RELATIONSHIP BETWEEN PARTICLE POOL SIZE IN THE RETICULO-RUMEN AND CHEWING TIME IN SHEEP

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Summary

Sixteen mature sheep were fed chaffed orchardgrass hay once a day. Jaw movement of the sheep was recorded for 24 hours before slaughter. Four sheep were slaughtered either prior to eating, 2, 8 or 16 hours after the commencement of eating to measure digesta pool size and particle size distribution in the reticulo-rumen. Eating time was restricted to 120 minutes. Rumination time and actual chewing time during rumination increased with time after the meal. Mean dry matter (DM) pool size before and 2 hours after the meal were 1.36 and 2.45 times of DM intake, respectively. The proportion of large particle (> 1.18 mm; LP) in the DM ingested during the meal was calculated to be about 70%. The mean DM and LP pool sizes per DM intake and the mean proportion of LP in the DM pool decreased with time after the meal. There were close negative relationships between either DM or LP pool sizes per DM intake and the chewing activities either expressed as time spent rumination, actual chewing time during rumination or total actual chewing time(total of eating time and actual chewing time during rumination). The difference between DM intake and LP pool size were assumed to be LP degradation in the present experiment, and correlated positively with the chewing activities. A large proportion of the digesta load was comprised of small particles, in excess of the daily intake.
(Key Words: Particle Pool Size, Chewing Activity, Reticulo-Rumen, Sheep)

Introduction

Voluntary intake of fibrous materials by ruminants is limited by such physical factors involving gut fill as reticulo-ruminal distention and ruminal turnover of undigested fiber (Balch and Campling, 1962; Campling, 1970). Few particles pass from the reticulo-rumen(RR) to the lower digestive tract before sufficient reduction in size (Poppi et al., 1980; Uden and Van Soest, 1982). Chewing during eating and during rumination is considered to be the major factor responsible for reducing the size of particles in the rumen (Ulyatt et al., 1986; McLeod and Minson, 1988a). Particle pool size in the RR could be affected by chewing activity through reduction in particle size, thereby acceleration of passage through reticulo-omasal orifice. Although a few instances of particle pool size have been reported (Pearce, 1967; Poppi et al., 1981; Waghorn et al., 1986; Okamoto and Miyazaki, 1990), little information is available on particle pool size in relation to chewing activity.

The present study was designed to study the relationship between particle pool size in the RR of sheep and chewing activity during and after feeding.

Materials and Methods

Sixteen mature sheep (4 breeds, 15 ewes and 1 ram), weighing 50.4 ± 12.3 kg, were kept in individual crates for 7 days. The sheep were fed chaffed orchardgrass hay (table 1) as a sole diet once a day. The hay was removed 2 hours after commencement of feeding. Water and trace mineralized salt block were available to all sheep at all times. Every four sheep were slaughtered at 2, 8, 16 and 24 hours after commencement of feeding on the

TABLE 1. COMPOSITION OF ORCHARDGRASS HAY

	g/kg DM
Dry matter (g/kg)	855
Crude protein	84
Neutral detergent fiber	703
Acid detergent fiber	429
Acid detergent lignin	66

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7th day. For measuring chewing activities, jaw movement was recorded using a baloon attached at lower jaw and a tambour with a proximity switch connected to an event recorder for 24 hours immediately before slaughter. Actual chewing time during rumination was obtained by subtracting time intervals spending for regurgitating and for reswallowing from rumination time (Gordon, 1965).

After slaughtering, contents of the RR were weighed and an aliquot sample was taken after thorough mixing. The particle size distribution of digesta was determined by wet sieving using nylon mesh sieves with openings of 1.18, 0.30 and 0.045 mm. Material retained on the sieves was collected on tared filter paper and air-dried at 55°C to use dry matter (DM) determination and chemical analysis. The particle size distribution in the sample was calculated as percentage (by weight) of total weight of DM. Large particles (LP) were defined as those retained on the 1.18 mm sieve. This fraction had a high resistance to escape from the rumen (Poppi et al., 1980; McLeod and Minson, 1988a).

Neutral detergent fiber (NDF), acid detergent fiber (ADF) and acid detergent lignin (ADL) were determined by the procedure of Goering and Van Soest (1970) and crude protein was analyzed by the Kjeldahl method (AOAC., 1980). Statistical analyses were made by the method of analysis of variance, correlation, regression and chi square test described by Steel and Torrie (1980).

Results

One of the sheep slaughtered 8 hours after feeding consumed extremely small amount of hay. This sheep had abscesses at the cardia and could not ruminate normally. Results obtained from that sheep were excluded from the analysis.

Mean daily DM intake and mean chewing activities for each group slaughtered at different times after the meal are presented in table 2. Although eating time was restricted to 120 minutes, most of the animals completed active prehension within the time. Mean eating time was not significantly different among groups and averaged 112 min., although sheep slaughtered at 2 hours after the feeding showed somewhat shorter mean eating time without statistical significance. Although there was a variation in daily DM intake among individuals, mean DM intake did not differ significantly among groups slaughtered at different times after meal. Daily DM intake averaged about 16 g/kg$BW^{0.75}$ for all sheep. Rumination time increased with time after the meal. The proportion of actual chewing time ranged from 66.2 to 92.2% of rumination time among individuals.

Mean DM and LP pools in the RR were presented in table 3. Mean DM pool in the RR of sheep slaughtered at 2 hours after the meal was 2.45 times of DM intake and that for those at 24 hours was 1.36. Results obtained at 2 hours after the meal are to be considered as those for immediately after the meal, whereas results obtained

TABLE 2. MEAN DRY MATTER INTAKE AND CHEWING ACTIVITIES OF SHEEP SLAUGHTERED AT DIFFERENT TIME AFTER THE MEAL

	Hours after commencement of feeding				MSD[2]
	2	8[1]	16	24	
Daily dry matter intake (g/kg $BW^{0.75}$)	15.5	14.9	19.3	16.8	5.2
Eating time (min)	96.0	120.0	117.5	114.8	15.3
Rumination time (min)	1.8[a3]	90.7[a]	212.3[b]	286.0[b]	65.2
Total chewing time (min)	97.8[a]	210.7[b]	329.8[c]	400.8[c]	61.8
Actual chewing time during rumination (min)	1.4[a]	73.7[ab]	164.3[bc]	244.6[c]	62.4
Total actual chewing time (min)	97.4[a]	193.7[ab]	281.8[b]	359.4[b]	55.7

[1] The mean was calculated with results obtained from 3 animals.
[2] Mean standard deviation.
[3] Means within a row followed by unlike superscripts differ significantly ($p < 0.05$).

TABLE 3. DRY MATTER(DM) AND LARGE PARTICLE (LP, RETAINED ON SIEVES OF 1.18 mm) POOLS IN THE RETICULO-RUMEN

	Hours after commencement of feeding				MSD[2]
	2	8[1]	16	24	
DM pool (g/kgBW$^{0.75}$)	37.2	26.1	32.7	22.6	10.6
Proportion of LP (%)	41.7[a3]	33.5[a]	35.1[a]	19.2[b]	6.7
LP pool (g/kgBW$^{0.75}$)	15.6	9.3	11.6	4.3	5.2
DM pool per DM intake	2.45[a]	1.76[b]	1.73[b]	1.36[b]	0.24
LP pool per DM intake	1.02[a]	0.60[b]	0.62[b]	0.26[c]	0.16
DM intake − LP pool (g/kgBW$^{0.75}$)	−0.1[a]	5.6[ab]	7.7[bc]	12.5[c]	3.5

[1] The mean was calculated with results obtained from 3 animals.
[2] Mean standard deviation.
[3] Means within a row followed by unlike superscripts differ significantly ($p < 0.05$).

from sheep slaughtered at 24 hours after the meal are those for immediately before a next meal. The proportion of LP in the increment of DM pool by the meal was calculated to be about 70% from these pool sizes per DM intake.

The mean DM and LP pools per DM intake decreased with the elapse of time after the meal. Similarly, the proportion of LP in the RR contents decreased with time after the meal, whereas the change in small particle (< 1.18 mm, SP) pool size was relatively small. A large proportion of the digesta load was comprised of small particles, in excess of the daily intake.

In the 4 sheep slaughtered 2 hours after the meal, DM intake for each animal closely agreed to the LP pool of the corresponding animals. Chi square test showed that probability of coincidence was higher than 0.995. Therefore, the difference between DM intake and LP pool size might be assumed to be LP degradation in the present experiment. The difference increased with the elapse of time after the meal.

No significant correlations were found either between daily DM intake and chewing activities (rumination time, actual chewing time during rumination and total actual chewing time), nor between DM pool size in the RR and the chewing activities (table 4). The proportion of LP in the DM pool and LP pool size in the RR correlated significantly with the chewing activities. Dividing

TABLE 4. CORRELATION COEFFICIENTS BETWEEN PARTICLE POOL SIZE AND CHEWING ACTIVITIES

	Rumination time	Actual chewing time during rumination	Total actual chewing time
DM intake	0.303	0.296	0.324
DM pool	−0.336	−0.373	−0.354
Proportion of LP	0.715**	−0.785**	−0.784**
LP pool	−0.527*	−0.583*	−0.571*
DM pool per DM intake	−0.731**	−0.863**	−0.891**
LP pool per DM intake	−0.804**	−0.854**	−0.875**
DM intake LP pool	0.847**	0.903**	0.914**

*,** $p < 0.05$ and $p < 0.01$, respectively.

DM and LP pool size by DM intake resulted in close negative correlation with the chewing activities. The difference between the DM intake and the LP pool size was positively correlated with the chewing activities. These correlations were higher when the actual chewing time during rumination or total actual chewing time was used as the index of chewing activity than when the rumination time or total chewing time was used as the index.

Discussion

The proportion of LP in digesta swallowed after ingestive mastication was calculated to be about 70% in the present experiment from the pool sizes per DM intake of DM and LP immediately before and after the meal. The proportion has been reported to vary with animals and maturity of forage eaten. Lee and Pearce (1984) reported that the proportion of particles greater than 1 mm for straw and hay ranged from 61 to 69% in steers, while Pond et al. (1984) and Luginbuhl et al. (1989) reported the proportion ranged from 79 to 85% for grass hay. Lower proportions of LP were reported for grazed forage by Pond et al. (1984) and Nelson (1988).

Mean DM pool size in the RR immediately after feeding increased by about the same amount of DM intake, when a calculation was made by subtracting DM pool size per DM intake for 24-hr-slaughter group from that for 2-hr-slaughter group. Thus, the amounts of DM pool increased immediately after the meal were well reflected to DM intake in the present study. This result showed that little amount of DM flowed from the RR while sheep were eating the meal. Furthermore, LP pool in the RR immediately after the meal agreed well with DM intake. The LP pool after the meal consisted of LP pool from the previous meals and LP pool provided by the meal. The DM eaten consisted of the LP and SP pools provided by the meal. Therefore, the LP pool size before the meal is assumed to be equivalent to the amount of SP entering in the rumen during eating. In addition, the ruminal capacity of LP pool may play an important role as a trigger to stop eating forage since LP pool size immediately after the meal amounted to DM intake. However, this is an indirect evidence and further investigation is required.

The DM and LP pool size per DM intake decreased with time after the meal. Pearce (1967) and Waghorn et al. (1986) reported similar results. Actual chewing time during rumination increased as the time elapsed after the meal. The LP pool size negatively regressed on actual chewing time during rumination (regression coefficient, $b = -0.034$). Thus, LP should have been broken down to a smaller particle size, thereby SP pool should increase as the time elapsed after the meal. The results in the present study, however, show no significant accumulation of SP pool with time after the meal. This fact suggests that the rate of the size reduction of LP is to be one of factors limiting the pass of SP through the reticulo-omasal orifice. On the other hand, a large proportion of SP being capable of passing readily through the reticulo-omasal orifice are retained in the RR for a considerable time. Reduction in size to dimensions allowing particle to enter flow pathway is a requisite but not a satisfactory factor to accelerate flowing out of digesta from the RR.

The processes involved in particle size reduction of rumen digesta is considered to be chewing during rumination, microbial digestion and ruminal detrition (Murphy and Nicoletti, 1984; McLeod and Minson, 1988a). The digestibility of LP in the rumen at 2 and 24 hours after the meal was estimated from the ADL concentration to be 26.1 and 40.9%, respectively. The proportional loss in weight of LP by digestion during the period was calculated as about 18%. This value is close to the value estimated by McLeod and Minson (1988a). Since the proportion of LP flow out of the RR is small, the proportional loss of LP by comminution is considered to comprise more than 70% of the weight loss of LP in the RR.

The importance of rumination in comminution of LP of rumen digesta has been examined by direct measurement of particle size reduction during a rumination cycle (Kennedy, 1985; Chai et al., 1988; McLeod and Minson, 1988a), by physical inhibition of rumination (Pearce and Moir, 1964; Welch, 1982; Chai et al., 1988) and by in situ or in vitro fermentation (Ehle et al., 1982; Murphy and Nicoletti, 1984; McLeod and Minson, 1988b). These studies indicate that chewing during rumination is the major factor in reducing particle size in the RR.

When particle size of rumen digesta are reduced by chewing during rumination, a pool size of a given particle size may change with chewing. The

difference between LP pool size and DM intake at different time after the meal were assumed to be amounts of LP degraded in the RR during the corresponding time after the meal in the present study. The difference between DM intake and LP pool size significantly correlated with the chewing activities, namely actual chewing time during rumination ($p < 0.01$). The coefficient of determination indicates that about 80% of the variation in LP disappearance in the RR is explained by the actual chewing activities during rumination. The regression coefficient showed that a minutes of chewing during rumination reduced 0.047 (± 0.006) g/kgBW$^{0.75}$ of LP in the RR. The reduction rate of LP size, however, appeared to be sufficient to reduce LP pool to zero at 24 hours after the meal. Thus, about 20% of DM pool in the RR were occupied by LP pool (table 4). The stimulation inducing rumination may decrease in the RR before LP pool size approaches to be zero. Increased chewing time during rumination or increased rate of LP size reduction, that is increased chewing efficiency, may be required to increase DM intake.

It is concluded that the reduction of pool size of LP depends upon the duration of chewing time or chewing efficiency, which may result in one of factors controlling DM intake. Thus, further investigation is required to be focused on the capacity of LP pool in the RR as a limiting factor of DM intake.

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