CONTROL OF FEED INTAKE IN RUMINANTS: A SEMI-PURIFIED LIQUID DIET FOR CONTINUOUS INTRARUMINAL INFUSION

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INTRODUCTION

Until recent years little attention has been given to maximizing nutrient or energy intake in ruminants. The amount of food consumed is a dominant factor in economical production of meat and milk since overhead cost of animal maintenance is always present. It must be remembered that only after the animals' requirement for maintenance has been satisfied can energy or nutrients be utilized for production. Approximately 11.2 Mcal. of digestible energy (DE) are required to maintain an 800 lb. yearling steer. This represents 7 to 9 lb. of feed daily, since most feedlot rations contain 1.3 to 1.5 Mcal. DE/lb. Thus, for steers gaining 2 lb. per day, approximately 16 to 19 lb. of feed are required, of which nearly 50% is used for maintenance. To gain 4 lb. daily a steer must usually consume more than 24 lb. of feed, but only about 30% of the amount is needed to maintain the steer. Thus, increasing intake of any given feedlot ration results in greater energy intake and consequently, improved performance and increased efficiency of feed utilization (Theurer, 1970). Increased intake is also important in dairy animals since such increases result in increased milk production, and an increase in gross efficiency. Peak gross efficiency for milk production seems to occur at a forage to grain ratio of approximately 40:60. However, the acetic:propionic acid (A/P) ratio must be considered if maximum efficiency of milk production is to be achieved since milk fat is depressed if the level of acetic acid is depressed. A ruminal A/P ratio of about 2.75 appears to result in maximum efficiency (Baumgardt, 1967). Under both extensive and intensive

systems of animal husbandry, economic margins will be reduced if animals fail to eat sufficient to provide optimum intake. There is need, therefore, for systems of predicting the voluntary intake of a specific diet by livestock and for knowledge of ways of insuring maximum intake. Application of existing knowledge has been limited and is believed that the failure to apply it is due to lack of information about the basic mechanisms governing voluntary intake of food by ruminants (Balch and Campling, 1962).

Three catagories into which regulation of feed intake in ruminants can be divided are: chemostatic, thermostatic and physical capacity regulation.

Although chemoreceptors sensitive to blood glucose level have been shown to be operative in the regulation of feed intake in the monogastric animal very little information indicates this to be true for ruminants. Dowden and Jacobson (1960) reported results which support this postulation. Intravenous infusions of glucose increased blood glucose level in ruminants but did not cause a depression of feed intake. Baile and Pfander (1966) suggested the possibility of a chemosensitive mechanism perceptive to changes in rumen fluid acetic acid concentration, since intraruminal infusion of this metabolite did result in a decrease in feed intake. Further support of a chemostatic mechanism was reported by Simkins et al. (1965b). These workers observed a reduction in voluntary feed intake following the intraruminal injections of isocaloric amounts of acetate, propionate and butyrate. Since very low concentrations of propionate and butyrate are found in the peripheral blood, chemoreceptors in the rumen wall and portal system are suspected.

The concept of thermostatic control sensitive to hypothalamic temperature is questionable, despite changes in hypothalamic temperature following a meal. Baile et al. (1967c) presented results which indicate that control of feed intake in ruminants is not normally a function of hypothalamic temperature.

Physical control or fill has been shown to be of great importance in the regulation of feed intake in ruminants, especially, in some rations (Montgomery and Baumgardt, 1965b). These workers showed that ruminants will adjust voluntary intake of various rations to meet their physiological demand for energy if rumen load or fill does not limit consumption. Conrad et al. (1964) reported that when the dry matter digestibility of high roughage rations fell below 67% there was an accompanying decrease in feed intake and digestible energy intake while dry matter digestibility of 67% or greater resulted in an almost constant level of digestible energy intake.

Hunger, appetite and satiety are terms commonly used in any discussion of the regulation of food intake. Hunger is defined as the physiological state which results from deprivation of food of a general or specific type and is abolished by the ingestion of those foods. Appetite is the desire to eat. Satiety is expressed as a lack of desire to eat. It is usual to take the amount of food voluntarily eaten by an animal as a measure of the appetite of the animal for that food (Balch and Campling, 1962).

Many factors must be considered in any discussion of control of feed intake in ruminants. In an attempt to describe some of these factors, the following topics are discussed in the literature review:

Physical Capacity, The Central Nervous System, Perception of Food, Thermostatic, Chemostatic, and Lipostatic Regulation.

LITERATURE REVIEW

Physical Capacity as a Regulatory Mechanism

Ruminants will apparently adjust voluntary food intake in relation to physiological demand for energy if fill or rumen load does not limit their consumption (Montgomery and Baumgardt, 1965b). Conrad, Pratt and Hibbs (1964) reported that with rations of 52 to 66 percent dry matter digestibility, feed intake increased with increasing digestibility and the factors limiting intake were bodyweight (reflecting capacity), undigested residue per unit bodyweight per day (reflecting rate of passage), and dry matter digestibility. For rations between 67 and 80% digestibility, feed intake decreased with increasing digestibility (control of energy intake) and energy intake appeared to be dependent on metabolic size, production, and digestibility. Dinius and Baumgardt (1970), using sheep, studied voluntary feed and energy intake of pelleted rations varying in digestibility and density and described rations on which intake is limited by fill. A basic concentrate mixture was diluted from 5 to 50% at 5% increments with each of four diluents: (A) oak sawdust, (B) oak sawdust with constant 3% kaolin clay, (C) verxite, (an expanded hydrobiotite), and (D) as (A), except nitrogen was kept constant at 17.4% crude protein equivalent. They observed that dry matter intake ($g/Wkg^{.75}$) increased as the digestible energy per gram increased to 2.5 kcal for ration sequences A, B, and D. With rations having digestible energy values above 2.5 kcal/g, dry matter intake decreased and digestible energy intake ($kcal/Wkg^{.75}$) remained

static. Apparently, fill limited intake in the sheep when the digestible energy of the rations was less than 2.5 kcal/gm, whereas above this level energy intake was regulated.

Nonpregnant Holstein heifers were fed three completely pelleted isonitrogenous rations consisting of alfalfa hay: concentrate ratios, 100:0, 67:33, and 33:67 to determine the effect of increasing energy concentration on voluntary intake. Daily dry matter intake decreased as the percent concentrate increased in the ration, and daily energy intake was similar for all rations. They concluded that ruminants, while being fed isonitrogenous rations varying in energy concentration will adjust voluntary feed intake in relation to physiological energy demands if fill or rumen load does not limit their consumption (Cowsert and Montgomery, 1969).

Montgomery and Baumgardt (1965b) reported that feeding of completely pelleted rations with alfalfa meal: ground shelled corn ratios of 100:0, 80:20, 60:40 to Holstein heifers and crossbred lambs resulted in decreased daily dry matter consumption as the corn increased. However, daily energy consumption was similar for all rations. Results support the hypothesis that ruminants will adjust voluntary food intake in relation to physiological demand for energy if fill or rumen load does not limit their consumptions. Donefer et al. (1963), and Brent et al. (1961) also found that in ruminants fed pelleted diets, voluntary intake decreased while the available energy consumption remained relatively constant.

Three pelleted diets based on rolled barley, whole oats and ground oats respectively were offered ad libitum to mature wethers and growing lambs (Andrews and Orskov, 1970). The bulk densities of the

barley, ground and whole oat diets were 0.41, 0.42, 0.32 respectively. They found that with wethers, intakes on the whole oat diet were significantly greater than on the barley diet but digestible dry matter intakes were not significantly different. With the young lambs, the overall mean intakes of the ground oat diet were higher than those of the barley diet but differences between the digestible dry-matter intakes of these two diets were not significant. These workers felt that their results lend support to the hypothesis of Montgomery and Baumgardt (1965b); that ruminants will adjust voluntary feed intake to physiological demand for energy if fill or rumen load does not limit their consumption. Montgomery and Baumgardt (1965a) studied the regulation of dry matter and energy intake in heifers of rations varying in energy concentration and physical form. Total dry matter intake was increased when pelleted corn was fed with long oat straw and long alfalfa hay compared to the roughages fed alone. Pelleted rations composed of 50% roughage and 50% corn resulted in higher digestible energy intake than the corresponding ground or pelleted roughages. The digestible energy intake of long hay plus corn, pelleted hay, or pelleted hay plus corn were not significantly different. However, the dry matter intake of the pelleted hay ration was significantly greater than the other two rations, suggesting that in these rations the animals may have been regulating voluntary feed intake in relation to physiological demand for energy.

Baumgardt (1967) stated that digestible energy intake can be increased by adding grain to an otherwise all forage ration -- up to a point. This is the point at which fill no longer limits intake, and physiological energy regulating mechanisms become operative; this seems

to occur at a forage: grain ratio of approximately 40:60. Van Soest (1965) concluded that the point at which fiber mass appears to become limiting occurs when cell-wall content lies between 50 and 60% of the forage dry matter.

Conrad et al. (1966) reported that in cows fed various levels of concentrate to roughage, the relative amount of digestible dry matter eaten decreased as the percent grain in the ration increased above 50% of the dry weight of the ration. Cellulose digestibility was observed to decrease as the percentage of grain concentrate in the ration was increased between 34 and 72%. The positive deviation in productive energy value of the ration per unit of intake, above that attributable to increased digestible nutrient intake, was almost completely accounted for by adjusting for the decrease in cellulose digestibility.

Owen et al. (1969) conducted an experiment to test the effect on the voluntary food intake of lambs, of giving diets containing 0, 20, 40, and 60% of either course or finely ground oat husk, in either a loose or pelleted form. The results showed that voluntary intake was uniformly depressed with increased dilution of the diet with oat husks when the oat husks were coarse and the diet given loose. In the older lambs, dry matter intake increased with increasing finely ground oat husk, enabling digestible dry-matter intake to be maintained to the 40% husk (55% digestibility) level, which was equivalent to the diets at 75% digestibility. However, when the coarse oat husk were included in the diet, either pelleted or in the meal form, digestible dry matter was reduced. They concluded that ruminants may sometimes respond to increased diet dilution so as to maintain their maximum digestible energy intake but this will often vary according to the physical form of the food (particle size and pellet or meal).

McCullough and Sisk (1969) studied the effects of silage alone and silage to corn or beet pulp ratios of 80:20, 60:40, and 40:60 when fed to dairy heifers and fistulated steers. When corn was fed, dry matter intake was not improved over the 80:20 ratio by higher levels of substitution. The same trend occurred with beet pulp. Due to increased ration digestibility, the two feeds resulted in similar and consistent increases in estimated net energy at each level of substitution. They reported that in all cases, no improvement in intake of energy resulted from using 60% concentrate instead of 40%.

Ward and Kelley (1969) reported differences in ad libitum consumptions of all hay, 5.5:1, 2.2:1, and 1:1 weight ratios of alfalfa hay and concentrate mixture by lactating cows. Total feed consumption increased consistently with increases in ration concentration. One kilogram of concentrate replaced 0.43 to 0.45 kg hay in feed capacity on the average ad libitum fed cow. Their results support the conclusion that physical fill regulates consumption of rations including 40% or more forage. Blaxter et al. (1961) reported that in sheep, voluntary intake varied with a fractional power of body weight close to 0.734. They concluded that voluntary intake of long fodders was related to apparent digestibility of their energy, increasing rapidly as digestibility increased from 38% to 70% and thereafter more slowly.

Baile and Mayer (1967) have shown that goats receiving a liquid diet intraruminally and concomitantly with spontaneous oral meals of the same diet compensated for the intraruminal feeding. The goats did this by reducing the size of the meal, not by changing the frequency of meals. Boling et al. (1967) reported that the addition of polyethylene, a non digestible-material, to the diets of steers resulted

in increases in feed intake. The data indicated that energy concentration of the diet is of importance in the regulation of food intake. They observed a trend toward compensatory food intake to meet energy requirements, when increased fill and dietary density, palatibility or quality were not factors decreasing intake. Carr and Jacobson (1967) and Jacobson et al. (1966) reported that intraruminal addition of inert 2-mm polyethylene cubes, comprising 13.5 and 22.6% of total food consumed, caused reductions in feed intake. When added mass was placed in the rumen at levels of 1.6, 4.9 and 8.2% of metabolic size, the greatest level was accompanied by the least suppression in intake. They concluded the animals appeared to compensate for the added inert particles and that bulk added to the rumen in physiological amounts was not an important factor determining the voluntary dry matter consumed.

Baile (1968) presented a hypothetical scheme showing the possible components and their function in the control of feed intake as a part of the regulation of energy balance in ruminants. The controller system has been characterized as having 4 elements: 1) control of meal size (or in hunger and satiety) which may involve the fatty acids, 2) receptors in lumen side of rumen sensitive to acetate, particularly, also may involve stretch receptors in the rumino-reticulum, 3) the ventrimedial area of hypothalamus (temporary or permanent loss causes increases in the desired body energy level), 4) the lateral area of the hypothalamus (stimulate it and elicit feeding; lesion and severe anorexis exists).

To predict whether or not fill will limit intake of a particular ration, some measure of that ration, such as density, must be considered in addition to digestibility. Also, the level of energy demand

for the particular animal must be considered (Baumgardt, 1969). There are important exceptions when energy balance in ruminants is not maintained. If a poor quality roughage is fed, insufficient amounts may be eaten due to bulkiness or unpalatability, resulting in a negative energy balance as compared with that level maintained when a more compact and palatable diet is fed (Blaxter et al., 1961). It has been suggested that voluntary intake of roughages is related to the amount of digesta in the reticulo-rumen, which is a function of the rate of digestion of food particles and their rate of passage out of the rumen (Balch and Campling, 1962).

Boling et al. (1967) observed the accumulation of polyethylene in the reticulo-rumen when fed to steers, and pointed out the necessity of adjusting the final body weight for fill when diets of widely different physical nature are fed. Conrad (1966) stated that aside from the primary physiological factors limiting feed intake, a close relationship exists in ruminants between the content of indigestible plant residues in the digestive tract and the total amount of feed consumed. Balch and Campling (1962) reported that differences in the intake of a variety of roughages can be related to the rate at which they disappear from the reticulo-rumen, and there is accordingly a direct relationship between the voluntary intake of roughages by ruminants and their digestibility.

Welch (1967) reported the effects of intraruminally added indigestible polypropylene fibers on roughage intake by sheep. The addition of polypropylene fibers similar to hay stems in shape and texture caused marked reductions in chopped hay intake. Examination of the rumen contents revealed no trace of the introduced polypropylene in the

animals treated with ground 7 cm length material while 95% of the initial dose was recovered from animals receiving the 30 cm fibers, indicating virtually no passage from the rumen during the 27 days trial. They concluded that one factor limiting hay intake appears to be the rate of remastication of indigestible fibers and the clearance of such materials from the rumen.

Hadjipieris and Holmes (1966) reported that in dry sheep, hay (61% organic matter digestibility) limited intake to 780 grams digestible organic matter per day and steadily increased with added grass cubes. Intake with grass cubes alone (apparent O. M. digestibility 56%) was 1140 grams D. O. M. per day. The higher intake at the lower level of apparent digestibility suggest fill may have been involved in rations of this type.

Ulyatt et al. (1967) observed in sheep, that with an increase in the amount of the poorest hay given, the proportion digested in the rumen fell while that distal to the rumen increased. The voluntary intakes of dry matter varied from 1.94 kg/day for dried grass to 1.28 for the poorest hay. Their results support the hypothesis that sheep voluntarily consume roughages at different qualities to achieve constant fill of their rumens, and that very little regulation of voluntary intake can be attributed to distension of the hind gut.

Hogan et al. (1969) showed that in sheep fed dried phalaris tuberosa forage at three stages of maturity, advancing maturity was associated with: 1) decreased food intake; 2) increased expenditure of time and energy in chewing activities; 3) decline in the rate of flow of digesta from the abomasum though not from the rumen; 4) decline in digestibility in the whole tract of organic matter, nitrogen, and the structural carbohydrates.

Simkins et al. (1965b) reported reductions in voluntary intake in cows fed ad libitum pellets or long hay following intraruminal infusions of acetate, propionate, butyrate and a VFA mixture. They suggested that when cows were fed the long-hay ration, it was possible that rumen load was limiting their intake although this was not likely the case in the pellet fed rations.

A study was made on factors limiting the intake of sheep fed a wheaten hay diet having an organic matter digestibility of approximately 57% and containing 4.4% crude protein and a mineral supplement. Voluntary consumption of chopped wheaten hay increased by 8-13% when protein was infused per abomasum or when the protein content of the diet was increased to 7-15% by the addition of wheat gluten. The addition of protein to ground and pelleted hay was accompanied by increased feed intake, digestable energy intake, digestable fiber intake, and the quantity of organic matter transferred through the alimentary tract. These results indicate that the primary factor limiting the intake of wheaten hay was a deficiency of nitrogen. After this was remedied the next limiting factor was the resistance of the diet to removal from the rumen (Weston, 1967).

Balch and Campling (1965) also reported that digestion in the rumen of a poor roughage such as straw is hampered by shortage of nitrogen. Urea dripped into the reticulo-rumen reduced the mean retention time by increasing the rate of breakdown. They also stressed the importance of particle size on the rate at which digesta will leave the reticulo-rumen. Specific gravity is also an important factor. Rubber particles with a specific gravity ranging from 1-1.4 when introduced into the rumen indicated that particles of specific gravity of 1.2 had

the shortest retention time in the reticulo-rumen while particles of specific gravity 1.0 passed most rapidly through the hind gut (Campling and Freer, 1962). Particles of 4.8 mm in diameter were retained 91 hours while particles of 3.2 mm in diameter were retained only 80 hours. These examples illustrate the very close interrelationships between rate of passage and rate of breakdown; basic factors in the determination of efficiency of food utilization, with such secondary factors as digestibility, the amount of contents in the digestive tract, the production of small particles during eating and rumination, and the voluntary intake of roughages.

The voluntary consumption of lucerne hay decreased by 15% when sawdust was introduced into the rumen at a rate equivalent (by weight) to the voluntary feed consumption during a control period. Decreases of 7 and 9% were found when finely ground polyvinyl chloride was introduced at rates equivalent by weight to 25 and 50% respectively of voluntary feed consumption during control periods. These decreases can be accounted for by the accumulation of digesta in the reticulo-rumen (Weston, 1966).

Grass cubes, a synthetic diet with casein as virtually the only source of nitrogen, and one without casein were given at a fixed level of intake to sheep in which the flow of digesta was exteriorized by means of re-entrant cannula fitted in various sections of the digestive tract. Nitrogen intake on the diets in the same order was 14.29, 7.82 and 0.27 gm daily. The diet lowest in nitrogen accumulated in the reticulo-rumen. Of the quantities of dry matter digested while the grass cubes and casein-containing diets were given, 56 to 64% disappeared in the fore-stomachs and abomasum, 16 to 30% in the small intestine

and 28 and 6% in the large intestine of sheep, respectively. The addition of protein to nitrogen-low but energy-adequate diets enhanced dry matter digestion in particularly the proventriculi (Cloete, 1966).

Daily allowances of 1.37 kg of concentrates containing 8.9 (treatment A), 13.6 (B), 19.1 (C) or 29.2% crude protein (D) were given to steers while being fed long barley straw. Voluntary straw intake on treatment B was 25% higher than on treatment A. There were no significant differences in straw intake between treatments B, C and D. It was concluded that voluntary straw intake was limited, at the lowest level of supplementary protein, by a deficiency of absorbed protein. At the higher levels of supplementary protein, intake was probably limited by the capacity of the alimentary tract (Lyons et al., 1970).

The Role of the Central Nervous System in the Control of Feed Intake

Brobeck (1957) stated that the most intimate concern with food intake is in the nervous system. The medial hypothalamus is apparently involved with satiety and the lateral portions with appetite, since destruction of the lateral region results in failure to eat, while medial lesions lead to overeating and obesity. Stimulation of the medial region induces satiety. Thus, he felt that interaction of these two regions of the hypothalamus account for most regulation of food intake. The cerebral cortex is concerned with feeding responses, necessary for recognition of objects suitable for food. He also felt that the reflexes beginning olfaction and taste plus those receptors within the wall of the digestive system take part in the control of feeding. Balch and Campling (1962) concluded from their review on feed intake regulation in ruminants that there is evidence that a central nervous regulatory mechanism does exist in ruminants. The hypothalamus is considered

by most authorities as the part of the brain responsible for the automatic execution of regulatory function controlling energy exchange (Conrad, 1966).

Baile et al. (1968) reported the effects of electrolytic lesions made in the hypothalamic region of a series of goats. In three of the goats, bilaterial lesions in the lateral area caused temporary aphagia lasting 4 to 12 days and adipsia lasted 8 and 23 days in the aphagic goats. In a fourth goat, bilaterial lesions in the anterior hypothalamic area caused aphagia and hypodipsia lasting 17 days; then the goat was sacrificed. Their results suggest that the central nervous system has a similar function in the control of feed intake in both ruminants and monogastric animals in spite of the fact that there are probably differences in the feedbacks and receptors making energy balance possible in the two types of animals.

Hypothalamic Function in Regulation of Feed Intake

Baile et al. (1967a) described a technique that makes possible the stimulation of hypothalamic centers in goats. The method provides for the required functional placement of electrodes in the brain, since stereoxtaxic atlases are not available for the larger domestic animals. The technique enables postoperative electrode placement in unanesthetized animals. These workers were primarily interested in the ventromedial and lateral areas of the hypothalamus. They first established the position of the lateral hypothalamus areas, which were determined by locating the areas in which electrode stimulation caused a satiated goat to eat. The lateral areas, once located, could then be used as reference points from which the ventromedial areas could be defined. Some of the responses resulting from stimulation of the hypothalamic

area were rumination, yawning, gulping of water, licking, voracious eating, and inhibition of eating. Baile (1968), in a hypothetical scheme summarizing some of the components thought to function in the control of feed intake of ruminants, indicated that the lateral area of the hypothalamus has many of the characteristics of a controlling element; that is, when it is sufficiently stimulated it can elicit feeding, or when it has been lesioned, feeding is not initiated, although severe nutritional depletion exits.

Baile et al. (1967b) reported sustained hyperphagia and subsequent rapid weight increases induced by lesions in the ventromedial areas of the hypothalamus of goats. The weight of one goat, which had been constant for two months, almost doubled in three months, when the animal was fed the same diet ad libitum. However, after about two months of hyperphagia and hyperdipsia, feed and water intakes decreased. They observed that another goat, which was always very active prior to lesion, became quite docile and apathetic to her surroundings. Their findings support the concept that the ventromedial area is functioning in the regulation of food intake of ruminants, although the stimuli monitored may be different from those in monogastric animals. Holmes and Fraser (1965) reported that ewes, following apparent bilateral electrolytic lesions in the ventromedial nuclei, did not exhibit hyperphagia, striking weight increases, or extreme fat deposition, in contrast to the finding of Baile et al. (1967b). Hoebel (1965) has shown that some radio-frequency lesions in the ventromedial hypothalamus do, in fact, produce hyperphagia and obesity. Further evidence for the involvement of the ventromedial area in control of feed intake in ruminants is that the injection of pentabarbital into the cerebral ventricles

of an apparently satiated goat caused temporary hyperphagia, and although the hypothalamic temperature decreased, eating started before the change in temperature. The hunger was present only during the initiation of the treatment. The eating was initiated probably because the inhibitory neural activity of the ventromedial areas of the hypothalamus was temporarily depressed (Baile and Mayer, 1966). Baile et al. (1967a) observed that food intake in goats was induced by bilaterial injections of 2.4 mg pentabarbital sodium. Baumgardt and Peterson (1970) showed that the ventricular injection of 25-30 mg pentabarbital sodium induced feeding in satiated sheep, within 2-3 minutes following the injections. These results suggest that satiety and feeding centers are operational in the hypothalamus of the sheep.

Mayer and Arees (1968) confirmed in mice the theory that the ventromedial nucleus contains certain glucoreceptors, specifically destroyed by goldthioglucose, permitting presentation of anatomical evidence for the concept that the ventromedial nucleus glucoreceptors act as a satiety brake on the lateral hypothalamic area. Baile et al. (1970) reported that mice, when injected intraperitoneally with glucose and insulin for one hour and then goldthioglucose and insulin for 30 minutes, developed ventromedial hypothalamic lesions, which usually resulted in hyperphagia and obesity. Glucose and insulin solutions were injected into jugular veins of goats and sheep for an hour to increase glucose utilization rate which in mice increased the severity of the hypothalamic lesions. Immediately following this, goldthioglucose and insulin were injected into a carotid artery for 30 minutes while the opposite carotid was occluded. This treatment caused high levels of goldthioglucose in the brain. Even though the gold concentration of

the venous blood was 30 to 40 times that of mice which developed hypothalamic lesions, the goats and sheep did not develop hypothalamic lesions.

Herberg (1960) reported that when rats were injected 19 hours postprandially in the lateral ventricles with approximately 2.5 mg glucose or fructose during the first ten minutes of a half hour feeding period, the food intake was reduced about 35 percent below non-injected controls. Baile and Mahoney (1966) reported that perfusion of the cerebral ventricular system of hungry goats with synthetic cerebral spinal fluid (SCSF), adjusted SCSF plus 500 mg glucose, or adjusted SCSF plus 50 mM acetate, all with similar tonicity and pH, did not cause any trend of food intake inhibition during the second hour of perfusion, at which time the goats were given food. The acetate treatment was about 25 times the normal blood level, while the glucose concentration change was in the order of ten times the normal blood level. Thus, both were large unphysiological changes which should have given maximum responses. Their data suggests that receptors sensitive to glucose or acetate do not exist in the ventromedial nuclei of the hypothalamus in ruminants. Baile and Mahoney (1967) perfused the cerebral ventricular system of hungry goats with 50 mM sodium acetate (approximately 50 times the level in the blood) and found no depression in intake. They considered this to be further evidence that the ventromedial areas, which are adjacent to the third ventricle, do not contain acetate receptors. Further evidence against hypothalamic acetate receptors was reported by Baile and Mayer (1968a). They observed that sodium acetate when infused intraruminally depressed feed intake in goats while the same amount injected intraveinously had no such effect. Their

results indicated that proposed receptors for acetate reside on the lumen side of the rumeno-reticulum and not in the hypothalamus or in the ruminal or portal veneous system. Although it seems apparent that there are acetate receptors in ruminants, they did not conclude that the feed intake depression following an acetate injection was related to satiety.

Andersson and Larsson (1961) observed that cooling of the anterior hypothalamus and preoptic areas (9 C) caused a satiated goat to eat, and warming (8 C) of these areas inhibited eating in a fasted goat. Their results appears to be direct evidence of some type of hypothalamic thermoregulatory mechanism. However, they felt that such a conclusion may be unwise, since very small physiologic changes in hypothalamic temperature could not be accurately measured. Baile et al. (1967c) reported that hypothalamic temperature in goats did not increase during a large meal, rapid intraruminal force feeding, or acetate injections. They felt this was evidence that short term satiety in ruminants is not normally a function of hypothalamic temperature. Dinius et al. (1970) reported that the hypothalamic temperature of goats did increase during oral, intraruminal, and false intraruminal feeding treatments. However, since the temperature at this location decreased when the goats laid down, they concluded that the hypothalamic temperature was related to activity rather than to food consumption per se, the goats being more active during eating. Baumgardt and Kavanaugh (1969) also reported increased temperature of the lateral and ventromedial hypothalamic areas during a meal. However, these temperatures tended to fall when the animal ceased eating. They concluded that hypothalamic temperature changes during a meal were more related to activity

than to the meal consumed, in agreement with Dinius et al. (1970).

Perception of Food

Balch and Campling (1962) concluded that in ruminants offered food without choice, the perceptive faculties, especially taste and smell, play a bigger part in the initiation of eating than in the determination of the amount eaten. It is common to give great importance to taste in determining the acceptability of food by animals, since it, with the sense of touch, leads directly to the retention, chewing and swallowing of food or to its rejection. Although the effects of the five senses are clearly greatest where there is a choice of foods, little is known of the part they play in controlling food intake.

Tribe (1949) has shown that the sense of smell in sheep is limited and is of only minor importance in influencing the ingestion of food by stall-fed sheep. If sheep are accustomed to the smell of feces they will eat food contaminated with feces. He concluded that sense of smell is important in initial stimulation of appetite in grazing sheep, but was of no importance in selection of particular grass or clover species. Fontenot and Blaser (1965) concluded that probably sense of smell is of no importance in selection of herbage species by sheep, although it appears to be important in initial stimulation of appetite, which is direct agreement with Tribe (1949). Roe and Mottershead (1962) suggested that selection or rejection of certain strains of phalaris arundinacea by sheep was made through smell rather than taste. Tribe and Gordon (1949) found that sheep were unable to distinguish between blue and red. Therefore they concluded that color vision is not a factor that influences the grazing behavior of sheep. Goatcher and Church (1970a) reportedly observed behaviorial taste responses of sheep

to alcohol and to sweet and salty compounds which were tested by the two choice preference technique. Tests with sugars and sodium saccharin showed adequately fed sheep to be essentially indifferent to compounds evoking sweet taste sensations, although individual sheep showed pronounced preferences for some sugars. The sheep also showed indifference to ethyl alcohol. However, the effectiveness of stimulation was greater with salts than with sugar. Goatcher and Church (1970b) reported taste responses in sheep to stimulants that evoke sour and bitter taste sensations in man. They found sheep sensitive to (in increasing order of sensitivity): sweet (glucose), salty (sodium chloride), sour (acetic acid) and bitter (quinine HCl).

Thermostatic Regulation

The possibility that food intake might act as a part of the thermoregulator system was suggested by Brobeck (1948). The heat load under normal conditions represents a large proportion of the kinetic energy of the body. Although the kinetic energy is generally less than 1% of the total energy content of the body, it is carefully regulated. Specifically, it is suggested that the temperature receptors of the anterior hypothalamus would, by some means, actuate feeding when a certain heat load minimum or temperature depression was reached, and satiety would develop when a certain heat load was realized. The specific dynamic action of food eaten, in particular, would serve as an immediate source of kinetic energy to cause a heat load and thus satiety (Brobeck, 1948). The thermostatic theory of regulation of food intake implies that animals eat to keep warm or to keep the hypothalamus at a constant temperature. (Strominger and Brobeck, 1953).

A thermostatic satiety mechanism would appear to be of particular interest in ruminants because of their high heat increment of feeding (Blaxter, 1962). Since acetic acid has a high heat increment (Armstrong, 1957), the effects of this metabolite on food intake have been studied. Bhattacharya and Warner (1968) reported that intraruminal infusions of acetic acid (neutralized to pH 6.5) reduced hay consumption in dairy heifers by 39% when administered at the rate of one g/kg of live bodyweight prior to a meal. These workers felt that the reduced intake following the infusion of acetate could be interpreted as an overall reflection of its high heat increment. Simkins et al. (1965b) noted a significant intake depression of pellets (75% alfalfa meal, 25% ground corn) in cows receiving intraruminal infusions of acetic acid (neutralized at pH 6.0) at the rate of 1.3 or 2.1 gm acetic acid per kilogram bodyweight over a 5 hour period during the morning feeding. However, during the same 5 hour period, they found that in the hay-fed cows receiving the neutralized acid at the rate of 1.3 or 1.7 g/kg bodyweight, there was no significant reduction in hay intake. The heat released during the assimilation of acetic acid may have been responsible for the food intake depression via a thermostatic mechanism. Cowsert and Montgomery (1969), working with completely pelleted isonitrogeneous rations fed to nonpregnant dairy heifers found that estimated heat increment values tended to decrease as the percent concentrate in the ration increased, due to the increased proportion of propionic acid produced on this diet. Based on these observations heat increment was not likely the cause of the food intake depression reported by Simkins et al. (1965b) since food intake was not significantly depressed in the hay-fed cows.

Baile et al. (1967c) implanted needle thermistors in the medial hypothalamus of goats in an attempt to determine the relationship between feeding behavior and body temperature changes. The goats were tested under the following conditions: water ad lib. (control), feeding period after a 20 hour fast, grain (1,000 g force fed through a rumen cannula), 250 ml of 1.0 M acetic acid injected intraruminally, and 2 ml/min of 2.5 M sodium acetate injected intraruminally for two hours. The hypothalamic temperature decreased following eating, force feeding, and both acid and the salt injections. The fact that hypothalamic temperature did not increase during a large meal or force-feeding is evidence that short term satiety in ruminants is not normally a function of hypothalamic temperature. These results indicate that the feed intake depression shown to follow intraruminal acetate injections is apparently not a result of an increased hypothalamic temperature. Baile and Mayer (1968b) presented further evidence against the thermostatic theory of food intake regulation. In this trial they again showed that the temperature of the medial hypothalamous of goats did not increase as a result of eating or of rapid force feeding. However, horn temperature did increase following force feeding but was variable between animals. Skin temperature did not increase as a result of feed intake, which is in general agreement with Dinius et al. (1970). Pentabarbital induced eating before it caused rapid cooling of the hypothalamus.

Preoptic temperature cannot be an essential determinant of hunger or satiety. After initial adjustment, cats fed very cold or warm food ate normal quantities although the preoptic temperature fell or rose to abnormal levels during the first few seconds of the meal. The changes in preoptic temperature may have been due to heating or cooling

of the mouth which radiated to adjacent regions of the brain. Cortical and hipocampal leads showed smaller changes (Grossman, 1968).

Dinius et al. (1970) monitored the temperature of goats by thermistor probes in the hypothalamus, rectum, and rumen and on the horn, ear, and chest every 2 minutes, from 30 minutes before feeding to 90 minutes after feeding (during oral, intraruminal, or false intraruminal feeding). The hypothalamic temperature increased at the time of feeding, irrespective of treatments, and also increased when ruminal fluid was sampled. They also observed a decrease in temperature at this location when the goats laid down. Thus, it appeared that hypothalamic temperature changes were related to activity rather than to food consumption per se, the goats being more active during eating. There were no consistent temperature changes at any of the body locations that could be correlated with food consumption, nor was there any correlation between rumen VFA concentration and body temperature. It is of interest that Dinius et al. (1970) reported an increase in hypothalamic temperature at the time of feeding while Baile and Mayer (1968b) reported no such increase. However, the reason for this could have been due to limited activity during eating since the goats were restrained in slings.

Andersson and Larsson (1961) produced alterations of hypothalamic temperature in goats that gave results which support the thermostatic hypothasis. Cooling the anterior hypothalamus and preoptic areas caused a satiated goat to eat, while warming these areas inhibited eating in a fasted goat. However, since these areas were cooled by 9 C or warmed by 8 C, the temperature was probably outside the physiological

range, thus, placing considerable doubt of any type of hypothalamic thermostatic mechanism of food intake control in ruminants under normal conditions.

Conrad (1966) reported that thermal stress from high environmental temperatures or from eating rations having a high calorigenic effect is manifested by marked reductions in feed intake in sheep and cattle. Also since the existance of thermosensitive areas in the hypothalamus have been demonstrated, he suggested that thermostatic mechanisms may dominate regulation of feed intake independently of other factors.

Gengler et al. (1970) placed cows in a climatically controlled chamber to determine volatile fatty acid concentrations at normal (18 C) and high (35 C) ambient temperature, and to determine the effect of increasing the rumen temperature with an intraruminal heating coil in an 18 C ambient temperature. Cows subjected to 18.2 C ambient temperature, but whose rumen temperatures were increased by intraruminal heating coils to 51 C, consumed significantly less ($P<0.05$) feed and water than cows subjected to the other treatments. These data indicate that lower ruminal volatile fatty acid concentrations which occur at high ambient temperatures cannot be explained by ruminal temperature.

Chemostatic Regulation of Food Intake

Although digestion in the abomasum and intestines of ruminants may be similar to that of simple stomach animals, there are marked differences in the digestive processes in the reticulo-rumen and ceacum. As a result of these differences in the breakdown of food, the peripherial blood of ruminants contain less glucose and more acetate and certain ketone bodies than that of non-ruminants (Balch and Campling,

1962). Because of their specialized digestive system, the food may be much bulkier and much less readily digested. Therefore they may, through necessity, sense different stimuli in order to activate hunger and satiety (Baile, 1968). In the monogastric animal, glucose is the major source of metabolic energy available to the animal, whereas the major sources of energy in the adult ruminant animal are the volatile fatty acids, mainly acetic, propionic and butyric (Jones et al., 1970). Chemoreceptors sensitive to these and other intermediate metabolites may be operative in the control of feed intake.

Chemoreceptor theory. Baile and Mayer (1968a) observed that sodium acetate injections into the rumen depressed feed intake while the same amounts injected intravenously had no such effect. While being fed a high grain ration ad libitum, goats were subjected to five-minute intravenous injections of acetate which caused blood levels to increase to 8 to 12 mM per liter while injections given intraruminally caused an increase of only 0.5 to 1.0 mM. The results of this study suggest that receptors sensitive to acetate are more likely to be situated in the lumen side of the rumino-reticulum than in an area where they would respond to blood levels. However, it cannot be concluded that the feed intake depression following acetate injections is related to satiety.

As previously reported, Bhattacharya and Warner (1968a) noted a 39% reduction in hay consumption when fistulated dairy heifers were given intraruminal infusions of acetic acid, which was neutralized to pH 6.5. These workers also reported that when a portion of the acetate was substituted with a equicaloric amount of propionate the depression was prevented. Also the depression was partially alleviated by addition

of citrate to the acetate, which suggests that a balance of the volatile fatty acids in the rumen may be a significant factor in control of voluntary feed intake.

Jacobson et al. (1966) reported similar results following intravenous infusions of acetate and propionate. They observed increased blood butyrate and sometimes increases in blood propionate with a reduction in voluntary intake of chopped hay following acetate injections. Propionate infusion decreased the blood acetate level but had no effect on the blood butyrate level, suggesting an interrelationship between the volatile fatty acids.

The intraruminal infusion of acetic acid significantly decreased daily hay consumption of dairy cows (Montgomery et al., 1963). When the acetic acid was supplied as the sodium salt or when partially neutralized to pH 5.0 with sodium hydroxide, there was only a small reduction in hay intake. Propionic and butyric acids caused only a slight decrease in hay consumption as did the infusion of lactic acid. Results indicate that one or more of these metabolites studied (either in the rumen or circulating blood) are important in controlling intake.

When isocaloric amounts of acetate, propionate, butyrate, and a VFA mixture (60, 20 and 20% of the calories from acetate, propionate, and butyrate, respectively) were infused intraruminally into cows fed a pelleted ration and cows fed a good quality alfalfa hay, reductions in feed intake were observed (Simkins et al., 1965b). The infusion of acetate, propionate and the VFA mixture reduced ($P<.05$) the voluntary consumption of the pelleted ration while propionate and butyrate infusion caused a significant reduction in the consumption of hay. Therefore acetate, propionate and butyrate can act as satiety signal compounds

in the regulation of food intake. If chemoreceptors are involved, it would appear that those for propionate and butyrate would have to be located in the rumen wall, in the portal system, or in the liver, since the concentrations of these two metabolites in the peripheral circulation are very low. Chemoreceptors for acetate could be located in the periphery in addition to those sites mentioned for propionate and butyrate (Simkins et al., 1965b).

Intraruminal infusions of acetic acid, propionic acid, or a mixture of acetic, propionic and butyric acids, providing 290 to 510 kcal of gross energy daily were accompanied by decreases in the voluntary consumption of lucerne hay and wheaten hay. The decreases ranged from 0.29 to 0.86 gm dry matter per kcal of energy infused. Similar decreases were obtained when propionic acid was infused into the abomasum of the sheep given lucerne hay. The intake of lucerne hay was 9% higher when given alone than when supplemented with 6% propionic acid (Weston, 1966).

Using identical twin cows (Dowden and Jacobson, 1960) sodium acetate (adjusted with acetic acid to pH 7), glucose, acetic, propionic, valeric, hexanoic and lactic acids were administered intravenously by constant drip over the same 8 hour period during each of three consecutive days. Administration of acetic acid and sodium acetate resulted in a highly significant reduction of feed intake during the eight hour injection period when higher levels of these metabolites were used. Similar reductions were observed during the 8 hour and 24 hour periods with propionic acid infusion, while none of the other metabolites infused caused a significant reduction in feed intake. Results of the trials suggest the existance of a chemoreceptor response to changes in

the blood constituents which may be triggered by the absorption of acetic and propionic acid. Similar results were reported by Holder (1963). Infusions of propionic acid did cause a reduction in voluntary intake although this metabolite is normally not present above trace levels in the peripheral circulation, but converted to glucose in the liver. Sodium acetate (40% solution) infusion also intravenously over 210 minutes did not cause a fall in intake even though blood VFA levels were almost 3 times the normal range. The results obtained when acetate was infused indicate that blood acetate level is not a major factor in regulating appetite in the sheep, thus strengthening the evidence of Baile and Mayer (1968a) that receptors may exist in the rumen.

Since preliminary studies indicated that the intraruminal injections of relatively small quantities of acetic acid inhibited feed consumption of sheep, an experiment was designed (Baile and Pfander, 1966) to help define and quantitate this observation. Intraruminal injections were made twice daily (immediately before feeding) of 250 ml of the following solutions: water, 1.0 M acetic acid, 0.5 M glucose, 1.85 M lactic acid or 1.0 M saline. A 60% decrease (in relation to the water treatment) in feed intake was found with sheep receiving the acetic acid treatment ($P<.01$), while feed intakes of the sheep receiving the saline and lactic acid treatments were about 75% of those of the sheep receiving the water treatment ($P<.05$). The injections of acetic acid caused a change in rumen fluid acetic acid concentration similar to that found during a normal feeding period. Feed intake results indicated that a chemosensitive feed intake regulatory mechanism perceptive to a change in rumen fluid acetic acid concentration may be functioning.

Baile and Mayer (1967) working with goats, found that intraruminal injections of water concomitant with ad lib. oral meals affected neither oral meal size nor frequency, while injections of diet reduced oral intakes (40 to 60%) but caused no change in meal frequency. When the amount of liquid diet that was normally consumed by a goat was continually fed intraruminally, oral intake was reduced (about 80%) as were meal size and frequency ($P<.01$). During intra-abomasal injections of diet, oral meal intake was little affected. Total intake and total meal size were greater. Data suggest that goats can regulate food reaching the rumen, although part of it bypasses oropharyngeal sensors.

Rook et al. (1960) injected acetic, propionic and butyric acid continuously into the rumen with water at a rate equivalent to 3500 K cal. per day, and reported a significant reduction in feed intake with the acetic acid injections. The intraruminal injections of 250 ml of 1.0 M acetic acid and injections of acetic acid (2 ml/min) at 2.5 M for two hours resulted in a feed intake depression in goats. (Baile et al. 1967c).

Cowsert and Montgomery (1969) reported that total volatile fatty acids increased significantly ($P<0.05$) as the ratios of alfalfa hay to concentrate decreased, due primarily to a substantial increase in propionic acid. Percentages of rumen acids indicate a significant decrease ($P<0.05$) in the percentage of acetic acid and a slight increase in the percentage of both butyric and valeric acid, which is in general agreement with Montgomery and Baumgardt (1965b). These data give no indication of the actual amount of VFA produced. They suggested that a chemostatic or thermostatic mechanism may be responsible for the decreasing intake with increasing corn in the ration.

Simkins et al. (1965a) reported that in lactating cows fed 5.45 Kg grain and alfalfa hay ad libitum once daily for a 6 hour period, rumen concentrations of acetic, propionic, butyric, and valerate were increased ($P<.05$) at 2 hours after feeding. Blood acetate concentration was directly proportional to rumen acetate concentration. Satiation occured when blood and rumen volatile fatty acid concentration were at a maximum. When heifers were fed a completely pelleted ration (60% corn, 40% alfalfa meal) ad libitum once daily for a 3 hour period, blood acetate and ketone concentrations increased ($P<.01$) after feeding. Since it is doubtful that rumen distension or gastrointestional tract fill limited intake of the pelleted high-energy ration suggests a chemostatic or thermostatic regulatory mechanism in rations of this type.

Based on dry matter removal after feeding, which resulted in an increase in feed intake, Carr and Jacobson (1967) suggested that it is the nutrient content of the feed which is consumed and allowed to remain in the gastrointestional tract, and its metabolic products that largely determine feed intake.

Glucostatic mechanism. According to the glucostatic theory for food intake regulation in monogastric animals, the increase in glucose utilization that occurs in the ventromedial nuclei of the hypothalamus after feeding is an important satiety signal (Mayer, 1964). However, since there is no apparent increase in glucose concentration in ruminants after feeding (Simkins et al., 1965a) and glucose utilization rate in ruminants tends to be proportional to the blood glucose concentration (Bergman, 1964) the glucostatic mechanism for monogastric animals appears to be of little importance in ruminants. Unlike the monogastric animal, glucose is not usually an important digestion product in the

ruminant (Blaxter, 1962). Thus ruminants possess relatively low blood sugar levels (Simkins, 1965b) which are little influenced by consumption of food (Reid, 1950).

Dowden and Jacobson (1960) conducted an experiment to examine several major intermediate metabolites for their effect on appetite. Glucose and other metabolites were administered intraveinously by constant drip over an 8 hour period during three consecutive days. The administration of glucose to dairy cattle did not elicit a reduction in daily intake. The injections in some trials were such that the blood glucose level was raised from 40 mg/100ml to 100mg/100ml with little or no effect on appetite. Holder et al. (1963) reported that no depression in voluntary intake of lucerne hay was observed with intraveinous glucose injections. These results indicated that blood glucose level is not a major factor in regulating appetite in the sheep.

Simkins et al. (1965b) investigated the effect of intraperitoneal glucose infusions on dairy heifers fed a completely pelleted ration (60% alfalfa meal, 40% ground corn) ad libitum once daily for a 3 hour period. Immediately before food was offered, heifers were subjected to infusions (one liter) of the following solutions in a 3x3 Latin-square designed trial: (I) 0.9% sodium chloride (control); (II) 5.4% glucose; (III) 25% glucose. The average food consumption for treatments I, II, and III was 62.6, 71.6 and 72.1 $g/BW_{kg}^{.75}$, and jugular blood glucose concentration 1 hour after feeding was 50.5, 57.2, and 69.2 mg per 100 ml respectively. Blood glucose was increased by the glucose infusions; however, only the difference between the saline infusion and the 25% glucose infusion was statistically significant ($P<.01$). Although the average blood glucose concentration was increased

18.7 mg per 100 ml by the 25% glucose infusion at 1 hour after feeding there was no depression in food intake as a result of the increased blood glucose, suggesting that a glucostatic mechanism for food intake is not important in ruminants.

Baile and Pfander (1966) reported that intraruminal injections twice daily of 250 ml of 0.5 M glucose solution immediately before feeding did not cause a depression of feed intake in sheep.

When the cerebral ventricular system of hungry goats was perfused with 500 mg of glucose solution for two hours, intake was not depressed during the second hour when feed was offered, even though the glucose concentration change was approximately ten times the normal blood level. The data suggest that receptors sensitive to glucose analogous to the glucoreceptors proposed to function in monogastric food intake regulation do not exist in the ruminant brain (Baile et al. 1966).

Hypoglycemia induced by insulin injections caused severe hunger in humans (Jonawitz and Ivy, 1948), and eating in rats (Epstein and Teitelbaum, 1967). Baile and Mayer (1968) studied the feeding behavior and changes during an induced hypoglycemia in goats. Even though the subcutaneous injections of protamine zinc insulin did induce severe hypoglycemia, there was no trend for the goats to eat to correct the hypoglycemia. Thus ruminants apparently do not have the response of other mammals of eating to correct hypoglycemia. The stability of blood glucose values is supported by the greater resistance of sheep than non-ruminants to injections of glucose (Tribe, 1950).

It has been shown that goldthioglucose injections in mice produce lesions in the ventromedial area of the hypothalamus (Marshall,

et al., 1955). Mayer and Arees (1968) concluded that the regulation of food intake in monogastrics is dependent on ventromedial glucoreceptors which can be destroyed by goldthioglucose. However since similar treatments with goldthioglucose did not cause hypothalamic lesions in sheep and goats (Baile et al., 1970), the mechanism as described for monogastrics apparently is unimportant in the regulation of food intake in ruminants.

Rumen pH as a Factor for Controlling Feed Intake in Ruminants

It is well established that diets having a high proportion of concentrates will often lower the rumen pH and total dry matter intake in ruminants. Bhattacharya and Warner (1967) have shown that a drop in rumen pH influences voluntary feed intake in steers and could be of physiological importance with some diets although the exact nature of the controlling mechanism is yet to be established.

The effect of concentrates in decreasing voluntary intake has been reported by several workers. Montgomery and Baumgardt (1965b), in studies with heifers fed pelleted rations varying in energy concentration, noted that as the percent concentrate was increased in the ration, daily dry matter consumption decreased, accompanied by decreased rumen pH and changes in molar proportion of volatile fatty acids. Similar results were reported by Cowsert and Montgomery (1969) with heifers fed completely pelleted isonitrogenous rations and by Donefer et al. (1963) with ewes fed completely pelleted rations at different levels of concentrate. A possible explanation for the decrease in feed consumption with increases in concentrate intake is the radicle change in the nature of the microbial fermentation in the rumen, as demonstrated by the changes in the molar proportions of the volatile fatty acids produced.

This would suggest that the addition of concentrate has caused marked changes in the rumen microbial population. The shift toward soluble carbohydrate fermentation may produce a lowering of the rumen pH, thus inhibiting the activity of cellulolytic organisms. The depression of cellulose digestion by the addition of corn to the ration has been reported by Montgomery and Baumgardt (1965b). As a consequence, the rate and extent of digestion of the fibrous component of the diet is reduced and intake limited (Crampton et al., 1960).

Balch (1958) observed lowered rumen pH on diets limited in roughage and suggested that saliva produced was inadequate to properly neutralize the VFA produced. Donefer et al. (1963) suggested that it was possible that the use of pelleted rations in their studies further augmented the development of low pH levels in the rumen by causing a decrease in saliva flow thus curtailing normal buffering action. In a study conducted by Bhattacharya and Warner (1967) rumen fistulated steers received intraruminal infusions of a) water, b) phosphoric acid, c) lactic acid, or d) citric acid, to study the effect of rumen pH on daily hay consumption. The rumen pH was lowered and maintained at about 6.0 by infusions of the dilute acid solution before and during the 6 hour feeding period. Daily air-dry hay intake dropped ($P<0.01$) from 12.3 kg in the control animals (water infused) to 6.0, 6.3, and 8.0 kg in the animals receiving the phosphoric acid, lactic acid, and citric acid solutions, respectively. The rumen pH in the control animals dropped from 7.03 before the infusion to 6.58 in the 6 hour feeding period, while the pH of the acid-infused animals dropped from 7.08 to about 6.0, where it was maintained through the 6 hour feeding period. Bhattacharya and Warner (1968) also investigated the effect of

raising a prevailing low rumen pH of pellet-fed sheep and cattle by including different alkaline reagents in the diet. The alkali treatments significantly increased the rumen pH and total rumen VFA concentration and resulted in reduced blood VFA levels. Based on their results they concluded that the significant elevation in rumen pH has reduced the rate of VFA absorption to the point where any satiety signal effect due to blood VFA (yet undefined) is reached at a higher level of food intake. Since rumen pH has been shown to effect feed intake in ruminants, at least under certain conditions, the involvement of pH as related to feed intake warrants further study.

Lipostatic Regulation

Due to the lack of information regarding the lipostatic regulation in ruminants, discussion of this topic will be limited. For a discussion of this subject, one can refer to the paper presented by Balch and Campling (1962). The following paragraph was taken from their review article:

> There is as yet no direct evidence for the operation in ruminants of a mechanism conforming to the lipostatic hypothesis of Kennedy[1] (1950, 1953). The circumstances under which such longterm regulation could be of importance may be rather infrequent. Evidence has been quoted that sheep and cattle eat less when fat than when thin. The ability to accumulate depot fat varies markedly between breeds within each species of domestic ruminant.

In assesing the feasibility of a control system, one must realize that any regulatory mechanisms must act not only rapidly but also accurately, since a meal is injested in a short period of time. For example, the metabolite evoking satiety must increase and peak at the time the animal stops eating.

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[1]References appear in literature cited.

INTRODUCTION TO RESEARCH

Since the rate or level of feed intake has such an important bearing upon the economics of livestock feeding, it has been the subject of much interest and research. Animals which voluntarily consume greater quantities of feed generally show an advantage in rate of gain over those on lower intake (Lofgreen and Garrett, 1968).

The mechanisms controlling voluntary intake in the monogastric animals are fairly well understood. However, the question of controlling mechanisms in the ruminant animal have not been satisfactorily explained or described.

As with other research, the first objective in studying appetite regulation is the control and standardization of all variables except those being studied. In this respect, the replacement of conventional feeding by a constant ruminal infusion of a complete ration would control practically all of the metabolic variations arising from the "meal eating" nature of the animals. The development of a complete liquid ration suitable for constant infusion and procedures for its introduction would be an invaluable tool for further studies on nutrient requirements and research into the mechanisms regulating appetite and satiety in the ruminant animal. The present research was carried out to develop such a complete liquid diet (with the ultimate objective of determining the metabolic capabilities of animals for increased feed intake), and assess its adequacy through measurement of rumen end products and blood components.

EXPERIMENTAL PROCEDURES

Six metabolism and nitrogen balance trials were conducted to evaluate a liquid ration suitable for use in studying feed intake control and regulation. Fistulated wethers were placed in metabolism crates for 3 week preliminary periods before trials began in order to adjust to the crate and preliminary ration. Metabolism crates were constructed with a sliding side to allow access to the fistula and to facilitate the taking of blood samples. The left side was constructed of sheet metal to prevent damage to the canula. Animals were tethered in the crate by use of two chains attached to the neck. Urine was collected via a full length pan and drained into a collection vessel. Fifty ml of 6N HCl was added to the collection vessel to prevent ammonia volatilization. Two inch duct tape was secured with back tag cement around the perimeter of a 15 cm square surrounding the anus. Sheep were closely shorn before application. Feces were collected by taping a plastic bag to this square with additional duct tape.

After the preliminary adaptation period, the animals were adjusted to a constant intake of a conventional ration (table 2) and a nitrogen balance trial was conducted. Water was provided ad libitum.

Following nitrogen balance on preliminary diets the animals were placed on a complete liquid diet (table 1). The liquid diet was prepared fresh daily, and brought up to the desired volume with distilled water in a 19 liter plastic carboy. Stock mineral solutions were made up in 5-day supplies using deionized distilled water. The ration was kept in suspension by use of a variable speed stirring motor and a 6.35 mm brass rod equipped with 3 folding plastic propellers. The stirring

TABLE 1. LIQUID RATION COMPOSITION

SOURCE	AMOUNTS[1]	
Corn starch	460.000	(230.000)[6]
Cane sugar	230.000	(115.000)[6]
Promosoy[3]	40.000	
Urea	7.000	
$MnSO_4$ H_2O	237.070[2]	
K_2CO_3 $1\frac{1}{2}H_2O$	37.396	
$ZnSO_4$ $7H_2O$	391.304[2]	
Na_2Mo O_4 $2H_2O$	6.944[2]	
$CaCl_2$	9.138	
Na_2HPO_4	11.916	
$MgSO_4$ $7H_2O$	10.761	
$MgCl_2$ $6H_2O$	4.068	
NaCl	10.000	
$CoCl_2$ $6H_2O$	0.806[2]	
$CuCl_2$	33.884[2]	
KI	0.980[2]	
CrK $(SO_4)_2$ $12H_2O$	1.440[2]	
$FeSO_4$ $7H_2O$	1.100	
Vitamin A[4]	4.400[2]	
Vitamin D[5]	0.600[2]	

1/ Expressed in grams per day unless otherwise indicated
2/ mgs per day
3/ Water-dispersable soy protein
4/ Vitamin A palmitate, water-dispersable, 250,000 I.U./gm
5/ Vitamin D_2, water-dispersable, 500,000 I.U./gm
6/ Concentration used in trials 3, 4, 5 and 6

TABLE 1a. DAILY REQUIREMENT[1/]

Nutrient	Requirement[5/]	Supplied
Digestible Energy	3000.00[2/]	2920.000[2/]
Digestible Protein	59.00	59.740
Mn	70.00[3/]	77.064[3/]
K	17.70	17.700
Zn	90.00[3/]	88.957[3/]
Mo	2.80[3/]	2.753[3/]
Ca	3.30	3.300
P	2.60	2.600
Mg	1.54	1.547
Na	3.95	7.793
Cl	6.07	13.337
Co	0.20[3/]	0.200[3/]
Cu	16.00[3/]	16.000[3/]
I	0.75[3/]	0.749[3/]
Cr	0.15[3/]	0.150[3/]
Fe	0.22	0.221
S	1.50	1.615
Vitamin A	1100.00[4/]	1000.000[4/]
Vitamin D	300.00[4/]	300.000[4/]

1/ Expressed in gm per day unless otherwise indicated
2/ Kcal per day
3/ Mg per day
4/ I. U. per day
5/ Value taken from N.R.C. and a purified diet (Sidhu *et al.*, 1969)

TABLE 2. CONVENTIONAL RATIONS

PELLET RATION

Trial	Composition	%
1 and 2	Dehy. Alfalfa	50.00
	Sorghum Grain	40.00
	Molasses	5.00
	Soy Bean Meal	5.00
		100.00

GRAIN-UREA RATION

Trial	Composition	%
3, 4, 5 and 6	Sorghum Grain	99.00
	Urea	1.00
		100.00

rod was supported and stabilized by means of two nylon bushings imbedded in a rubber stopper in the mouth of the carboy. One to two gm Poloxalene[1] was added to the ration to prevent foaming in the carboy. Constant 24 hour ruminal infusion of the diet was obtained by use of a variable speed peristaltic pump[2] using approximately 300 cm of tygon tubing (.79 mm I.D. X 3.97 mm O.D.). Water and the conventional ration were offered until voluntary intake ceased.

Blood samples were obtained by juglar puncture using an 18 gauge needle. Twenty ml of blood was taken, of which approximately 3 ml was heparinized for hematocrit (HCt) and hemoglobin (Hb) determination. The remainder was allowed to clot and the serum collected for mineral, serum protein, and serum glutamic oxaloacetic transaminase (SGOT) determinations. Blood for pH, pCO_2, and pO_2 was collected in a 5 ml glass heparinized syringe. The needle was imbedded in a rubber stopper and syringe and sample were kept in an ice water bath until analyzed (approximately 15 minutes). Hematocrit was determined by use of a Clay Adams micro hematocrit centrifuge. Hemoglobin was determined by colorimetric analysis as described by Crosby et al., 1964. Serum protein was determined by differential spectrophotometric analysis using the method of Waddell and Hill (1956). Na and K were determined by flame emission spectrophotometry and Ca, Mg, Zn, and Cu by atomic absorption using a Jarrel Ash atomic absorption-flame emission spectrophotometer (Ullery et al., 1967). Phosphorus was determined by the

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[1] polyoxypropylene polyoxyethylene block polymer
Smith Kline and French Laboratories, No. 18667, Philadelphia, Pa.

[2] Cole-Parmer, pump model no. 7545-15, pump head no. 7013
7425 North Oak Park Avenue, Chicago, Illinois 60648.

phosphomolybdate blue technique (Varley, 1960). Blood pH, pO_2 and pCo_2 were determined on a blood gas analyzer.[1] SGOT was determined by the method of Reitman and Frankel (1957).

Daily fecal samples were taken during N balance studies by removal and replacement of the plastic collection bag. Daily urine samples were also taken. Feed samples during the conventional feeding N-balance study were taken at 2 day intervals. Feed and feces samples were analyzed for nitrogen by the Kjeldahl method (A.O.A.C., 1955) without drying or grinding. Two gm feed samples and 2 to 4 gm feces samples were digested. Urine samples (2 ml) were also analyzed by the Kjeldahl method. Approximately 10% of the daily urine and feces were refrigerated or frozen respectively for other possible analysis.

Rumen canulas were prepared by a modification of the method of Yarns and Putnam (1960). A hard plastic tube was placed in the neck of the canula and secured with a hose clamp. A rubber stopper with holes for the infusion and sampling tubes was fitted tightly into the hard plastic tube and secured with duct tape. The sampling tube consisted of 9.53 mm plastic tubing with several 3.18 mm holes along the internal end, which was corked. The external end was closed with a screw-type pinch clamp except when samples were being taken. Rumen fluid samples were taken by fitting the sampling tube to a drench gun and aspirating.

Samples of rumen fluid were taken for pH determination and aliquots were frozen after addition of acid for volatile fatty acid

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[1] Corning model 16

analysis. Volatile fatty acids were separated on a 183.0 cm X 3.18 mm stainless steel column packed with (60-80 mesh) Chromosorb 101, using a flash vaporization inlet, hydrogen flame detection, and an oven temperature of 200 C (isothermal). The carrier gas was nitrogen.

Trial I A mature wether (49.0 kg) was placed in a metabolism crate, fed 800 gm per day of a pelleted ration (composition shown in table 2). A six day nitrogen balance study was conducted. Following this trial infusion of the liquid diet (table 1) was begun at the rate of 12 liters per day. After a 15 day adjustment period a four day nitrogen balance study was conducted. Rumen samples were obtained and pH measured. The samples were also examined microscopically. Sodium bicarbonate was given via the sampling tube when the pH appeared to be dropping to a dangerous level (below pH 5.0). After a total of 19 days on the liquid ration the animal died and was taken to Dykstra Veterinary Clinic for necropsy.

Trial II A mature wether (54.5 kg) was fed 600 gm of the same pelleted ration used in trial I in a metabolism crate. After the adjustment period a nitrogen balance study was conducted for six days. Two hundred and eighty gm of a synthetic plastic roughage[1] was placed in the rumen via the canula. At the conclusion of this study the liquid diet was infused at the rate of 8 liters per day. Rumen and urine samples were taken and pH determined. Urine pH was determined on freshly voided samples. Sodium bicarbonate was given when rumen pH dropped to hazardous levels (below pH 5.0). Samples of rumen fluid

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[1] Ruff tabs by Farmland Industries

were frozen for volatile fatty acid (VFA) determination. Blood samples were taken for hemoglobin, hematocrit, mineral, and serum protein determination. Respiration rate was counted. After 7 days liquid infusion was ended due to increased respiratory rate and diarrhea. A nitrogen balance study was not run during this trial due to loss of canula plug and the short duration of the trial.

Trial III The animal used in trial II was adapted to a sorghum grain-urea diet (table 2) in a free stall for 30 days after the conclusion of trial II. The animal, then weighing 49.0 kg, was put on a constant intake (800 gm) of the sorghum grain-urea ration in the metabolism crate and a 5 day N-balance study conducted. Following this study the liquid diet was infused at 8 liters per day, however, the energy and protein content were reduced to 1/2 the original concentration (table 1) by reduction in the amounts of sugar, starch, soy protein, and urea. Rumen and urine pH were determined periodically and rumen fluid saved for VFA determination. Sodium bicarbonate was not given during this trial. Blood samples were taken for Hb, HCt, SGOT, serum minerals, pH, pCO_2, and pO_2. Respiratory rate was counted periodically. The trial concluded after 19 days on the liquid diet because of very apparent respiratory distress. The animal was taken to the veterinary clinic as soon as the distress became apparent but died within minutes after arrival.

Trial IV A wether lamb (36.4 kg) was fistulated using a modification of the technique used on previous animals. The neck of the canula was passed through a hole in the center of a 10.0 cm square

Dacron surgical patch[1] and the patch cemented in position approximately 3.18 mm from the inside flange, using epoxy cement. During surgical installation of the canula the Dacron patch was sutured in position between the rumen wall and the wall of the peritoneum. The use of this method was intended to minimize leakage around the canula.

After complete surgical recovery the animal was put on a constant intake of 800 gm of sorghum grain-urea ration in a metabolism crate. A five day nitrogen balance trial was conducted following which the animal was put on the liquid ration. The energy concentration was cut to 1/2 (by reducing the starch and sugar by - table 1 - 1/2) the original value. However, the protein content was left as shown in table 1. Infusion was at the rate of 8 liters per day. Data collected were as in trial III with the exception of N-balance on liquid ration. The trial ended after five days when acute respiratory distress was observed. The animal was immediately taken to the clinic for treatment but lived only approximately 3 hours after arrival.

Trial V A wether lamb (36.4 kg) was fistulated by the technique described in trial IV. After adaptation to the sorghum grain-urea ration a constant intake of 800 gm per day was maintained and a 6-day nitrogen balance study conducted. The liquid diet was infused at the rate and concentration used in trial IV. Data collected were as in trial IV except that rectal temperature was monitered periodically. The trial concluded after three days when increased respiration rate and elevated rectal temperature were observed. Due to the short time, nitrogen balance data were not collected during the liquid infusion

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[1] Usher's Marlex Mesh (Mid-west Surgical Supply Co., Inc. Wichita, Kansas)

phase of the trial.

Trial VI A wether lamb (31.8 kg) was prepared as in trials IV and V. A six day nitrogen balance study was conducted while the animal was on the sorghum grain-urea ration. Data collected were as in trial V. In addition, serum was checked for antibody reaction to promosoy by a modification of the gel immunodiffusion technique described by Ouchterlony (1948).

RESULTS AND DISCUSSION

Trial I The pelleted ration used during the preliminary period contained 13.4% protein. The amount fed during the nitrogen balance study furnished an average of 17.20 grams of nitrogen per day (table 3). Average nitrogen excretion in the feces and urine combined was approximately 15.10 gm per day, the net result being a positive nitrogen balance of 2.10 gm per day.

During the liquid infusion phase of the trial, it was necessary to strain the liquid ration and dilute to a total of 12 liters to prevent clogging of the infusion tube. A preliminary period of 15 days was required to work out problems in the infusion technique. A four day nitrogen balance was then conducted. The liquid diet furnished 9.20 grams of nitrogen per day. Combined urinary and fecal nitrogen averaged 9.18 gram giving an average nitrogen balance of 0.02 gram per day. Although the volume of urine increased to over 10 times the amount of nitrogen excreted in the urine decreased. The amount of feces excreted during liquid infusion was greatly reduced but contained a higher concentration of nitrogen.

The pH of the liquid diet was reduced from 9.8 to 7.5 by addition of 6 N HCl. However, when the ruminal pH was observed to drop, the addition of acid was discontinued. Further falling of ruminal pH caused increased concern and doses of sodium bicarbonate were given intraruminally (50 gm in 100 ml H_2O) in an attempt to maintain a higher pH. The addition of sodium bicarbonate resulted in an increase in pH from 4.9 to 6.5. The pH returned to 4.85 within 12 hours.

TABLE 3

NITROGEN BALANCE STUDIES

Day	Intake[2]	Feces[2]	Urine[2]	N-Balance[2]
		TRIAL I CONVENTIONAL RATION[1]		
1	17,216.00	6,436.67	12,408.50	-1629.17
2	17,216.00	6,792.66	8,688.00	+1735.34
3	17,216.00	5,772.96	8,464.00	+2974.04
4	17,216.00	6,339.65	7,985.25	+2891.10
5	17,216.00	6,245.00	8,308.00	+2663.00
6	17,216.00	6,275.20	6,815.00	+4125.80
			mean	+2126.69
		TRIAL I LIQUID RATION[3]		
1	9,620.00	3,141.27	5,600.00	+878.73
2	9,620.00	4,039.65	6,473.25	-892.90
3	8,818.37	3,265.70	5,888.40	-335.73
4	9,219.21	2,952.00	5,824.00	+443.21
			mean	+ 23.33

1/ Alfalfa pellet ration (800 gm/day), composition as in table 2
2/ Mg nitrogen per day
3/ 12 liters/day, composition as in table 1

Microscopic examination of the rumen fluid samples revealed a decrease in protozoa numbers, until after 7 days of infusion, protozoa were not observed. During this time, the gross microscopic bacterial population shifted from predominately rods to predominately cocci.

Soon after infusion began, a considerable amount of distension of the rumen became apparent. Unsuccessful regurgitation and erructation attempts were observed. After 2 weeks on the infusion, excessive nasal discharge were observed which dried into a caked mass in the nostrils. Respiration rate, however, remained normal.

The animal died suddenly on the 19th day of infusion. Approximately 1 hour before death the animal showed no apparent distress. There was no apparent cyanosis or edema. Necropsy indicated possible aspiration pneumonia with pulmonary and pericardial edema. Gastrointestinal mucosa and other organs were normal. Absence of digesta distal to the abomasum indicated complete digestion and absorption in the rumen.

Trial II During the conventional feeding phase of this trial the amount of pelleted ration was reduced from 800 gm to 600 gm to insure constant intake. Nitrogen balance data shown in table 4 indicate that this amount was adequate to provide a positive nitrogen balance.

When liquid infusion was begun it was found that by increasing the size of the tubing from the carboy to the pump (from .79 mm to 1.59 mm I.D.) the volume of the liquid could be reduced from 12 to 8 liters without plugging the infusion line. The decision to reduce the volume was prompted by the distension of the rumen and possible elevation of the liquid level above that of the cardia, resulting in inhibition of erructation and possible aspiration pneumonia. The

TABLE 4

NITROGEN BALANCE STUDIES[1/]

TRIAL II

Day	Intake[2/]	Feces[2/]	Urine[2/]	N-Balance[2/]
1	14,250.00	4,576.00	7,140.00	+2,534.00
2	14,250.00	2,573.88	3,003.00	+8,673.12
3	14,250.00	5,514.60	8,667.00	+ 68.40
4	14,250.00	4,626.35	5,968.00	+3,655.65
5	14,250.00	4,077.85	8,420.50	+1,751.65
6	14,250.00	4,746.00	8,487.60	+1,016.40
			mean	+2,949.87

1/ Alfalfa pellet ration (600 gm/day), composition as in table 2
2/ Mg nitrogen per day

placing of a plastic synthetic roughage in the rumen was hoped to stimulate salivation and increase buffering in the rumen. As the trial proceeded it was found that the synthetic particles were removed from the rumen by regurgitation and many were dropped from the mouth and lost during rumination attempts.

Rumen samples were taken for pH determination and aliquots frozen for VFA determination. When pH dropped to hazardous levels, sodium bicarbonate was given as in trial I. Results of VFA determinations are shown in table 5. During the feeding phase the acetate: propionate (A:P) ratio was normal for a ration of this type (Jorgensen and Schultz, 1963). The A:P ratio (liquid phase) is much higher than expected on a highly fermentable ration. The reason for this is not readily apparent. The propionate and butyrate concentrations appeared to be within a reasonable range but acetate concentration was extremely high.

Blood samples were taken and analyzed for serum minerals, serum protein, hemoglobin and hematocrit during both phases of the trial. Results of mineral analysis (table 6) indicate that an electrolyte imbalance did not develop as was suspected following observation of edema at necropsy in trial I. Serum protein determination showed no change between the two phases of the trial. Hematocrit and hemoglobin analysis (table 7) seem to indicate slight hemodilution, although values remained within the "normal" range (Merck Veterinary Manual, 1957).

During the liquid infusion phase additional blood was taken for determination of pH, pO_2, and pCO_2. All values were maintained within the "normal" range (table 7). Urine pH was maintained at an average of 8.1.

TABLE 5

RUMINAL VFA CONCENTRATIONS

TRIAL II

Day[3]	Ration	Acetic (uM/ml)	Acetic (M%)[4]	Propionic (uM/ml)	Propionic (M%)	Butyric (uM/ml)	Butyric (M%)	A:P[5]
1	Conv.[2]	110.41	66.87	34.44	20.86	20.25	12.27	3.21
3		84.64	68.69	19.43	15.77	19.15	15.54	4.36
5		58.98	65.81	14.55	16.23	16.10	17.96	4.05
6		92.92	63.03	29.87	20.26	24.62	16.71	3.11
	means	86.74	66.10	24.57	18.28	20.03	15.62	3.68
1	Liq.[1]	101.03	74.12	22.91	16.81	12.37	9.07	4.41
2		108.10	71.31	29.64	19.55	13.85	9.14	3.65
3		98.54	54.92	46.67	26.01	34.23	19.08	2.11
4		106.85	55.04	50.88	26.21	36.41	18.75	2.10
5		91.47	70.93	10.12	7.85	27.37	21.22	9.04
6		96.37	72.94	29.16	22.07	6.60	5.00	3.31
7		101.86	76.20	7.74	5.79	24.08	18.01	13.16
	means	100.60	67.92	28.16	17.76	22.13	14.32	5.40

1/ 8 liters/day, composition as in table 1
2/ 600 gm/day, alfalfa pellet ration (table 2)
3/ Days 1-7 of 7 day liquid ration infusion, days 1, 3, 5 and 6 of 6 day N-Balance on conventional ration
4/ Molar percent
5/ Acetate:propionate ratio

TABLE 6

SERUM MINERAL CONCENTRATION

Trial II

Day[3]	Ration	mg/100 ml Na	K	Mg	Ca	P	mcg/ml Cu	Zn
4	Conventional[1]	370.0	28.5	2.67	11.9	6.40	1.18	0.69
6		326.0	19.4	1.71	10.9	5.90	1.85	0.66
3	Liquid[2]	377.0	21.5	1.69	12.8	4.65	1.53	0.53
5		370.5	19.3	1.43	11.2	5.00	1.50	0.50
7		337.5	44.5	1.50	11.5	3.22	2.38	1.25

1/ 600 gm/day pelleted ration, composition as in table 2
2/ 8 liters/day, composition as in table 1
3/ Day 4 and 6 or 6 day N-balance on conventional ration, days 3, 5, and 7 of 7 day liquid ration infusion

TABLE 7

BLOOD HCt, Hb, pH, pO_2, pCO_2 AND SERUM PROTEIN VALUES

Trial II

Day 3/	Ration	HCt (%)	Hb (gm/100 ml)	pH	pO_2 mmHg	pCO_2	Serum Protein (gm/100 ml)
4	Conventional 1/	41.45	14.37	-	-	-	5.18
6		39.45	14.00	-	-	-	6.84
3	Liquid 2/	44.25	16.19	-	-	-	6.41
5		29.25	19.60	7.51	39.00	40.00	6.62
7		31.00	9.88	7.48	34.25	39.00	5.07

1/ 600 gm/day pelleted ration, composition as in table 2
2/ 8 liters/day, composition as in table 1
3/ Days 4 and 6 of 6 day N-Balance on conventional ration, days 3, 5 and 7 of 7 day liquid ration infusion

After one week of the liquid infusion it was necessary to end the trial because of increased respiration rate (over 100/min) and diarrhea of the animal.

Trial III The problems in controlling ruminal pH during trials I and II suggested that adaptation to a high concentrate ration prior to infusion might be helpful. The animal used in trial II was therefore adapted to an all concentrate ration prior to the beginning of trial III.

Nitrogen balance data is shown in table 8. During the conventional feeding, a mean nitrogen retention of 5.0 gm/day was obtained. The fact that the animal weighed 5.45 kg less at the start of the study may help to explain the relatively high N-balance. The animal may have been in a strongly anabolic state because of efforts of the body to maintain and replace body tissues broken down during trial II.

During the liquid phase of the trial, a net nitrogen balance of -2.35 gm/day was obtained. Since the protein content of the ration was reduced it is doubtful that minimum maintainance requirements were met.

Rumen pH during the feeding phase was maintained at an average of 5.8. Although the ration fed during this trial contained a much higher concentration of energy than that used in previous trials, there was no drop in ruminal pH. The pH of ruminal fluid increased to an average of 6.5 when the liquid diet was infused. This increase in pH could have been due to the decrease in readily available carbohydrate.

This decrease in readily available CHO was also accompanied by a decrease in VFA concentration (table 9) when compared to the conventional feeding during this trial or to the infusion phase of trial II.

TABLE 8

N-BALANCE STUDIES

Day	Intake[2]	Feces[2]	Urine[2]	N-Balance[2]
		TRIAL III CONVENTIONAL RATION[1]		
1	16,576.00	4,222.37	5,160.00	+7,193.63
2	16,576.00	4,564.00	9,620.00	+2,391.12
3	16,576.00	3,519.94	6,886.00	+6,170.06
4	16,576.00	2,866.50	7,624.50	+6,085.00
5	16,576.00	6,175.00	6,762.00	+3,639.00
			mean	+5,095.76
		TRIAL III LIQUID RATION[3]		
1	3,607.50	514.00	4,259.20	-1,165.70
2	4,509.38	5,265.00	3,710.00	-4,465.62
3	4,509.38	1,435.00	5,655.00	-2,580.62
4	4,509.38	406.40	4,425.00	- 322.02
5	3,006.25	1,233.05	4,992.00	-3,218.80
			mean	-2,350.55

1/ Grain+urea ration (800 gm/day), composition as in table 2
2/ Mg nitrogen per day
3/ 8 liters/day, composition as in table 1 except starch, sugar, protein and urea were each reduced by 50 percent

TABLE 9

RUMINAL VFA CONCENTRATIONS

TRIAL III

Day[3]	Ration	Acetic (uM/ml)	Acetic (M%)[4]	Propionic (uM/ml)	Propionic (M%)	Butyric (uM/ml)	Butyric (M%)	A:P[5]
1	Conv.[1]	59.14	45.12	52.48	40.04	19.45	14.84	1.23
2		54.92	43.68	51.75	41.16	19.06	15.16	1.06
3		68.92	56.86	35.75	29.49	16.55	13.65	1.93
4		30.62	44.67	29.00	42.31	8.92	13.01	1.06
5		56.21	44.36	51.00	40.25	19.50	15.39	1.10
	means	53.96	46.94	44.00	38.65	16.70	14.41	1.28
1	Liq.[2]	24.84	49.68	19.02	38.04	6.14	12.28	1.31
2		25.21	49.38	19.28	37.77	6.56	12.85	1.31
3		22.36	55.44	15.78	39.13	2.19	5.43	1.42
4		28.21	54.60	13.54	26.20	9.92	19.20	2.08
5		30.13	55.21	12.48	22.87	11.96	21.92	2.41
6		28.83	56.34	15.21	29.72	7.13	13.93	1.90
7		30.24	56.77	15.68	29.43	7.35	13.80	1.93
8		32.51	55.78	16.08	27.59	9.69	16.63	2.02
9		55.89	47.12	49.91	42.08	12.80	10.79	1.12
10		28.92	51.40	13.21	23.48	14.14	25.13	2.19
11		33.58	57.46	14.57	24.93	10.29	17.61	2.30
12		34.50	61.00	15.94	28.18	6.12	10.82	2.16
13		33.21	54.90	19.58	32.37	7.70	12.73	1.70
14		15.31	63.61	5.14	21.35	3.62	15.04	2.98

TABLE 9 (continued)

Day[3]	Ration	Acetic (uM/ml)	Acetic (M%)[4]	Propionic (uM/ml)	Propionic (M%)	Butyric (uM/ml)	Butyric (M%)	A:P[5]
15		16.26	64.42	4.86	19.26	4.12	16.32	3.35
16		33.75	52.69	13.32	20.80	16.98	26.51	2.53
17		39.85	43.47	28.63	31.23	23.19	25.30	1.39
18		39.25	46.16	25.88	30.44	19.90	23.40	1.52
19		25.92	57.54	8.88	19.71	10.25	22.75	2.92
	means	30.46	54.37	17.21	28.66	10.00	16.97	1.87

1/ 800 gm/day grain+urea ration (table 2)
2/ 8 liters/day, composition as in table 1 except starch, sugar, protein and urea were each reduced by 50 percent
3/ Days 1-5 of 5 day N-Balance on conventional ration, days 1-19 of 19 day liquid ration infusion
4/ Molar percent
5/ Acetate:Propionate ratio

The decrease in the A:P from that observed in trial II is, however, difficult to explain considering the reduction in energy. Based upon VFA concentration and ratios, the energy reduction apparently set up conditions in the rumen which more closely approximated the "normal" condition.

Serum mineral values of both liquid and conventional rations appeared to be within the normal range. Based on the mineral analysis data, there was no apparent electrolyte imbalance. Daily variation was observed, as was the case in all trials. Although part of the variation may have been due to contamination, the bulk of the variation was apparently normal (table 10).

The hematocrit and hemoglobin values (table 11) showed a consistant decrease on the liquid ration, as compared to the conventional. Blood pH, pO_2, pCO_2 and serum protein values appeared to be in the normal range (table 11) with no change between treatments.

Blood SGOT levels (table 24) were much higher for the liquid ration. The day prior to the animals' death these values were observed to reach a level of approximately 10 times that seen during the conventional ration.

The animal had an increased respiration rate on day 19 of the liquid ration infusion, and was rushed to the veterinary clinic, but died within minutes after arrival with an observed rectal temperature of 109.5 F. The edemic condition found in the animal in trial I was not present at necropsy. No signs of aspiration pneumonia were observed. The gut mucosa and kidneys appeared to be normal.

TABLE 10

SERUM MINERALS AND REGRESSION EQUASIONS

TRIAL III

Day[3]	Ration	mg/100 ml Na	K	Mg	Ca	P	mcg/ml Cu	Zn
1	Conventional[1]	343.0	20.7	2.30	14.0	6.50	1.80	0.60
3		337.0	19.7	1.92	9.8	7.25	3.50	0.68
5		330.0	22.0	1.91	8.8	6.00	3.18	0.49
2	Liquid[2]	347.0	25.3	2.05	9.5	6.88	1.40	0.78
5		329.0	21.2	2.15	13.5	4.77	2.18	0.76
7		330.0	21.8	2.15	13.8	6.38	2.25	0.67
9		329.0	25.9	2.08	14.1	4.56	.75	0.63
12		334.0	25.3	2.10	10.5	5.00	1.05	0.93
14		333.0	27.9	2.19	12.5	6.60	2.55	0.72
16		336.0	23.0	2.13	14.6	8.90	1.63	0.76
19		318.0	22.3	2.35	9.4	6.06	1.10	0.87

1/ 800 gm/day grain+urea ration, composition as in table 2

2/ 8 liters/day, composition as in table 1 except starch, sugar, protein and urea were each reduced by 50 percent

3/ Days 1,3 and 5 of 5 day N-Balance on conventional ration, days 2 through 19 of 19 day liquid ration infusion

TABLE 10 (continued)

MINERAL	REGRESSION EQUASION	PROBABILITY (b ‡ o)
Na	y = 341.00-.812x	.1-.2
K	y = 23.90+.021x	.5
Mg	y = 2.03+.011x	.05-.1
Ca	y = 12.45-.020x	.5
P	y = 5.37+.073x	.4-.5
Cu	y = 1.79-.017x	.5
Zn	y = .70+.006x	.1-.2

TABLE 11

BLOOD HCt, Hb, pH, pO_2, pCO_2 AND SERUM PROTEIN VALUES

TRIAL III

Day[3]	Ration	HCt (%)	Hb (gm/100 ml)	pH	pO_2 mmHg	pCO_2	Serum Protein (gm/100 ml)
1	Conventional[1]	28.00	7.86	7.468	41.5	29.5	6.70
3		28.25	9.85	7.350	37.5	49.5	6.12
5		28.85	9.79	7.330	43.5	37.0	5.90
2	Liquid[2]	26.00	9.55	7.380	50.5	41.5	6.77
5		24.50	8.40	7.430	43.5	30.8	5.33
7		22.75	7.38	7.478	49.0	30.0	5.69
9		22.50	7.24	7.415	-[4]	38.5	6.22
12		22.00	7.96	7.440	-	41.3	6.26
14		21.75	7.43	7.485	-	37.8	5.69
16		21.15	7.86	7.398	-	42.5	6.26
19		23.00	8.22	7.470	-	32.5	5.69

1/ 800 gm/day grain+urea ration
2/ 8 liters/day, composition as in table 1 except starch, sugar, protein and urea were each reduced by 50 percent
3/ Days 1, 3 and 5 of 5 day N-Balance on conventional ration, days 2 through 19 of 19 day liquid ration infusion
4/ pO_2 electrode inoperative

Trial IV Although leakage around the cannula caused no severe problems in the previous trials, a new method of fistulation was devised to insure minimum leakage.

During the conventional phase the nitrogen intake was sufficient to maintain a positive nitrogen balance of approximately 7.0 grams per day (table 12). The mean nitrogen retention was much higher than that of any of the previous trials. Since the animal used in this trial was a young, growing lamb, these results were not surprising.

The ruminal pH values increased from approximately 5.6 on the conventional ration to 6.7 during the liquid infusion.

The total VFA concentration decreased as a result of the liquid infusion (table 13). The decrease in VFA concentrations helps to explain the increased pH during the liquid phase. The A:P ratio was increased by the liquid infusion. Higher A:P ratios and VFA concentrations may indicate a decrease in highly fermentable carbohydrates in the liquid ration compared to the conventional phase of the trial. Even though the A:P ratio was widest during the liquid phase of the trial, the values observed closely approximated those observed during the liquid phase of trial III.

The serum mineral concentrations, shown in table 14, are normal in both phases of the trial.

The hematocrit and hemoglobin values (table 15) appear to be within the normal range in both phases of the trial and are representative of values observed in the previous trials. Due to electrode problems the pO_2 values were not determined. However, pCO_2, pH and serum protein values were measured. Changes during the two phases of the trial were not great.

TABLE 12

NITROGEN BALANCE STUDIES[1/]

TRIAL IV

Day	Intake[2/]	Feces[2/]	Urine[2/]	N-Balance[2/]
1	18,256.00	4,815.15	4,830.00	+8,610.85
2	18,256.00	5,685.75	6,480.00	+6,090.25
3	18,256.00	4,988.15	7,363.00	+5,904.85
4	18,256.00	5,199.95	6,127.00	+6,929.05
5	18,256.00	5,947.20	4,500.00	+7,808.80
			mean	+7,068.76

1/ Conventional ration, 800 gm/day grain+urea (table 2)
2/ Mg nitrogen per day

TABLE 13

RUMINAL VFA CONCENTRATIONS

TRIAL IV

Day[3]	Ration	Acetic (uM/ml)	Acetic (M%)[4]	Propionic (uM/ml)	Propionic (M%)	Butyric (uM/ml)	Butyric (M%)	A:P[5]
1	Conv.[1]	38.28	41.88	46.00	50.32	7.13	7.80	0.83
2		40.22	43.00	45.59	48.74	7.72	8.25	0.88
3		40.15	43.15	45.80	49.22	7.10	7.63	0.88
4		40.13	41.62	49.05	50.87	7.25	7.52	0.82
5		45.12	44.19	49.97	48.94	7.02	6.87	0.90
	means	40.78	42.77	47.28	49.62	7.24	7.61	0.86
2	Liq.[2]	29.33	59.48	17.62	35.73	2.36	4.79	1.66
3		30.05	54.00	20.10	36.12	5.50	9.88	1.50
4		63.18	53.35	42.94	36.26	12.31	10.39	1.47
	means	40.85	55.61	26.89	36.04	6.72	8.35	1.54

1/ 800 gm/day grain+urea ration (table 2)
2/ 8 liters/day, composition as in table 1 except each carbohydrate source reduced by 50 percent
3/ Days 1-5 of 5 day N-Balance on conventional ration, days 2, 3 and 4 of 7 day liquid ration infusion
4/ Molar percent
5/ Acetate:propionate ratio

TABLE 14

SERUM MINERAL CONCENTRATIONS

TRIAL IV

Day[3]	Ration	mg/100 ml Na	K	Mg	Ca	P	mcg/ml Cu	Zn
1	Conventional[1]	325.0	17.8	2.50	12.8	7.20	2.08	0.71
3		320.0	18.2	2.52	9.8	6.00	1.88	0.64
5		315.0	14.8	1.88	13.0	5.85	2.55	0.77
3	Liquid[2]	330.0	17.8	2.30	10.5	6.80	2.14	0.64
5		330.0	18.0	2.60	10.8	5.60	2.61	0.88

1/ 800 gm/day grain+urea ration (table 2)
2/ 8 liters/day, composition as in table 1 except each carbohydrate source reduced by 50 percent
3/ Days 1, 3 and 5 of 5 day N-Balance on conventional ration, days 3 and 5 of 7 day liquid ration infusion

TABLE 15

BLOOD HCt, Hb, pH, pO_2, pCO_2 AND SERUM PROTEIN VALUES

TRIAL IV

Day 3/	Ration	HCt (%)	Hb (gm/100 ml)	pH	pO_2 mmHg	pCO_2	Serum Protein (gm/100 ml)
1	Conventional 1/	32.45	11.44	7.438	- 4/	37.00	6.48
3		36.35	13.53	7.358	-	37.25	6.20
5		24.00	9.00	7.355	-	34.50	5.76
3	Liquid 2/	31.00	11.52	7.340	-	37.00	6.48
5		31.25	12.89	7.394	-	34.50	5.91

1/ 800 gm/day grain+urea ration, composition as in table 2
2/ 8 liters/day, composition as in table 1 except each carbohydrate source reduced by 50 percent
3/ Days 1, 3 and 5 of 5 day N-Balance on conventional ration, days 3 and 5 of 7 day liquid ration infusion
4/ pO_2 electrode inoperative

SGOT values were abnormally high during both the liquid and conventional phases of the trial. The values were slightly higher during the liquid phase of the trial. These higher values suggest cellular breakdown, since glutamic-oxalacetic transaminase is usually intracellular (table 24).

When the animal was observed to have an apparent respiratory problem, the assistance of a veterinarian was obtained. The animal lived approximately 3 hours after arrival at the veterinary clinic. Labored breathing was observed during this time. Rectal temperature increased from 105 F to 108.5 F during the three hour period. During necropsy tissue cultures of the upper, middle and lower gut were taken for clostridium perfringes analysis. Lung and liver tissue was cultured. Lung abscesses were observed but were not associated with the treatment. The gut mucosa and kidneys were in normal condition. The results obtained from the tissue cultures did not explain the cause of death.

Trial V The animal used in the trial was young and growing rapidly. Nitrogen balance data for the conventional phase is given in table 16. The net result is a positive nitrogen balance of 6.4 grams per day.

The liquid diet was infused at the rate and concentration used in trial IV. The average ruminal pH during the conventional ration was 5.6 compared to 5.4 during the liquid phase.

Volatile fatty acid data is given in table 17. Propionic acid concentration showed very little change from that observed during the feeding phase. However, the acetic acid values showed a slight increase. Total VFA concentration did not decrease as a result of the

TABLE 16

NITROGEN BALANCE STUDIES[1/]

TRIAL V

Day	Intake[2/]	Feces[2/]	Urine[2/]	N-Balance[2/]
1	19,192.00	3,802.50	5,692.50	+9,697.00
2	19,192.00	4,625.60	15,045.00	- 478.60
3	19,192.00	4,559.84	8,843.55	+5,788.61
4	19,192.00	4,067.25	9,785.00	+5,339.75
5	19,192.00	4,411.80	7,087.50	+7,692.70
6	19,192.00	3,700.40	5,112.50	+10,379.10
			mean	+6,408.09

1/ Conventional ration, 800 gm/day grain+urea (table 2)
2/ Mg nitrogen per day

TABLE 17

RUMINAL VFA CONCENTRATIONS

TRIAL V

Day[3]	Ration	Acetic (uM/ml)	Acetic (M%)[4]	Propionic (uM/ml)	Propionic (M%)	Butyric (uM/ml)	Butyric (M%)	A:P[5]
1	Conv.[1]	31.05	37.38	42.52	51.17	9.51	11.45	0.73
2		39.45	42.64	44.64	48.25	8.43	9.11	0.88
3		36.87	41.06	43.94	48.93	8.99	10.01	0.84
4		38.14	43.62	40.11	45.88	9.18	10.50	0.95
5		36.65	40.65	44.05	48.85	9.47	10.50	0.83
6		34.27	40.54	41.75	49.38	8.52	10.08	0.82
		36.07	40.98	42.84	48.74	9.02	10.28	0.84
1	Liq.[2]	48.41	49.13	40.25	40.85	9.87	10.02	1.20
2		48.22	51.23	39.24	41.69	6.66	7.08	1.23
		48.32	50.18	39.73	41.27	8.27	8.55	1.22

1/ 800/gm day train+urea ration, composition as in table 2
2/ 8 liters/day, composition as in table 1 except each carbohydrate source reduced by 50 percent
3/ Days 1-6 of 6 day N-Balance on conventional ration, days 1 and 2 of 2 day liquid ration infusion
4/ Molar percent
5/ Acetate:Propionate ratio

liquid infusion as compared to trial IV. A possible explanation for these results as compared to trial IV could have been the short duration of the liquid infusion phase.

Serum mineral data appears in table 18. All values were maintained within the normal range.

Hematocrit and hemoglobin values showed very little change between treatments (table 19). Values for pO_2, pCO_2, pH and serum protein were also maintained within the normal range.

SGOT values are given in table 24. Observed values were slightly higher than normal during both phases of the trial. Respiration rate almost doubled during the two day infusion period while rectal temperature increased from 103.0 to 106 F.

After 2 days of liquid infusion signs of distress, labored breathing and excessive nasal discharge were readily apparent. Therefore, the animal was taken off the liquid diet.

Trial VI The animal used in this trial was approximately the same age and condition as the animal in trial V. A positive nitrogen balance of approximately 5.7 grams per day was maintained during the conventional phase of the trial (table 20).

The liquid diet was infused at the rate and concentration used in trials IV and V. Mean ruminal pH values increased from 5.9 during the feeding phase to 6.2 during the liquid infusion. Volatile fatty acid data is shown in table 21. Total VFA concentrations decreased following the liquid infusion. The A:P ratios were observed to be very similar to those seen in trial IV. Butyric acid concentration was considerably higher during the feeding phase as compared to trial IV.

TABLE 18

SERUM MINERAL CONCENTRATIONS

TRIAL V

Day 3/	Ration	mg/100 ml Na	K	Mg	Ca	P	mcg/ml Cu	Zn
1	Conventional 1/	325.0	17.4	1.90	11.3	6.15	2.50	0.80
3		320.0	16.0	2.20	12.2	6.10	2.58	0.78
5		328.0	16.4	2.20	10.8	5.15	2.42	0.80
2	Liquid 2/	330.0	18.5	2.50	10.0	4.95	1.90	0.82

1/ 800 gm/day grain+urea ration, composition as in table 2
2/ 8 liters/day, composition as in table 1 except each carbohydrate source reduced by 50 percent
3/ Days 1, 3 and 5 of 6 day N-Balance on conventional ration, day 2 of 2 day liquid ration infusion

TABLE 19

BLOOD HCt, Hb, pH, pO_2, pCO_2 AND SERUM PROTEIN VALUES

TRIAL V

Day[3/]	Ration	HCt (%)	Hb (gm/100 ml)	pH	pO_2 mmHg	pCO_2	Serum Protein (gm/100 ml)
1	Conventional[1/]	30.00	10.95	7.428	48.75	36.00	6.77
3		35.00	11.85	7.385	46.25	40.00	6.34
5		34.00	11.05	7.400	42.50	40.50	6.45
2	Liquid[2/]	35.50	10.17	7.480	49.50	35.75	7.06

1/ 800 gm/day grain+urea ration (table 2)
2/ 8 liters/day, composition as in table 1 except each carbohydrate source reduced by 50 percent
3/ Days 1, 3 and 5 of 6 day N-Balance on conventional ration, day 2 of a 2 day liquid ration infusion

TABLE 20

NITROGEN BALANCE STUDIES[1/]

TRIAL VI

Day	Intake[2/]	Feces[2/]	Urine[2/]	N-Balance[2/]
1	19,192.00	4,129.19	8,389.25	+6,673.56
2	19,192.00	4,491.90	10,606.25	+4,093.85
3	19,192.00	3,115.20	12,037.50	+4,039.30
4	19,192.00	3,675.25	12,033.00	+3,483.75
5	19,192.00	2,565.00	10,780.00	+5,847.00
6	19,192.00	2,245.65	7,012.50	+9,933.85
				mean +5,678.55

1/ Conventional ration, 800 gm/day grain+urea (table 2)
2/ Mg nitrogen per day

TABLE 21

RUMINAL VFA CONCENTRATIONS

TRIAL VI

Day[3]	Ration	Acetic (uM/ml)	Acetic (M%)[4]	Propionic (uM/ml)	Propionic (M%)	Butyric (uM/ml)	Butyric (M%)	A:P[5]
1	Conv.[1]	23.11	34.87	28.47	42.96	14.69	22.17	0.80
2		27.45	40.06	30.75	44.87	10.33	15.07	0.89
3		29.54	34.79	38.12	44.90	17.24	20.31	0.77
4		27.61	38.11	32.34	44.64	12.50	17.25	0.85
5		30.86	36.37	39.38	46.41	14.62	17.22	0.78
6		28.56	37.20	34.48	44.91	13.73	17.89	0.83
		27.86	36.90	33.92	44.78	13.85	18.32	0.82
3	Liq.[2]	23.80	45.88	21.45	41.35	6.63	12.77	1.11
4		25.70	47.44	22.98	42.42	5.49	10.14	1.12
		24.75	46.66	22.22	41.89	6.06	11.46	1.12

1/ 800 gm/day grain+urea ration, composition as in table 2
2/ 8 liters/day, composition as in table 1 except each carbohydrate source reduced by 50 percent
3/ Days 1-6 of 6 day N-Balance on conventional ration, days 3 and 4 of 4 day liquid ration infusion
4/ Molar percent
5/ Acetate:Propionate ratio

Serum mineral data for this trial is shown in table 22. The results are similar to that seen in trial V. Hb, HCt, pH, pO_2, pCO_2 and serum protein values are shown in table 23.

SGOT values are given in table 24. Values during the conventional phase were within the normal range, however tissue breakdown was apparent during the liquid phase of the trial. The respiration rate almost doubled during the liquid phase. Rectal temperature increased from 103.0 during the feeding phase to 106 F on the last day of the liquid infusion. When signs of distress became apparent (labored breathing and excessive nasal discharge), the animal was subjected to veterinary evaluation. The evaluation revealed an apparent respiratory infection.

Mechanical problems encountered in the infusion technique, at the beginning of the study, have for the most part been alleviated. Based on the metabolism and nitrogen balance studies the liquid diet is, apparently, nutritionally adequate. However, no plausible explanation for the sudden deaths can be given. Some of the possible causes of death were studied and ruled out. Since vitamin E was not present in the diet and tissue breakdown was apparent in some instances tests were carried out to investigate the possible role of vitamin E as a causative factor. SGOT data disproves the possibility of vitamin E as the agent evoking death. The possibility of a metabolic acidosis or alkalosis was also investigated. Blood pH data strongly indicates that this was not the problem. Hypersensitivity to some ration component was also investigated. One component investigated was promosoy. However, gel immunodiffusion studies indicate that promosoy was not the causative agent.

TABLE 22

SERUM MINERAL CONCENTRATIONS

TRIAL VI

Day 3/	Ration	mg/100 ml Na	K	Mg	Ca	P	mcg/ml Cu	Zn
2	Conventional 1/	320.0	16.5	2.42	12.6	7.10	2.40	0.62
4		330.0	17.0	2.54	12.8	6.10	1.54	0.70
2	Liquid 2/	328.0	18.4	2.81	11.8	7.10	2.10	0.69
4		324.0	18.5	2.83	14.4	4.95	1.80	0.75

1/ 800 gm/day grain+urea ration (table 2)
2/ 8 liters/day, composition as in table 1 except each carbohydrate source reduced by 50 percent
3/ Days 2 and 4 of 6 day N-Balance on conventional ration, day 2 and 4 of 4 day liquid ration infusion

TABLE 23

BLOOD HCt, Hb, pH, pO_2, pCO_2 AND SERUM PROTEIN VALUES

TRIAL VI

Day[3]	Ration	HCt (%)	Hb (gm/100 ml)	pH	pO_2 mmHg	pCO_2	Serum Protein (gm/100 ml)
2	Conventional[1]	27.80	10.42	7.433	42.25	38.00	5.33
4		32.00	11.80	7.400	44.75	42.00	6.48
2	Liquid[2]	33.00	11.20	7.448	49.00	31.25	8.93
4		33.50	10.90	7.484	34.00	36.50	6.42

1/ 800 gm/day grain+urea ration (table 2)
2/ 8 liters/day, composition as in table 1 except each carbohydrate source reduced by 50 percent
3/ Days 2 and 4 of 6 day N-Balance on conventional ration, day 2 and 4 of 4 day liquid ration infusion

TABLE 24

SERUM GLUTAMIC OXALACETIC TRANSAMINASE LEVELS

Trial	Day		Ration	Level[1]
3	3		Conventional	80.00
	5			90.00
	7		Liquid	845.00
	14			875.00
	19			1,325.00
4	1		Conventional	415.00
	3			495.00
	5			765.00
	1		Liquid	590.00
	4			645.00
5[4]	1	Day of surgery	Conventional	190.00[2]
	6	days post-surgery		455.00[3]
	3			120.00
	4			110.00
	5			120.00
	2		Liquid	130.00
6[5]	1	Day of surgery	Conventional	235.00[2]
	6	days post-surgery		130.00[3]
	3			95.00
	4			75.00
	2		Liquid	100.00
	5			120.00

1/ Expressed in F.U. (Sigma Frankel units) 2/ Day animals were fistulated
3/ Day placed in crate
4/ Days 3, 4 and 5 of 6 day N-balance, 3 weeks following surgery
5/ Days 3 and 4 of 6 day N-balance, 3 weeks following surgery

SUMMARY

Six metabolism and nitrogen balance trials were conducted in an attempt to develop a complete liquid ration suitable for constant intraruminal infusion with the ultimate objective of determining the metabolic capabilities of animals for increased feed intake. The animals (fistulated wethers) were subjected to a preliminary period of 3 weeks in order to adjust to the metabolism crates and preliminary ration. Measurements of rumen and blood components were used to evaluate the adequacy of the diet.

A positive nitrogen balance was maintained during the conventional (grain + urea or alfalfa: grain pellet ration) phase of the trials. The liquid diet (8 liters per day) contained 460 gm corn starch, 230 gm cane sugar, 40 gm water-dispersable soy protein, and an electrolyte-mineral solution calculated to meet the requirements of the animal. Only two nitrogen balance studies were conducted during the liquid infusion (8 or 12 liters/day) phase. Although a mean negative nitrogen balance was observed during one of the two trials, additional evidence suggests the nutritional adequacy of the diet.

Total volatile fatty acid (VFA) concentrations (micromoles/ml) were generally lower during the liquid infusion phase when compared to the conventional diet. The acetic: propionic acid (A:P) ratio was increased by the liquid infusion. Ruminal pH values were observed to increase following the liquid infusion. The decrease in total VFA concentration helps explain the increase in ruminal pH. Although the VFA concentrations and A:P ratios did show changes between the two phases of the trials, normal values were observed.

An edemic condition observed at necropsy of one animal suggested a possible electrolyte imbalance. However, serum mineral data from all other animals indicates that this was not the case. All values were within the normal range with no apparent differences between treatments.

Serum glutamic oxalacetic transaminase (SGOT) values were determined. Although in some trials values increased following the liquid infusion, lack of consistency fails to disprove the nutritional adequacy of the liquid diet.

The mechanical problems encountered in the infusion technique have been solved. The liquid diet is, apparently, nutritionally adequate as demonstrated by the metabolism and nitrogen balance data. However, a syndrome characterized by respiratory distress, pyrexia, and sudden death was a common occurance throughout the study. Several possible causes of death were examined. Necropsy findings failed to disclose any possible cause of death. Mineral data suggest that an electrolyte imbalance did not exist. SGOT data gives evidence that tissue breakdown was not the causitive factor. According to blood pH data, metabolic acidosis or alkalosis was not present. Gel immunodiffusion studies help rule out the possibility of hypersensitivity to some ration component. Although some possible causes of death have been ruled out, no plausible explanation is evident from these data.

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CONTROL OF FEED INTAKE IN RUMINANTS: A SEMI-PURIFIED LIQUID DIET FOR CONTINUOUS INTRARUMINAL INFUSION

by

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Six metabolism and nitrogen balance trials were conducted in an attempt to develop a complete liquid ration suitable for constant intraruminal infusion with the ultimate objective of determining the metabolic capabilities of animals for increased feed intake. The animals (fistulated wethers) were subjected to a preliminary period of 3 weeks in order to adjust to the metabolism crates and preliminary ration. Measurements of rumen and blood components were used to evaluate the adequacy of the diet.

A positive nitrogen balance was maintained during the conventional (grain + urea or alfalfa: grain pellet ration) phase of the trials. The liquid diet (8 liters per day) contained 460 gm corn starch, 230 gm cane sugar, 40 gm water-dispersable soy protein, and an electrolyte-mineral solution calculated to meet the requirements of the animal. Only two nitrogen balance studies were conducted during the liquid infusion (8 or 12 liters/day) phase. Although a mean negative nitrogen balance was observed during one of the two trials, additional evidence suggests the nutritional adequacy of the diet.

Total volatile fatty acid (VFA) concentrations (micromoles/ml) were generally lower during the liquid infusion phase when compared to the conventional diet. The acetic: propionic acid (A:P) ratio was increased by the liquid infusion. Ruminal pH values were observed to increase following the liquid infusion. The decrease in total VFA concentration helps explain the increase in ruminal pH. Although the VFA concentrations and A:P ratios did show changes between the two phases of the trials, normal values were observed.

An edemic condition observed at necropsy of one animal suggested a possible electrolyte imbalance. However, serum mineral data

from all other animals indicates that this was not the case. All values were within the normal range with no apparent differences between treatments.

Serum glutamic oxalacetic transaminase (SGOT) values were determined. Although in some trials values increased following the liquid infusion, lack of consistency fails to disprove the nutritional adequacy of the liquid diet.

The mechanical problems encountered in the infusion technique have been solved. The liquid diet is, apparently, nutritionally adequate as demonstrated by the metabolism and nitrogen balance data. However, a syndrome characterized by respiratory distress, pyrexia, and sudden death was a common occurance throughout the study. Several possible causes of death were examined. Necropsy findings failed to disclose any possible cause of death. Mineral data suggest that an electrolyte imbalance did not exist. SGOT data gives evidence that tissue breakdown was not the causitive factor. According to blood pH data, metabolic acidosis or alkalosis was not present. Gel immunodiffusion studies help rule out the possibility of hypersensitivity to some ration component. Although some possible causes of death have been ruled out, no plausible explanation is evident from these data.