Effects of Volatile Fatty Acid Proportions on Energy and Nitrogen Utilization in Early Weaned Calves Nourished by Intragastric Infusion of Nutrients

Taketo OBITSU, Kohzo TANIGUCHI and Yoji YAMATANI

Faculty of Applied Biological Science, Hiroshima University, Higashihiroshima-shi 724

(Received October 7, 1992)

Abstract Six male Holstein calves aged 6 to 14 wk were intraruminally given volatile fatty acids (VFA) containing acetic, propionic and butyric acids in the molar proportions 48:42:10 and 76:14:10 with abomasal infusion of casein. Calves were weaned at 5 to 7 wk of age and were then wholly nourished by intragastric infusion of nutrients. Gross energy and nitrogen (N) infused was 570 kJ/kg BW^{0.75} and 1.0 g/kg BW^{0.75}, respectively. Heat production, N balance and concentrations of plasma metabolites were determined every 2 wk from age 6 to 14 wk. Plasma concentrations of glucose and β -hydroxybutyrate were affected by the proportion of VFA. Heat production per unit metabolic body weight was not affected by the proportion of VFA, but tended to decrease with advancing age. At age 10 and 12 wk, N retention for calves with the low propionate was lower than with the high propionate. These results indicate that, for a few weeks after weaning, the decrease in the ruminal propionate proportion probably reduces the N use for body protein synthesis in young calves, even though the decrease in the propionate proportion is within the normal range found in ruminants.

Anim. Sci. Technol. (Jpn.) 64 (6) : 568-577, 1993

Key words: volatile fatty acids, heat production, nitrogen retention, calves, early weaning

Early weaning of calves contributes to early development of the rumen because of accelerated intake of dry feed²⁰⁾. After weaning, calves depend largely on volatile fatty acids (VFA) instead of glucose to satisfy their energy needs for growth. For the few weeks after weaning, however, rumen function²⁰⁾ and the ability to utilize VFA in tissues²⁵⁾ do not reach a mature level. Thus, the efficiency of utilization of VFA for energy retention in early-weaned calves may differ from that in mature ruminants.

In mature ruminants, the decrease in the ruminal propionate proportions within the physiological range did not affect nitrogen (N) retention in the whole body^{18,19)}, although

hepatic removal of amino acids for glucose production increases with decreased propionate release by portal-drained viscera²³⁾. Young ruminants, however, require large quantities of amino acids as well as glucose in comparison with mature³⁰⁾. Thus, early-weaned calves may decrease the efficiency of N use for body protein synthesis with low ruminal proportions of propionate, even though the reduction in the propionate proportion is within the normal range.

Recently, an intragastric infusion technique was developed¹⁷⁾, in which ruminant animals are wholly nourished by purified nutrients infused into the rumen and abomasum. Because the supply of nutrients is controlled

VFA Utilization in Early Weaned Calves

Fig. 1. Experimental scheme during milk-fed period (▤) and infusion period (□) for individual calves infused with VFA mixtures containing acetic, propionic and butyric acids in the molar proportions 48:42:10 (P) and 76:14:10 (A).

▨: measurement period, ▼: cannulation, ▽: weaning.

quantitatively, this technique allows direct estimation of the contribution of VFA to nutrient utilization in the host animal without the complications of ruminal fermentation. However, few studies were reported, in which the intragastric infusion technique was used for young calves less than 100 kg body weight.

The purpose of this study was to determine the effects of different proportions of VFA infused into the rumen on utilization of energy and N and plasma metabolites in the early-weaned calves sustained by intragastric infusion of nutrients.

Materials and Methods

Animals, management and treatments: Six male Holstein calves (average birth weight 43 ± 7.7 kg) were used. The animals and the experimental scheme are shown in Fig. 1. At 3 d of age, the calves were housed in metabolism crates in a room at 20°C. The calves were fed colostrum until 3 d of age. Subsequently, two calves (calves 1 and 2) were fed whole milk at 10% of body weight daily until 39 d old, and the remainder (calves 3, 4, 5 and 6) were given

the same amount until 54 d old. At 18 d (calves 1 and 2) and 33 d (calves 3, 4, 5 and 6), the calves were fitted with a ruminal cannula (26 mm OD $\times$ 70 mm $\times$ 2 mm wall thickness) and an abomasal catheter (5 mm OD $\times$ 40 cm $\times$ 0.5 mm wall thickness) as described elsewhere¹⁶. At 7 d after surgical preparation, the calves were assigned to two treatments (P and A), and nutrient infusion commenced. The calves in treatment P (calves 1, 3 and 4) and in treatment A (calves 2, 5 and 6) were infused with VFA mixtures containing acetic, propionic and butyric acids in the following molar proportions, respectively: 48, 42 and 10; 76, 14 and 10. These high and low propionic acid mixtures were planned as the maximum and minimum level within the range of the propionic acid proportions normally found in mature ruminants¹⁸.

During the first 14 d of infusion, the amount of both VFA and casein infused gradually increased to reach a level 1.3 times maintenance requirement. In our preliminary experiment¹⁶, this level of infusion was at a maximum to successfully maintain the pH and osmotic pres-

sure in the rumen of early-weaned calves. After weaning, they were wholly nourished by purified nutrients infused into the rumen and abomasum; the total daily energy and casein infused were 570 kJ/kgBW^{0.75} and 1.0 g N/kg BW^{0.75}, respectively. These levels (1.3 times maintenance) are equal to the requirements of metabolizable energy²⁷⁾ and absorbed N^{1,2)} which support approximately 0.3 kg/d of live-weight gain. The planned amounts of VFA infused were based on the heat combustion of acetic (875 kJ/mol), propionic (1527 kJ/mol) and butyric acid (2184 kJ/mol)⁶⁾. The planned amount of casein infused was based on the gross energy (21.9 kJ/g) and the total N content (135 g/kg) determined by bomb calorimeter (model CA-3, Shimazu) and by a Kjeldahl method, respectively. The average amounts of VFA and casein actually infused are shown in Table 1. Major and trace minerals and vitamins were also infused according to the energy level as described by ØRSKOV *et al.*¹⁷⁾. Polypropylene ropes, as substitute roughage, were placed in the rumen to stimulate ruminal development and to maintain ruminal motility.

Infusion procedures: The details of the modified technique for the infusion procedures for sheep¹⁷⁾ were described in our other report¹⁶⁾. In brief; the solution of the VFA

Table 1. Daily amounts of VFA and casein infused into calves

Infusate	Treatment	
	P	A
VFA, mmol/kg BW ^{0.75}		
Acetic acid	155 ± 13.8	286 ± 19.3
Propionic acid	136 ± 10.7	50 ± 3.3
Butyric acid	35 ± 2.8	38 ± 2.6
Casein, g/kg BW ^{0.75}	7.4 ± 0.3	7.4 ± 0.6
Gross energy, kJ/kg BW ^{0.75}	581 ± 36.5	571 ± 29.6
Nitrogen, g/kg BW ^{0.75}	1.0 ± 0.04	1.0 ± 0.03

^a Means with standard deviations of 9 measurement periods of nitrogen balance between 6 and 14 wk of age.

mixture (10 l/d) containing major minerals and the buffer solution (10 to 15 l/d) were infused into the rumen separately, and a casein-vitamin mixture (3 l/d) and trace minerals (50 ml/d) were infused into the abomasum. These infusates were prepared daily according to the body weight measured every 2 wk. The daily amount of buffer infused was approximately 0.4 mol bicarbonate/mol VFA. The actual amount and concentration of the buffer solution were adjusted daily according to ruminal pH and osmotic pressure to keep ruminal pH above 5.5 and ruminal osmotic pressure below 350 mOsm/l.

Measurements: Measurement of plasma metabolites, N balance and heat production was conducted at 6 and 8 wk of age for calves 1 and 2, at 8, 10, 12 and 14 wk for calves 3 and 5, and at 10, 12 and 14 wk for calves 4 and 6 (Fig. 1). These differences in measurement age were due to variation of weaning age, incidence of diarrhoea and use for other measurements. During each measuremental period, urine and feces were collected daily for 5 d. Daily urine samples were pooled in each period and stored at -20°C. Daily samples of feces were dried at 60°C in an air-forced oven, and then the dried samples were pooled in each period. On both the first and last day during each collection period, blood samples were taken from the jugular vein at 15:00. Plasma was immediately separated and stored at -20°C.

During the collection period, heat production over 24 h was measured by indirect calorimetry with a ventilated hood¹⁴⁾. A head cage (60 × 80 × 90 cm) with both an inlet and an outlet duct was set on the metabolism crate 12 h prior to the respiratory trial. Air was drawn through the hood at the rate of 100 l/min by negative pressure created by a pump (model VFC084P, Fuji Electric) downstream. The actual flow rate was measured by mass flow meter (model 2010, Kojima) setting prior to the pump. Oxygen concentration of the gas sample obtained from the outlet of the flow

meter was continuously analyzed by a mass spectrometer (model WSMR-1400B, Westron). The flow rate and oxygen concentration of the outlet gas were recorded every 12 s by a recorder (model DL1200, NEC Sanei). Outside air was sampled for 15 min every 4 h. Calibration of this system was conducted after each respiration trial by the N recovery test¹⁴⁾. Hourly heat production was calculated by McLEAN's equation¹⁴⁾.

Nitrogen in feces and urine was analyzed by a Kjeldahl method. Concentrations of plasma glucose¹²⁾ and β -hydroxybutyrate³³⁾ (β HOB) were determined by enzymatic methods. Plasma urea-N concentration was analyzed by calorimetry without deproteinization⁷⁾. Plasma concentration of free amino acids was determined by HPLC (JASCO) with post-column o-phthalaldehyde detection⁹⁾.

Results

Animal health : Daily body-weight gain for calves 1 and 2 from 6 to 8 wk was 0.16 and 0.28 kg, respectively. The other four calves gained weight at the rate of 0.24 to 0.50 kg/d from age 8 to 14 wk. These values were nearly equal to expected body-weight gain, and were not affected by the proportion of VFA. During the infusion period, no leakage of ruminal fluid through the fistula was observed. However, calves in each treatment sometimes had diarrhoea associated with ruminal acidity and high ruminal osmotic pressure until 10 wk of age. After 12 wk, diarrhoea was not observed.

Concentration of plasma metabolites : Plasma glucose concentration (Fig. 2a) for calves 1 and 2 increased from 6 to 8 wk of age. After 8 wk, plasma glucose levels for calves in each treatment (calves 3 and 4 in treatment P and calves 5 and 6 in treatment A) were relatively constant, and the levels tended to be higher for calves in treatment P than for those in treatment A. Plasma concentration of β HOB (Fig. 2b) for calf 1 in treatment P did not change from 6 to 8 wk of age, whereas that for calf 2 in treatment A increased from 6 to 8 wk. Plasma concentration of β HOB for calves in each treatment increased slightly from age 8 to 12 wk, but then remained relatively constant. After 12 wk of age, β HOB was higher in calves in treatment A (calves 5 and 6) than in those in treatment P (calves 3 and 4). Plasma urea-N concentration (Fig. 3a) was not affected by VFA proportions or by age. Plasma concentrations of total, essential and nonessential amino acids (Fig. 3b, 3c, and 3d) for calf 1 were higher than those in calf 2. After 8 wk of age, neither VFA proportions nor age affected the plasma concentrations of amino acids.

Heat production and N retention : Daily heat production of calves at various ages is shown in Fig. 4. The lack of data for calf 3 at 10 wk and calf 5 at 12 wk was due to troubles associated with the measurement system. Heat

Fig. 2. Plasma concentration of glucose (a) and β -hydroxybutyrate (b) from 6 to 14 wk of age for individual calves infused with VFA mixtures containing acetic, propionic and butyric acids in the molar proportions 48:42:10 (■: calf 1, ▲: calf 3, ●: calf 4) and 76:14:10 (□: calf 2, △: calf 5, ○: calf 6).

Fig. 3. Plasma concentration of urea-N (a), total amino acids (b), essential amino acids (c) and nonessential amino acids (d) from 6 to 14 wk of age for individual calves infused with VFA mixtures containing acetic, propionic and butyric acids in the molar proportions 48:42:10 (■: calf 1, ▲: calf 3, ●: calf 4) and 76:14:10 (□: calf 2, △: calf 5, ○: calf 6).

Fig. 4. Daily heat production from 6 to 14 wk of age for individual calves infused with VFA mixtures containing acetic, propionic and butyric acids in the molar proportions 48:42:10 (■: calf 1, ▲: calf 3, ●: calf 4) and 76:14:10 (□: calf 2, △: calf 5, ○: calf 6).

production for calves 1 and 2 at 6 wk of age tended to be higher than that for calves at other ages. For calves in treatment A, there was a negative relationship ($r = -0.81$, $P < 0.05$) between heat production and age. For calves

in treatment P, although there was no significant relationship ($r = -0.59$, $P > 0.10$), heat production also tended to decrease with advancing age. However, heat production was not affected by VFA proportions at any age. Mean heat production and standard deviation of 8 observations for calves in each treatment was 545 ± 37.5 (treatment P) and 522 ± 43.6 kJ/kg BW^{0.75} (treatment A).

Fecal N excretion was negligible (8 to 44 mg/kg BW^{0.75}); therefore, the change in N retention (Fig. 5) reflected urinary N excretion. Nitrogen retention for calves in treatment P slightly decreased with advancing age, so there was a negative relationship ($r = -0.66$, $P < 0.10$) between N retention and age. Nitrogen retention for calves 5 and 6 in treatment A rapidly decreased at 10 and 12 wk respectively, but at 14 wk, it again reached the level of 8 or 10 wk. Mean N retention and standard deviation of 9 observations between 6 and 14 wk of age for calves in each treatment was 435 ± 44.6

Fig. 5. Daily nitrogen retention from 6 to 14 wk of age for individual calves infused with VFA mixtures containing acetic, propionic and butyric acids in the molar proportions 48:42:10 (■: calf 1, ▲: calf 3, ●: calf 4) and 76:14:10 (□: calf 2, △: calf 5, ○: calf 6).

(treatment P) and 373 ± 105.6 mg/kg $BW^{0.75}$ (treatment A).

Discussion

Plasma metabolites: Blood glucose concentration for newborn calves gradually decreases with advancing age, reaching the mature level within a few weeks after weaning due to physiological and dietary factors²¹. In the present study, plasma glucose concentration increased from 6 to 8 wk of age, and thereafter it maintained a constant level. Between 8 and 14 wk age, plasma glucose concentration with the high propionate tended to be higher than with the low propionate infusion. This difference in glucose concentration probably reflects the supply of glucogenic precursors to the animals. However, ØRSKOV *et al.*¹⁹ reported that reduction in plasma glucose concentration did not occur in steers nourished by intragastric infusion until the propionate proportion in the VFA mixture reduced below 6 mol/100 mol.

Plasma β HOB concentration increased from 6 to 10 wk of age, similar to early-weaned calves fed conventional diets as reported by

QUIGLEY *et al.*²¹. Metabolic activity converting butyrate to β HOB in ruminal tissue increases rapidly after weaning⁴. The similar change in metabolism of butyrate in the ruminal tissue probably occurred in our calves nourished by intragastric infusion. After 10 wk, plasma β HOB concentration for calves was higher when the VFA contained 14 mol propionic acid/100 mol than when it contained 42 mol/100 mol. Because a shortage of oxalacetic acid derived from glucose or glucose precursors in the liver increases hepatic ketogenesis from acetyl-CoA²⁴, the elevation in blood β HOB concentration implies a shortage of glucose precursors. However, ØRSKOV *et al.*¹⁹ found that plasma β HOB concentration in steers nourished by intragastric infusion did not increase until propionate in the VFA mixture reduced below 11 mol/100 mol.

Plasma concentration of urea-N and free amino acids, which generally related to the nutritional condition of protein in animals, did not reflect N balance in the present study. However, ESKELAND *et al.*¹⁰ reported that low plasma concentration of essential amino acids associated with decreased urinary N excretion was observed when propionate was infused intravenously into sheep. Because propionate absorbed from the rumen was extensively metabolized by the splanchnic visceral tissues³, the amount of propionate present in the circulation is small. Therefore, the results obtained by intraruminal infusion of VFA may differ from the results by intravenous administration.

Utilization of VFA energy: The proportion of VFA infused into the rumen, in the present work, did not affect heat production in early-weaned calves. Similar results for sheep and steers have been reported by ØRSKOV *et al.*^{18,19}. In steers given 1.5 times maintenance energy¹⁹, alteration of the molar proportion of VFA (from 1 to 81 mol propionic acid/100 mol) did not affect heat production until the propionic acid proportion decreased to 1 mol/100 mol. In

their experiment¹⁹⁾, the efficiency of utilization of VFA for energy retention was 0.55, irrespective of VFA proportions.

SEKINE *et al.*²⁸⁾ reported that efficiency of utilization of metabolizable energy for growth in early-weaned calves at 7, 9 and 13 wk was 0.48, 0.52 and 0.52, respectively. In the present study, heat production by calves was the highest at 6 wk, but then it slightly decreased with advancing age. This change in heat production with advancing age may be associated with alteration in the energy cost of protein synthesis in the tissues. The rate of protein synthesis is high in young animals, and decreased with advancing maturity¹¹⁾. In fact, in the present study, N retention tended to decrease with advancing age. Generally, energy expenditure for body protein synthesis is higher than that for fat synthesis²²⁾. Therefore, efficiency of utilization of VFA energy for growth probably increased with decreases in the proportion of protein deposition in empty-body weight gain.

Wasteful utilization of acetate associated with a shortage of glucose or glucose precursors^{13,31)} may account for the high heat production in the calves 1 and 2 at 6 wk in this study. Glucose produced from glucogenic precursors is probably affected not only by the availability of the precursors but also by the activity of gluconeogenic enzymes. The activity of these enzymes in milk-fed calves is low, but it increases twofold between 8 to 12 wk⁵⁾. Therefore, for the calves weaned early in the present study, the supply of glucose produced from glucogenic precursors may be insufficient for animal's need; plasma glucose concentration was relatively low in these calves at 6 wk of age.

Nitrogen utilization: In the present study, when the proportion of propionic acid was 14 mol/100 mol, reduction in N retention occurred at 10 and 12 wk. This reduction in N retention is presumably attributable to an increase in contribution of amino acids to

gluconeogenesis. However, in steers nourished by intragastric infusion¹⁹⁾, N retention did not decrease until the propionic acid proportion reduced below 6 mol/100 mol, which is lower than that normally found in conventionally fed ruminants. This difference between our study and others¹⁹⁾ is probably due to the differences in glucose need between animals; our young calves probably required more glucose than the steers used by ØRSKOV *et al.*¹⁹⁾. This assumption may be supported by the disagreement between our results and findings by ØRSKOV *et al.*¹⁹⁾ as described above: the response of the plasma concentration of glucose and β HOB to low propionic infusion differed. Therefore, in young calves during a few weeks after weaning, high propionate supply probably has a important significance in sparing amino acids used for glucose production in the liver. In the case of feeding high concentrate diets to early-weaned calves, the ruminal molar proportion of propionate reached above 40 mol/100 mol³²⁾. On the other hand, STOBO *et al.*²⁹⁾ found that feeding high roughage diets to young calves reduced the propionate proportion to approximately 17 mol/100 mol. Under such conditions of the low propionate proportion, amino acids may be used preferentially as a glucogenic precursor rather than for body protein synthesis, even though calves require large quantities of amino acids for body protein synthesis.

Nitrogen retention of calves infused with the low propionate mixture reduced at 10 and 12 wk of age, but N retention did not differ between treatments at 14 wk. This temporary reduction and subsequent elevation in N retention for calves infused with low propionate mixture may have occurred due to the change in utilization of glucose associated with advancing age⁸⁾ or nutritional adaptation¹⁵⁾. In rats¹⁵⁾, changing a high carbohydrate diet to a high fat diet induced a temporary reduction in N retention for a few days, but subsequently N retention returned to the initial levels. This change in N retention was related to alteration

of amino acid dehydrogenase activity in the liver¹⁵⁾. In ruminants, the change in activity of gluconeogenic enzymes associated with dietary change²⁶⁾ and ruminal development⁵⁾ also have been reported.

In conclusion, the results of the present study indicate that, for a few weeks after weaning, the decrease in the ruminal propionate proportion probably reduces the N use for body protein synthesis in young calves, even though the decrease in the propionate proportion is within the normal range found in ruminants.

Acknowledgments

This study was supported by a Grant-in-Aid for Scientific Research (No. 63760231) from the Ministry of Education, Science and Culture, Japan.

References

- 1) Agricultural Research Council, The Nutrient Requirements of Ruminant Livestock. 121-181. Commonwealth Agricultural Bureaux. England. 1980.
- 2) Agricultural Research Council, The Nutrient Requirements of Ruminant Livestock. Supplement no. 1. 15-24. Commonwealth Agricultural Bureaux. England. 1984.
- 3) ARMENTANO, L.E., Ruminant hepatic metabolism of volatile fatty acids, lactate and pyruvate. *J. Nutr.*, **122**: 838-842. 1992.
- 4) BALDWIN, R.L., VI, and B.W. JESSE, Developmental changes in glucose and butyrate metabolism by isolated sheep ruminal cells. *J. Nutr.*, **122**: 1149-1153. 1992.
- 5) BARTLEY, J.C., R.A. FREEDLAND and A.L. BLACK, Effect of aging and glucose loading on the activities of glucose-6-phosphatase and phosphorylase. *Am. J. Vet. Res.*, **27**: 1243-1248. 1966.
- 6) BLAXTER, K.L., Energy Metabolism in Animals and Man. 295-297. Cambridge University Press. Cambridge. 1989.
- 7) CERIOTTI, G., Ultramicrodetermination of plasma urea by reaction with diacetylmoxime-antipyrine without deproteinization. *Clin. Chem.*, **17**: 400-402. 1971.
- 8) COLVIN, H.W., JR., J.T. ATTEBERY and L.B. DANIELS, Effect of diet on glucose tolerance of dairy calves one to thirteen weeks old. *J. Dairy Sci.*, **50**: 362-370. 1967.
- 9) DEYLE, Z. and M. HORAKOVA, Profiling of amino acids in fluids and tissues by means of liquid chromatography. *J. Chromatogr.*, **379**: 177-250. 1986.
- 10) ESKELAND, B., W.H. PFANDER and R.L. PRESTON, Intravenous energy infusion in lambs: effects on nitrogen retention, plasma free amino acids and plasma urea nitrogen. *Br. J. Nutr.*, **31**: 201-211. 1974.
- 11) HARRIS, P.M. and G.E. LOBLEY, Amino acids and energy metabolism in peripheral tissues of ruminants. in *Physiological Aspects of Digestion and Metabolism in Ruminants*. (TSUDA, T., Y. SASAKI and R. KAWASHIMA, eds.) 201-230. Academic Press. San Diego. 1991.
- 12) KABASAKALIAN, P., S. KALLINEY and A. WESTCOTT, Enzymatic blood glucose determination by colorimetry of N, N-diethyl-aniline-4-aminoantipyrine. *Clin. Chem.*, **20**: 606-607. 1974.
- 13) MACRAE, J.C. and G.E. LOBLEY, Some factors which influence thermal energy losses during the metabolism of ruminants. *Livest. Prod. Sci.*, **9**: 447-456. 1982.
- 14) MCLEAN, J.A. and G. TOBIN, Animal and Human Calorimetry. 94-112. Cambridge University Press. Cambridge. 1987.
- 15) NAKANO, K. and K. ASHIDA, Energy metabolism and amino acid metabolisms. *Protein Nucleic acid Enzyme*, **14**: 1328-1335. 1969. (in Japanese)
- 16) OBITSU, T., K. TANIGUCHI and Y. YAMATANI, Application of a method of intragastric nutrient infusion to young calves. *Anim. Sci. Technol. (Jpn.)* (in Press)
- 17) ØRSKOV, E.R., D.A. GRUBB, G. WENHAM and W. CORRIGALL, The sustenance of growing and fattening ruminants by intragastric infusion of volatile fatty acid and protein. *Br. J. Nutr.*, **41**: 553-559. 1979.
- 18) ØRSKOV, E.R., D.A. GRUBB, J.S. SMITH, A.J.F. WEBSTER and W. CORRIGALL, Efficiency of utilization of volatile fatty acids for maintenance and energy retention by sheep. *Br. J. Nutr.*, **41**: 541-551. 1979.
- 19) ØRSKOV, E.R., N.A. MACLEOD and Y. NAKASHIMA, Effect of different volatile fatty acids mixtures on energy metabolism

- in cattle. *J. Anim. Sci.*, **69**: 3389-3397. 1991.
- 20) OMORI, S., Development of digestive function and metabolic alterations in the young ruminant. *Jpn. J. Zootech. Sci.*, **43**: 231-238. 1972. (in Japanese)
  - 21) QUIGLEY, J.D., III, L.A. CALDWELL, G.D. SINKS and R.N. HEITMANN, Changes in blood glucose, nonesterified fatty acids, and ketones in response to weaning and feed intake in young calves. *J. Dairy Sci.*, **74**: 250-257. 1991.
  - 22) REID, J.T., O.D. WHITE, R. ANRIQUE and A. FORTIN, Nutritional energetics of livestock: some present boundaries of knowledge and future research needs. *J. Anim. Sci.*, **51**: 1393-1415. 1980.
  - 23) REYNOLDS, C.K., H.F. TYRRELL and P.J. REYNOLDS, Effects of diet forage-to-concentrate ratio and intake on energy metabolism in growing beef heifers: net nutrient metabolism by visceral tissues. *J. Nutr.*, **121**: 1004-1015. 1991.
  - 24) ROOK, J.A.F., Nutritional imbalances, in *Nutritional Physiology of Farm Animals*. (ROOK, J.A.F. and P.C. THOMAS, eds.) 369-379. Longman · London. 1983.
  - 25) SASAKI, Y., K. TAKESHITA, S. WATANABE and T. ASAI, Development of the utilization of volatile fatty acids in young calves observed by arterio-venous difference. *Jpn. J. Zootech. Sci.*, **40**: 139-150. 1969.
  - 26) SCAIFE, J.R. and N.S. JESSOP, The influence of diet on the activity of certain lipogenic and glucogenic enzymes in sheep liver and adipose tissue. *Biochem. Soc. Trans.*, **15**: 827-828. 1987.
  - 27) SEKINE, J., T. MOROOKA, M. OKUBO and Y. ASAHIDA, The estimation of metabolizable energy requirements for maintenance and growth of growing calves weaned at six weeks of age. *Jpn. J. Zootech. Sci.*, **58**: 266-272. 1987.
  - 28) SEKINE, J., R. OURA, S. MORITA, T. MOROOKA, and Y. ASAHIDA, Effect of age on energy utilization of early weaned growing calves weighing less than 100 kg. *Anim. Prod.*, **48**: 75-79. 1989.
  - 29) STOBO, I.J.F., J.H.B. ROY and H.J. GASTON, Rumen development in the calf. 2. The effect of diets containing different proportions of concentrates to hay on digestive efficiency. *Br. J. Nutr.*, **20**: 189-215. 1966.
  - 30) TRENKLE, A.H., Amino acid metabolism and hormonal control during growth. in *Digestive Physiology and Metabolism in Ruminants*. (RUCKEBUSH, Y. and P. THIVEND, eds.) 505-522. MTP Press. England. 1979.
  - 31) TYRRELL, H.F., P.J. REYNOLDS and P.W. MOE, Effects of diet on partial efficiency of acetate use for body tissue synthesis by mature cattle. *J. Anim. Sci.*, **48**: 598-606. 1979.
  - 32) WILLIAMS, P.E.V., G.M. INNES, A. BREWER and J.P. MAGADI, The effect on growth, food intake and rumen volume of including untreated or ammonia-treated barley straw in a complete diet for weaning calves. *Anim. Prod.*, **41**: 63-74. 1985.
  - 33) WILLIAMSON, D.H., J. MELLANBY and H.A. KREBS, Enzymic determination of D(-)- β -hydroxybutyric acid and acetoacetic acid in blood. *Biochem. J.*, **82**: 90-98. 1962.

精製栄養素の胃内給与法により飼育した早期離乳子牛の
エネルギーと窒素利用に及ぼす
揮発性脂肪酸組成の影響

小櫃剛人・谷口幸三・山谷洋二

広島大学生物生産学部，東広島市 724

精製栄養素の胃内給与法を用いて，第一胃内注入揮発性脂肪酸（VFA）組成と週齢の違いが，早期離乳子牛のエネルギーと窒素利用に及ぼす影響を検討した．ホルスタイン種雄子牛6頭を用い，3頭には酢酸，プロピオン酸，酪酸のモル比を48:42:10とするVFA混合液を，残りの3頭には同76:14:10とするVFA混合液を，主要ミネラルおよび緩衝液とともに第一胃内へ注入した．第四胃内へはカゼイン，微量ミネラル，ビタミンを注入し，離乳（5から7週齢）後はこれらの注入精製栄養素のみで飼育した．総エネルギーおよび窒素注入量は，それぞれ570 kJ/kg BW^{0.75} および1.0 g/kg BW^{0.75} とした．6から14週齢の間，2週間毎に血液成分，発熱生量，窒素出納を測定した．血漿中グルコース濃度と β -ヒドロキシ酪酸濃度にはVFA組成の影響が認められた．熱発生量にはVFA組成の影響は認められなかったが，週齢の進行にともない減少する傾向がみられた．窒素蓄積量は，プロピオン酸割合の低いVFA液を注入した場合に，10から12週齢にかけて低い傾向にあった．以上の結果より，幼齢子牛では，反芻家畜において通常の飼育下でみられるVFA組成の範囲内であっても，プロピオン酸割合が低い場合には，離乳後一時的に窒素蓄積量が低下することが示唆された．

日畜会報，64（6）：568-577，1993