Absorption Rates of Different Volatile Fatty Acid Mixtures Infused into the Rumen of Young Calves

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The development of ruminal absorptive capacity for volatile fatty acids (VFA) in young calves partly depends on the facilitation of papillary growth stimulated by VFA produced in the rumen^{9,14}. The promotive effect of VFA on papillary growth is not only dose dependent but also varies with individual fatty acids⁹. Thus, the composition of VFA produced in the rumen may affect the ruminal absorption rate of VFA in young calves via change in ruminal absorptive capacity. The determination of the VFA absorption rate from the rumen requires quantification of the ruminal production rate of VFA. However, accurate measurement of the VFA production rate is difficult under normal feeding conditions¹⁵. Application of the intragastric infusion technique⁶, whereby infusates are exactly controllable, may be useful for measuring the ruminal absorption rate of VFA.

In this study, we compared the VFA absorption rate from the rumen of young calves given high (42 mol/100 mol) and low (17 mol/100 mol) propionate VFA mixtures into the rumen by

the intragastric infusion technique.

Materials and Methods

Animals and management : Six male Holstein calves (birth weight 47 ± 8 kg ; mean $\pm$ SD) born at the experimental farm of Hiroshima University were used. Whole cow's milk (10% of body weight) was nipple-fed in two equal portions at 09 : 00 and 17 : 00 until 6 or 8 wks of age. Four calves were fitted with a ruminal cannula and an abomasal catheter at 2 wks of age, but two calves were fitted at 5 wks of age. The surgical procedures were the same as those described in a previous study⁵. Intragastric nutrient infusion started 7 d after surgery and continued for 43 d.

Intragastric nutrition : The details of infusion procedures for young calves are described elsewhere⁵. In brief, VFA mixtures containing major minerals and a bicarbonate buffer solution were infused separately into the rumen : one peristaltic pump was used for the VFA infusion and two pumps were used for the buffer infusion. The infused VFA mixture

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contained 0.6–1.1 mol total VFA/l (with 2.2 g CaCO_3/l , 0.6 g $\text{MgCl}_2 \cdot 6\text{H}_2\text{O}/\text{l}$ and 2.0 g $\text{Ca}(\text{H}_2\text{PO}_4)_2 \cdot \text{H}_2\text{O}/\text{l}$). The infused buffer solution contained 0.174 mol NaHCO_3/l and 0.076 mol KHCO_3/l . The maximum volume of ruminal infusate (VFA mixture plus buffer solution) was approximately 1.0 l/BW^{0.75}. A casein solution containing 33 g casein/l, 1.7 g $\text{Na}_2\text{CO}_3/\text{l}$ and vitamin mixture was infused continuously into the abomasum, but the suspension of trace minerals was infused rapidly into the abomasum once a day. No solid diet was offered from birth until the end of the experiment. As substitute roughage to maintain ruminal motility, polypropylene ropes (3 m) were placed in the rumen on the first day of infusion.

During the first 14 d of infusion (adaptation period), the infusate supply was gradually increased with a gradual decrease in the milk supply to reach the planned level of 1.3 times the maintenance requirement of metabolizable energy¹⁰⁾ (570 kJ/BW^{0.75}) at the end of the adaptation period. During this period, the amount of infused VFA was increased at the rate of approximately 20 mmol/BW^{0.75} per day to reach the level of the maintenance requirement¹⁰⁾ (440 kJ/BW^{0.75}). Similarly, the amount of infused casein was also increased at the rate of approximately 60 mg/BW^{0.75} per day to reach 1.0 g nitrogen/BW^{0.75} (130 kJ/BW^{0.75}). After the adaptation period, calves were nourished by the infusates only. The total energy supply from infusates during 15 to 43 d of the infusion (measurement period) was planned to be kept at 1.3 times the maintenance requirement. The amount of infused bicarbonate was planned to be approximately 0.4 mol bicarbonate/mol VFA. However, the actual amounts of VFA and bicarbonate were adjusted according to the ruminal pH and osmotic pressure, to be kept above 6.0 and below 280 mOsm/l, respectively.

Treatments: Three calves were intraruminally infused with a high-propionic acid mixture (mixture HP) containing acetic, propi-

onic and butyric acids in the proportions 48, 42 and 10 mol/100 mol, respectively, throughout the whole infusion period. The other three calves were intraruminally infused with a low-propionic acid mixture (mixture LP) containing acetic, propionic and butyric acids in the proportions 76, 14 and 10 mol/100 mol, respectively. These high- and low-propionic acid mixtures were close to the maximum and minimum compositions of propionic acid found in young calves^{13,17)}. Because of the isocaloric infusion of total VFA for the both treatments, planned daily amounts of infused total VFA after 15 d were 340 and 400 mmol/BW^{0.75} for HP and LP, respectively.

Measurements: Ruminal pH and osmotic pressure were measured every day at 17:00 during the whole infusion period as described previously⁹⁾.

The volume and fractional outflow rate of ruminal liquor were estimated every 1–2 wks during the measurement period. A pulse dose of 10 g polyethylene glycol (PEG; average molecular weight 3000; 20% (W/V) aqueous solution) was injected through the ruminal cannula at 10:00, and then ruminal liquor (every 50 ml) was collected at 0.5, 1, 2, 4, 6, 10, 14, 18, 22, 26 and 30 h after administration of PEG. Ruminal PEG concentration was measured by turbidimetry¹¹⁾ for all samples, but the ruminal concentration of VFA¹⁶⁾, pH⁵⁾ and osmotic pressure⁵⁾ were measured at 6, 14 and 22 h only. The volume and fractional outflow rate of ruminal liquor were estimated by linear regression of the natural logarithm of ruminal PEG concentration on time after the dose of PEG^{3,7)}.

Because VFA infused into the rumen is absorbed via the rumen wall and (or) flows out to the post-rumen, the relationship of the fractional absorption rate of total VFA from the rumen (k_A ; %/h), the fractional outflow rate of total VFA from the rumen (k_o ; %/h), the ruminal concentration of total VFA (C ; mol/l) and the volume of ruminal liquor (V ; l) to the infusion rate of total VFA (I ; mol/h) is defined

by the following equation ;

$$I = (k_A + k_o) \times C \times V / 100. \quad (\text{eq. 1})$$

Thus, the fractional absorption rate of total VFA (k_A) is estimated by the following equation ;

$$k_A = [100 \times I / (C \times V)] - k_o. \quad (\text{eq. 2})$$

In this equation, the fractional outflow rate of VFA was assumed to be equal to the fractional outflow rate of ruminal liquor. In addition, ruminal VFA concentration was assumed to be maintained in a steady state within the measurement day. In our other experiment with a calf nourished by intragastric infusion, the coefficient variation for the diurnal VFA concentration in the rumen, measured at every 4 h, was only 2.0% (unpublished date). Thus, the average value of ruminal concentrations of total VFA at 6, 14 and 22 h after the dose of PEG was used in the calculation. The total VFA absorbed from the rumen (mol/h) was estimated as $k_A \times C \times V$. The proportion of the amount of VFA absorbed to that infused on the measurement day was also calculated.

The treatment means for fractional absorption rates during 15 to 28 d (period I) and 29 to 43 d (period II) were calculated. The treatment means on the ruminal infusate amount and ruminal liquor characteristics on the day of VFA absorption measurement were also calculated as described above. Because the VFA absorption rate for the one calf infused with the mixture HP could not be measured during period II, the treatment means for calves infused with the mixture HP during this period were calculated as $n=2$. The significance of difference ($P<0.05$) in these results between calves infused with different VFA mixtures in period I and period II was analyzed by the t -test¹²⁾.

Results and Discussion

Nutritional state : The means of daily energy supply from milk plus infusates through the adaptation period were 753 ± 88 kJ/BW^{0.75} for calves infused with mixture HP

and 718 ± 150 kJ/BW^{0.75} for calves infused with mixture LP (mean $\pm$ SD, $n=3$). Total nitrogen supply from milk plus casein during this period was 1.1 ± 0.1 g/BW^{0.75} for both groups (mean $\pm$ SD, $n=3$). Thus the energy and nitrogen intake of calves in both groups exceeded their maintenance requirements^{1,10)} throughout the adaptation period.

The amount of VFA infused during the measurement period was approximately 80-95% and 75-85% of the planned level for HP and LP, respectively, due to the prevention of low ruminal liquor pH. The mean daily amounts of total VFA infused (mmol/BW^{0.75}; mean $\pm$ SD) during periods I and II were 278 ± 47 ($n=3$) and 329 ± 29 ($n=2$) for HP and 302 ± 55 ($n=3$) and 332 ± 52 ($n=3$) for LP, respectively.

The ruminal pH and osmotic pressure measured at 17 : 00 every day for each calf during the whole infusion period ranged from 5.2 to 7.0 and from 260 to 330 mOsm/l, respectively. These figures did not deviate from the range of normal feeding²⁾.

Ruminal VFA absorption : The data for the fractional absorption rate of total VFA are shown in Tabel 1 together with the infusion rate of ruminal infusate and ruminal liquor characteristics on the day of VFA absorption measurement. The fractional absorption rate of total VFA from the rumen did not differ ($P>0.05$) between the treatments in period I, but was greater ($P<0.05$) for HP calves than for LP calves in period II. The fractional absorption rate of total VFA for HP calves, in contrast with that for LP calves, increased rapidly with the advancement of the infusion period. In addition, regression analysis of the fractional absorption rate of total VFA throughout the whole measurement period on the day after infusion started gave regression coefficients of 2.07 (SE ; 0.35, $P<0.01$) for HP calves and 0.82 (SE ; 0.37, $P<0.10$) for LP calves. This implies that the incremental increase in VFA absorption rate with infusion day advancement was greater ($P<0.05$) for HP than for LP. The daily

Ruminal VFA Absorption in Calves

Table 1. Daily amounts of ruminal infusates, characteristics of ruminal liquor and fractional absorption rate of total VFA from the rumen of calves infused with different VFA mixtures¹

Item	Infusion period			
	I (15-28 d)		II (29-43 d)	
	HP	LP	HP	LP
Number of calves	3	3	2	3
Infusate				
Total VFA (mmol/BW ^{0.75})	319 ± 34	352 ± 43	324 ± 47	350 ± 26
Bicarbonate (mmol/BW ^{0.75}) ²	148 ± 25	157 ± 10	124 ± 1	146 ± 25
Liquor (ml/BW ^{0.75}) ³	1049 ± 80	1132 ± 153	862 ± 61	950 ± 103
Ruminal liquor				
pH	6.2 ± 0.2	5.7 ± 0.5	6.6 ± 0.4	5.7 ± 0.4
Osmotic pressure (mOsm/l)	281 ± 22	310 ± 23	282 ± 2	297 ± 17
Total VFA (mmol/l)	103 ± 26	119 ± 20	91 ± 12	112 ± 20
Volume (ml/BW ^{0.75})	301 ± 29	365 ± 48	188 ± 17	320 ± 49
Fractional rate (%/h)				
Outflow	10.6 ± 0.6	12.5 ± 3.7	11.2 ± 0.1	14.2 ± 2.2
Absorption	35.2 ± 14.9	21.0 ± 3.2	69.0 ± 7.3 ^a	31.1 ± 6.6 ^b
VFA absorption (mmol/BW ^{0.75})	240 ± 45	219 ± 58	278 ± 47	237 ± 27
% of infused (%)	74.5 ± 7.3	61.4 ± 9.5	85.2 ± 2.4 ^a	67.6 ± 3.1 ^b

¹ Means and standard deviation.

² Containing sodium and potassium bicarbonate in the molar proportions 70 : 30.

³ Total volume of VFA solution plus buffer (bicarbonate) solution.

^{a, b} Means within the same period in the same row with different superscripts differ significantly (P < 0.05).

HP : Acetic : propionic : butyric acid = 48 : 42 : 10 (molar basis).

LP : Acetic : propionic : butyric acid = 76 : 14 : 10 (molar basis).

amount of total VFA absorbed from the rumen did not differ (P > 0.05) between the treatments in either period I or period II. However, the proportion of total VFA absorbed from the rumen to the total VFA infused was greater (P < 0.05) for HP calves than for LP calves in period II.

Early findings have indicated that the promotional effect of propionate on papillary growth is greater than that of acetate⁹, and that the development of ruminal absorptive capacity through papillary growth affects the VFA absorption rate¹⁴. In this study, therefore, the high-propionic acid mixture possibly facilitated ruminal absorptive capacity via promoted papillary growth.

The characteristics of ruminal liquor, for example pH^{4,14}, osmolarity⁸ and ruminal liquor volume⁴, also affect the ruminal absorption rate of VFA. In this study, unfortunately, ruminal pH and ruminal liquor volume tended to differ (P < 0.20 and P < 0.10, respectively) between HP calves and LP calves in period II (Table 1).

Thus, the influence of these variables, besides VFA composition, on VFA absorption may not be disregarded. Further research is needed to clarify the relationship between the composition of VFA infused into the rumen and the development of the absorptive capacity for VFA in young calves.

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