Development of Rumen Function in Calves: Nature of Protein Reaching the Abomasum[1,2]

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ABSTRACT

Effects of weaning age (4 and 8 wk) and ration (complete pelleted starter and unpelleted starter plus alfalfa-grass hay) on development of ruminal function were tested in a split-plot design. Maturity of ruminal function was estimated by the contribution of bacterial nitrogen to total nitrogen reaching the abomasum, essential amino acid composition of bacterial and abomasal protein, and ruminal volatile fatty acid concentrations. Sixteen Holstein bull calves were fitted with rumen and abomasal cannulas by 1 wk of age, and ingesta were sampled twice weekly from 2 to 11 wk of age. Contribution of bacterial nitrogen to total nitrogen in abomasal contents was similar to that of mature ruminants by 5 and 7 wk of age for calves weaned at 4 and 8 wk of age, respectively. Concentrations of ruminal volatile fatty acids indicative of mature ruminal function were reached by 5 wk of age. Pattern of essential amino acids in bacterial cells of the rumen was not affected by age, weaning age, or ration and was similar to that of mature ruminants. Analysis of abomasal digesta indicated no effect of starter ration and no effect of age or weaning age on the relative proportion of essential amino acids except lysine and arginine. Lysine decreased and arginine increased linearly from 2 wk until weaning.

INTRODUCTION

Development of mature ruminal function has been defined traditionally by physical development of the organ (15, 32, 34, 35, 36) and ruminal concentrations of volatile fatty acids (VFA) (1, 8, 16, 20, 37, 39). Ruminal function defined by end products of synthesis and degradation of ruminal protein in early weaned calves has not been determined.

Amino acids available for absorption from the small intestine of the mature ruminant are derived from feed protein escaping ruminal degradation, microbial protein synthesized in the reticulorumen, and endogenous protein in the form of abomasal secretions and desquamated epithelial cells, the former two being dependent on size and activity of microbial populations in the rumen. As ruminal function develops in the young calf, potential changes of ruminal metabolism may affect the quantity and quality of protein reaching the small intestine. First, the proportion of feed protein escaping degradation in the rumen may change as the calf begins to consume dry feed. Second, populations of bacteria change in response to increasing starter intake (6, 20, 33, 40) and may affect the amino acid composition of bacteria reaching the lower gut. Finally, as intake of dry feed increases, changing proportions of undegraded feed protein relative to bacterial protein reaching the lower gut may alter quality and quantity of protein available for absorption. Studies by abomasal infusion (10, 29) indicated methionine is first limiting for nitrogen retention of early weaned calves fed complete pelleted starter rations from 5 to 11 wk of age.

In view of the possible influence of diet, weaning age, and advancing age on changes of source and composition of protein reaching the lower gut, objectives of this study were to estimate development of ruminal function by proportion of bacterial nitrogen to total nitrogen

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reaching the abomasum and ruminal VFA concentrations, and to determine concentrations of essential amino acids in samples of isolated bacterial cells and abomasal digesta in calves under practical feeding conditions from 2 to 11 wk of age.

MATERIALS AND METHODS

General

Twenty Holstein bull calves were purchased at 1 to 3 days of age, and 16 were assigned to a factorial arrangement of starter ration (complete pelleted vs. unpelleted plus hay) and weaning age (4 vs. 8 wk). On arrival, calves were injected intramuscularly near the hip with 1 ml of a preparation containing vitamins A, D, and E[4] and vaccinated against IBR-PI_3 viruses.[5] At 1 wk of age (on average), T-cannulas (adapted from 13) were placed surgically into the rumen and abomasum of all calves.

Calves were housed in individual stalls bedded with sawdust in an uninsulated barn. Saleable or waste milk as available was fed from open buckets at 0730 and 1630 h. Calves weaned at 4 wk received 1.8 kg milk twice daily to day 21; thereafter milk was reduced gradually to zero on day 28. Calves weaned at 8 wk received 1.8 kg milk twice daily to day 49; thereafter milk was reduced gradually to zero on day 56.

Starter rations were closed formula commercial calf rations. The complete pelleted starter ration (CPSR)[6] was based on processed grain and roughage products and the unpelleted starter (USR)[7] on grain, plant, and processed grain products. Second-cut mixed alfalfa-grass hay was fed with USR. Dry feeds were offered for ad libitum consumption beginning at 5 to 10 days of age. Water and salt were available for ad libitum consumption. Known quantities of dry feed were offered at approximately 1.05 times intake once daily to each calf at approximately 0730 h. Spoiled feed was replaced as required and composited for each calf. Feed refusals and body weights were recorded weekly. Feed was sampled weekly and stored at 4°C until analyzed.

Collection and Sampling of Digesta

From 300 to 900 ml of ruminal fluid and 100 to 150 ml of abomasal fluid were collected from every animal twice weekly from 2 to 11 wk of age and transported immediately to the laboratory. Animals in replicates 1 and 2 and replicates 3 and 4 were sampled at 0900 and 1300 h, respectively, on Wednesday and at 0900 and 1400 h, respectively, on Friday. Milk was withheld before morning sampling prior to weaning.

Ruminal fluid was strained through two layers of cheesecloth, and approximately 200 ml was centrifuged at 1500 × *g* to remove feed particles. No attempt was made to determine amounts of ruminal bacteria associated with feed particles after strained through cheesecloth or centrifugation. Supernatant fluid was transferred to clean bottles and centrifuged at 26,500 × *g*; resulting precipitate was resuspended in 200 ml of methanol (28) and recentrifuged at 26,500 × *g*. Precipitated bacterial cells were dried in a convection oven at 60°C to a constant weight, ground through a .64-mm screen,[8] and stored in glass vials until analyzed. Approximately 25 ml of strained ruminal fluid was placed in a plastic vial, frozen immediately, and stored at −20°C until analyzed for VFA. Strained ruminal fluid was examined microscopically (× 400) for presence of ruminal protozoa. No attempt was made to quantitate ciliates or flagellates. Abomasal fluid was weighed into petri dishes and dried in a forced-air oven at 60°C to a constant weight. Dried abomasal solids were ground through a 1.27-mm screen[8] and stored in glass jars at room temperature until analyzed.

Feed and Digesta Analysis

Samples of feed were ground through a 1-mm screen in a Wiley mill and analyzed for dry matter (DM) (vacuum oven, 60°C), total nitrogen (N) (4),[9] proximate nutrients (4), acid

[4] Hoffman-LaRoche Inc., contains 500,000 IU vitamin A, 75,000 IU vitamin D_3, and 50 IU vitamin E/ml.

[5] IBR-PI_3, Bio-ceutic Laboratories, Inc., St. Joseph, MO.

[6] TCR I, Agway Inc., Syracuse, NY.

[7] Calf Grower, Agway Inc., Syracuse, NY.

[8] Thomas Wiley Intermediate Mill, Arthur H. Thomas Co., Philadelphia, PA.

[9] Apparatus: Model BD-20 block digester and Autoanalyzer II, and Sampler IV, Technicon Industrial Systems, Tarrytown, NY.

detergent fiber (17), and insoluble N. Insoluble N was measured after .5 h in sodium-bicarbonate potassium-phosphate sodium-phosphate buffer.[10] Semiweekly samples of strained ruminal fluid frozen prior to VFA analysis were thawed, pooled separately by week for each calf, and analyses were duplicate as in (2) with a gas chromatograph equipped with a 183 cm x .2 cm glass column packed with 10% SP-1200/1% H_3PO_4 on 80/100 Chromasorb W AW (column temperature 130°C, inlet temperature 265°C, detector: FID, temperature 275°C, carrier gas: helium, 35 ml/min).

Semiweekly samples of dried bacterial cells and abomasal solids were pooled separately by week for each calf and analyzed for total N (4). Contribution of bacterial N to total N in abomasal contents was to be determined by the marker ratio technique (ratio of marker : N of abomasal contents / marker : N of bacterial cells) with D-alanine as the marker of bacterial protein as described in (14). Analysis of samples for D-alanine eventually was abandoned after many estimates for contribution of bacterial N to total N in abomasal contents appeared unrealistic, with several exceeding 100%. Results subsequently were shown to be inconsistent with estimates by diaminopimelic acid (DAPA) as a bacterial marker and an amino acid ratio method (26). Weekly samples of approximately 1 g of dried bacterial cells and 5 g of dried abomasal solids from each calf were composited separately by treatment and analyzed for amino acids, including DAPA. Compositing was necessitated by the large number of samples generated and cost of analyses. Hay and starter rations pooled separately by shipment were analyzed for amino acids only. Amino acid composition of 5 to 10 mg of pooled samples was measured with a Beckman 118CL amino acid analyzer[11] following hydrolysis in 1 ml constant boiling 6 N HCl and 1 drop .5 *M* hydrazine at 108°C for 24 h under vacuum. Combined cystine and cysteine were determined as cysteic acid (24) in a second sample of dried bacterial cells, dried abomasal solids, and feeds as described in (29). Amino acid concentrations were corrected to 100% recovery by addition of 800 nmoles of norleucine. Content of DAPA in 75 mg of ruminal bacterial cells and 150 mg of abomasal digesta was determined spectrophotometrically following hydrolysis in 3 ml of 6 N HCl and column separation by a modification of (9) and (11).

Statistical Analysis

Feed intake and VFA concentrations were analyzed as a split plot design with treatments as main plots and age as subplots (30). Means were separated by Tukey's procedure (30) after F tests were significant. Essential amino acid composition of ruminal bacterial cells and abomasal digesta, and percent contribution of bacterial nitrogen to total abomasal nitrogen were not analyzed statistically because of pooling of samples prior to analyses.

RESULTS AND DISCUSSION

Chemical composition of starter rations and hay is in Table 1. The relatively high content of insoluble protein in starters was due to use of by-product feeds as sources of protein. Essential amino acid (EAA) content of starters and hay varied only slightly between feeds with most differences influenced largely by content of crude protein rather than by differences in pattern of EAA.

Calves generally were healthy throughout the trial. Three calves died at 3, 15, and 30 days postsurgery and were replaced. Scours occurred sporadically and appeared unrelated to treatments. During the last week of the trial, failure of abomasal cannulas in three calves forced their removal from the study. Therefore, only three observations were during wk 11 for each of the two groups of calves fed CPSR, and calves fed USR plus hay and weaned at 8 wk of age.

Growth and feed intake data compared favorably with those of (25) for calves of similar ages, suggesting that cannulation did not affect animal performance adversely. Growth was not affected by treatment; average daily gains for ages 2 to 4 wk, 4 to 8 wk, and 8 to 11 wk were .14, .56, and .80 kg. Daily intake of starter DM increased with advancing age ($P<.01$) (Table 2). A significant ($P<.01$) interaction of age x treatment also was present.

[10] New York forage testing lab, Ithaca, NY.
[11] Beckman Instrument Co., Palo Alto, CA.

TABLE 1. Chemical composition[1] of starter rations and hay.

Item	Complete pelleted starter ration (CPSR)	Unpelleted starter ration (USR)	Hay
Crude protein[2]	17.2	22.3	15.3
Insoluble protein[2]	12.7	15.6	11.4
Ash[2]	7.6	9.2	8.1
Crude fiber[2]	9.5	4.4	30.2
Acid-detergent fiber[2]	13.3	6.1	35.3
Ether extract[2]	3.6	3.5	2.6
Essential amino aicds (EAA)[3]			
Arginine	1.06	1.30	.77
Cystine plus cysteine[4]	.36	.40	.20
Histidine	.45	.52	.33
Isoleucine	.59	.78	.68
Leucine	1.30	1.62	1.26
Lysine	.68	.86	.84
Methionine	.26	.28	.24
Phenylalanine	.77	.99	.81
Threonine	.61	.76	.78
Valine	.77	.88	.85
Total EAA	6.5	8.0	6.6
Total NEAA[5]	9.2	11.1	7.4
Total amino acids	15.7	19.1	14.0

[1] Percent of dry matter. Dry matter content of CPSR, USR and hay were 91.5, 90.9, and 93.7.

[2] Mean of 10 weekly composites.

[3] Mean of 2 starters or 1 hay composite(s).

[4] Measured as cysteic acid (24).

[5] Nonessential amino aicds.

Intake of DM from dry feeds tended to be higher from 4 to 7 wk of age when calves were weaned at 4 wk of age.

Content of total VFA in ruminal fluid increased with age ($P<.01$) (Table 3) with maximums reached by about 2 wk postweaning. However, weekly means were not significantly different ($P>.05$) from 5 to 11 wk of age. Total ruminal VFA reach adult concentrations by 6 to 8 wk of age if calves are offered dry feed from about 1 wk of age (1, 8, 16, 20, 37, 39). Mature ruminal function tends to be reached at an earlier age in calves weaned at 4 wk than those weaned at 8 (present study) or 12 wk (1) as assessed by ruminal VFA concentrations; this reflects greater intake of dry and fermentable feeds. Williams and Dinusson (39) reported that total VFA approached that of mature ruminants as early as 3 wk of age, when calves were consuming a high roughage pelleted starter ration at 1.5% of body weight. Calves fed CPSR also tended to maintain higher concentrations of ruminal total VFA than calves fed USR plus hay.

TABLE 2. Daily intake of feed dry matter[1] from complete pelleted starter (CPSR) and unpelleted starter (USR) plus hay for calves weaned at 4 or 8 wk of age.

	CPSR		USR plus hay	
Age	4 wk	8 wk	4 wk	8 wk
(wk)	(kg)			
2	.1	.0	.1	.1
3	.3	.1	.4	.2
4	$.9^{a}$	$.2^{b}$	$.6^{ab}$	$.4^{ab}$
5	1.2^{a}	$.4^{c}$	1.1^{ab}	$.6^{bc}$
6	1.7^{a}	$.6^{c}$	1.4^{ab}	$.8^{bc}$
7	1.9^{a}	1.2^{b}	1.8^{a}	1.2^{b}
8	2.5^{a}	1.9^{b}	1.9^{b}	1.9^{b}
9	2.6	2.3	2.1	2.4
10	2.7	2.6	2.6	2.4
11[2]	3.1	2.7	2.5	2.9

[a,b,c] Means in a row with different superscripts differ ($P<.05$).

[1] Least squares means; four observations per treatment. Standard error = .11.

[2] Three observations per treatment. Standard error = .12.

TABLE 3. Total volatile fatty acids[1,2] (VFA) in rumen fluid of calves fed a complete pelleted starter (CPSR) or unpelleted starter (USR) plus hay and weaned at 4 or 8 wk of age.

	CPSR		USR plus hay	
Age	4 wk	8 wk	4 wk	8 wk
(wk)	(mmole/liter)			
2	30.0	12.9	33.8[3]	35.6
3	69.1	36.6	77.0	70.4
4	92.5	71.5[3]	87.9	71.8
5	127.4	96.2	112.2	89.7
6	151.9	104.8	125.0	87.3
7	125.2	143.1	109.9	101.2
8	138.9	140.2	119.6	113.1
9	149.6	158.0	126.0	123.6
10	112.7[3]	175.5[3]	118.3	150.5
11	141.8[3]	180.0[3]	120.8	132.2[3]

[1] Least squares means: 4 observations per treatment. Standard error = 15.3.

[2] Total VFA = acetate + propionate + butyrate + valerate + isobutyrate + isovalerate.

[3] Three observations per treatment. Standard error = 17.9.

Ciliate protozoa were not observed in ruminal fluid of calves during the trial. Flagellate protozoa were observed in ruminal fluid of 14 calves from as early as 3 wk of age.

Contribution of bacterial N to total N in abomasal contents as estimated by DAPA analysis (Table 4) followed trends similar to those of total VFA production. Percentages were low for all treatments at 2 wk of age except for calves fed CPSR and weaned at 8 wk of age, but percentages increased with increasing consumption of dry feed. Contribution of bacterial N in calves weaned at 4 and 8 wk of age was similar to that of mature animals (exceeding 40 to 50% of abomasal protein) at approximately 5 and 6 to 7 wk of age, respectively. Calves weaned at 8 wk of age tended to have lower bacterial contribution from 4 to 6 wk of age, likely because of less substrate available for fermentation resulting from lower starter intake during this period (Table 2).

Results in Table 4 agree with those of Liebholz (22), who reported increasing contribution of microbial N to total duodenal N from 0 to 4 wk postweaning in calves weaned at 5 wk of age. It is probable that availability of substrate for fermentation and rapid adaptation of bacterial populations to ruminal conditions (40) contribute to the rapid increase of bacterial contribution to total abomasal N as consumption of dry feeds by young calf increases. Contribution of bacterial N to total N has been determined experimentally to be between 30 and 90% in mature ruminants (21) but varies considerably according to diet, amount fed, and method of determination. Contributions of bacterial N to total N reaching the abomasum were estimated also by the amino acid ratio technique of Nikolic and Jovanovic (26), by the formula (feed ratio − abomasal ratio)/(feed ratio − bacterial ratio) × 100, where ratio = (glutamic acid plus proline)/(aspartate plus isoleucine plus lysine). Estimates of proportion of bacterial N in this manner correlated .71 with those estimated by DAPA and averaged 10% higher for all observations.

Weekly least squares means of intake of DM from dry feeds and total ruminal VFA concentration were correlated .83 as were intake and bacterial contribution by DAPA (r=.62) and bacterial contribution and VFA concentration (r=.73). These relationships indicate the dependence on dry matter intake of maturing ruminal function.

Treatment means for EAA in feed, ruminal bacterial cells, and abomasal digesta grouped by

TABLE 4. Contribution[1] (%) of bacterial nitrogen to total nitrogen in abomasal contents of calves fed complete pelleted starter (CPSR) or unpelleted starter (USR) plus hay and weaned at 4 or 8 wk of age.

	CPSR		USR plus hay		
Age	4 wk	8 wk	4 wk	8 wk	
(wk)	(%)				$\bar{y}$
2	23.8 23	54.7 53	4.9 5	6.0 6	22
3	24.5 25	20.8 20	23.9 23	37.2 36	27
4	29.9 29	40.7 39	28.3 27	18.6 18	29
5	58.9 57	35.7 35	52.6 51	19.5 19	42
6	52.9 51	55.8 54	61.4 59	22.1 18	45
7	53.0 51	71.1 69	54.8 53	59.5 57	60
8	48.5 47	52.2 50	55.6 54	44.7 43	50
9	49.4 48	62.9 61	45.9 44	48.2 47	52
10	55.9 54	80.8 78	59.0 57	36.6 35	58
11	46.8 45	81.6 79	71.2 68	82.9 80	71

[1] Estimated by isolated bacterial cells and abomasal solids analyzed for diaminopimelic acid and nitrogen.

TABLE 5. Mean content[1] of essential amino acids (EAA) in diet,[2,3] ruminal bacterial cells, and abomasal digesta of calves fed complete pelleted starter ration (CPSR) or unpelleted starter (USR) plus hay and weaned at 4 or 8 wk of age for the 10-wk experimental period.

	Diet				Rumen bacterial cells				Abomasal digesta			
	CPSR		USR plus hay		CPSR		USR plus hay		CPSR		USR plus hay	
EAA	4 wk	8 wk	4 wk	8 wk	4 wk	8 wk	4 wk	8 wk	4 wk	8 wk	4 wk	8 wk
	(g/100 g EAA)											
Arg	15.1	13.0	15.0	12.9	11.0	11.0	10.7	10.3	10.9	10.3	10.1	9.7
Cys[4]	3.6	3.2	3.3	3.0	2.4	2.6	2.4	2.5	2.0	2.4	1.9	2.1
His	6.8	6.5	6.4	6.1	4.6	4.5	4.3	4.1	5.6	5.6	5.4	5.4
Ile	9.3	9.5	9.8	10.0	10.9	10.9	11.1	11.4	9.8	10.0	10.1	10.1
Leu	20.1	20.3	20.2	20.2	17.3	17.8	17.3	17.2	19.5	19.3	20.1	19.9
Lys	11.4	12.8	11.6	12.9	15.3	15.4	15.3	15.2	13.7	14.6	13.7	14.3
Met	4.2	4.5	3.7	4.1	7.0	6.7	7.1	7.2	5.2	5.4	5.2	5.1
Phe	11.8	11.8	12.3	12.2	9.5	9.6	9.5	9.6	10.3	10.5	10.7	10.5
Thr	9.4	9.5	9.6	9.8	11.6	11.6	12.0	12.0	11.2	10.8	11.2	11.3
Val	11.9	12.1	11.3	11.7	13.0	12.7	12.7	13.1	13.8	13.6	13.6	13.7

[1]Mean of 10 weekly samples.

[2]Means for diet consider all feeds in proportions consumed.

[3]Amino acid composition of milk was assumed (g/100 g EAA): arginine 7.1, histidine 5.8, isoleucine 10.2, leucine 20.7, lysine 16.9, methionine 5.4, phenylalanine, 11.7, threonine 9.6, and valine 12.6 (12).

[4]Measured as cysteic acid (24). Grams/100 g nonessential amino acids.

treatment for the 10-wk experimental period (Table 5) and by advancing age for all treatments (Figure 1) are presented. Because animals were fed starters for ad libitum intake and weaned at 4 or 8 wk of age, varying proportions of dietary proteins were consumed. Nevertheless, intakes of histidine, isoleucine, leucine, phenylalanine, threonine, and valine relative to intake of total EAA were similar among treatments (Table 5) and ages (Figure 1) and averaged (g/100 g EAA) 6.4, 9.6, 20.2, 12.0, 9.6, and 11.7, respectively. Higher concentration of arginine (15.1 vs. 13.0 g/100 g EAA) and lower concentration of lysine (11.5 vs. 12.9 g/100 g EAA) and methionine (4.0 vs. 4.3 g/100 g EAA) consumed by calves weaned at 4 wk of age (Table 5) reflect lower arginine and higher lysine and methionine in milk protein (12) relative to that in dry feeds. Arginine and lysine in feeds consumed increased and decreased, respectively, as starter intake increased and milk intake decreased (Figure 1). Slightly higher phenylalanine in feed protein consumed by calves fed USR plus hay was due to higher concentrations in both USR and hay.

Content of N and EAA in ruminal bacterial cells were similar for all treatments, and no ration, weaning age (Table 5), or advancing age (Figure 1) had apparent effect. Nitrogen in ruminal bacterial cells averaged 8.2% of DM. Essential amino acids in ruminal bacteria averaged (g/100 g EAA): argine 10.8, histidine 4.4, isoleucine 11.1, leucine 17.4, lysine 15.3, methionine 7.0, phenylalanine 9.6, threonine 11.8, and valine 12.9. These data are consistent with reports that the amino acid composition of ruminal bacteria is similar regardless of dietary regimen (5, 18, 22, 23, 31) and, with the exception of higher methionine, these data indicate similarity to that of bacteria isolated from older cattle (5, 18, 22, 23, 31). Although populations of ruminal bacteria change in response to increasing starter intake prior to and immediately following weaning (20, 40), these changes do not appear to affect amino acid composition of the total bacterial pool (Figure 1).

Essential amino acids, except arginine and lysine, in dried abomasal digesta were similar for all treatments (Table 5) and ages (Figure 1). Histidine, isoleucine, leucine, methionine, phenylalanine, threonine, and valine were similar from 2 to 11 wk of age and averaged 5.5, 10.0, 19.7, 5.2, 10.5, 11.1, and 13.7

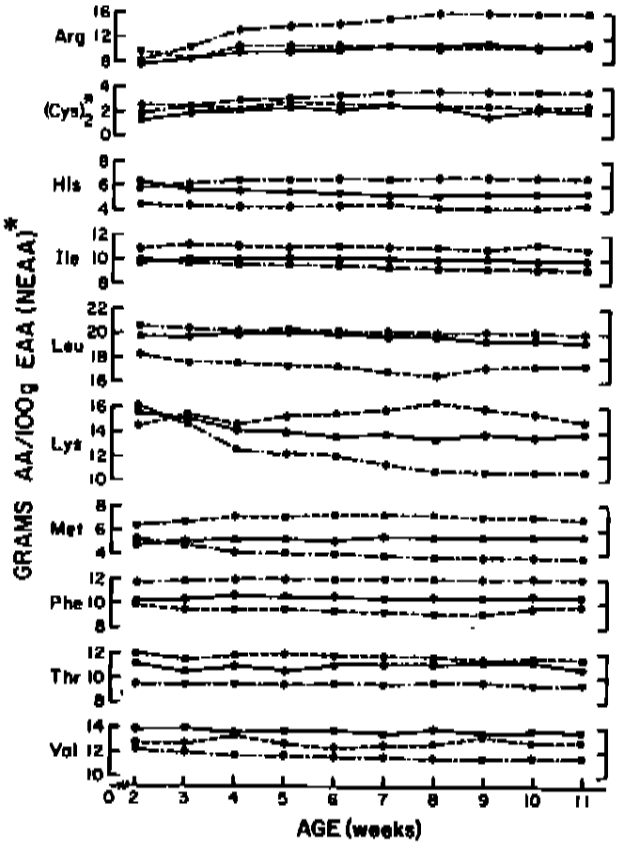

Figure 1. Relative content of essential amino acids (EAA) and contribution of combined cysteine and cystine to total nonessential amino acids (NEAA) in feed consumed (●—·—●—·—●), in rumen bacterial cells (●– – –●– – –●), and pooled abomasal solids (●——●——●). Arg = Argine, His = histidine, Ile = isoleucine, Leu = leucine, Lys = lysine, Met = methionine, Phe = phenylalanine, Thr = threonine, Val = valine.

(g/100 g EAA), respectively. As expected from an apparent lack of treatment effects for content of these seven EAA in ruminal bacterial cells and their similar pattern in diet protein with increasing age (Figure 1), their pattern in abomasal digesta was similar with advancing age (Figure 1). Profile of EAA in abomasal digesta reflected that of feed and ruminal bacteria, suggesting that both bacterial and feed proteins influence composition of EAA reaching the lower gut.

Choice and content of protein in dietary supplement affected the profile of amino acids in digesta (3, 7, 19, 31). Because the pattern of amino acids in bacterial protein is relatively constant, differences in undegraded feed proteins will affect the amino acid profile of digesta reaching the small intestine (3). As noted by Laughren and Young (19), this effect will be noticeable only if the amino acid composition of undegraded feed protein differs from that of microbial protein. In our study, EAA patterns of all feed proteins were similar except for lysine and arginine, but different from those of bacterial cells.

Effects of age on concentration of lysine and arginine in total EAA of abomasal digesta are in Figures 2 and 3, respectively. A trend toward higher lysine and lower arginine from 3 to 6 wk of age in calves weaned at 8 wk of age was due to lower consumption of starter DM during this period. Milk protein made a larger contribution to total protein reaching the abomasum; higher lysine and lower arginine in milk protein relative to dry feeds elevated lysine and lowered

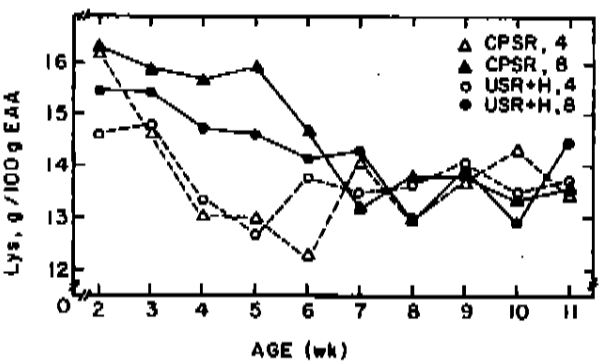

Figure 2. Contribution of lysine (Lys) to total essential amino acids (EAA) in abomasal digesta from 2 to 11 wk of age of calves fed complete pelleted starter ration (CPSR) or unpelleted starter plus hay (USR+H) and weaned at 4 or 8 wk of age.

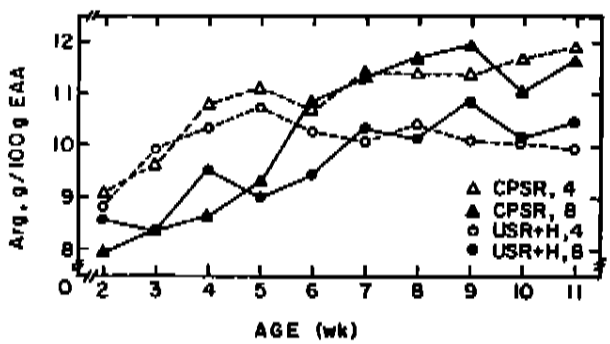

Figure 3. Contribution of arginine (Arg) to total essential amino acids (EAA) in abomasal digesta from 2 to 11 wk of age of calves fed complete pelleted starter ration (CPSR) or unpelleted starter plus hay (USR+H) and weaned at 4 or 8 wk of age.

arginine in abomasal digesta. Calves weaned at 4 wk of age tended to consume more solid feed from 3 to 6 wk of age, thereby reducing lysine from milk protein reaching the abomasum (Figure 2). Higher arginine in dry feeds increased arginine reaching the abomasum as intake increased (Figure 3). From 7 to 11 wk of age, calves fed CPSR tended to exhibit higher concentrations of arginine in abomasal digesta (Figure 3), reflecting higher arginine in the undegraded feed fraction of CPSR than in USR plus hay. Treatment had no effect on lysine in abomasal digesta from 7 to 11 wk of age.

Methionine is the first limiting EAA for nitrogen retention in early weaned calves (4 wk of age) fed complete pelleted starter rations of variable ingredient composition from 5 to 11 wk of age (10, 29). The nearly identical contribution of methionine to total EAA in abomasal digesta in our study among treatments (Table 5) and with advancing age (Figure 1) indicates that physical form of starter ration (pelleted vs. unpelleted plus long hay) and advancing age have little or no effect on the contribution of methionine to the pool of absorbable EAA and, hence, on the order of amino acid limitation. Further, the lower contribution of methionine to total EAA, and of combined cysteine and cystine to total NEAA (Table 1) in the postweaning rations fed, as compared to (10, 29), suggests methionine was first limiting also for the starter rations. The extent that low methionine may depress utilization of protein in these closed-formula commercial feeds is unknown. It may, however, be substantial as methionine is first limiting in microbial protein for growing steers (27), and in our study, methionine in the nonbacteiral fraction was considerably lower than that of bacterial protein (Figure 1).

Whitelaw and Preston (38) concluded that both solubility and amino acid composition are important in determining the nutritive value of proteins for young ruminants. Research is needed to determine amounts and composition of amino acids required by ruminants and effects of manipulating dietary and microbial protein to meet those needs.

Young calves possess mature ruminal function within 1 wk of weaning as determined by both ruminal concentrations of total VFA and contribution of bacterial N to total N in abomasal contents. Therefore, dietary management practices relevant to enhancing N utilization in older animals should be pertinent also to the young calf at weaning. The consistency of the pattern of EAA in ruminal bacterial protein from 2 wk of age indicates that the pattern of absorbable amino acids is influenced only by quantity and quality of feed protein escaping ruminal degradation. These results in conjunction with abomasal infusion studies (10, 29) indicate methionine is first limiting for nitrogen retention in calves as early as 2 wk of age when they are fed milk and conventional closed formula starters and that it continues to be limiting at least until 3 mo of age.

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