Association of preweaning and weaning serum cortisol and metabolites with ADG and incidence of respiratory disease in beef cattle

A. P. Foote,^{1,2} S. A. Jones, and L. A. Kuehn

USDA, ARS, U.S. Meat Animal Research Center, Clay Center, NE 68933-0166³

ABSTRACT: The objectives of this experiment were to determine the association of circulating cortisol, lactate, and glucose at, and prior to, weaning with ADG and incidences of bovine respiratory disease (BRD) in beef cattle. A blood sample was collected approximately 3 wk prior to weaning and at weaning from genetically diverse steers and heifers ($n = 451$). Cattle were weighed periodically throughout the study and ADG was calculated for the preweaning period (152 ± 15 d), the receiving period (45 d postweaning), the finishing period (200 d), and total postweaning ADG. Incidences of BRD were recorded and analyzed as a binary trait. Lung lesions were recorded at slaughter. Preweaning serum cortisol concentrations were positively associated ($P = 0.040$) with receiving ADG and explained 0.74% of the variance of receiving ADG. Preweaning glucose concentrations were positively associated ($P < 0.001$) with preweaning ADG and negatively associated with receiving ($P = 0.003$), finishing ($P = 0.008$), and total postweaning ADG ($P = 0.002$) and explained

2.0% of the variance in total postweaning ADG. Variation in preweaning serum glucose concentrations could be indicative of variation in milk consumption, and therefore indicate calves receiving less milk grow slower prior to weaning, but experience compensatory gain postweaning. Cattle that were diagnosed with BRD ($n = 130$) grew slower during the receiving phase ($P = 0.004$), but total postweaning ADG was not different from cattle not diagnosed with BRD ($P = 0.683$). Additionally, cattle that were diagnosed with BRD in the feedlot tended ($P = 0.062$) to have slightly lower preweaning serum glucose concentrations. Using a logistic regression analysis, none of the serum variables measured at or before weaning were predictive of developing BRD ($P > 0.180$). Weaning serum glucose concentrations tended to be predictive of the presence of lung lesions at weaning ($P = 0.060$). These data indicate that glucose measured early in life is associated with growth rate, and could indicate that carbohydrate metabolism could contribute to variation in ADG.

Key words: beef cattle, bovine respiratory disease, glucocorticoids, metabolites

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INTRODUCTION

Two of the most important factors for profitability in the beef industry, especially in the feedlot sector, are ADG and respiratory disease (**BRD**). Favorable ADG translates to fewer days on feed, thereby decreasing

costs in feeding and other yardage costs. Respiratory disease is considered the most costly disease in beef cattle (Griffin, 1997). Recent research has focused on discovering metabolic and other physiological markers for efficient growth. Some of the physiological mechanisms could have a dual impact by impacting both growth efficiency and health of cattle. Ideal physiological markers should be relatively easy and cheap to measure, as well as provide some insight into the biology contributing to efficient growth and resistance to disease. Glucocorticoids and metabolites have been shown to be associated with ADG of finishing beef cattle (Montanholi et al., 2010; Montanholi et al., 2013; Foote et al., 2016a). Additionally, cortisol has been shown to have a slight genetic correlation

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²Corresponding author: Andrew.Foote@ars.usda.gov

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with BRD (Cockrum et al., 2016), and lactate concentrations at receiving have been shown to be associated with BRD (Buczinski et al., 2015).

To be utilized fully in a selection program, it would be desirable that physiological markers measured early in life could be used to predict later growth rate or disease development. Therefore, the objectives of this experiment were to determine the association of circulating cortisol, lactate, and glucose early in life on ADG and incidences of BRD in cattle in the feedlot. It was hypothesized that cortisol and lactate concentrations prior to and at weaning would be negatively associated with ADG and positively associated with the development of BRD or lung lesions.

MATERIALS AND METHODS

This experiment was reviewed and approved by the U.S. Meat Animal Research Center (USMARC) Animal Care and Use Committee.

Calves used in this study (total $n = 451$; steers $n = 271$ and heifers $n = 180$) were part of the USMARC continuous Germplasm Evaluation Program (Schiermister et al., 2015) and allocated to study the genetics of BRD resistance. Calves were born in the spring of 2012 and weaned at a mean age of 152 ± 15 d. Details on the overall experiment and handling of animals have been previously described (Leach et al., 2013). Prior to weaning, calves were managed in 4 separate locations within the USMARC property, but with common management procedures. The number of animals used from each location are as follows: location 1 $n = 98$, location 2 $n = 151$, location 3 $n = 108$, and location 4 $n = 94$. Calves received a vaccine (Bovi-Shield Gold One Shot; Zoetis, Parsippany, NJ) approximately 6 wk prior to weaning and a booster 3 wk after the initial dose. Calves were comingled at weaning. At weaning, calves received an additional 5-way vaccination (Bovi-Shield Gold 5; Zoetis). Preweaning blood samples (25 mL) were collected via jugular venipuncture at the time of administration of the booster vaccination and an additional blood sample was collected at weaning. Blood was allowed to clot at ambient temperature and then centrifuged at $3,000 \times g$ for 25 min to collect serum. Serum was stored at -80°C until analyses were conducted.

At the time of weaning, cattle were randomly assigned to pens within sex so that there were 4 pens for heifers and 5 pens for steers with 70 to 75 animals in each pen. Cattle were given ad libitum access to a ration that contained on a DM basis 51% corn silage, 25% alfalfa hay, 20% wet distillers grains with solubles, and 4% of a commercial vitamin and mineral supplement. The supplement contained on a DM basis: 25.00% CP, 3.17% ether extract, 14.49% calcium,

0.33% phosphorus, 3.99% salt, 1.64% sodium, 0.50% magnesium, 0.61% potassium, 0.26% sulfur, 41.86% ash, 0.0018 mg/kg cobalt, 0.4157% copper, 0.0042% iodine, 0.5164%, 0.0907% manganese, 0.0008% selenium, 0.1449% zinc, 0.0334% thiamin, 0.0070% Vitamin A (1,000,000 IU/g), and 0.1050% Vitamin E (500 IU/g). Cattle received this ration for approximately 21 d, and then were transitioned to a ration containing 26.5% corn silage, 25% soybean straw, 25% wet distillers grains with solubles, 20% dry-rolled corn, and 3.5% of a commercial vitamin and mineral supplement (described above). Cattle received this ration for 50 d. The first 71 d in the feedlot are considered the receiving phase for this experiment. Cattle were then transitioned to a finishing ration containing 59.5% dry-rolled corn, 32% wet distillers grains with solubles, 5% corn silage, and 3.5% of a commercial vitamin and mineral supplement containing tylosin (described above with the addition of 0.23 g tylosin phosphate/kg supplement). Cattle received the finishing ration for approximately 200 d. Time from weaning to slaughter averaged 298 d.

Body weights were recorded at birth, weaning, and periodically during the experiment. Cattle were weighed a minimum of 6 times during the entire time in the feedlot, including weaning weight through shipping for slaughter. If cattle were processed for sickness, BW was recorded, so that some animals were weighed a maximum of 9 times. Preweaning ADG was calculated as the difference of weaning BW and birth BW divided by the number of days. Postweaning ADG was broken up into a receiving phase and a finishing phase. The receiving phase was defined as the time prior to the cattle being placed on the finishing ration; however, during the receiving phase, cattle were only weighed 45 d after weaning, unless they were treated for illness. Therefore, the receiving ADG was calculated as the difference of the BW at d 45 postweaning and the weaning weight divided by 45 d. To calculate ADG during the finishing phase, the BW measurements collected during the finishing phase were regressed on days of study using a quadratic equation to better describe the data and minimize errors in single BW measurements. Average daily gain for the finishing phase was calculated as predicted BW gain divided by days on study. Total postweaning BW gain was calculated using the same method as the finishing phase ADG, except all BW from weaning until the end of the study were used in the regression equation.

All animals were monitored for BRD during all phases of production and incidences were diagnosed by trained personnel as previously described (Leach et al., 2013). Cattle did not receive prophylactic antibiotics during this experiment, other than tylosin during the finishing phase. For analysis of the binary parameter of BRD incidence, cattle that were diagnosed with BRD

were assigned a value of 1 and cattle that were not diagnosed with BRD received a 0. Cattle that were diagnosed with BRD more than once ($n = 11$) were only counted once. Cattle were slaughtered over 2 d at a commercial facility. Lungs were scored for incidence of lesions by trained personnel. Lungs were scored on a scale from 0 to 3, where 0 indicated no lesions, 1 indicated lesions affecting less than 25% of the lung, 2 indicated lesions affecting 25% to 50% of the lung, and 3 indicated lesions affecting more than 50% of the lung. For logistic regression, lung lesions were treated as a binary trait, so that lungs that did not have lesions were given a 0 and lungs with lesions were given a 1.

Serum cortisol was analyzed in duplicate using a commercial coated-tube RIA kit (MP Biomedicals, Irvine, CA) in duplicate. The intra- and interassay CV for the cortisol were determined by including a bovine control in duplicate in each assay, and were determined to be 3.3% and 2.5%, respectively. Glucose and L-lactate were quantified using an immobilized enzyme system (YSI model 2700; YSI Inc., Yellow Spring, OH).

All data were analyzed using SAS 9.3 (SAS Inst. Inc., Cary, NC). Variables were tested for normality using the Shapiro-Wilk test in PROC UNIVARIATE. Lactate and glucose were found to be non-normal (Shapiro-Wilk test statistic [W] < 0.95) and near-normality ($W > 0.98$) was achieved through log-base 10 transformation. Log-transformed glucose and lactate variables were used in all analyses. Animal was the experimental unit in all analyses. Denominator degrees of freedom were calculated using the Kenward-Roger's approximation. The effect of time (preweaning vs. weaning) on serum parameters was analyzed using a mixed model with sex as a fixed effect, covariates of preweaning location and breed composition, and sire as a random variable. The effect of sex on serum and growth parameters was analyzed using a mixed model with the fixed effects of sex, covariates of preweaning location and breed composition, and sire as a random variable. The association of serum parameters at preweaning and weaning with ADG was analyzed using a mixed model regression approach to statistically control for other sources of variation, such as age at weaning, sex, and breed composition. Preweaning and weaning cortisol, log-transformed lactate, log-transformed glucose, and the change from preweaning to weaning (delta) were analyzed in a mixed model regression, separately. Nontransformed lactate and glucose values were tested in the mixed model regression, but model fit was slightly better using log-transformed values and it was preferred to use the same log-transformed lactate and glucose data for all analyses. Sex was included as a fixed effect, weaning age and breed composition were included as covariates, and sire was included as a random effect. A pseudo- R^2

was calculated (Foote et al., 2016b) by subtracting the residual of the full model from the intercept-only model and dividing by the residual of the intercept-only model. The random variable parameter was constrained to the value obtained in the full model. The amount of variation explained by a variable was calculated as the difference in pseudo- R^2 with and without the variable included in the model. The association of ADG and serum variables with incidence of BRD was analyzed using a mixed model analysis. Sex and BRD status were included as fixed effects; weaning age, preweaning management group, and breed composition were included as covariates; and sire was included as a random effect. For the model to determine the association of ADG and BRD, preweaning management group was removed as a covariate. To determine if cortisol, lactate, or glucose were predictive of BRD or lung lesion incidence, a multivariate logistic regression was fitted using the logistic procedure. Variables measured at preweaning were fitted simultaneously in the same model, as were weaning variables, and delta variables in separate respective models. P -values < 0.05 were considered significant.

RESULTS AND DISCUSSION

The descriptive statistics of ADG and serum variables used in the analyses are presented in Table 1. Serum cortisol and glucose increased and lactate decreased from preweaning to weaning ($P < 0.01$; Table 2). This could be a consequence of the diet of calves shifting from milk to increased forage during the late preweaning phase. Cortisol values in this experiment are slightly higher than previous data collected on finishing steers and heifers at USMARC (Foote, unpublished). It is likely that the slightly elevated cortisol values in the current study are representative of the increased stress associated with working the calves prior to weaning and at weaning, both of which involve separation from the dam, human interaction, and additional processing. There are no obvious environmental or nutritional stressors that were experienced by a large proportion of these cattle that would contribute additionally to the slightly elevated cortisol values observed in these young calves.

Heifers in this study displayed consistently greater concentrations of cortisol, lactate, and glucose at both the preweaning and weaning time points ($P < 0.05$ for all comparisons; Table 3). Data presented here are in slight contrast to Foote et al. (2014), which showed plasma glucose concentrations were not different between steers and heifers. However, Foote et al. (2014) measured plasma glucose at the end of the finishing period, and concentrations were much greater than the values reported in this current data set. In agreement

Table 1. Descriptive statistics of variables used in analyses of data from growing and finishing beef steers and heifers ($n = 451$)

Variable	Mean	SD	Min	Max
Weaning age, d	152	15	99	187
Prewearing ADG	1.10	0.14	0.62	1.50
Receiving ADG, kg/d	1.21	0.27	0.16	2.11
Finishing ADG, kg/d	1.35	0.18	0.72	2.06
Total ADG, kg/d	1.35	0.15	0.82	1.76
Prewearing				
Cortisol, nmol/L	91.1	39.2	4.7	188.5
Lactate, ¹ mM	5.09	2.71	1.19	16.9
Glucose, ² mM	4.74	0.816	2.72	10.40
Weaning				
Cortisol, nmol/L	108.6	44.3	7.9	259.6
Lactate, ³ mM	4.37	2.068	1.30	14.90
Glucose, ⁴ mM	5.18	1.045	1.69	9.76
Delta				
Cortisol, nmol/L	17.5	45.5	-133.1	214.0
Lactate, mM	-0.72	2.71	-11.53	8.62
Glucose, mM	0.44	0.96	-3.28	5.27

¹Log transformed values used in analyses; SD = 0.22.²Log transformed values used in analyses; SD = 0.072.³Log transformed values used in analyses; SD = 0.19.⁴Log transformed values used in analyses; SD = 0.086.**Table 2.** Effect of time of sample collection on serum cortisol, lactate, and glucose of growing beef steers and heifers ($n = 451$)

Variable	Prewearing	Weaning	SEM	P-value
Cortisol, nmol/L	94.4	111.9	2.18	< 0.001
Log-lactate	0.65	0.60	0.013	< 0.001
Lactate, mM	4.47	3.98	.	.
Log-glucose	0.67	0.70	0.0059	< 0.001
Glucose, mM	4.64	5.04	.	.

Table 3. Effect of sex on serum cortisol, lactate, and glucose and growth traits of beef steers ($n = 271$) and heifers ($n = 180$)

Variable	Steers	Heifers	SEM	P-value
Prewearing				
Cortisol, nmol/L	85.1	100.4	3.50	< 0.001
Log-lactate	0.62	0.68	0.018	0.005
Lactate, mM	4.17	4.79	.	.
Log-glucose	0.66	0.68	0.006	0.003
Glucose, mM	4.57	4.79	.	.
Weaning				
Cortisol, nmol/L	102.9	123.8	3.06	< 0.001
Log-lactate	0.58	0.63	0.015	0.025
Lactate, mM	3.80	4.27	.	.
Log-glucose	0.69	0.71	0.007	0.011
Glucose, mM	4.90	5.13	.	.
Prewearing ADG, kg/d	1.11	1.06	0.010	< 0.001
Receiving ADG, kg/d	1.25	1.15	0.024	< 0.001
Finishing ADG, kg/d	1.42	1.27	0.016	< 0.001
Total postweaning ADG, kg/d	1.39	1.27	0.012	< 0.001

with the current data, Foote et al. (2014) reported that plasma lactate was greater in heifers than steers. Cortisol differences were not observed between steers and heifers previously (Gettys et al., 1988). The cortisol differences between steers and heifers could be due to temperament differences (Voisinet et al., 1997), or it could be related to differences in glucose metabolism.

A mixed model regression analysis was used to determine the association of cortisol, lactate, and glucose concentrations with ADG, accounting for sex, age at weaning, and breed composition (Table 4). Blood parameters that were associated with preweaning ADG included weaning lactate ($P = 0.04$), delta lactate ($P = 0.02$), preweaning glucose ($P < 0.01$), and weaning glucose ($P < 0.001$). Both measures of serum glucose displayed a positive association with preweaning ADG and explained about 4% of the variance in preweaning ADG. Although it was not measured in this study, it is possible that serum glucose concentrations prior to and at weaning are related to either quantity or quality of milk consumption. These data would suggest that calves that consume more milk relative to grazing grow faster prior to weaning. Somewhat surprisingly, the association of weaning serum lactate concentrations with preweaning ADG was negative, which is in the opposite direction of the association of glucose with preweaning ADG. Circulating lactate is a result of anaerobic metabolism of glucose and can be an indicator of a stress response (Mitchell et al., 1988), an indicator of postabsorptive anaerobic metabolism of glucose, or a product of ruminal fermentation of carbohydrates. If circulating lactate were indicative of incomplete metabolism of glucose, it would be expected that the association of glucose and lactate with ADG would be in the same direction (i.e., greater glucose concentrations lead to greater lactate concentrations). However, the negative association of weaning lactate with preweaning ADG, which is the opposite of the glucose association, could indicate that circulating lactate is not associated with glucose metabolism, but potentially indicative of a stress response or ruminal fermentation.

Factors associated with receiving ADG included preweaning cortisol ($P = 0.04$), preweaning lactate ($P = 0.02$), weaning lactate ($P < 0.01$), preweaning glucose ($P < 0.01$), and weaning glucose ($P = 0.04$). Similarly to the observations for serum lactate with preweaning growth, associations of serum lactate with receiving ADG were negative, and weaning lactate explained 2.27% of variance in receiving ADG. In contrast to the results for preweaning ADG, glucose concentrations were negatively associated with receiving ADG and explained a smaller proportion of the variance in receiving ADG (0.77%–1.63%). Factors associated with finishing ADG included preweaning lactate ($P = 0.02$) and preweaning glucose

Table 4. Association of the dependent variables cortisol, lactate, and glucose at preweaning or weaning with the independent variable of ADG of growing and finishing beef steers and heifers ($n = 451$)¹

Variable	Solution	SEM	<i>P</i> -value	Pseudo- <i>R</i> ²	% Variance explained
Preweaning ADG					
Preweaning cortisol	0.001	0.0002	0.094	0.14	0.11
Weaning cortisol	0.0003	0.0002	0.097	0.13	< 0.01
Delta cortisol	-0.0001	0.0002	0.932	0.13	< 0.01
Preweaning lactate	0.016	0.030	0.606	0.13	< 0.01
Weaning lactate	-0.068	0.013	0.044	0.14	0.91
Delta lactate	-0.005	0.0024	0.024	0.14	0.73
Preweaning glucose	0.41	0.092	< 0.001	0.17	3.40
Weaning glucose	0.41	0.077	< 0.001	0.18	4.68
Delta glucose	0.011	0.0067	0.120	0.14	0.06
Receiving ADG					
Preweaning cortisol	0.0008	0.0004	0.040	0.07	0.74
Weaning cortisol	0.0001	0.0003	0.887	0.06	< 0.01
Delta cortisol	0.0005	0.0003	0.076	0.07	0.44
Preweaning lactate	-0.14	0.061	0.021	0.08	0.94
Weaning lactate	-0.22	0.069	0.001	0.07	2.27
Delta lactate	-0.002	0.0272	0.760	0.06	< 0.01
Preweaning glucose	-0.56	0.188	0.003	0.08	1.63
Weaning glucose	-0.34	0.160	0.035	0.07	0.77
Delta glucose	0.002	0.0136	0.903	0.06	< 0.01
Finishing ADG					
Preweaning cortisol	0.0001	0.0002	0.869	0.20	< 0.01
Weaning cortisol	0.0003	0.0002	0.189	0.20	0.18
Delta cortisol	0.0002	0.0002	0.284	0.20	0.09
Preweaning lactate	0.092	0.0389	0.018	0.16	0.53
Weaning lactate	0.067	0.0445	0.134	0.20	0.21
Delta lactate	0.0001	0.0032	0.994	0.20	< 0.01
Preweaning glucose	-0.32	0.121	0.008	0.24	3.20
Weaning glucose	-0.05	0.10	0.595	0.19	< 0.01
Delta glucose	0.0132	0.0087	0.128	0.20	0.24
Total postweaning ADG					
Preweaning cortisol	-0.0001	0.0002	0.631	0.19	< 0.01
Weaning cortisol	0.0001	0.0002	0.568	0.19	< 0.01
Delta cortisol	0.0001	0.0002	0.361	0.19	0.04
Preweaning lactate	0.049	0.032	0.127	0.20	0.22
Weaning lactate	0.014	0.037	0.701	0.19	< 0.01
Delta lactate	-0.001	0.0026	0.711	0.19	< 0.01
Preweaning glucose	-0.31	0.099	0.002	0.21	2.00
Weaning glucose	-0.13	0.084	0.112	0.19	0.44
Delta glucose	0.0068	0.0071	0.337	0.20	< 0.01

¹Dependent variables were modeled separately. Fixed effect of sex and covariates weaning age and breed composition, and random effect of sire.

($P < 0.01$). Additionally, preweaning glucose was the only serum parameter associated with total postweaning ADG ($P < 0.01$). The association of preweaning glucose with finishing and total postweaning ADG was negative and explained 3.2% of the variance of finishing ADG and 2.0% of the variance in total postweaning ADG. This observation for glucose with ADG was similar for all 3 postweaning ADG measures. A negative correlation of circulating glucose with ADG has been shown in multiple studies conducted at USMARC (Foote et al., 2014, 2016a). It is not known why greater glucose concentra-

tions would be associated with slower growth rates, but it could be related to depressed insulin sensitivity.

The data regarding the association of serum glucose with ADG indicate that cattle that have lesser preweaning glucose concentrations have greater postweaning ADG. This could be associated with compensatory gain, where calves that consume less milk and have less circulating glucose, grow slower preweaning, but compensate postweaning. This could also indicate that these cattle graze more during the preweaning period and are less stressed by the diet change

associated with weaning. Experiments designed to induce compensatory gain in cattle repeatedly showed a decrease in plasma glucose concentrations during the restriction period compared to the controls, which sharply increased with 10 to 30 d of realimentation to be similar to the control cattle (Hayden et al., 1993; Yambayamba et al., 1996). It is speculated that this could contribute to the improved efficiency during the early realimentation period because of the balance of increased nutrient availability and low maintenance requirements for cattle undergoing compensatory gain. In contrast, it also appears that the majority of compensatory gain due to preweaning growth restriction is limited to the backgrounding or receiving period, and is not observed through the finishing phase (Greenwood and Cafe, 2007). It is possible that natural variation in preweaning nutrition and metabolism could induce natural compensatory gain.

Prewaning cortisol was ($P = 0.04$) negatively associated with receiving ADG and explained 0.74% of the variance in receiving ADG, but no other associations were found with cortisol related to ADG. Previous studies in finishing cattle have shown that a single measure of cortisol during the finishing period was negatively associated with ADG (Foote et al., 2016a; Trenkle and Topel, 1978). Additionally, Foote et al. (2016a) showed no association of fecal corticosterone, which is a measure of blood glucocorticoids 12 to 18 h before the fecal collection, with ADG. It was thought from these data (Foote et al., 2016a) that the response to stress was more predictive of ADG than basal cortisol concentrations. In sheep, it has been shown that more efficient lambs have a lesser response to an ACTH challenge than less efficient lambs and that basal cortisol levels were less associated with feed efficiency than the concentration at the peak of the response (Knott et al., 2008, 2010). It appears that a single measure of cortisol early in life is not associated with postweaning growth, but may be more indicative of short-term growth rates.

In total, there were 130 animals that were diagnosed as having BRD and 321 that did not develop BRD. Of the 130 animals that were diagnosed with BRD, 26 of these occurred prior to weaning, 103 occurred within 60 d of weaning, and 1 occurred during the finishing phase. Additionally, at slaughter, there were 321 with lung lesions present and 127 animals with no lung lesions. Of the 321 animals with lung lesions, 171 were scored a 1, 70 were scored a 2, and 80 were scored a 3. From 2009 to 2016, the proportion of cattle from this population that presented lung lesions at slaughter averaged 69% and ranged from 56% to 82%, which is similar to the 72% observed in this group of cattle. Lung scores at slaughter were not different between cattle that had been diagnosed with

Table 5. Effect of diagnosis of bovine respiratory disease (BRD) on lung scores at slaughter, growth (ADG, kg/d), and serum cortisol (nmol/L), lactate (mM), and glucose (mM) of growing and finishing beef steers and heifers

Variable	BRD				P-value
	No		Yes		
	Mean	SEM (n = 321)	Mean	SEM (n = 130)	
Lung score ¹	1.25	0.061	1.15	0.101	0.395
Prewaning ADG	1.10	0.011	1.08	0.014	0.248
Receiving ADG	1.21	0.018	1.13	0.026	0.004
Finishing ADG	1.35	0.011	1.36	0.017	0.498
Total ADG	1.34	0.010	1.33	0.014	0.683
Prewaning					
Cortisol	93	3.0	90	3.9	0.452
Log lactate	0.64	0.014	0.64	0.021	0.807
Lactate	4.39	.	4.35	.	.
Log glucose	0.67	0.0051	0.66	0.0070	0.062
Glucose	4.68	.	4.54	.	.
Weaning					
Cortisol	114	2.8	109	3.6	0.147
Log-lactate	0.61	0.011	0.60	0.018	0.831
Lactate	4.04	.	3.97	.	.
Log glucose	0.704	0.0059	0.698	0.0082	0.455
Glucose	5.06	.	4.99	.	.
Delta cortisol	21.6	3.9	19.0	4.9	0.625
Delta lactate	-0.68	0.15	-0.40	0.24	0.328
Delta glucose	0.40	0.051	0.45	0.085	0.633

¹0, no lesions; 1, lesions affecting less than 25% of the lung; 2, lesions affecting 25 to 50% of the lung; 3, lesions affecting more than 50% of the lung.

BRD compared to cattle that had not been diagnosed with BRD ($P = 0.39$; Table 5). Cattle that developed BRD were slightly slower growing during the receiving phase ($P < 0.01$), but did not have different finishing phase ADG or total postweaning ADG than cattle that did not develop BRD ($P = 0.50$ and 0.68 , respectively). Cortisol concentrations at preweaning and weaning were not different ($P = 0.45$ and 0.14 , respectively) due to BRD classification. There was a tendency ($P = 0.06$) for cattle diagnosed with BRD to have slightly lesser preweaning glucose concentrations, but not at weaning ($P = 0.45$). Montgomery et al. (2009) showed that both glucose and lactate measured at initial processing in the feedlot linearly decreased as the number of times cattle were treated for BRD increased. Also, Cole et al. (1988) showed that cattle fasted for 24 h and transported for 12 of those hours, had reduced fasting serum glucose and increased morbidity in the feedlot. Altogether, these data indicate that reduced circulating glucose is possibly related to increased instances of BRD. While the mechanisms are unclear, it is possible that cattle with reduced circulating glucose concentrations have a diminished ability to mount an immune response to pathogens because of reduced metabolic reserves.

Table 6. Logistic regression for factors associated with incidence of bovine respiratory disease (BRD) in growing and finishing beef cattle ($n = 451$)

Variable	Coefficient	SE	Odds ratio (95% CI) ¹	P-value
Prewaning ²				
Cortisol	-0.0004	0.0039	0.98 (0.73 to 1.33)	0.913
Lactate	-0.55	0.65	0.89 (0.67 to 1.18)	0.399
Glucose	2.65	1.96	1.21 (0.92 to 1.59)	0.176
Weaning ³				
Cortisol	0.0002	0.0032	1.01 (0.76 to 1.34)	0.940
Lactate	0.12	0.68	1.02 (0.80 to 1.31)	0.858
Glucose	-0.57	1.53	0.95 (0.74 to 1.23)	0.711
Delta ⁴				
Cortisol	0.001	0.0029	1.06 (0.82 to 1.38)	0.645
Lactate	-0.026	0.049	0.93 (0.72 to 1.21)	0.589
Glucose	-0.14	0.13	0.88 (0.68 to 1.12)	0.291

¹Odds ratio and 95% CI for 1 SD increase in each variable. Mean $\pm$ SD for each variable are presented in Table 1.

²Prewaning cortisol, lactate, and glucose modeled together ($R^2 = 0.16$).

³Weaning cortisol, lactate, and glucose modeled together ($R^2 = 0.16$).

⁴Change in concentrations from preweaning to weaning. Delta cortisol, lactate, and glucose modeled together ($R^2 = 0.16$).

Results from the logistic regression analysis indicate that none of the serum variables measured was predictive of developing BRD in the feedlot (Table 6). Logistic regression of serum variables against presence or absence of lung lesions at slaughter showed that there was a tendency ($P = 0.06$; Table 7) for weaning serum glucose concentrations to be positively associated with lung lesions. This seems to be in contrast to the association of reduced serum glucose and treatment for BRD in the feedlot (discussed above). However, cattle that display lung lesions at slaughter do not necessarily display symptoms of BRD, and cattle that are diagnosed with BRD do not necessarily have lung lesions observable at slaughter. This disparity could be related to the manifestation of the disease in the animals and an interplay with nutrient metabolism. It is possible that the increased glucose concentrations are associated with mounting an immune response to pathogens in the respiratory tract, but they do not display the classical symptoms of BRD to result in pulling for treatment.

Previous research has shown that blood lactate concentrations can be predictive of developing respiratory disease (Buczinski et al., 2015), but it also depended on temperament of the cattle. Additionally, Cockrum et al. (2016) showed a slight negative genetic correlation of cortisol with respiratory disease. Data presented here indicate there is not a strong association of cortisol, glucose, or lactate with development of BRD in cattle. It is possible that including other information such as a temperament score could strengthen the associations of these measures with BRD diagnoses.

Table 7. Logistic regression for factors associated with incidence of lung lesions in beef cattle ($n = 451$)

Variable	Coefficient	SE	Odds ratio (95% CI) ¹	P-value
Prewaning ²				
Cortisol	0.0009	0.119	1.04 (0.79 to 1.37)	0.803
Lactate	-0.500	0.605	0.89 (0.69 to 1.17)	0.408
Glucose	0.25	1.832	1.02 (0.79 to 1.32)	0.893
Weaning ³				
Cortisol	0.0023	0.0029	1.11 (0.86 to 1.43)	0.431
Lactate	-1.01	0.68	0.83 (0.65 to 1.06)	0.136
Glucose	3.05	1.62	1.30 (0.99 to 1.70)	0.060
Delta ⁴				
Cortisol	0.0007	0.0027	1.03 (0.81 to 1.32)	0.793
Lactate	0.033	0.047	1.09 (0.85 to 1.40)	0.486
Glucose	0.21	0.13	1.22 (0.96 to 1.55)	0.102

¹Odds ratio and 95% CI for 1 SD increase in each variable. Mean $\pm$ SD for each variable are presented in Table 1.

²Prewaning cortisol, lactate, and glucose modeled together ($R^2 = 0.09$).

³Weaning cortisol, lactate, and glucose modeled together ($R^2 = 0.11$).

⁴Change in concentrations from preweaning to weaning. Delta cortisol, lactate, and glucose modeled together ($R^2 = 0.11$).

In conclusion, measurement of cortisol and lactate prior to or at weaning has limited utility in predicting growth and BRD diagnoses. However, it is possible that glucose measures could be indicative of postweaning ADG. While it may seem that explaining 2% of the variation in ADG is marginal, it is important to consider the multitude of contributing factors that affect growth. It is highly likely that a single variable that can explain approximately 2% of the variation of ADG could be extremely useful in a selection or evaluation program. It should be considered as well that glucose may not be the physiological marker that needs to be included in selection and evaluation criteria, but further study of carbohydrate metabolism and its effect on growth may yield better metabolic markers that are less influenced by other factors and more predictive of growth. In addition to the utility of glucose as a metabolic marker for growth, it is interesting to consider the underlying physiology and that preweaning glucose metabolism could potentially have large impacts on postweaning growth.

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