Effect of rapid or gradual grain adaptation on subacute acidosis and feed intake by feedlot cattle[1,2]

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ABSTRACT: The effects of grain adaptation protocol on subacute acidosis and feed intake by cattle were studied in a completely randomized experiment using 12 crossbred heifers (384 ± 25 kg BW). The dietary proportion of concentrate was increased from 40 to 90% (DM basis) either by rapid adaptation (65% concentrate diet fed for 3 d) or by gradual adaptation (five intermediate diets containing 48.3, 56.7, 65.0, 73.3, and 81.7% concentrate, fed for 3 d each). Feed intake and ruminal pH (by indwelling ruminal electrodes) were monitored over 20 d. Mean daily pH variables did not differ ($P \geq 0.10$) between treatments on any of the 3 or 4 d that 65 or 90% concentrate was fed. Variances of a number of pH variables were greater ($P < 0.05$) for rapidly adapted heifers than for those on the gradual adaptation protocol during adaptation to 65 and 90% concentrate. Mean hourly pH did not differ over the first 24 h of adaptation to 65% concentrate, but variance of hourly pH tended ($P < 0.10$) to be greater for rapidly adapted than for gradually adapted heifers for eight of the first 24 h. On the first day of feeding 90% concentrate, ruminal pH tended ($P = 0.07$) to be less at 11 and 12 h after feeding with rapid adaptation than with gradual adaptation. Variance of hourly pH increased steadily in rapidly adapted heifers from 6 h after feeding onward. Ruminal VFA concentration and osmolality did not differ between treatments. Ruminal lactate concentration was <1 m*M*, except in two rapidly adapted heifers and one gradually adapted heifer after introduction to 90% concentrate. Adaptation method did not affect DMI or day-to-day variation in DMI. Detection of acidosis was associated with increased variance in ruminal pH variables. A range of individual responses to grain challenge was observed, but current management strategies for preventing acidosis in pens of cattle are based on responses of the most susceptible individuals. A better understanding of factors governing individual responses to acidotic challenge may allow for the development of more effective acidosis prevention practices.

Key Words: Acidosis, Concentrate, Grain Adaptation, Ruminal pH, Volatile Fatty Acids

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Introduction

Adaptation of feedlot cattle from high-forage to high-concentrate diets causes marked changes in the ruminal environment, and time is required to establish a stable microbial population. The introduction of rapidly fermentable carbohydrate results in a major reduction of fibrolytic bacteria and rapid growth of amylolytic bacteria (Goad et al., 1998; Tajima et al., 2001), and a decrease in ruminal pH. An abrupt change from a high-forage to a high-concentrate diet can result in acute or subacute acidosis (Goad et al., 1998; Coe et al., 1999). Acute acidosis manifests as a marked illness (Owens et al., 1998), but subacute acidosis is more difficult to recognize. Decreased feed intake and per-

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Table 1. Proportion of concentrate (%, DM basis) in diets fed during two strategies for adaptation of heifers to barley grain-based finishing diets

	Days on which adaptation diet was fed (inclusive)						
Treatment	≤0[a]	1 to 3	4 to 6	7 to 9	10 to 12	13 to 15	16 to 19
Rapid adaptation	40.0	65.0	90.0	90.0	90.0	90.0	90.0
Gradual adaptation	40.0	48.3	56.7	65.0	73.3	81.7	90.0

[a]The initial diet was fed to all heifers for 8 wk before commencement of measurement period.

formance are commonly believed to result from subacute acidosis (Koers et al., 1976; Owens et al., 1998).

To minimize problems of acidosis, cattle feeders have traditionally increased dietary concentrate in an incremental manner by feeding a series of diets containing sequentially increasing concentrations of grain over a period of 3 to 4 wk. Rapidly adapting cattle to grain is desirable because ADG and gain efficiency typically are enhanced when high-concentrate diets are consumed. However, some acidosis prevails even with gradual adaptation to grain (Burrin and Britton, 1986), and more rapid rates of grain adaptation may result in increased acidosis.

Designing high-grain adaptation programs for feedlot cattle involves balancing the opportunity for enhanced growth performance against the risk of acidosis. The objective of this study was to determine whether gradual adaptation to a high-grain diet modulates ruminal pH, feed intake, and ruminal fermentation patterns to a greater extent than rapid adaptation to a high-grain feedlot diet.

Materials and Methods

Animals, Housing, and Experimental Design

Twelve spayed, crossbred heifers were assigned randomly to two groups of six each, and used in two consecutive 20-d measurement periods (BW ranging from 302 to 418 kg). The heifers were surgically fistulated 4 to 8 wk before the study, at which time they were fitted with soft plastic, 10-cm (i.d.) ruminal cannulas (Bar Diamond, Parma, ID). Seven days before starting the trial, all heifers received a Component E-H implant (Elanco Animal Health, Guelph, Ontario, Canada).

Within each group, heifers were assigned randomly to two treatments (Table 1). The experiment comprised a 20-d measurement period conducted using one group of six heifers, repeated immediately thereafter with the second group. During the 20-d measurement period, the six subject heifers were housed individually in 152 cm × 203 cm indoor stalls with rubber flooring, and were allowed approximately 1 h of exercise daily at 1300. All of the heifers were cared for according to guidelines of the Canadian Council on Animal Care (CCAC, 1993).

Treatments and Diets

The heifers used in this study had consumed no high-grain finishing diets before the experiment. During the 8 wk leading up to the start of the first measurement period, all 12 heifers were provided ad libitum access (minimum 10% daily refusals) to a barley silage/barley grain/grass hay diet containing 40% concentrate (DM basis). Dietary transition from 40 to 90% concentrate (DM basis) was accomplished either over 3 d using one intermediate diet of 65% concentrate (rapid adaptation; **RA**), or over 15 d using five intermediate diets (gradual adaptation; **GA**). All diets were formulated to meet NRC (1996) requirements for minerals and vitamins and to contain 33 mg of monensin sodium per kilogram of diet DM (Elanco Animal Health, Calgary, Alberta, Canada). The final finishing diet was formulated for a targeted gain of 1.35 kg/d.

Diets were prepared fresh each day in a feed mixer. Sufficient feed to meet ad libitum consumption (at least 10% orts) was delivered daily at 1400. The concentration of dry-rolled barley was increased in the diets by replacing barley silage and grass hay (Table 2). Barley grain for this experiment was purchased from a single source and was dry-rolled as a single batch to a processing index of 84.6% (Yang et al., 2000).

Feed Intake and Body Weight

Amounts of feed offered and refused were recorded daily. Samples of diets were collected on the first day of feeding and every 3 d thereafter for immediate determination of DM content and storage for chemical analyses. Samples of orts were collected and dried daily. Daily DMI for each heifer was calculated as feed DM offered minus DM refused. The DMI variation was calculated for each individual heifer as the difference in intake between consecutive days. Samples of dietary ingredients were collected weekly and composited for analysis. The heifers were weighed at 0800 at the beginning (d 0) and end (d 19) of the experiment.

Ruminal pH

Ruminal pH of each heifer was monitored continuously for 23 h of each day over the entire 20-d measurement period. An industrial electrode (model PHCN-37, Omega Engineering, Stamford, CT) was inserted through the cannula into the rumen of each heifer. The electrode was enclosed in a protective shield with perforations large enough to allow ruminal fluid to percolate freely, and which prevented the electrode from contacting the ruminal epithelium. The shield

Table 2. Ingredients and chemical composition of the experimental diets fed to heifers on gradual or rapid protocols of adaptation to barley-based finishing diets[a]

	Proportion of concentrate in diet						
Item	40.0	48.3	56.7	65.0	73.3	81.7	90.0
Ingredients, % of DM							
Barley silage	45.0	41.7	38.3	35.0	26.7	18.3	10.0
Grass hay	15.0	10.0	5.0	0	0	0	0
Concentrate							
Barley grain[b]	35.0	43.3	51.7	60.0	68.3	76.7	85.0
Supplement[c]	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Chemical composition, %[d]							
DM	56.7	58.6	61.6	63.7	67.9	76.3	83.2
OM	93.6	93.5	94.0	93.6	93.8	95.7	95.2
CP	14.1	14.0	15.6	15.0	15.4	15.5	15.3
NDF	38.2	37.9	32.6	32.9	31.2	31.5	31.3
ADF	17.7	17.4	14.2	13.0	11.0	8.5	7.7

[a]On the rapid adaptation protocol, only the 40, 65, and 90% concentrate diets were fed. All diets were used in the gradual adaptation protocol (see Table 1).
[b]The barley grain was dry-rolled as a single lot to a processing index of 84.6%: [(volume weight after processing/volume weight before processing) × 100%].
[c]Supplement contained urea as a N source, as well as Ca, 10.9%; Na, 1.4%; Zn, 1,150 ppm; Mn, 530 ppm; Cu, 290 ppm; I, 13.0 ppm; Se, 5.7 ppm; Co, 4.7 ppm; vitamin A, 96,000 IU/kg; vitamin D, 9,500 IU/kg; vitamin E, 630 IU/kg; and monensin sodium, 684 ppm.
[d]Values determined from analysis. All values except DM, %, are expressed on a DM basis.

was weighted to keep the electrode positioned in the ventral sac. The pH electrodes were removed for 1 h daily, from 1300 to 1400. During that time, the heifers were allowed exercise, and the electrodes were calibrated using pH 4.0 and 7.0 standards. Ruminal pH was measured every 5 s, and averages over 5-min intervals were recorded by a data logger.

Ruminal pH data from the 23-h postfeeding period were summarized for each heifer as daily mean pH, maximal and minimal pH, and areas under the curves (**AUC**) of pH 5.2, 5.6 and 6.2 by time. Each AUC was calculated by adding the absolute value of deviations in pH below pH 5.2, below 5.6, or below 6.2 for each 5-min interval, and was expressed as pH units × h. Durations of time when pH registered below the 5.6 or 5.2 thresholds were interpreted as the duration of subacute or acute acidosis, respectively, and the area between the curves and the pH thresholds as the severity of subacute or acute acidosis. Subacute ruminal acidosis was considered to have occurred when ruminal pH remained below 5.6 for more than 12 h of a given day; acute ruminal acidosis was considered to have occurred when ruminal pH remained below 5.2 for more than 6 h during a day of measurement (Owens et al., 1998).

Ruminal Fermentation

On d 1, 4, 7, 10, 13, 16, and 19, samples of ruminal contents were collected from each heifer before feeding, and 8 and 18 h after feed delivery. Sample collection was delayed deliberately from time points typically used in ruminal metabolism experiments because the heifers had ad libitum access to feed. Ruminal contents (200 mL per site) were obtained from the reticulum, the dorsal and ventral sacs, and the feed mat, composited by animal, and placed directly into crushed ice. Once all heifers had been sampled, whole ruminal contents were immediately strained through four layers of cheesecloth. For each heifer, 5 mL of filtrate was preserved for subsequent determination of VFA and lactate by adding 1 mL of 25% (wt/vol) of metaphosphoric acid. An additional 5 mL of filtrate for determination of ammonia and glucose concentrations was preserved by adding 0.8 mL 65% trichloroacetic acid. The samples for VFA, lactate, ammonia, and glucose were transferred to storage at –20°C in sealed plastic vials until analysis. Ruminal fluid osmolality was determined for each heifer within 2 h of ruminal sampling. Approximately 200 mL of ruminal content filtrate was placed in 250-mL centrifuge tubes and centrifuged at 13,000 × *g* for 30 min at 4°C. Osmolality of the supernatant was determined by freezing point depression using an automatic osmometer (μOsmette model 5004, Precision Systems, Inc., Natick, MA).

Blood Chemistry

At 0800 on d 0, 4, and 19 (18 h after feeding), blood samples were collected from each heifer by jugular venipuncture into three 10-mL vacuum tubes (Becton Dickinson, Franklin Lakes, NJ), which were transported to the Lethbridge Regional Hospital for clinical analysis of blood pH and CO_2 (both within 2 h of collection), glucose, lactate dehydrogenase, and packed cell volume, as described by Beauchemin et al. (2003).

Chemical Analyses

Feed DM was determined by oven drying at 55°C for 48 h. Samples were ground to pass a 1-mm screen

and analytical DM content of feed samples was determined by drying at 135°C for 3 h (AOAC, 1990). The methods of Van Soest et al. (1991) were used to determine NDF and ADF contents, with amylase and sodium sulfite included in the NDF procedure. Organic matter was calculated after ashing for 5 h at 500°C. Samples were reground using a ball grinder (mixer mill MM2000, Retsch, Haan, Germany) for determination of N. The concentration of CP (N × 6.25) in feed was quantified by flash combustion with gas chromatography and thermal conductivity detection (Carlo Erba Instruments, Milan, Italy).

Ruminal VFA were quantified, with an internal standard of crotonic acid, by gas chromatography (model 5890, Hewlett Packard, Little Falls, DE) with a capillary column (30 m × 0.32 mm i.d., 1-μm phase thickness, bonded polyethylene glycol; Supelco Nukol, Sigma-Aldrich Canada, Oakville, Ontario, Canada), and flame-ionization detection. Lactic acid also was determined by gas chromatography, but only after derivatization with boron trifluoride-methanol as described by Supelco (1998). Ruminal ammonia was determined by the phenol-hypochlorite method (Broderick and Kang, 1980), and glucose by the ferricyanide method (Snell and Snell, 1953), both conducted on a Technicon autoanalyzer II.

Statistical Analyses

Animal was considered the experimental unit for analysis for all variables in a completely randomized design. Preliminary analysis determined that results did not differ between experimental groups and as a result, group was removed from the model. For the 3 d of feeding the 65% concentrate diet, and for the first 4 d of feeding the 90% concentrate diet, daily pH variables were summarized by day, classified by treatment, and analyzed using the *t*-test procedure of SAS (SAS Inst., Inc., Cary, NC). Log transformation was required to improve the normality of certain daily pH variables (AUC for pH 5.2, 5.6, and 6.2; time <pH 5.2). Data were then reported as arithmetic means. Mean hourly pH and ruminal fermentation variables from the first day of feeding 65% concentrate, and the first and fourth days of feeding 90% concentrate also were classified by treatment and analyzed using the *t*-test procedure of SAS, as were DMI and variation in DMI data from the 3 d of feeding 65% concentrate and the first 4 d of feeding 90% concentrate. The *t*-test procedure used an *F*-test (Steel and Torrie, 1980) for testing the equality of variance of means between treatments. A Satterthwaite (1946) approximation was used to provide an alternate *P*-value for testing means when variances differed ($P < 0.05$). Alternate *P*-values were reported as the equality of variance. On the first day of feeding the 90% concentrate diet, one of the RA heifers expelled the cannula plug, resulting in loss of ruminal contents. Ruminal data from this animal were consequently excluded from all analyses.

Variances in DMI and blood characteristics were not different between treatments; thus, treatment effects were determined using the MIXED model procedure of SAS. Variation of DMI was calculated as the difference in intake between consecutive days. Data were analyzed by day, with treatment in the model. Effects were declared significant at $P < 0.05$, and trends are discussed at $P < 0.10$.

Results and Discussion

Ruminal pH

Mean daily pH values for cattle consuming high-concentrate barley-based diets are reported to range between 6.06 and 5.71 (Beauchemin et al., 2001; Ghorbani et al., 2001; Koenig et al., 2003). In the present study, mean daily ruminal pH remained above these values until the first day of feeding 90% concentrate, when values of 5.62 and 5.70 were observed for the RA and GA heifers, respectively (Tables 3 and 4). On the first day of feeding 65% concentrate, mean ruminal pH values were 5.86 (RA) and 5.97 (GA).

In grain engorgement studies in which subacute acidosis was induced, minimum pH values of 5.0 to 5.5 have been recorded on the day of grain challenge (Bauer et al., 1995; Krehbiel et al., 1995; Goad et al., 1998), which are comparable to the minimum values of 5.01 and 5.10 recorded for RA and GA on d 1 of feeding 90% concentrate in the present study. This suggests that the severity of the challenge may have been as great as that which has been previously used to induce subacute acidosis; however, it is more likely that this is a reflection of the superior ability of continuous pH monitoring to identify the true pH minima compared with the periodic measurements used in earlier studies. Continuous pH monitoring has revealed pH minima of 5.1 to 5.2 once adaptation to similar barley-based diets was complete (Ghorbani et al., 2001; Schwartzkopf-Genswein et al., 2004). In the present study, ruminal pH in the GA heifers did not fall to those levels, and in the RA group, minimum pH values were only slightly lower than those observed on the first and third day of feeding 90% concentrate.

Introduction of the 65% concentrate diet represented an increase of dietary concentrate from 40 to 65% for the RA heifers compared with an increase from 56.7 to 65% for GA. Thus, grain challenge was substantially greater with RA than with GA. Although all daily pH variables (Table 3) for d 1 were numerically indicative of a lower pH for RA than for GA, the differences between treatments were not significant ($P \geq 0.17$).

In the present study, the SD of pH variables were large, sometimes approximating the measurement of the variable itself (e.g., SD of the AUC for pH 6.2, 5.6, and 5.2; duration of pH < 6.2, 5.6, and 5.2; Tables 3 and 4). Such large individual animal variation contributed to the lack of statistical differences between treat-

Table 3. Effects of rapid vs. gradual adaptation protocol on daily ruminal pH variables in heifers during the first three days of introduction to a barley-based diet containing 65.0% concentrate[a]

	1st day				2nd day				3rd day			
	Adaptation protocol[b]		*P*-values[c]		Adaptation protocol		*P*-values		Adaptation protocol		*P*-values	
	Rapid	Gradual	TRT	EOV	Rapid	Gradual	TRT	EOV	Rapid	Gradual	TRT	EOV
Ruminal pH												
Mean	5.86 ± 0.42	5.97 ± 0.12	0.58	0.02	6.12 ± 0.41	6.13 ± 0.12	0.98	0.02	6.01 ± 0.43	6.16 ± 0.19	0.47	0.10
Minimum	5.29 ± 0.37	5.36 ± 0.17	0.72	0.12	5.62 ± 0.49	5.53 ± 0.14	0.68	0.02	5.48 ± 0.35	5.66 ± 0.29	0.36	0.71
Maximum	6.53 ± 0.18	6.54 ± 0.16	0.95	0.76	6.55 ± 0.27	6.59 ± 0.10	0.76	0.04	6.53 ± 0.26	6.57 ± 0.14	0.78	0.18
Area under the curve, pH × h												
6.2	9.42 ± 7.24	6.40 ± 2.45	0.37	0.03	5.03 ± 6.01	3.63 ± 1.25	0.59	0.004	6.89 ± 6.43	3.18 ± 2.40	0.23	0.05
5.6	2.43 ± 2.64	0.62 ± 0.70	0.81	0.01	0.69 ± 1.12	0.08 ± 0.18	0.24	0.001	0.98 ± 1.55	0.06 ± 0.08	0.20	<0.001
5.2	0.28 ± 0.45	0.01 ± 0.27	0.17	<0.001	na[d]	na	na	na	na	na	na	na
Duration of pH, h/d												
<6.2	16.00 ± 6.99	16.00 ± 2.54	1.00	0.04	11.08 ± 10.05	13.58 ± 4.55	0.59	0.11	14.06 ± 9.73	11.83 ± 6.80	0.66	0.45
<5.6	7.96 ± 7.56	3.88 ± 2.91	0.26	0.06	3.35 ± 5.20	0.67 ± 0.91	0.27	0.002	5.08 ± 6.29	0.72 ± 0.84	0.15	<0.001
<5.2	2.47 ± 3.45	0.18 ± 0.44	0.20	<0.01	na	na	na	na	na	na	na	na

[a]Values shown are mean ± SD (n = 6). Daily refers to a 23-h period extending from feeding time (1400) to 1300 the next day.

[b]All heifers were fed a diet containing 40% concentrate for 57 d. With rapid adaptation, the 65% concentrate diet was introduced immediately thereafter. With gradual adaptation, 48.3 and 56.7% concentrate diets were each fed for 3 d before feeding 65% concentrate diet (see Table 1).

[c]TRT = Significance of treatment effect (rapid vs. gradual adaptation); EOV = equality of variance of means between treatments; EOV was examined using an *F*-test procedure (Steel and Torrie, 1980); where variances differed, a Satterthwaite (1946) approximation was used to provide an alternate *P*-value.

[d]na = not available.

Table 4. Effects of rapid or gradual adaptation protocol on daily ruminal pH variables in heifers during the first four days of feeding a barley-based finishing diet containing 90% concentrate[a]

	1st day				2nd day				3rd day				4th day			
	Adaptation protocol[b]		*P*-values[c]		Adaptation protocol		*P*-values		Adaptation protocol		*P*-values		Adaptation protocol		*P*-values	
	Rapid	Gradual	TRT	EOV	Rapid	Gradual	TRT	EOV	Rapid	Gradual	TRT	EOV	Rapid	Gradual	TRT	EOV
Ruminal pH																
Mean	5.62 ± 0.30	5.70 ± 0.23	0.61	0.54	5.80 ± 0.42	5.81 ± 0.31	0.97	0.51	5.60 ± 0.46	5.76 ± 0.29	0.48	0.33	5.67 ± 0.29	5.69 ± 0.20	0.89	0.42
Minimum	5.01 ± 0.29	5.10 ± 0.16	0.53	0.22	5.16 ± 0.20	5.26 ± 0.42	0.59	0.12	4.95 ± 0.59	5.16 ± 0.22	0.43	0.053	5.20 ± 0.28	5.17 ± 0.13	0.86	0.12
Maximum	6.47 ± 0.37	6.40 ± 0.20	0.73	0.21	6.40 ± 0.60	6.51 ± 0.14	0.63	0.01	6.11 ± 0.56	6.36 ± 0.19	0.33	0.03	6.28 ± 0.28	6.56 ± 0.36	0.16	0.59
Area under the curve, pH × h																
6.2	13.96 ± 6.51	11.46 ± 4.50	0.46	0.44	10.98 ± 7.00	9.97 ± 6.06	0.80	0.76	14.63 ± 10.06	10.56 ± 5.56	0.41	0.22	12.23 ± 6.55	11.52 ± 4.17	0.83	0.35
5.6	4.27 ± 4.08	2.72 ± 1.92	0.77	0.12	2.61 ± 2.98	2.39 ± 2.04	0.89	0.42	5.05 ± 6.07	2.31 ± 1.97	0.33	0.03	3.11 ± 3.83	2.22 ± 1.68	0.62	0.09
5.2	1.11 ± 1.69	0.24 ± 0.33	0.62	0.003	0.28 ± 0.54	0.22 ± 0.38	0.80	0.47	1.57 ± 2.39	0.18 ± 0.24	0.21	<0.001	0.49 ± 0.77	0.09 ± 0.13	0.25	0.001
Duration of pH, h/d																
<6.2	19.6 ± 2.85	19.22 ± 2.87	0.79	0.99	17.21 ± 7.19	16.65 ± 6.16	0.89	0.74	18.67 ± 4.41	19.39 ± 5.46	0.81	0.65	21.04 ± 2.04	19.75 ± 2.62	0.36	0.60
<5.6	11.99 ± 6.55	10.18 ± 5.20	0.61	0.62	8.92 ± 6.49	8.47 ± 6.67	0.91	0.95	10.33 ± 9.63	8.90 ± 6.04	0.76	0.33	9.08 ± 8.44	9.75 ± 5.12	0.87	0.30
<5.2	4.58 ± 5.28	2.18 ± 1.19	0.85	0.04	3.19 ± 5.48	2.22 ± 2.66	0.70	0.14	5.49 ± 8.24	1.89 ± 1.97	0.34	0.01	3.90 ± 5.86	1.21 ± 1.56	0.32	0.01

[a]Values shown are mean ± SD (for Rapid, n = 5; for Gradual, n = 6). Daily refers to a 23-h period extending from feeding time (1400) to 1300 the next day.

[b]All heifers were fed a diet containing 40% concentrate for 57 d. With rapid adaptation, a 65% concentrate diet was fed for 3 d, followed immediately by the final finishing diet (90% concentrate). Gradual adaptation included five diets fed for 3 d each before introducing the 90% concentrate diet (see Table 1).

[c]TRT = significance of treatment effect (rapid vs. gradual adaptation); EOV = equality of variance of means between treatments; EOV was examined using an *F*-test procedure (Steel and Torrie, 1980); where variances differed, a Satterthwaite (1946) approximation was used to provide an alternate *P*-value.

ments and represents a greater likelihood of ruminal pH of individual animals falling into the lower and more critical levels indicative of subacute (pH <5.6) and acute acidosis (pH <5.2). Thus, even when treatment means are similar, the dissimilar variances may reflect different degrees of compensation or tolerance of animals to acidotic conditions as dictated by the adaptation regimens.

Variances of mean pH, as well as AUC and durations of pH <6.2, 5.6, and 5.2, were greater ($P < 0.05$; $P = 0.06$ for duration of pH <5.6) for RA than for GA on the first day of feeding 65% concentrate (Table 3). The greater variance for RA indicates that the risk of encountering acidosis was greater for individuals in group RA than for those in GA. By the definition of subacute acidosis used in this study (pH <5.6 for more than 12 h; Owens et al. 1998), three RA heifers experienced acidosis on d 1 of feeding 65% concentrate compared with no heifers on the GA protocol. Given that the mean duration of pH <5.6 was only 7.96 h for the RA group, the occurrence of three cases of subacute acidosis was unexpected; however, the high SD (7.56) for duration of pH <5.6 illustrates the high variation among animals in that group. By comparison, the duration of pH <5.6 was 3.88 ± 2.91 h for the GA heifers. In a similar manner, the lower SD may be indicative of their decreased risk of subacute acidosis, which is supported by the fact that subacute acidosis did not occur in any GA heifers on that day.

Over the second and third days of feeding the 65% concentrate diet, mean ruminal pH in both treatment groups returned to levels above 6.0 (Table 3). The variables AUC for pH 6.2 and 5.6, and duration of pH <5.6 remained numerically indicative of lower pH for RA than for GA, but these variables did not differ ($P \geq 0.15$) between treatments. The variance of all pH variables, except duration of pH <6.2, remained larger for RA than GA ($P < 0.05$) on the second day of feeding 65% concentrate, and some (e.g., variances for AUC for pH 6.2 and 5.6, and duration of pH <5.6) for the third day as well. This indicates that the ability of individual heifers to modulate ruminal pH may have been compromised on the RA protocol compared with GA, even 2 or 3 d after the increase in dietary concentrate. Single incidents of subacute acidosis in the RA group on the second and third days (different animals) vs. none among the GA heifers further supports this hypothesis.

Introduction of the 90% concentrate diet represented an increase directly from 65 to 90% for the heifers in treatment RA vs. an increase from 81.7 to 90% concentrate for GA cattle (Table 4). Similar to the 65% challenge, daily pH values on d 1 of the 90% concentrate diet were numerically indicative of lower ruminal pH with RA than with GA, but significance was not attained ($P \geq 0.46$). Whereas the increase to 65% concentrate resulted in variances of most pH variables being greater for RA than GA, the increase to 90% did not. On the first day, subacute acidosis occurred in both treatments (three cases in RA; two cases in GA). Of note, however, is that variances for pH variables at the more threatening threshold (AUC for pH <5.2; duration of pH <5.2) were greater ($P = 0.003$ and 0.04, respectively) for RA than for GA. With the greater variance in duration of pH <5.2 for RA compared with GA taken into account, the opportunity for acute acidosis (ruminal pH <5.2 for more than 6 h in that day) to occur in some individuals on the RA protocol was considerable, whereas the lesser variance of AUC for pH <5.2 and duration of pH <5.2 observed for GA heifers suggests that their likelihood of encountering acidosis was lower. Consistent with that rationale, acute acidosis occurred in two RA heifers on the first day of feeding the 90% concentrate diet, but was not observed in any of the GA heifers.

On the second day of feeding 90% concentrate, the variances of AUC for pH 5.2 and duration of pH <5.2 did not differ ($P \geq 0.14$) between treatments. Acute acidosis was observed in one animal from each treatment. The only statistically significant difference on this day was in the variance of maximum pH (RA > GA; $P = 0.01$). Variance of maximum pH also remained greater ($P = 0.03$) in RA than GA through the third day of feeding 90% concentrate. Variances in the AUC for pH 5.2 and duration of pH <5.2 were again greater ($P \geq 0.01$) with RA than with GA, and variance of AUC for pH 5.6 tended to be greater ($P \geq 0.09$), on the third and fourth days on the 90% concentrate diet. This was associated with one case of acute acidosis in the RA group on d 3 and two cases on d 4 compared with no cases occurring among the GA heifers on either day. Subacute acidosis was observed nine times in each of the treatment groups over the first 4 d of feeding 90% concentrate.

Postfeeding decreases in mean hourly ruminal pH on the first day of feeding 65% concentrate did not differ between treatment groups (Figure 1a). For both groups, mean hourly ruminal pH was lowest 8 h after feeding. These values (5.52 for RA; 5.58 for GA) were the only hourly means that registered below pH 5.6. Ruminal pH >6.0 was reestablished in the GA heifers by 15 h after feeding, compared with 18 h in the RA group; beyond that time, the GA ruminal pH continued to increase toward prefeeding levels, whereas RA did not. Treatment effects on mean hourly pH were minor ($P \geq 0.12$) on the first day of feeding a 65% concentrate diet.

Variance of the hourly mean pH (depicted as SD; Figure 1b) is an indication of the degree of uniformity of pH response among animals within a treatment group (RA, GA). Variance was initially similar between treatments, but from 7 h after feeding onward, it was more pronounced ($P < 0.05$ for four of the 17 time points; $P < 0.10$ for two others; arrows, Figure 1b) with RA than with GA. These observations are consistent with the summarized daily pH variables (Table 3) and again suggest that rapid adaptation of cattle to 65% concentrate gives rise to greater varia-

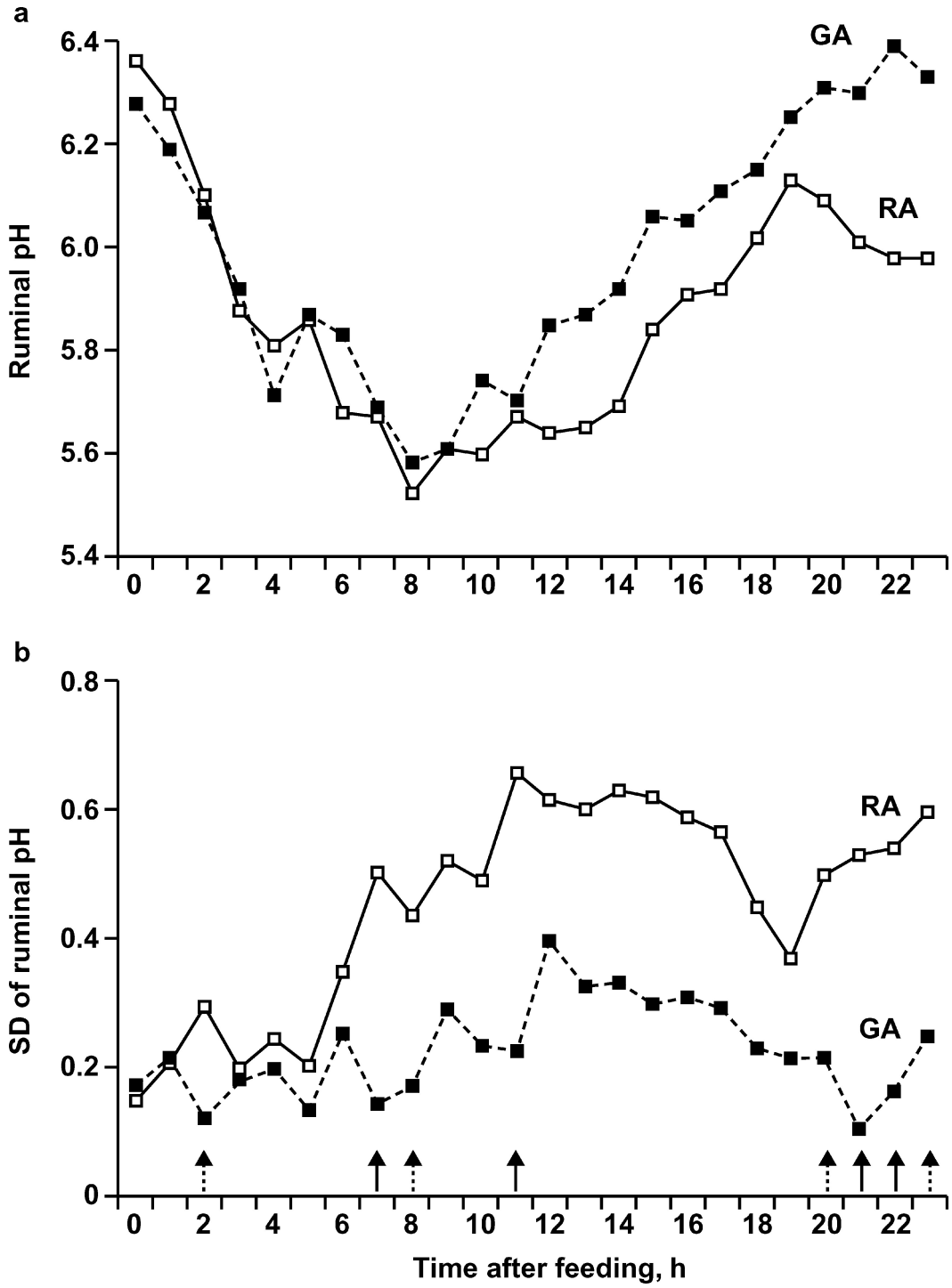

Figure 1. Mean hourly ruminal pH (a) and variance (b) in mean hourly pH (expressed as SD) in heifers during rapid (RA) or gradual (GA) adaptation to high-concentrate diets on the first day of feeding a 65% concentrate diet (n = 6). Adaptation protocols for RA and GA are outlined in Table 1. Hours for which treatment effects were significant are marked with solid ($P < 0.05$) or broken ($P < 0.10$) arrows.

tion in ruminal pH response compared with gradual adaptation.

In the first 24 h after the introduction of the 90% concentrate diet, treatment effects on mean hourly pH were more evident than on d 1 of 65% (Figure 2a). The slightly lower (5.79 vs. 6.10; $P \geq 0.12$) initial pH with GA than with RA was not unexpected, given that the GA heifers were consuming 81.7% concentrate for the 3 d prior, compared with 65% concentrate for the RA group. The ruminal pH of GA cattle decreased after feeding to a minimum of 5.43 at 6 h after feeding, but in the heifers on RA, the decline continued until 8 h postfeeding, to a minimum value of 5.34. Recovery of ruminal pH to the pH 5.6 was accomplished by 11

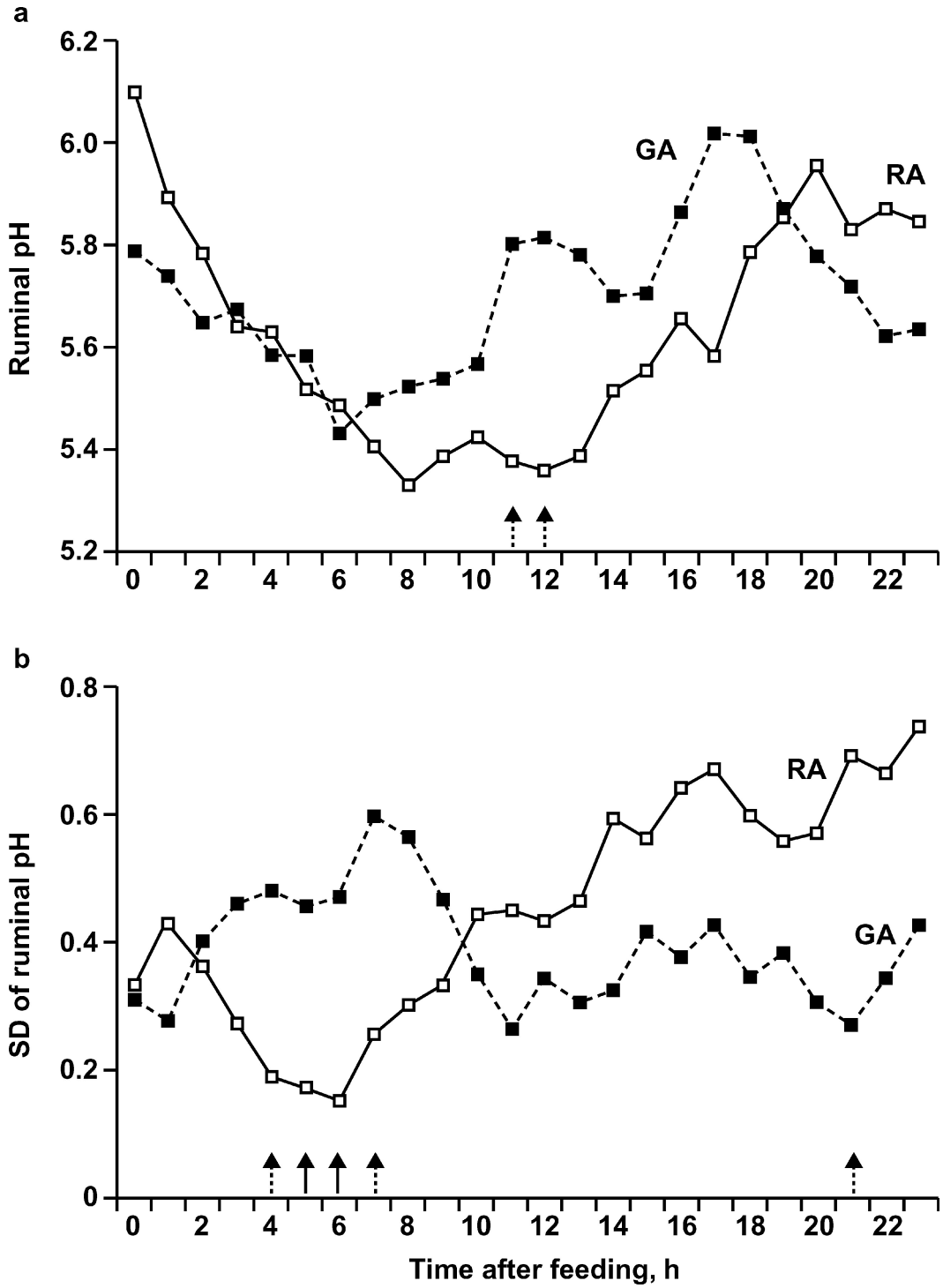

Figure 2. Mean hourly ruminal pH (a) and variance (b) in mean hourly pH (expressed as SD) in heifers during rapid (RA) or gradual (GA) adaptation to high-concentrate diets on the first day of feeeding a 90% concentrate diet. Adaptation protocols for RA and GA are outlined in Table 1. Hours for which treatment effects were significant are marked with solid ($P < 0.05$) or broken ($P < 0.10$) arrows. For RA, n = 5; for GA, n = 6.

h after feeding in the GA heifers, whereas with RA, ruminal pH remained near the minimum value for approximately 5 h, and did not rise above pH 5.6 until 16 h after feeding. The pH of RA cattle tended to be lower ($P = 0.07$) than the pH of GA cattle at 11 and 12 h after feeding (e.g., 5.38 ± 0.45 vs. 5.81 ± 0.26 at 11 h), which represents a delayed pH recovery that extends the exposure of RA cattle to low ruminal pH compared with GA.

Variance of mean hourly pH of cattle fed 90% concentrate diets (Figure 2b) tended to be less ($P < 0.10$) for RA than GA at 4, 5, 6, and 7 h after feeding, but after

7 h, the RA variance increased steadily for the rest of the day. The sharp drop in ruminal pH after feeding, together with the relatively smaller variance suggests that initially after introduction to the 90% concentrate diet, the RA heifers responded to the grain challenge with a uniform decrease in ruminal pH. At 7 h after feeding, ruminal pH decline of most RA heifers began to diminish, but some continued to drop to levels associated with acute acidosis. The increasing variance in RA ruminal pH beginning at this time reflects the widening range of pH responses, which continued throughout the remainder of the day. The initial decrease in ruminal pH among the GA heifers was less uniform (higher variance), but beyond 7 h after feeding, when acute acidosis would have been most likely to occur, their pH variance began to decrease. Together with the increasing mean hourly pH that also commenced 7 h after feeding, this finding demonstrates that ruminal pH recovery was more uniform and occurred earlier in the GA than the RA heifers. Increasing variance in RA, the decreasing variance in GA at ≥7 h after feeding, and the tendency ($P < 0.10$) toward lower ruminal pH in RA than in GA suggests that the RA protocol promoted acidosis in specific individuals following introduction of the 90% concentrate diet.

The great variation in the abilities of individual animals to cope with grain challenge, as was evident in this trial, has been reported by other researchers (Dougherty et al., 1975; Brown et al., 2000). An abrupt increase from a 50% concentrate diet (dry-rolled corn) to a 95% concentrate diet (dry-rolled corn and dry-rolled wheat) resulted in substantial variation in ruminal pH among six steers, in which postchallenge ruminal pH ranged from 5.69 to 4.47 (Bauer et al., 1995). In that same study, the researchers took steps to minimize variation in ruminal pH response in a second experiment by introducing a 100% concentrate diet (finely ground corn and dry-rolled wheat) directly into ruminally cannulated animals. Other attempts to minimize variation in ruminal pH response have combined this technique with withholding feed from cattle before the grain challenge (Coe et al., 1999; Brown et al., 2000). Using these methods seems to have increased the occurrence of acidosis and also seems to have resulted in more uniform ruminal pH response among animals within a treatment, which improves the opportunity to identify statistically significant differences. This increased frequency and uniformity of acidosis has helped with achieving research objectives in a number of studies, but by minimizing variation, this method has inadvertently contributed to a lack of recognition of the level of pH variation that occurs under conventional feeding conditions and also of how management strategies may affect this biological phenomenon. Examination of the variance of pH variables measured under rapid vs. gradual grain adaptation strategies in the present study is an effective indicator of individual animal variation, and has revealed that rapid grain adaptation results in a more variable pH response than gradual adaptation. The greater variance observed with RA compared with GA corresponded with increased incidence of subacute acidosis following introduction of 65% concentrate and of acute acidosis after immediate introduction to 90% concentrate. The fact that this degree of variability exists accentuates the futility of trying to modulate pH in group-housed cattle using bunk management techniques. Demonstration that the variance increases with the severity of challenge represents a useful approach to assessing the potential of acidotic conditions developing in cattle under varying feeding management practices. Furthermore, the degree of challenge was clearly reflected in the degree of variance equality, even though the present experiment only had six animals per treatment. Consequently, measuring the equality of variance may enable the severity of acidotic challenge to be assessed using fewer animals and under conditions more indicative of those normally encountered in commercial feedlots (ad libitum consumption, optimal grain processing, desirable forage:concentrate ratio, etc.).

Ruminal Fermentation

Ruminal lactate concentration has been reported to exceed 50 m*M* during acute acidosis, when ruminal pH was between 3.9 and 4.5 (Dunlop, 1972; Nagaraja et al., 1985). During cases of perceived subacute acidosis, however, lactic acid may not accumulate (Horn et al., 1979; Beauchemin et al., 2003), and when it does, concentrations seldom exceed 10 m*M* (Goad et al., 1998; Hristov et al., 2001; Ghorbani et al., 2002). When Coe et al. (1999) adapted steers from a 100% roughage diet to 100% concentrate (65% cracked corn:25% cracked wheat, DM basis) in 6 d using two intermediate diets, measured mean ruminal lactate concentrations did not exceed 0.4 m*M*. Similarly, ruminal lactate concentrations in the present study were generally very low, often below the 1 m*M* level of detection (data not shown). However, there were some exceptions. On the first day of feeding 90% concentrate, elevated lactic acid concentrations were measured in two RA heifers (22.3 and 6.5 m*M*) and one GA heifer (34.6 m*M*) at 8 h after feeding. This observation was not unexpected in the RA group, being consistent with previous findings for rapidly adapted cattle (Bauer et al., 1995), but its occurrence in the GA heifer was surprising and indicates that even with gradual adaptation to grain, ruminal lactate can accumulate in some individuals. At the time of the elevated lactate concentrations, ruminal pH values recorded for the affected heifers were 5.45 and 5.44 (RA) and 5.20 (GA). In two of the three individuals (i.e., the RA heifer with 6.5 m*M* lactate and the GA heifer), minimum ruminal pH had been logged at 7 (pH 5.24) and 7.5 h (pH 5.00) after feeding, respectively, and as it continued to increase beyond the 8-h sampling, acute acidosis was averted. In contrast, ruminal pH of the RA heifer with 22.3 m*M* lactate

Table 5. Effects of rapid vs. gradual adaptation protocol on ruminal fermentation variables (mean ± SD) measured 0, 8, and 18 h after introduction of 65 and 90% concentrate diets, and on the fourth day of feeding the 90% diet[a,b]

Time after feeding:	0 h		8 h		18 h	
Adaptation protocol:	Rapid	Gradual	Rapid	Gradual	Rapid	Gradual
Item						
1st day at 65% concentrate						
Total VFA, m*M*	103.3 ± 8.5	109.4 ± 11.1	162.6 ± 22.4	162.7 ± 9.9	137.4 ± 22.9	134.2 ± 15.3
Acetate, mol/100 mol	60.7 ± 4.0	58.6 ± 2.3	56.0 ± 5.3	52.1 ± 3.2	54.9 ± 5.7	49.4 ± 6.9
Propionate, mol/100 mol	26.0 ± 4.9	24.6 ± 4.5	30.3 ± 8.6	30.1 ± 5.5	30.3 ± 8.9	30.8 ± 6.4
Butyrate, mol/100 mol	9.2 ± 1.8	11.3 ± 3.9	9.8 ± 2.9	12.8 ± 4.7	10.2 ± 4.3[d]	14.7 ± 3.1[c]
Acetate:propionate	2.5 ± 0.7	2.5 ± 0.5	2.1 ± 0.9	1.8 ± 0.4	2.0 ± 0.8	1.7 ± 0.6
Ammonia, m*M*	2.1 ± 1.4	2.5 ± 2.7	5.2 ± 3.9	6.8 ± 3.7	7.7 ± 5.5	5.6 ± 2.9
Osmolality, mOsm/kg	300 ± 11	309 ± 11	357 ± 40	357 ± 16	342 ± 31	333 ± 22
1st day at 90% concentrate						
Total VFA, m*M*	113.3 ± 19.3	121.4 ± 17.8	161.4 ± 21.8	148.6 ± 40.3	126.8 ± 23.8	115.4 ± 11.0
Acetate, mol/100 mol	56.4 ± 6.8	41.6 ± 3.7	49.8 ± 5.7	45.9 ± 8.5	45.8 ± 4.4	45.9 ± 5.5
Propionate, mol/100 mol	25.0 ± 7.4	28.7 ± 6.7	33.8 ± 8.5	32.9 ± 9.7	36.7 ± 7.6	34.4 ± 5.1
Butyrate, mol/100 mol	13.3 ± 3.5	14.0 ± 2.8	12.7 ± 3.8	16.2 ± 3.6	12.8 ± 6.4	13.0 ± 1.7
Acetate:propionate	2.5 ± 0.9	1.9 ± 0.6	1.6 ± 0.7	1.7 ± 1.2	1.3 ± 0.3	1.4 ± 0.4
Ammonia, m*M*	3.3 ± 3.1	4.3 ± 2.6	4.6 ± 1.9	7.4 ± 3.5	6.5 ± 4.7	10.4 ± 3.8
Osmolality, mOsm/kg	308 ± 6[d]	333 ± 14[c]	366 ± 31	378 ± 37	333 ± 19	332 ± 42
4th day at 90% concentrate						
Total VFA, m*M*	132.8 ± 19.5	120.0 ± 30.4	140.4 ± 25.3	137.1 ± 37.4	121.4 ± 9.2	114.1 ± 16.7
Acetate, mol/100 mol	45.2 ± 6.7	48.1 ± 10.0	47.1 ± 8.8	46.8 ± 9.8	44.2 ± 7.0	47.6 ± 6.4
Propionate, mol/100 mol	39.9 ± 7.6	35.7 ± 11.3	33.2 ± 8.1	36.7 ± 10.4	38.1 ± 9.3	35.1 ± 8.5
Butyrate, mol/100 mol	10.1 ± 6.6	11.4 ± 4.3	13.9 ± 6.9	11.1 ± 4.2	10.2 ± 8.0	10.7 ± 3.1
Acetate:propionate	1.2 ± 0.3	1.7 ± 1.2	1.6 ± 0.7	1.5 ± 0.9	12 ± 0.3	1.5 ± 0.7
Ammonia, m*M*	2.8 ± 3.3	5.2 ± 3.6	3.6 ± 3.9[f]	7.5 ± 3.1[e]	6.3 ± 2.8[f]	10.6 ± 4.5[e]
Osmolality, mOsm/kg	323 ± 18	335 ± 18	340 ± 16	355 ± 33	328 ± 10	339 ± 43

[a]Rapid adaptation (RA) entailed transition from 40 to 90% concentrate diets in 3 d using one intermediate diet (65% concentrate); with gradual adaptation (GA), the transition from 40 to 90% concentrate was accomplished over 15 d using five levels of concentrate (see Table 1).

[b]For the 1st day on 90% concentrate, n = 5 for RA and n = 6 for GA; for all other measurements, n = 6.

[c,d]Within a row and sampling time, values that do not have a common superscript differ, $P < 0.05$.

[e,f]Within a row and sampling time, values that do not have a common superscript differ, $P < 0.10$.

continued to decrease from 5.45 at 8 h to a minimum of 4.53 at approximately 18 h after feeding. Quite possibly, continued accumulation of lactate contributed to this prolonged decrease in ruminal pH.

Lactic acid accumulation occurs when abrupt introduction of rapidly fermentable carbohydrate stimulates proliferation of the rapidly growing lactic acid-producing bacterium, *Streptococcus bovis*, so that it exceeds the growth rate of lactic acid-utilizing bacteria (Russell and Hino 1985; Dawson and Allison, 1988). As a result of the imbalance between production and utilization, an accumulation of lactic acid occurs, but often only in specific individuals. The factors (microbial or otherwise) that may predispose certain animals to lactic acid accumulation remain largely unknown.

Heifers with no detectable ruminal lactate were observed in both treatment groups in the present study. Low ruminal pH in these animals was attributed primarily to high ruminal VFA concentrations. These results are consistent with total acid load, not lactate alone, being responsible for low pH (Britton and Stock, 1987). In this study, low ruminal pH seemed to be associated primarily with accumulated VFA, as ruminal VFA concentrations followed a pattern inverse to that observed for pH (Table 5).

In general, VFA concentrations at the three sampling times in this study followed a pattern of lowest before feeding (0 h), highest at 8 h after feeding, and intermediate at 18 h after feeding. The fact that VFA concentrations were still high 8 h after feeding is a reflection of the multiple meals that the heifers consumed during the day as VFA concentrations would have been far lower at this time point had heifers been restricted to a single morning meal. On the first day of feeding 65 or 90% concentrate diet, total ruminal VFA concentrations (Table 5) were higher 8 h after feeding than the values of 97 to 120 m*M* previously reported for cattle consuming a similar barley-grain based finishing diet (Ghorbani et al., 2002; Beauchemin et al., 2003; Koenig et al., 2003). Concentrations were comparable to those achieved (130 to 140 m*M*) in studies designed to simulate acidosis (Burrin and Britton, 1986; Bauer et al., 1995), suggesting that VFA production did not limit the severity of the challenge in the present study.

Few treatment effects were observed for the other ruminal fermentation variables that were measured. Adaptation protocol did not affect individual VFA concentrations or acetate:propionate ratios measured 0, 8, and 18 h after feeding on the first day of feeding

Table 6. Effects of rapid vs. gradual adaptation to a high-concentrate diet on blood chemistry of heifers during a 20-d transition from 40 to 90% concentrate diets[a,b]

Measurement	Sampling day	Rapid adaptation	Gradual adaptation	SE	*P*-value
Blood pH	0	7.41	7.38	0.01	0.17
	4	7.38	7.40	0.01	0.19
	19	7.38	7.37	0.02	0.77
pCO_2, mEq/L	0	49	50	3	0.77
	4	48	48	1	0.91
	19	47	45	1	0.32
Packed cell volume, %	0	30	31	1	0.61
	4	29	32	1	0.16
	19	31	31	1	0.65
Glucose, g/L	0	1.02	1.08	0.04	0.30
	4	1.05	1.06	0.05	0.85
	19	1.02	1.00	0.04	0.73
Lactate dehydrogenase, U/L	0	4,629	4,118	265	0.20
	4	4,524	3,750	234	0.04
	19	3,991	3,839	294	0.71

[a]Rapid adaptation (RA) entailed transition from 40 to 90% concentrate diets in 3 d using one intermediate diet; with gradual adaptation (GA), transition from 40 to 90% concentrate was accomplished over 15 d using five levels of concentrate (see Table 1). Day 4 was the 1st day that the 90% concentrate diet was fed to the RA heifers. Day 19 was the 4th day of 90% concentrate for the GA heifers (16th day at 90% for RA).

[b]Blood samples were collected at a single time point each day (18 h after feeding; n = 6) due to limited equipment for measurement of blood gases.

65% concentrate, or on the first or fourth days of feeding 90% (Table 5). Free glucose concentrations measured 8 h after feeding of 65 or 90% concentrate diets did not differ across treatments (data not shown). Accumulation of glucose in the rumen has been associated with clinical acidosis (Owens et al., 1998), which was confirmed in the one RA heifer that registered 22.3 m*M* ruminal lactate (d 1 of 90% concentrate) and of 4.4 m*M* ruminal glucose. Osmolality of ruminal fluid differed with treatment (GA > RA; $P < 0.05$) only once, in the prefeeding (0 h) sample collected on the first day of feeding 90% concentrate. Ruminal ammonia concentrations were not different across treatments, except on the fourth day of feeding 90% concentrate, when they tended ($P < 0.10$) to be lower in RA than in GA heifers at 8 and 18 h after feeding. These treatment differences may have arisen from variation in ammonia utilization for AA synthesis by microbial populations or in absorption of ammonia across the rumen wall.

Blood Variables

The pH of blood samples collected on d 0, 4, and 19 did not differ among days or between treatments (Table 6), indicating that no heifers (RA or GA) were experiencing metabolic acidosis as a result of the grain challenge at the time of sampling. Under normal conditions, blood pH is highly regulated and rarely fluctuates, because it is saturated with bicarbonate (Owens et al., 1998). During acute acidosis, however, excess acid production may exhaust the buffering capacity of the bicarbonate and blood pH decreases. When metabolic acidosis occurs, decreased levels of bicarbonate in blood result in increased concentrations of CO_2 (Owens et al., 1998). Decreased blood CO_2 levels are therefore taken to represent a lower risk of metabolic acidosis (Brown et al., 2000). Given the limited blood sampling regimen that was used in the present study, it was unlikely that differences in blood pH would be detected. However, heifers on the RA protocol exhibited a higher ($P = 0.04$) lactate dehydrogenase concentration than did the GA heifers on d 4, which likely reflects greater absorption of lactate from the rumen in RA cattle fed 90% concentrate on this day vs. the GA cattle that were fed a 56.7% concentrate diet. Lactate dehydrogenase concentration in blood tends to increase during acidosis as a result of a greater need to metabolize lactic acid (Owens et al., 1998), and may therefore also be considered as an indicator of metabolic acidosis risk. Packed cell volume and blood glucose were not affected by treatment, which also indicates that at the days and times blood samples were collected, metabolic acidosis was not occurring in either treatment group (Owens et al., 1998; Brown et al., 2000). Blood was not collected from the GA heifers on their first day of consuming 90% concentrate diets (d 16) as it was for the RA heifers (d 4), but it is unlikely that metabolic acidosis would have arisen on d 1 of 90% concentrate in the more subtle GA protocol, given that it was not indicated among the RA heifers.

Feed Intake

Overall DMI averaged 9.55 kg/d over the 20-d experimental period in the present study, and did not differ between treatments. Decreased feed intake is commonly observed during adaptation to high-grain diets (Tremere et al., 1968; Hironaka, 1969; Fulton et al., 1979) and is often accentuated when digestive distur-

Table 7. Effect of rapid vs. gradual adaptation on DMI and DMI variation among heifers in the first three or four days following introduction of diets containing 65 and 90% concentrate[a]

Item	Rapid adaptation	Gradual adaptation	*P*-value	
			TRT[b]	Equality of variance[d]
65% concentrate				
DMI, kg				
1st day	10.17 ± 1.37	11.02 ± 1.78	0.37	0.58
2nd day	9.31 ± 1.77	10.25 ± 1.76	0.38	0.99
3rd day	8.85 ± 1.96	10.25 ± 2.65	0.32	0.52
DMI variation, kg[c]				
1st day	1.16 ± 0.66	1.45 ± 0.96	0.55	0.42
2nd day	0.96 ± 1.21	1.08 ± 1.07	0.87	0.79
3rd day	0.74 ± 0.50	0.77 ± 0.82	0.94	0.31
90% concentrate				
DMI, kg				
1st day	10.23 ± 2.12	9.84 ± 1.70	0.73	0.64
2nd day	8.76 ± 4.18	8.00 ± 1.05	0.71	0.31
3rd day	9.21 ± 1.96	9.04 ± 2.44	0.90	0.64
4th day	9.15 ± 1.49	8.81 ± 1.55	0.70	0.93
DMI variation, kg				
1st day	2.07 ± 1.08	1.21 ± 1.30	0.23	0.71
2nd day	2.04 ± 3.46	1.84 ± 1.05	0.90	0.02
3rd day	1.87 ± 2.14	1.92 ± 1.34	0.96	0.33
4th day	1.00 ± 0.70	1.18 ± 0.53	0.65	0.54

[a]Rapid adaptation (RA) entailed transition from 40 to 90% concentrate diets in 3 d using one intermediate diet; with gradual adaptation (GA), transition from 40 to 90% concentrate was accomplished over 15 d using five levels of concentrate (see Table 1).

[b]TRT = effect of adaptation protocol (rapid vs. gradual adaptation). For the 1st day at 90% concentrate, n = 5 for RA, and n = 6 for GA; for all other measurements, n = 6.

[c]DMI variation = difference in DMI between the current and previous day.

[d]Equality of variance of means between treatments was examined using an *F*-test procedure (Steel and Torrie, 1980); where variances differed, a Satterthwaite (1946) approximation was used to provide an alternate *P*-value.

bance is severe (Owens et al., 1998). In the present study, DMI on each of the days of feeding identical diets (i.e., the 3 d of feeding 65% concentrate and the initial 4 d of feeding 90% concentrate) did not differ between treatments (Table 7). However, DMI by individual animals was not consistent over time, and widely ranging DMI was observed among individuals on both adaptation protocols. For example, on the second day of feeding 90% concentrate diets, DMI ranged from 0.59 to 11.2 kg for RA heifers, and from 5.35 to 12.7 kg for those in the GA group.

Treatment × day interactive effects on intake were not observed ($P = 0.76$) in this study, but intake was affected by day of feeding of a particular diet (Table 8). Dry matter intake was lower ($P < 0.05$) on the second and third days of feeding 65% and the second day of 90% concentrate than on the first days that these diets were fed. Intake by all but one of the heifers (RA and GA) in the study decreased on d 2 compared with d 1 of feeding 90% concentrate, but most were relatively small decreases. The most severe drop in DMI from the first to second day of feeding 90% concentrate was 8.99 kg recorded for a heifer on the RA protocol, but these fluctuations in intake were not clearly related to adaptation regimen as the second largest reduction (2.91 kg) occurred with a GA heifer. The RA heifer with the 8.99-kg reduction in DMI on d 2 also had the lowest ruminal pH on d 1. This is consistent with a highly positive correlation between minimum ruminal pH on the day of grain insult and feed intake on the following day reported by Brown et al. (2002).

Some day-to-day fluctuation in intake is normal for cattle confined in metabolism stalls and fed to appetite (Schwartzkopf-Genswein et al., 2004), but increased variation in feed intake has been identified as an indicator of subacute acidosis (Britton and Stock, 1987; Bauer et al., 1995; Stock et al., 1995). In the present study, DMI variation between consecutive days was not affected by treatment (or day) on any days that 65 or 90% concentrate diets were fed, but on d 2 of feeding 90% concentrate, the variance (range) of the day-to-day variations was greater ($P < 0.05$) with RA than with GA. This indicates that individual heifers in the RA group may not have regulated their feed intake as uniformly as did those in the GA group following the increase to 90% concentrate.

Individual Animal Concentrate Intake and Ruminal pH

Previous research on clincial and subacute ruminal acidosis and efforts at their diagnosis have been ham-

Table 8. Dry matter intake and variance in DMI following introduction of diets containing 65 or 90% concentrate to feedlot heifers on two protocols of grain adaptation[a]

	Day of feeding diet				
Diet	1st	2nd	3rd	4th	SE[b]
65% concentrate diet					
DMI, kg/d	10.59[e]	9.78[f]	9.55[f]	NA[c]	0.55
DMI variation, kg[d]	1.30	1.02	0.75	NA	0.33
90% concentrate diet					
DMI, kg/d	10.03[e]	8.38[f]	9.13[ef]	8.98[ef]	0.69
DMI variation, kg	1.64	1.94	1.89	1.09	0.73

[a]Adaptation protocols are described in Table 1. No treatment effects or treatment × day interactive effects were observed ($P = 0.76$); therefore, values shown are averaged across treatments.
[b]n = 12, except 1st day at 90% concentrate, when n = 11.
[c]NA = not applicable (the 65% diet was fed for 3 d during the adaptation protocol).
[d]DMI variation = difference in DMI between the current and previous day.
[e,f]Within a row, means that do not have a common superscript letter differ, $P < 0.05$.

pered by the low incidence of this condition within populations of cattle (Galyean and Rivera, 2003). Feeding management strategies prescribed by nutritionists and feedlot managers are developed with the intent of preventing acidosis, which typically means they are designed with greater consideration of the individuals prone to acidosis than for the majority of the low-susceptibility animals within a pen. Data from the present study confirm previous observations that considerable variation exists in the ability of individual animals to cope with grain challenge.

Mean hourly ruminal pH and daily intake of concentrate over the 20-d measurement periods were plotted for each individual heifer, and assessed for the desirability of the relationship between these variables. The perceived most desirable (i.e., consistent circadian periodicity of pH, steadily increasing DMI) and, conversely, the least desirable (disrupted periodicity of ruminal pH, fluctuating daily DMI) relationships, as well as treatment means, are presented in Figure 3. From both treatment groups, the heifers with the most desirable profiles exhibited exceptionally effective moderation of ruminal pH during high concentrate intake. Introducing the 90% concentrate diet, however, did constitute a nutritional challenge to these heifers, decreasing their ruminal pH and slightly decreasing intake of concentrate on d 2, 3, and 4. Nonetheless, DMI by these heifers remained high, and in spite of the availability of additional fermentable substrate, the classical conditions of subacute (i.e., ruminal pH < 5.6 for 12 h) or acute acidosis (i.e., ruminal pH < 5.2 for 6 h) did not occur.

The least desirable profiles from both RA and GA heifers were characterized by decreased intake and reduced, more variable ruminal pH. One of the RA heifers (Figure 3) exhibited markedly increased feed intake on the first day that 90% concentrate was fed after having registered rather low intake of the 65% diet. Although the heifer's ruminal pH had been relatively high, this substantially increased intake of concentrate resulted in a drastic decrease in pH and the onset of acute acidosis (minimum pH = 4.53; AUC for pH 5.2 = 4.31, duration of pH <5.2 = 10.08 h). Feed intake on the third and fourth days on 90% concentrate was improved, but remained very low in comparison to the mean intake for RA heifers, suggesting prolonged effects of the d-2 disturbance on intake.

None of the individuals in the GA group responded to grain increase as drastically as did this RA heifer, but neither was the transition to 90% concentrate entirely smooth. In the heifer exhibiting the least desirable profile, ruminal pH was often low, and concentrate intake was variable. For this heifer, each increase in concentrate intake resulted in lower ruminal pH on that day, and decreased DMI for several days thereafter. Introduction of the 90% concentrate diet resulted in a major pH decrease during the first day, and low intake the day after. Intake on the third and fourth days of feeding 90% concentrate returned to levels above the treatment average, suggesting that the effects of adaptation were less severe for this heifer than for the RA heifer whose intake remained low. These results indicate that acidosis does occur in some animals; even incorporating additional diets into the adaptation protocol (i.e., a multidiet adaptation program) will not likely completely eliminate the occurrence of acidosis. Rather, the incidence (total number) and the severity of individual cases of acidosis are likely to be decreased by a multidiet adaptation program compared with when only one or two diets are included in the adaptation protocol.

It is difficult to explain why some heifers managed uneventful transition to finishing diets, whereas others, even in the same treatment group, became acidotic. It is important to recognize that acidosis does not result solely from high intake of rapidly fermentable carbohydrate. In this trial, heifers that maintained a healthy ruminal pH often consumed more rapidly fermentable carbohydrate on the day of grain challenge than did other heifers that became acidotic. It seems more likely that differences in ruminal pH arose from different rates of VFA absorption, different rates

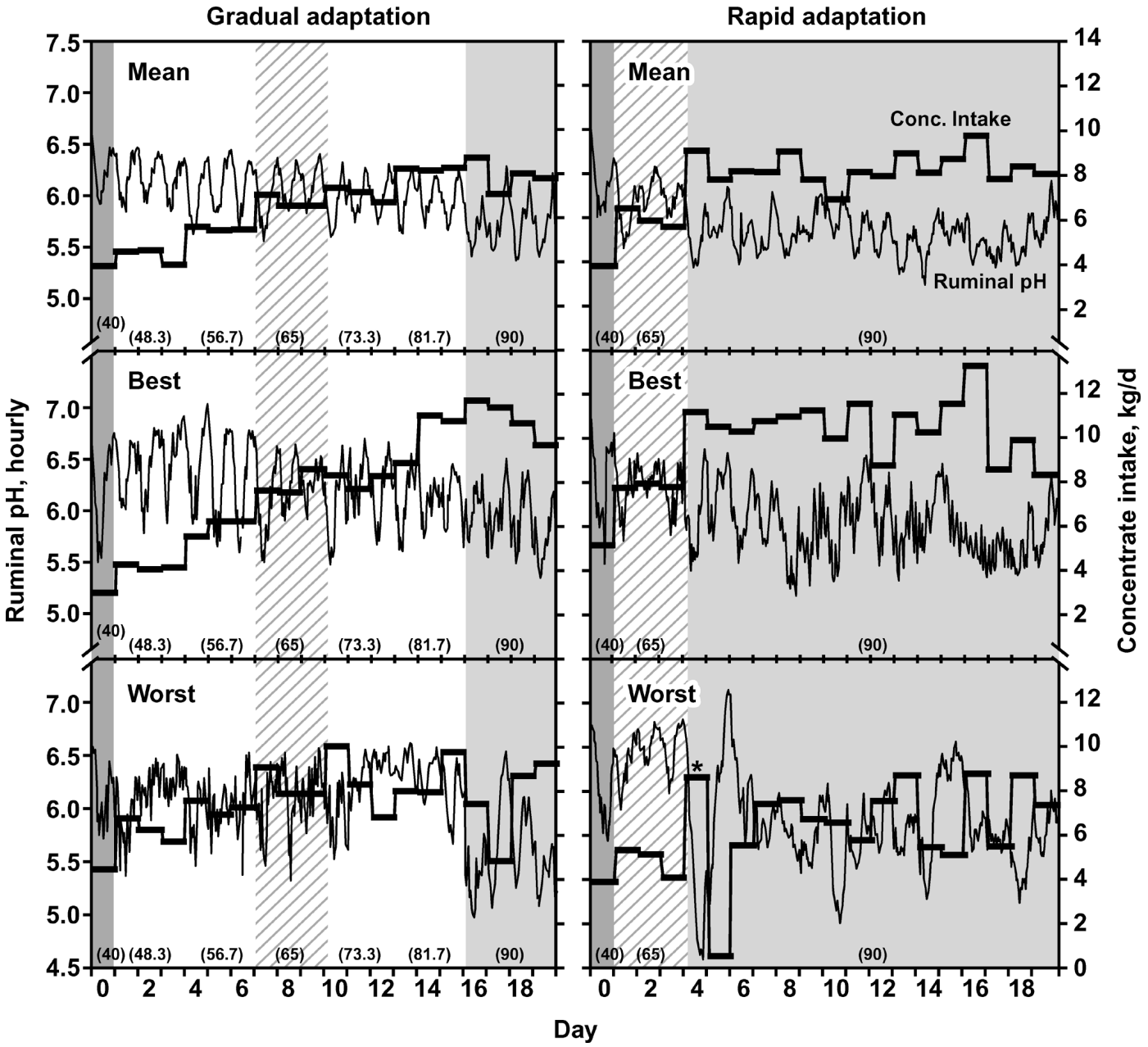

Figure 3. Mean hourly ruminal pH (thin line) and daily intake of dietary concentrate (thick bars) by heifers during gradual (five intermediate diets; 15 d) or rapid (one intermediate diet; 3 d) adaptation from a 40 to a 90% concentrate diet. Profiles shown are means for treatment groups (n = 6; top panels), and those of the individual heifers in each treatment group deemed to have exhibited the most desirable (best; middle panels) and least desirable (worst; bottom panels) moderation of ruminal pH and maintenance of DMI over the 20-d adaptation periods. Values in parentheses are the percentages of concentrate in each of the adaptation diets (DM basis). On the day marked with an asterisk (*), the ruminal lactate concentration in the RA heifer was 22.3 m*M* (measured 8 h after feeding).

of fluid passage out of the rumen, differences in saliva production (buffering capacity), and/or differences in VFA metabolism among animals, but identification of the specific metabolic factors that predispose certain individuals to acidosis is beyond the scope of this study. Thus, although the present observations document the range of susceptibility that exists among individual cattle, preventing acidosis in commercial feedlots must remain linked to management strategies based on outcomes for the most acidosis-prone individuals, rather than on means for the pen.

Implications

In this study, few ruminal pH measurements or other fermentation variables were affected by rapid

vs. gradual adaptation to a high-concentrate diet, but the equality of variance of most pH values (e.g., daily mean, minimum and maximum pH, areas under the curve, and daily durations) was far greater for rapidly adapted than for gradually adapted heifers. This increased variance represents a greater opportunity for acidosis to occur in some individuals and suggests that this may be a useful approach to assess the effect of feeding management techniques on subclinical acidosis. The current objective of high-grain adaptation programs in commercial feedlots is to minimize or prevent cases of acidosis, which requires that management of grain adaptation be tailored to the most susceptible individuals. In that approach, consideration of individual animal response is essential. Although data suggest that most cattle can be rapidly adapted to high-grain diets in few incremental steps, minimizing acidosis in the most susceptible individuals requires decreasing the pace of grain adaptation for the entire group. Defining metabolic factors that give rise to acidosis in high-risk individuals could provide a key to developing new preventive strategies for subacute and acute acidosis.

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