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The effect of calving assistance and supplementation of colostrum with sodium bicarbonate on newborn calf vigor, success of passive transfer, health, and growth of dairy calves

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Abstract

The objective of this research was to examine the efficacy of supplementing colostrum with sodium bicarbonate for improving passive transfer, health, and growth. An additional objective was to evaluate the effects of calving difficulty on calf vigor. A total of 543 heifer and bull calves from 9 commercial dairy herds were enrolled in this randomized double-blind field trial. At birth, calves were assessed for vigor by the dairy producer, using a prototype calf vigor assessment tool which rated Visual appearance, Initiation of movement, General responsiveness, Oxygenation, and Rates of heartbeat and respiration (VIGOR). Subsequently, calves were fed colostrum supplemented with either 20 g of sodium bicarbonate (SB) or placebo powder. Blood was collected from each calf between 1 and 8 days of age for serum total protein (STP). Each calf was assessed with a standardized clinical score for general health, and measured for growth using a heart girth weight tape at 1, 2, 3, and 6 weeks of age. The findings suggest that calves born with assistance, or that were malpositioned at calving, had lower vigor than those born unassisted. Yet, calf vigor improved with time following birth. Measures from the VIGOR score, including slower responsiveness and a higher heart rate, were associated with reduced health. There was a significant interaction between sex of the calf and SB supplementation of colostrum with STP. Sodium bicarbonate supplementation of colostrum was not significantly associated with improved passive transfer, and had no significant effect on weight gain. Assessment of calf vigor in calves born with assistance may be an important management tool for dairy producers as an indicator that further intervention may be needed to improve health.

Key words: calf, health, vigor, sodium bicarbonate, passive transfer

Résumé

L'objectif de cette recherche était de déterminer si l'ajout de bicarbonate de soude au colostrum pouvait améliorer le transfert passif, la santé et la croissance. Un objectif additionnel était d'évaluer l'effet de la difficulté du vêlage sur la vigueur du veau. Cet essai randomisé à double aveugle sur le terrain comportait 543 veaux mâles et femelles provenant de neuf troupeaux laitiers commerciaux. La vigueur des veaux à la naissance a été évaluée par le producteur laitier à l'aide d'un outil prototype d'évaluation de la vigueur. Par la suite, les veaux ont reçu du colostrum avec soit un supplément de 20 g de bicarbonate de soude ou soit une poudre placebo. Des échantillons de sang ont été prélevés chez chaque veau entre les jours 1 et 8 d'âge pour évaluer le taux sérique des protéines totales. On a utilisé un score clinique standardisé pour évaluer la santé générale de chaque veau et la croissance des veaux a été mesurée aux semaines 1, 2, 3 et 6 suivant le vêlage. Les résultats suggèrent que l'assistance à la naissance et la malposition au vêlage étaient associées à une moins grande vigueur. Néanmoins, la vigueur des veaux s'améliorait avec le temps suivant le vêlage. Des mesures tirées du score VIGOR, incluant une moins grande capacité de réaction et une fréquence cardiaque élevée, étaient associées à une moins bonne santé. Il y avait une interaction significative entre le sexe du veau et la supplémentation du colostrum pour le taux sérique des protéines totales. L'ajout de bicarbonate de sodium au colostrum n'a pas améliorer le transfert passif et n'a pas eu d'effet significatif sur le gain de poids. L'évaluation de la vigueur chez les veaux nés avec assistance peut être un outil de gestion important pour les producteurs laitiers lorsque vient le temps de décider si d'autres interventions sont nécessaires pour améliorer la santé.

Introduction

The consequences of dystocia on the newborn calf are vast, yet not widely considered or dealt with in the dairy industry. During a difficult birth, calves are at risk of injury, inflammation, pain, hypoxia, acidosis, and an inability to maintain homeostasis.[42] Depending on the extent and severity of these issues, calves may suffer short or long-term consequences to their vitality, health, and productivity. These consequences may be reduced by good calving management or through various intervention strategies performed at birth.

Prolonged dystocia or forced extraction may rupture the umbilical cord, terminating blood oxygenation from the placenta prematurely.[26,53] This may cause the development of asphyxia and respiratory acidosis if the calf is not able to regulate its own respiration.[54] In addition, anaerobic glycolysis will produce lactic acid and metabolic acidosis if the hypoxia becomes severe enough. Severe respiratory and metabolic acidosis may compromise survival in the newborn calf.[7,25]

Newborn calves experiencing acidosis may have reduced intake or absorption of colostral immunoglobulins, increasing the risk of failure of passive transfer (FPT).[5,10,25,56] Calves with FPT have increased susceptibility to disease, reduced average daily gain (ADG), decreased future milk production, and increased risk of being culled during the first lactation.[18,21,22] Strategies to reduce acidosis at birth to prevent FPT need to be implemented.

The efficacy of sodium bicarbonate (SB) supplementation of colostrum has recently been tested in newborn calves as a buffer therapy for the correction of acidosis; much of this work has produced conflicting results. Researchers at the University of New Hampshire reported that supplementing colostrum replacer with 30 g of SB split over the first 2 feedings increased serum IgG concentration and apparent efficiency of IgG absorption when compared to calves fed colostrum replacer alone.[40] In addition, another research group from the same university found that supplementing 20 g of SB in a single feeding resulted in greater IgG concentrations than 30 g over 2 feedings.[13] In other studies, supplementing SB into colostrum resulted in decreased IgG absorption, whereas[11,12] Chapman et al[16] found no effect of SB supplementation on IgG absorption. The objective of the current project was to determine the efficacy of supplementation of colostrum with SB in a randomized, controlled clinical trial in a large population of dairy calves for the improvement of passive transfer, health, and growth. The effects of calving assistance on calf vigor, passive transfer, health, and growth were also examined.

Materials and Methods

Study Farms

Dairy farms were selected from a convenience sample of herds, which were chosen to participate if they had previous research experience with the University of Guelph and were within a 2 h drive from the main campus. Using this approach, a total of 9 farms in southwestern Ontario were identified and enrolled in the study.

Calf Enrollment and Vigor Assessment

Before the study commenced, the experiment was approved by the University of Guelph Animal Care Committee (#10R084, Guelph, ON, Canada), and all work with animals was done according to the guidelines set by the Canadian Council on Animal Care.[15] Sample size was calculated in Stata-IC 10.1,[a] using data from a previous study investigating the effect of SB supplementation into colostrum replacer on IgG absorption.[40] These authors found a significant difference in 24 h serum IgG concentrations (16.3 vs 13.2 g/L). Using these treatment means, a power of 80% and confidence level of 95%, it was determined that there was a requirement of 189 calves per experimental treatment group. Holstein heifer and bull calves born between May 01 and August 30, 2010 were enrolled in this study. The producer or farm worker in charge of calving management completed a VIGOR score sheet at the time of discovery and/or delivery of a newborn calf, and prior to colostrum feeding.[41] Scores for each variable included in the VIGOR score were added together to obtain a composite VIGOR score. As such, a higher VIGOR score was indicative of a less vigorous calf. The producer or farm worker also recorded the time interval from birth to when the calf was assessed using the VIGOR score sheet. This variable was later categorized into 0 to 30 min, 30 min to 1.5 h, 1.5 to 3 h, and >3 h.

Treatments, Randomization, and Blinding

Following VIGOR assessment, calves received either 20 g of SB or 20 g of a placebo powder supplemented into their first feeding of colostrum. The placebo used in this study was lactose powder, which was visually similar to SB. These treatments were prepared and placed into individual plastic vials. Treatment allocation was randomized using a random number generator, and vials were labeled in a consecutive numbering sequence to facilitate conduct of this study as a double-blinded, randomized clinical trial. Three separate randomized blocks of 10 vials were created with an equal number of treatments and controls in each block. In total, 600 vials were created numbered from "001" to "600", with the randomization repeating every 30 vials. Treatment vials were distributed to farms in multiples of 10 to ensure that an equal number of treated and control calves were enrolled on each farm.

Calf Birth Record

Following the birth of each calf, and the preparation and feeding of colostrum supplemented with either SB or placebo, producers completed a birth record documenting information about the calving event. The birth record included the date and time of calving, the assessment of calving ease, quantity, timing, and source of colostrum fed to each calf, and the experimental treatment vial number used to supplement the colostrum. Time of birth and colostrum feeding was recorded by producers as a categorical time interval rather than an exact time. Date of calving was later categorized into month of birth.

Farm Visits and Calf Sampling

On a regular weekly interval, trained technicians visited each farm to enroll new calves as well as to collect measurements and samples from previously enrolled animals during their first, second, third, and sixth week of life. Bull calves were enrolled on 7 farms and were followed until they left the farm (1 farm kept bulls for the 6-week study duration, whereas 6 farms did not keep bull calves past 1 week of age). Blood was collected from each calf from 1 to 8 days of age. Blood was collected via jugular venipuncture into 10 mL sterile Vacutainer[b] collection tubes. Following blood collection on farm, samples were transported on ice to the laboratory, where it was allowed to clot and centrifuged at 970 × *g* for 12 minutes at ~68°F (20°C). Serum was harvested and analyzed for STP using a digital refractometer.[c]

Each calf was assessed for health and growth at 4 separate weekly farm visits over the course of the study. These assessments were conducted during the first, second, third, and sixth week of life for each calf. At each assessment, calf weight was recorded using a heart girth weight tape for Holstein calves.[d] Shoulder height was measured with a height measuring tape.[e] These measurements were conducted by 2 trained individuals, and no comparison between the tape measure and scale weight was made. Based on weight measurements obtained at the first and final calf visit, ADG and total weight gains were calculated. Rectal temperatures were taken at each visit using a digital thermometer. In addition, calves were assessed for attitude, eye discharge, ear droop, nasal discharge, and fecal consistency using a standardized scoring system adapted from McGuirk[37] as referenced by Murray et al.[41]

Statistical Analyses

Data were entered in Microsoft Excel[f] and exported into Stata-IC 10.1[g] for variable screening and statistical modeling. A causal diagram was built to examine the possible relationships to be tested by each model. All variables were examined with descriptive statistics to determine the distribution of the data, and to identify missing values. If abnormal values were detected, electronic data were checked against the original hard copy data source to ensure accuracy.

Four separate multivariable linear regression models were constructed using the "xtmixed" command in Stata, including farm as a random intercept in all models. Individual models were built to determine factors associated with total VIGOR score, STP, weight gain in the first 3 weeks, and total health score. A manual model building approach was utilized incorporating a backward stepwise method. The variable tongue length was excluded from the total VIGOR score tabulation, as there were insufficient observations recorded for this category of the VIGOR score.

All variables hypothesized to be related to the outcome of interest were screened for unconditional associations with the outcome variable in univariable analysis, while controlling for the random effect of farm. Any predictor variables that were liberally associated with the outcome ($\alpha<0.2$) were considered for inclusion in the final model. Experimental treatment was included in each model regardless of the level of significance, since it was the predictor of interest.

Spearman correlation coefficients were calculated with all main effects variables that were considered for inclusion in the final model to avoid issues associated with collinearity. Consequently, if the correlation coefficient between 2 variables had an absolute value greater than 0.75, the variable that made the most biological sense, or had the fewest missing observations, was included in the multivariable model building process.

Linearity was assessed graphically for all main effects variables with the outcome variable, using locally weighted regression (lowess smoothers). If a variable was non-linear, a quadratic term was constructed and tested in the model. If the quadratic term was significant ($\alpha<0.05$) in the model, and the relationship was adequately modeled using a curve, the quadratic term was retained in the model. If not, the quadratic term was removed and log and square root transformations were assessed for linearity and significance. If none of the presented transformations appeared to improve linearity, the variable was transformed into categorical data.

Confounding was assessed by backward elimination. A confounding variable was defined as a non-intervening variable whose removal resulted in a >25% change in the coefficient of significant variables. Regardless of the *P*-value, a confounding variable was retained in the model.

Interaction terms between experimental treatment and main effects variables were tested in each multivariable model. In addition, interaction terms between VIGOR score and main effects were investigated. Interaction effects were interpreted graphically or through assessing contrasts among different combinations of the interacting variables. In the final multivariable model, variables were retained if their significance level was $\alpha<0.05$.

Model fit was assessed by plotting residuals and best linear unbiased predictors (BLUPs), as well as visually assessing whether the assumptions of heteroscedasticity and normality were met. Standardized residuals were examined graphically to look for outliers.

Results of the multivariable models are presented in tables with coefficients, 95% confidence intervals, and *P*-values for each main effect variable. Coefficients indicate the magnitude and direction of the association with the outcome variable, when compared to the referent category. The 95% confidence intervals represent the interval which has a 0.95 probability of containing the population mean. *P*-values indicate the significance of the association between the main effect and outcome variable. *P*-values <0.05 were considered statistically significant.

Results

Animal Enrollment and Calving Environment

In total, 543 neonatal Holstein calves were enrolled on 9 farms located in southwestern Ontario. Animal enrollment by farm was highly variable, and ranged from 15 to 179 calves, with a mean of 60 animals enrolled per farm. Calves were considered to be enrolled on the study at the time of treatment administration and calf VIGOR scoring by the producer, regardless of whether or not the calf survived to the first sampling event (1 to 8 days of age). Twenty-three calves (10 heifers and 13 bull calves) did not receive treatment in their colostrum, but were included in the data when examining associations with VIGOR score, excluding treatment. Descriptive summaries of categorical variables by experimental treatment group are presented in Table 1. It is noteworthy that the double-blind random assignment of each calf to receive either SB or placebo powder in their colostrum resulted in successful randomization to treatment groups, as indicated by the similar percentage of calves in each treatment group by category. In Table 1, the number of calves by category does not consistently equal 520 calves, due to missing observations. Missed data recordings also contributed to the varying sample size presented in the multivariable models.

Calf Vigor

Accounting for the random effect of farm, and controlling for the time to VIGOR assessment after birth, all variables included in the composite VIGOR score were significantly associated with being born from a hard pull, except tongue length (Table 2). To be specific, being born following a hard pull was significantly associated with having higher scores for meconium staining, visual appearance of the tongue and head, initiation of movement after birth, general responsiveness to straw in the nasal cavity, tongue pinch, and a touch of the eyeball, as well as mucous membrane color, heart rate, and respiration rate (Table 2).

Total VIGOR score, excluding tongue length, was used as the outcome variable in a mixed linear regression model, with farm included as a random effect (Table 3). The time after birth that the score was measured by the farm staff was linearly associated with total VIGOR score. Compared to being scored within 30 min of birth, calves scored between 30 min and 1.5 h, 1.5 and 3 h, or >3 h had a 1.4, 2.1, and 2.7 point lower total VIGOR score (improved vigor), respectively. Calves born following an easy and hard pull had a 1.1 and 3.7 point higher total VIGOR score (reduced vigor), respectively, compared to calves from an observed but unassisted calving. In addition, malpositioned calves including backwards position and retention of 1 or both forelimbs at the time of calving had a 2.2 point higher total VIGOR score (lower vigor), following birth than calves in a forward position.

Colostrum Feeding and Passive Transfer

The quantity, timing, and state of colostrum was not standardized across calves in this study, but was recorded in the birth record for the purpose of accounting for the

Table 1. Summary of the number and percentage of calves in each category by experimental treatment group.

	Placebo		Sodium bicarbonate	
	n	%	n	%
Sex				
Heifer	170	32.7	165	31.7
Bull	84	16.2	101	19.4
Calving assistance				
Unobserved	130	25.6	133	26.2
Observed but unassisted	48	9.5	41	8.1
Easy pull	60	11.8	71	14.0
Hard pull	12	2.4	12	2.4
Position at calving				
Forward	241	46.8	258	50.1
Malpresentation	10	1.9	6	1.2
Source of colostrum				
Replacer	18	3.5	20	3.9
Dam	101	19.8	106	20.7
Other cow	103	20.2	114	22.3
Pooled	27	5.3	22	4.3
Route of first colostrum feeding				
Esophageal feeder	97	19.3	98	19.5
Bottle	86	17.1	99	19.7
Dam	0	0	2	0.4
Bucket	1	0.2	0	0
Combination	63	12.5	56	11.2

Table 2. Results of a multivariable linear regression model examining the associations between the impact of being born from a hard pull on each individual variable included in the VIGOR score, including farm as a random effect and controlling for the time to conduct the VIGOR assessment after birth.

VIGOR score component	Coefficient*	95% Confidence Interval		*P*-value
		lower limit	upper limit	
Visual appearance				
Meconium staining	0.46	0.23	0.70	<0.001
Tongue/head	0.78	0.58	0.98	<0.001
Initiation of movement				
Calf movement	0.62	0.22	1.02	0.002
General responsiveness				
Straw in nasal cavity	0.32	0.022	0.62	0.035
Tongue pinch	0.45	0.18	0.72	0.001
Eye reflex	0.19	0.0018	0.39	0.048
Oxygenation				
Mucous membrane color	0.36	0.11	0.62	0.005
Tongue length	-0.077	-0.55	0.39	0.75
Rates				
Heart rate	0.35	0.031	0.67	0.031
Respiration rate	0.58	0.31	0.84	<0.001

*Independent variable = hard pull vs observed but unassisted calving

Table 3. Mixed multivariable linear regression model of the predictor variables for the outcome 'total VIGOR score' (excluding tongue length), including a random effect for farm (n=412).

Total VIGOR score	Coefficient*	95% Confidence Interval		*P*-value
		lower limit	upper limit	
Calving assistance				
Observed but unassisted	Ref**	-	-	-
Unobserved	0.51	-0.26	1.27	0.20
Easy pull	1.05	0.25	1.85	0.01
Hard pull	3.69	2.40	4.99	<0.001
Calf position at calving				
Forward	Ref	-	-	-
Malpresentation	2.17	0.86	3.48	0.001
Time VIGOR score assessed after birth				
0-30 min	Ref	-	-	-
30 min-1.5 h	-1.41	-2.08	-0.73	<0.001
1.5-3 h	-2.10	-2.83	-1.37	<0.001
>3 h	-2.36	-3.11	-1.61	<0.001

*Coefficients indicate the magnitude and direction of the association with the outcome variable, when compared to the referent category**
The intra-class correlation coefficient reveals that 5.7% of the total variance in the VIGOR score can be attributed to variation between farms.

variability between calves in the data analyses. Within farm, the variation in feeding time (average standard error across farms [SE] = 0.28 h) and volume (SE = 0.066 L) was low. The majority of calves were fed colostrum within 2 h of birth (68% of heifers, 69% of bulls). Between 2 and 6 h after birth, 28% of heifers and 29% of bulls were fed. Only a small proportion of calves were fed after 6 h (4% of heifers, 2% of bulls). The average volume of colostrum fed in the first feeding was 3.4 ± 0.82 L. There was no significant difference in the volume fed between heifer and bull calves (*P*=0.33). The source of colostrum and method of feeding by experimental treatment can be seen in Table 1. Two calves born in the middle of the night received colostrum through suckling their dam. These calves received their assigned treatment in their colostrum at the morning feeding.

Failure of passive transfer was described as having a STP value <5.2 g/dL.[14] The overall mean (±SD) STP across all farms was 5.56±0.71 g/dL. All but 1 farm achieved an average STP of ≥5.2 g/dL. The prevalence of FPT among all study calves was 28% (134/477 calves). At the individual herd level, FPT ranged from 11.4% to 46.5% of calves per farm. Serum total protein by experimental treatment can be seen in Table 4. Supplementation of colostrum with SB was not significantly associated with STP based on a univariable model (β=0.044; 95% CI=-0.078 to 0.17; *P*=0.48).

Factors associated with STP were evaluated in a multivariable model, shown in Table 5. Calves born in August had a 0.29 g/dL lower STP than those born in May. Calves fed colostrum replacer had a 0.5 g/dL lower STP than calves given fresh colostrum following birth. Being treated with vitamin E/selenium following birth was associated with reducing STP by 0.31 g/dL. In addition, the number of days between enrollment at birth to blood collection at the first sampling event, was negatively associated with STP. A sex by experimental treatment interaction was found to be statistically significant in the model (Table 6; Figure 1). Of calves given placebo, bulls had a 0.28 g/dL higher STP than heifers. There was no significant association between STP with assistance at calving or VIGOR score (Table 5).

Table 4. Serum total protein (STP), weekly health scores, weekly weights and average daily gain (ADG) by experimental treatment (mean ± standard deviation).

	Placebo	Sodium bicarbonate
STP (g/dL)	5.53±0.73	5.58±0.70
Health scores		
Week 1	0.94±0.81	0.86±0.71
Week 2	1.05±0.95	0.90±0.90
Week 3	0.81±0.82	0.76±0.79
Week 6	0.37±0.66	0.27±0.65
Total	3.10±1.81	2.78±1.75
Weight (lb)		
Week 1	94.31±13.25	96.30±9.66
Week 2	100.22±10.87	101.41±11.84
Week 3	106.46±13.87	107.59±14.84
Week 6	149.14±23.21	150.51±27.98
ADG	1.37±0.71	1.37±0.46

Calf Health

Higher calf health scores for attitude, eye discharge, ear droop, nasal discharge, and fecal consistency were indicative of a less healthy calf. A hard pull at calving (*P*=0.26), reduced calf vigor (*P*=0.14), and STP concentrations (*P*=0.14) were not significantly associated with reduced calf health. Weekly mean health scores by experimental treatment can be seen in Table 4.

Using the 4 cumulative health scores over the 6-week sampling period as a combined single outcome variable, a multivariable linear mixed model was constructed to assess predictors of health (Table 7). The association between the supplementation of colostrum with SB and total health score was not significant. Twin calves had a 1.6 point higher total health score (reduced health) compared to single-born calves. Two components of the VIGOR score were significantly associated with total health score; having a faster blinking reflex in response to a touch of the eyeball, as well as having a heart rate of >100 beats/minute (**bpm**) compared to between 80

Table 5. Mixed multivariable linear regression model of the predictor variables for the outcome serum total protein (STP), including a random effect for farm (n=433).

STP (g/dL)	Coefficient*	95% Confidence Interval		*P*-value
		lower limit	upper limit	
Month of birth				
May	Ref**	-	-	-
June	-0.042	-0.32	0.23	0.77
July	-0.22	-0.49	0.050	0.11
August	-0.29	-0.57	-0.0055	0.046
Sex				
Heifer	Ref	-	-	-
Bull	0.28	0.072	0.48	0.008
Treatment				
Placebo	Ref	-	-	-
SB	0.10	-0.041	0.24	0.16
Sex*Treatment interaction	-0.29	-0.55	-0.034	0.027
Vitamin E / selenium at birth				
No	Ref	-	-	-
Yes	-0.31	-0.54	-0.077	0.009
Colostrum state				
Fresh	Ref	-	-	-
Frozen	-0.15	-0.53	0.23	0.43
Replacer	-0.50	-0.78	-0.21	0.001
Days of age at blood sampling for STP	-0.054	-0.084	-0.024	<0.001

*Coefficients indicate the magnitude and direction of the association with the outcome variable, when compared to the referent category**
The intra-class correlation coefficient reveals that 15.8% of the total variance in STP can be attributed to variation between farms.

Table 6. Summary of sex by treatment interaction with serum total protein (STP).

Sex treatment interaction	Diff. in STP	95% CI		P-value
Bulls with SB* vs heifers with SB	-0.018	-0.21	0.18	0.86
Bulls with SB vs heifers with placebo	0.084	-0.11	0.28	0.39
Heifers with SB vs heifers with placebo	0.1	-0.041	0.24	0.16
Bulls with SB vs bulls with placebo	-0.19	-0.41	0.026	0.083
Bulls with placebo vs heifers with placebo	0.28	0.072	0.48	0.008

*SB = sodium bicarbonate

Table 7. Mixed multivariable linear regression model of the predictor variables for the outcome 'total health score' over the 6-week follow-up period, including a random effect for farm (n=260).

Total health score	Coefficient*	95% Confidence Interval		P-value
		lower limit	upper limit	
Treatment				
Placebo	Ref**	-	-	-
SB	-0.38	-0.78	0.020	0.063
Twins				
No	Ref	-	-	-
Yes	1.55	0.58	2.52	0.002
Eye reflex	0.94	0.41	1.47	0.001
Heart rate				
80-100 bpm	Ref	-	-	-
>100 bpm	-0.99	-1.65	-0.32	0.004
<80 bpm	-0.21	-0.87	0.46	0.54
†Time VIGOR Score assessed after birth				
0-30 min	Ref	-	-	-
30 min-1.5 h	0.88	0.33	1.43	0.002
1.5-3 h	0.20	-0.42	0.81	0.53
>3 h	0.33	-0.27	0.94	0.28

*Coefficients indicate the magnitude and direction of the association with the outcome variable, when compared to the referent category**
†Confounded with eye reflex
The intra-class correlation coefficient reveals that 11.8% of the total variance in the total health score can be attributed to variation between farms.

and 100 bpm were both associated with almost a 1 point reduction in total health score (better health). The blinking reflex results were confounded by the time to VIGOR score assessment after birth.

Calf Growth

Weights from the first and sixth week were used to calculate ADG over the study period for each calf that remained in the herd for that duration. The mean ADG for calves from all farms was 1.37±0.60 lb (0.62±0.27 kg)/day. The mean weight gain for these calves over the 6-week period was 55.3±21.3 lb (25.1±9.67 kg). Assistance at calving, vigor at birth, and supplementation of colostrum with SB were not significantly associated with ADG or weight gain from birth to the second, third, or sixth week of life.

Factors affecting weight gain up to the third week of life were evaluated in a multivariable linear regression model, accounting for the random effect of farm (Table 8). Calves that were dull and depressed at week 1 (attitude score of >1) were 3.7 lb (1.7 kg) lighter at 3 weeks of age compared to bright and alert calves. Rectal temperature in the third week of life had a significant negative quadratic relationship with weight gain in the first 3 weeks. As rectal temperature increased, weight gain also increased until temperature reached approximately 103.1°F (39.5°C), where weight gain began to decrease. Supplementation of colostrum with SB was not significantly associated with weight gain in the multivariable model.

Discussion

Calves born following dystocia may have considerable difficulty adapting to extra-uterine life. Furthermore, the effects of dystocia may result in long-term risks for increased morbidity and mortality.[7,25,48] These risks may be linked to the decrease in IgG intake or absorption seen in calves born from difficult calvings.[4,20,22] Both reduced intake and absorption of IgG can be caused by hypoxia and acidosis, commonly experienced in newborns following a prolonged and stressful calving event.[5,10,56] However, the mechanism of the relation-

Table 8. Mixed multivariable linear regression model of the predictor variables for the outcome 'weight gain in the first 3 weeks of life' including a random effect for farm (n=366).

Weight gain in first 3 weeks (lb)	Coefficient*	95% Confidence Interval		*P*-value
		lower limit	upper limit	
Treatment				
Placebo	Ref**	-	-	-
SB†	0.28	-1.63	2.20	0.77
Week 1 attitude score				
0	Ref	-	-	-
>1	-3.74	-7.16	-0.33	0.032
Week 3 rectal temp	147.48	6.16	288.79	0.041
Quadratic week 3 rectal temp	-0.71	-1.40	-0.024	0.043

*Coefficients indicate the magnitude and direction of the association with the outcome variable, when compared to the referent category**
†SB = sodium bicarbonate
The intra-class correlation coefficient reveals that 19.1% of the total variance in weight gain can be attributed to variation between farms.

ship between acidosis and reduced IgG status is unclear. Studies have shown that calves with severe acidosis have lower vigor and are less likely to achieve sternal recumbency, stand, and consume colostrum in a timely manner following birth.[3,48,56] Other studies have suggested a direct link between acidosis and the absorption of IgG at the intestinal level.[5,10] Investigations of these associations, as well as assessment of methods to prevent or lessen the effects on passive transfer, are needed.

Sodium bicarbonate has been well researched in its use for treating metabolic acidosis in diarrheic calves a few weeks old[32,36,34] and has been successfully used for correcting acidosis (pH<7.2) in newborn calves injected intravenously.[34] However, Ayers and Besser[2] found that the correction of acidosis through SB treatment did not improve IgG absorption in newborn calves.

Experiments studying the effects of supplementing SB into colostrum on IgG absorption have produced conflicting results. In the current large-scale field study, there was no effect of SB supplementation on STP. This finding is in agreement with researchers at the University of New Hampshire, who found no effect of SB supplementation on serum IgG concentration.[16] However, another study reported increased serum IgG concentration and apparent efficiency of IgG absorption in calves fed supplemented colostrum replacer compared to calves fed colostrum replacer alone.[40] This difference between studies may be due to the use of colostrum replacer,[40] rather than different sources, such as pooled or maternal colostrum. The use of colostrum replacer for all calves created a more controlled study, as a constant and known IgG concentration was being fed to all study calves. Furthermore, Morrill et al[40] fed 30 g of SB split over 2 feedings, whereas the current study supplemented only 20 g of SB into the first feeding of colostrum.

Another difference between previous studies investigating the association between SB supplementation and passive transfer, and the current study, is the use of IgG rather than STP. It has been shown in other reports that STP concentration may not be a precise method of quantitative assessment of passive transfer of Ig in individual calves. In an early study of 185 calves, STP had only a moderate correlation with serum IgG concentration, as measured using radial immunodiffusion ($R^2 = 0.72$).[36] Consequently, the assessment of the success of passive transfer through STP concentrations may result in periodic misclassification of individual calves.[23] In addition, it was found in the current study that as the days of age at blood sampling for STP increased, STP concentrations decreased. Although it was not possible in this study due to the design and scale of the study, it is recommended that blood samples are collected between 24 and 72 hours of age to reduce variation and improve accuracy when assessing passive transfer of immunity. However, given that the objective of this study was not to assess the state of nature, but to assess the difference between calves that received colostrum supplemented with sodium bicarbonate compared to calves that did not receive the supplement, the variation in age does not greatly influence the interpretation of the effectiveness of sodium bicarbonate on passive transfer. Yet, the moderate correlation between STP and IgG, as well as the wide range in sampling dates for STP, presents limitations for the interpretation of other associations with STP in this study.

In the current study, calves fed colostrum replacement products had significantly lower STP compared to calves given fresh colostrum. Although colostrum replacer is widely used as an acceptable alternative to fresh colostrum, studies have shown that serum IgG and total protein is lower in calves fed colostrum replacer.[51,52] It is likely that producers feed smaller amounts of replacer due to the higher cost compared to maternal colostrum. In the current study, calves that were given colostrum replacer received significantly lower volumes in their first feeding compared to calves given fresh colostrum (β=-0.21; 95% CI= -0.41 to -0.0092; *P*=0.04). Colostrum volume may have confounded the negative association between receiving colostrum replacer and STP.

It has been suggested that the efficacy of IgG absorption from colostrum replacement products can be affected by the source of IgG used, the method of IgG fractionation, the amount and type of non-IgG protein, as well as the presence and amount of casein, lactose, and fat.[1,17,38,46] In the current study, there was no difference in STP concentrations by experimental treatment, indicating that the addition of lactose to colostrum did not significantly reduce IgG absorption. It has been speculated that the addition of lactose to colostrum may affect IgG absorption by altering bacterial populations and nutrient density.[49] Bacteria in colostrum may reduce IgG absorption through binding IgG in the small intestine or directly blocking the uptake of IgG by intestinal cells.[23] Since lactose and SB powders were added to colostrum immediately before feeding, this prevented bacteria from utilizing supplements for replication and growth. In colostrum replacers, ingredients are added together during manufacturing, increasing the risk of bacterial contamination and proliferation. Furthermore, higher nutrient densities of colostrum products increase abomasal emptying rate, delaying the time to absorption. Since both treatment groups received 20 g of powder into their colostrum, it is unlikely that this amount would have negatively impacted STP concentrations between treatment groups.

Season of birth may also affect colostrum quality or passive transfer. In the current study, month of birth was found to be significantly associated with STP. Calves born in August had lower STP than calves born in May. In agreement, researchers in Florida found that calves born in February and March had increased passive transfer when compared to those born in the summer months. [20] This may be due to decreased colostrum quality, as hot weather can have a negative effect on IgG concentration in colostrum.[23] It may also be due to colostrum storage practices allowing for an increase in bacterial contamination of colostrum during the warmer months.

There is limited research on the effects of selenium or vitamin E injections at birth on IgG absorption. A recent randomized field trial involving 835 calves treated with a combined selenium and vitamin E injection at birth versus a placebo injection, found no effect of injection on passive transfer.[43] In contrast, a small intensive study found that the addition of selenium to colostrum resulted in an increase in IgG absorption.[31] These authors believed that the increase was caused by a pharmacological effect, due to the activation of intestinal epithelial cell pinocytosis. In the current study, there was a negative association between STP concentration and treatment with selenium and vitamin E at birth. It is possible that not recording or controlling for variables such as the method, amount or timing of selenium/vitamin E treatment, has confounded these results and caused a spurious negative association between treatment and passive transfer. In addition, receiving selenium/vitamin E treatment following birth was negatively associated with the volume of colostrum fed (β=-0.25, 95% CI= -0.39 to 0.11; P=0.001). Thus, colostrum volume may have confounded these results. It is most likely that there is no direct causal association between selenium/vitamin E treatment and passive transfer, given the known properties of selenium and lack of support for an association with passive transfer in the selenium literature.

It was demonstrated by the current study that calving difficulty plays a large role in newborn calf vigor. Calves born with assistance, or were malpresented at calving, had significantly reduced vigor. This is in agreement with researchers at the University of Guelph, using the same VIGOR score following birth.[41] Also, Scottish researchers found that calves born with assistance tended to be less likely to stand and walk within the first 3 h after birth and spent more time lying on their flank.[3] Reduced newborn vigor may have long-term consequences for calf health if they are unable to get up and suckle colostrum.[3,56] The risk of FPT is increased in calves with malpresentations at birth.[4] In addition, dystocia resulting in calves with poor vitality and FPT had a reduced rate of gain and a higher incidence of disease.[22] In the current study, no association was found between reduced vigor and STP. This is perhaps because the majority of calves were fed colostrum by bottle or esophageal tube feeder. Thus, colostrum feeding was not dependent on newborn vigor. Depending on the difficulty of delivery and the degree of trauma experienced by the neonate, newborn calf vigor will generally improve with time, as is shown in the current study.

It was hypothesized that newborn calf vigor would be associated with future health. The overall VIGOR score was not significantly associated with calf health in the first 6 weeks. Yet, specific components of the VIGOR score were associated with overall calf health. Calves that had a slower blinking reflex in response to a touch of the eyeball, as well as having a heart rate of 80 to 100 bpm compared to >100 bpm, were associated with having reduced health. Researchers from Ireland suggested that a regular heart rate of 100 to 150 bpm indicates good newborn calf vitality.[39] It is known that calves with good cardiac output are less likely to suffer hypercapnia and acidosis.[28] Good vitality enables behaviors for survival, such as getting up and suckling colostrum, quickly and more efficiently,[3,55,56] perhaps leading to improved long-term health.

In the current study, twin-born calves had significantly higher 6-week total health scores compared to single calves. It has been shown that twins are at greater risk of neonatal mortality compared to singles.[44,50,58] The higher mortality in twins may be due to greater incidence of dystocia, smaller birth weights or shorter gestation lengths.[24,35,44] It is possible that these factors also have implications on neonatal calf health, and that the increased mortality is associated with reduced health.

Sodium bicarbonate has been shown to be an effective alkalinizing agent in calves with metabolic acidosis immediately after birth, as well as in diarrheic calves and in calves with acidosis without dehydration syndrome 1 to 4 weeks old.[6,8,32,33] However, no previous research has been performed to determine if treatment with SB at birth has long-term benefits for calf health. In the current study, SB supplementation resulted in a numerically lower total calf health score (improved health). However, this association was not statistically significant. Further investigation of the relationship between SB supplementation and future outcomes including calf health is warranted.

In several other studies, calf health status has been measured through observations of droopy ears, reduced activity and dullness for signs of illness.[9,29] In the current study, calves with a week 1 attitude score of >1, indicating dullness, were associated with having a lower total weight gain in their first 3 weeks compared to calves with a normal attitude score. It is speculated that calves with reduced health are dull or depressed, resulting in lower energy and motivation to eat and lower feed conversion. Consequently, calves with reduced health and increased incidence of disease have lower growth rates.[20,57] Rectal temperature may also be used as a method to detect illness in calves. In the current study, a negative quadratic relationship was found between rectal temperature and weight gain in the first 3 weeks of life. Calves with a rectal temperature above 103°F (39.5°C) were associated with having reduced weight gain. Since fever is associated with illness, this finding is not surprising.

Sodium bicarbonate supplementation at birth had no significant effect on growth during the study period. No previous research has examined the effects of SB on weight gain. It was hypothesized that SB supplementation would enhance growth by improving passive transfer, as previous studies have shown that FPT is associated with decreased ADG.[18,22,47] It is noteworthy that in the current study, calves supplemented with SB had consistently higher average body weight at each sampling time (Table 4). However, these differences were not statistically significant. It is important to note that weights in this study were collected with a heart girth weight tape, not with a scale. The heart girth tape method has been validated, and is widely used in heifer calves.[27] Yet, tape weights are not as accurate as scale weights,and have been shown to be 5 to 8% variable in calves less than 330 lb (150 kg).[19,27] It is noteworthy that all calves in this study were measured with the same heart girth tape, so the variability in weights by treatment group is evenly distributed and an accurate comparison of growth between SB supplementation treatment groups can be made.

In the current study, a sex-by-treatment interaction suggests that bulls had significantly higher STP than heifers within the placebo group. This result is unusual, and has not been previously reported in other literature. In fact, a study in beef calves found the opposite effect, with heifers having higher serum IgG levels when compared to bull calves.[45] This finding is not surprising, as bull calves are generally larger at birth, which puts them at greater risk of experiencing dystocia and the effects that follow.[30,35,45] It is possible that the finding in the current study was due to a type I error. In other words, it may be that another factor caused bull calves to have a higher STP that was not evaluated, or controlled for, in this study.

Conclusion

Supplementation of SB into the first feeding of colostrum did not result in an improvement in passive transfer, health or growth. Dull calves in the first week of life had significantly lower weight gain than alert calves. Dystocia, involving assistance or malpresentation at calving, resulted in calves with reduced newborn vigor. Components of the VIGOR score, including slower eye reflex and heart rate, were associated with reduced health. On-farm strategies, such as the calf vigor assessment used to identify calves that need extra help following birth, may be needed to improve calf health and performance through the pre-weaning period, rather than nutritional interventions such as SB supplementation into colostrum.

Endnotes

[a]StataCorp, College Station, TX, USA
[b]Vacutainer, Becton, Dickinson and Company, Franklin Lakes, NJ, USA
[c]KS – 0050, Kernco Instruments Co., Inc, El Paso, TX, USA
[d]Nasco, Modesto, CA, USA
[e]Ketchum Manufacturing Inc., Brockville ON, Canada
[f]Microsoft Excel, Redmond, WA, USA
[g]Stata-IC 10.1, StataCorp, College Station, TX, USA

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