolidated). Lung characteristics such as necrosis, abscessation, or pleural effusion were noted. Fecal scores ranged from 0 to 3 (0 = normal, formed feces; 1 = semi-formed feces; 2 = loose feces but stays on top of bedding; 3 = watery feces that sifts through bedding; McGuirk, 2008).

One researcher (MCC) weighed calves at each health examination using a calf weigh tape (Nasco, Fort Atkinson, WI). The tape was placed around the heart girth and pulled snug. Average daily gain was calculated between enrollment and 50 d of age by performing a simple linear regression (SAS Institute Inc., Cary, NC) for each calf using all weights.

BRD Definitions and Treatment Criteria

For analysis, USS6 scores (Table 1) and CRS status were based on the first BRD event identified at health exams during the study period. Calves were immediately treated when identified as CRS+ according to a standardized treatment protocol developed in cooperation with the farm management and farm veterinarians. Before administering the second-line antibiotic, the farm protocol required waiting 48 h after the first antibiotic was administered. Research staff treated the first 2 respiratory events detected to ensure consistency and

accuracy of treatment records. Treatment for the first CRS+ event was ceftiofur crystalline free acid (6.6 mg/kg of BW subcutaneous at the base of the ear once; Excede; Zoetis Services LLC, Parsippany, NJ). Treatment for the second CRS+ event was gamithromycin (6 mg/kg of BW subcutaneous once; Zactran; Merial Inc., Duluth, GA). For any subsequent CRS+ events, the farm staff was responsible for administering treatments as defined by the farm protocol. Flunixin meglumine (2.2 mg/kg of BW once intravenous; Vetameg; Aspen Veterinary Resources Ltd., Greeley, CO) was administered to calves with a rectal temperature ≥39.4°C and to calves that were depressed, slow to stand, or reluctant to lie down. Calves with diarrhea (fecal score = 3), infected navel (navel score ≥2), or infected joints (joint score ≥2) were reported to and treated by farm staff according to a standardized treatment protocol.

Statistical Analysis

Calves with missing data or that were lost to follow-up (due to death or leaving the ACFB before 50 d of age) or inadvertently enrolled (without meeting eligibility requirement) were not included in final analyses. Data were stored, cleaned, and analyzed using Excel (Microsoft Corp., Redmond, WA) and SAS software (SAS Institute Inc., Cary, NC). A priori sample size calculations determined the necessary sample size to

be 115 calves per group using $\alpha = 0.05$, a power of 0.8, and a mean \pm SD difference of 0.06 ± 0.16 kg/d ADG between calves with and without any category of BRD (Ollivett, 2014).

The experimental unit was the calf. The outcome of interest was ADG (kg/d) between entry to ACFB and 50 d of age and was analyzed as a continuous variable. As a method to control for time, a cohort was defined as a group of calves that were enrolled into the study within 1 wk of each other. Categorical explanatory variables included USS6 (0–5), cohort (1–8), and birth weight category (low: ≤ 29.1 kg; medium: >29.1 but <40 kg; high: ≥ 40 kg; categories were based on the first quartile, median, and third quartile). Dichotomous explanatory variables included CRS (0 = CRS–; 1 = CRS+), sex (male = 0; female = 1), breed (Holstein = 0; Jersey = 1), dystocia (no assistance or easy pull = 0; hard pull or surgical delivery = 1), failure of passive transfer (STP ≥ 5.5 g/dL = 0; STP <5.5 g/dL = 1; Weaver et al., 2000), diarrhea (fecal score always <3 in ACFB = 0; fecal score of 3 at least once in ACFB = 1), farm diagnosed diarrhea before study enrollment (no = 0; yes = 1), and farm diagnosed and treated respiratory disease before study enrollment (no = 0; yes = 1). All continuous explanatory variables were assessed for normality using the Shapiro-Wilk test and visual inspection of graphical data. Measures of central tendency for raw data are presented as mean \pm SD or median (first quartile, third quartile). Estimates from multivariable models are presented as mean \pm standard errors.

Associations between explanatory variables and the outcome of interest were evaluated using univariable analyses (PROC MIXED). Variables were offered to the multivariable model if they were associated with the outcome and the predictor of interest (Dohoo et al., 2003; $P < 0.20$ level). Backward stepwise elimination was used to select variables for the final model to include only variables with $P \leq 0.05$. Before the final elimination of a variable, a change in estimate criterion of $\geq 30\%$ for the predictor of interest was used to detect confounding. All potential interactions with the predictor of interest and the remaining variables in the model were assessed and interactions with $P > 0.05$ were removed. Predicted means for ADG were assessed using the LSMEANS statement and adjusted using the DIFF option. P -values in multivariable models were adjusted for multiple comparisons using Tukey's method for multiple comparisons. Residuals were plotted and used to check model assumptions.

The first multivariable linear model assessed the association between USS6 (predictor of interest) and ADG (outcome). The full model included USS6, CRS,

dystocia, birth weight category, breed, and cohort. The final model included USS6, CRS, birth weight category, breed, and cohort. Results from the first multivariable model were used to determine a cut point on USS6 that was associated with ADG. Differences in LSMEANS estimates for ADG were compared between all scores to determine the cut point on the USS6 at which ADG was affected. Categories of USS6 were collapsed to form a simplified 2-level ultrasound score (USS2; 0 = lung consolidation <1 cm²; 1 = with lung consolidation ≥ 1 cm²; Table 1). The second model assessed the association between USS2 (predictor of interest) and ADG (outcome). The full model included USS2, CRS, dystocia, birth weight category, breed, and cohort. The final model included USS2, CRS, breed, and cohort. Post hoc power calculations (PROC POWER; SAS Institute Inc.) were performed when no difference was observed.

RESULTS

Of the 835 calves that were born in the facility during the study period, farm records indicated that 259 calves were removed before 30 d of age and therefore before the age criterion for study enrollment ($n = 211$ were sold or sent off-site; $n = 48$ died). The farm elected not to send 268 calves through the ACFB because of limited space in the ACFB. A total of 308 calves entered the ACFB and were examined for eligibility. However, 24% (75/308) of calves were excluded from analysis because they were lost to follow-up ($n = 11$ sold; $n = 26$ died), were missing birth weights ($n = 10$), or did not meet the study eligibility enrollment age criterion (cohort 4; $n = 28$; entered ACFB at 40 d of age). Therefore, 233 calves were confirmed eligible and included in the final analyses. Calves were 21 ± 6 d of age at entry to ACFB and housed in groups of 13 ± 3 . For calves that were lost to follow-up, 27% (10/37), 0, 30% (11/37), 8% (3/37), 14% (5/37), and 22% (8/37) had USS6 scores of 0, 1, 2, 3, 4, or 5 at their last health exam, respectively. Before enrollment, 5% (12/233) and 27% (62/233) calves were treated by farm staff for respiratory disease and diarrhea, respectively. At the first health exam, 17% (39/233) and 6% (13/233) were identified with USS6 ≥ 2 and CRS+, respectively.

Calf descriptive information is presented in Table 2. Calves were 30 ± 8 d of age at the first BRD event. Forty percent of calves (93/233) of calves received pasteurized maternal colostrum, 35% (81/233) received colostrum replacer mixed with maternal colostrum, and 2% (5/233) received colostrum replacer; colostrum type was missing for 23% of calves (54/233). Overall, no calves were identified with USS6 = 1 at their first BRD event, and 27% (64/233) of calves had USS6 = 0 for

Table 2. Proportion [% (no.)] of preweaned dairy calves with failure of passive transfer (FPT) and dystocia, and proportion of calves for each sex, breed, and birth weight category, by cohort

Cohort ¹	FPT ²	Dystocia ³	Sex: male	Breed		Birth weight category (kg)		
				Holstein	Jersey	≤29.1	29.2–39.9	≥40
1 (n = 31)	58 (18)	13 (4)	81 (25)	90 (28)	10 (3)	19 (6)	58 (18)	23 (7)
2 (n = 48)	50 (24)	23 (11)	85 (41)	81 (39)	19 (9)	15 (7)	44 (21)	42 (20)
3 (n = 35)	11 (4)	14 (5)	83 (29)	63 (22)	37 (13)	31 (11)	49 (17)	20 (7)
5 (n = 15)	27 (4)	13 (2)	53 (8)	53 (8)	47 (7)	47 (7)	33 (5)	20 (3)
6 (n = 26)	12 (3)	8 (2)	54 (14)	85 (22)	15 (4)	19 (5)	58 (15)	23 (6)
7 (n = 26)	19 (5)	15 (4)	46 (12)	92 (24)	8 (2)	23 (6)	54 (14)	23 (6)
8 (n = 26)	19 (5)	12 (3)	81 (21)	92 (24)	8 (2)	23 (6)	42 (11)	35 (9)
9 (n = 26)	15 (4)	19 (5)	100 (26)	100 (26)	0 (0)	4 (1)	62 (16)	35 (9)
Overall (n = 233)	28 (65)	15 (36)	75 (176)	83 (193)	17 (40)	21 (48)	51 (118)	29 (67)

¹A cohort is a group of calves that were enrolled into the study within 1 wk of each other. Calves in cohort 4 were excluded from the final analysis because they were not enrolled by 30 d of age.

²Serum protein refractometry value <5.5 g/dL.

³Calf was delivered by hard pull or surgery.

the entire study period (Table 1). Seventy-four percent (172/233) and 26% (61/233) of calves were identified as CRS– and CRS+, respectively (Table 3). All calves (61/61) that were CRS+ at their first BRD event received an antibiotic. Forty-seven percent (30/64) and 64% (109/169) of calves that were identified without and with lung consolidation, respectively, received an antibiotic at a subsequent health score because they were later identified as CRS+. The overall ADG for all calves in this study was 0.93 ± 0.34 kg/d. Raw mean (\pm SD) ADG for each USS6 score were as follows: USS6 score of 0: 0.99 ± 0.41 kg/d; USS6 score of 2: 0.87 ± 0.30 kg/d; USS6 score of 3: 0.91 ± 0.31 kg/d; USS6 score of 4: 0.93 ± 0.31 kg/d; and USS6 score of 5: 0.97 ± 0.28 kg/d (no cows had a USS6 score of 1). Calves that were CRS– and CRS+ had raw mean (\pm SD) ADG of 0.94 ± 0.34 and 0.89 ± 0.36 kg/d, respectively.

The 6-level USS was associated with ADG ($P = 0.07$) using the multivariable model. We did not observe a difference in ADG (predicted mean \pm SE) among calves with USS6 scores of 2 (0.71 ± 0.04 kg/d), 3 (0.74 ± 0.04 kg/d), 4 (0.71 ± 0.07 kg/d), or 5 ($0.87 \pm$

0.10 kg/d) ($P > 0.60$). Average daily gain was also not different for calves with USS6 score of 0 (0.85 ± 0.04 kg/d) versus 3, 4, or 5 ($P > 0.39$). Average daily gain was different between calves with USS6 scores of 0 and 2 ($P = 0.08$). The power to detect a difference in ADG between USS6 score of 2 and USS6 scores of 3, 4, and 5 was ≤ 0.28 .

Using the multivariable model that assessed the association between USS6 and ADG, we defined the cut point on the USS6 scoring system at a score of 2, leading to a simplified 2-level scoring system (USS2; Table 1). Calves with lung consolidation (defined as a consolidation ≥ 1 cm²) at their first BRD event were compared with calves without lung consolidation (defined as no lung consolidation or consolidation < 1 cm²) at their first BRD event. Seventy-three percent of calves (169/233) were identified with lung consolidation (Tables 1 and 3). Calves without and with lung consolidation had raw ADG (mean \pm SD) of 1.0 ± 0.41 and 0.90 ± 0.30 kg/d, respectively. Using a multivariable linear model that assessed the association between USS2 and ADG, we found that calves with lung consolidation had lower ADG (predicted mean \pm SE) than calves without lung consolidation (0.73 ± 0.03 vs. 0.84 ± 0.04 kg/d, respectively; $P = 0.01$; Table 4; Figure 1). Calves that were CRS+ had lower ADG than calves that were CRS– (0.74 ± 0.04 vs. 0.84 ± 0.03 kg/d, respectively; $P = 0.04$; Table 4). Clinical respiratory score did not affect the relationship between USS2 and ADG (interaction $P = 0.2873$).

Table 3. A 2×2 contingency table comparing the distribution of CRS¹ and USS2² at the first bovine respiratory disease event in preweaned dairy calves (n = 233)

USS2	CRS	
	+	–
Consolidation	30	139
No consolidation	31	33

¹Clinical respiratory score adapted from McGuirk (2008); calves were considered CRS+ when 2 categories with a score of ≥ 2 were observed.

²Simplified ultrasound score adapted from Ollivett and Buczinski (2016); lung consolidation was defined as ≥ 1 cm² on ultrasound.

DISCUSSION

To our knowledge, this is the first cohort study to simplify a 6-point ultrasound score (Ollivett and Buczin-

Table 4. Multivariable linear regression model for ADG in 233 preweaned dairy calves for calves that survived to 50 d of age^{1,2}

Variable	ADG estimate (kg/d)	SE	P-value
Intercept	0.4157	0.0889	<0.0001
USS2			
No consolidation	0.1147	0.0459	0.0132
Consolidation	Referent		
CRS ³			
–	0.0975	0.0471	0.0398
+	Referent		
Breed			
Holstein	0.3674	0.0536	<0.0001
Jersey	Referent		
Cohort ⁴			
1	0.1992	0.0783	0.0116
2	0.2505	0.0715	0.0006
3	–0.0159	0.0771	0.8366
5	0.0348	0.0977	0.7218
6	0.1599	0.0816	0.0511
7	0.0786	0.0804	0.3295
8	–0.0235	0.0805	0.7706
9	Referent		

¹Calves were enrolled in the study at (mean \pm SD) 21 \pm 6 d of age and underwent twice-weekly health exams. Estimates for ADG and reported *P*-values are from solutions for fixed effects.

²This model contained USS2 as the predictor of interest; USS2 = simplified ultrasound score adapted from Ollivett and Buczinski (2016); lung consolidation was defined as ≥ 1 cm² on ultrasound.

³Clinical respiratory score adapted from McGuirk (2008); calves were considered CRS+ when 2 categories with a score of ≥ 2 were observed.

⁴A cohort is a group of calves that were enrolled into the study within 1 wk of each other. Calves in cohort 4 were excluded from the final analysis because they were not enrolled by 30 d of age.

ski, 2016) to identify calves at risk for poor growth. Our first objective was to identify a cut point that predicted ADG using a previously described USS6. We simplified the USS6 to form USS2 and discovered that calves with lung consolidation ≥ 1 cm² at their first BRD had a 0.11 kg/d reduction in ADG compared with calves without lung consolidation. The USS2 we propose will likely be faster to perform on-farm because it requires the person scanning to identify the presence or absence of lung consolidation, rather than differentiating between the extent of lung consolidation, as in USS6. Furthermore, we observed separate but not interactive effects of USS2 and CRS on ADG, which demonstrates the importance of incorporating both scoring systems into calf management to identify sick calves that are at risk for poor growth.

Research regarding the effects of lung consolidation on ADG is limited in dairy calves. We observed a more marked effect of lung consolidation on ADG compared with Ollivett et al. (2014), who found that calves with lung consolidation between 1 wk and 8 to 12 wk of age had a 0.04 kg/d decrease in ADG. One potential explanation for the different ADG estimates for lung consolidation is that our study defined consolidation as ≥ 1 cm², whereas Ollivett et al. (2014) defined consoli-

dation as ≥ 3 cm². As a result, it is possible that the estimates for ADG from Ollivett et al. (2014) were biased toward the null, as their normal calves could have included calves with consolidation < 3 cm². Our study and Ollivett et al. (2014) both observed an association between lung consolidation and growth; however, the present study focused on a calf's first BRD event, whereas Ollivett et al. (2014) examined the effect of lung consolidation at any point during preweaning on ADG. Future studies should examine a calf's worst or average ultrasound score or duration of lung consolidation to give a more representative estimate of the effect of BRD on performance.

We previously proposed that it would be more efficient for veterinarians to focus solely on using TUS and not CRS because TUS had a greater sensitivity and specificity for the identification of lung consolidation (Buczinski et al., 2015; Ollivett et al., 2015). However, in the present study, both USS2 and CRS were associated with ADG. Furthermore, USS2 and CRS identify different populations of animals: those with lung consolidation and those with clinical BRD. Therefore, although it may be more time intensive, veterinarians should consider using both TUS and CRS in calf programs to accurately identify all calves at risk for poor

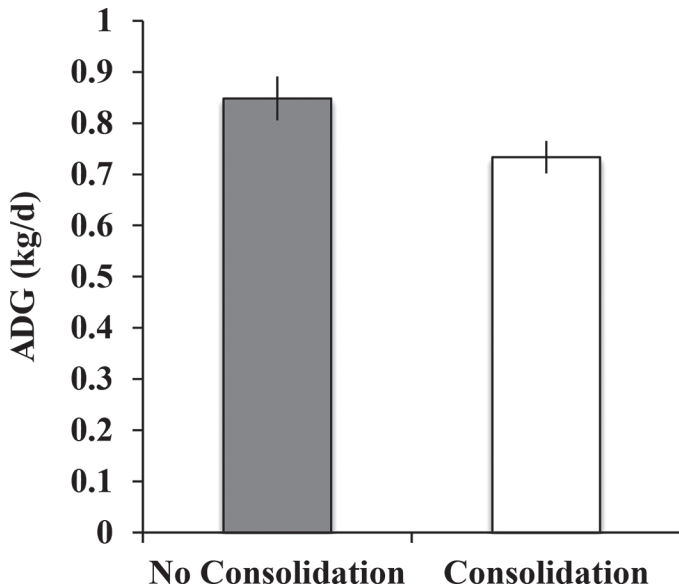


Figure 1. Least squares means (\pm SE) estimates for ADG (kg/d) for 233 preweaned, group-housed calves with no lung consolidation (<1 cm² of consolidation at all ultrasound exams) or with lung consolidation (≥ 1 cm² of consolidation for at least one ultrasound exam; $P = 0.01$). This simplified ultrasound score was adapted from Ollivett and Buczinski (2016). Estimates were obtained from a multivariable linear model that controlled for clinical respiratory disease status of the calf, cohort, and breed.

growth. Our simplified scoring system (USS2) is most useful for veterinarians interested in identifying calves at risk for poor growth, measuring lung consolidation prevalence, or measure herd-level lung consolidation before and after interventions.

Interestingly, despite a large proportion of calves with BRD, the mean ADG in the present study population was 0.93 kg/d, which is numerically higher than that of Soberon et al. (2012), who reported ADG in preweaning calves to be 0.82 or 0.66 kg, depending on the herd. Bateman et al. (2012) reported ADG of 0.52 kg for all calves through 8 wk of age, which is lower than the ADG for all calves in the present study. It is possible that because calves in the present study were on a high plane of nutrition, the effect of disease on ADG was somewhat ameliorated, similar to previous work (Ollivett et al., 2012). Furthermore, calves in the present study were treated with an antibiotic immediately after they were identified as CRS+ and underwent rigorous health examinations by research staff. It is likely that the disease detection methods used in the present study were more sensitive than in previous studies that used producer-reported disease definitions, as producers often have poor sensitivity for overall disease detection (Sivula et al., 1996). The effects of BRD categories on ADG might be more pronounced if the producer per-

formed disease identification and treatment. Additionally, calves were enrolled in the present study by 30 d of age, thus excluding ADG from the first 2 to 3 wk of life, when gain in calves is slower than later in life (Davis and Drackley, 1998).

We attempted to enroll a larger number of calves; however, fewer calves entered the ACFB than expected and we were unable to enroll the a priori calculated sample size because of time constraints. We performed analysis on fewer calves than originally intended to determine whether an association was observed between USS6 and ADG. Although we proposed a simplified ultrasound score, we were unable to differentiate between USS6 of 2, 3, 4, and 5 due to the inadequate power. We would expect a difference in growth because of the difference in the amount of lung mass (Jericho and Langford, 1982); greater amounts of affected lung might result in less energy available for growth. We encourage future studies to investigate whether a multi-level ultrasound scoring system would better describe the impact on gain, which may be useful to veterinarians or producers making treatment or culling decisions based on the extent of lung consolidation.

Moreover, ultrasound score and CRS statuses in the present study were based on a calf's first BRD event after study enrollment. However, we did not enroll calves until 21 d of age, whereas clinical BRD (Cramer and Stanton, 2015) and lung consolidation (Binversie, 2017) have been reported in calves younger than 3 wk and at 7 d of age, respectively. Therefore, it is possible that calves in the present study had a first BRD event before study enrollment, which may have resulted in a decrease in ADG (Virtala et al., 1996) and could have lasted several months (Stanton et al., 2012). However, if calves with BRD before study enrollment recovered before entry to the ACFB, we would have identified these calves as normal, thus biasing our findings toward the null.

Finally, analysis for the present study only included calves that entered the ACFB by 30 d of age and survived to 50 d of age, effectively excluding calves that died. The farm used genomic selection, and calves that did not meet the farm's standards were sold before 30 d of age. These calves were therefore not enrolled in the study. The exclusion of calves that died may have biased our results toward the null, as calves that died were likely most affected by disease and therefore may have been the poorest growing. The exclusion of low genomic calves may have further biased our results toward the null, because these calves may have poor growth compared with high genomic calves. Additionally, we included observations only until 50 d of age, despite weaning being completed at 70 d of age. Many

calves left the ACFB between 50 and 70 d of age because of space concerns and transport to other facilities. To include as many calves as possible in the analysis, we chose to observe calves until 50 d of age. However, BRD that occurs around weaning has been associated with reduced ADG (Stanton et al., 2012). As a result of our study design, calves may have had BRD after the study ended but before weaning was completed. Therefore, we may not have fully estimated the impact of all preweaning BRD on ADG. It would be useful to understand the effect of the duration of lung consolidation on ADG throughout the preweaning period.

CONCLUSIONS

This is the first study to offer a simplified lung ultrasound score based on the associations between ultrasound score and ADG. Calves with lung consolidation at their first BRD event had lower ADG than calves without lung consolidation. We also found that calves with clinical signs at their first BRD event had lower ADG than calves without clinical signs. Therefore, both ultrasound scoring and clinical scoring systems should be implemented in calf programs to identify calves all with BRD that are at risk for poor growth.

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