EFFECTS OF DIETARY FATTY ACIDS UPON RUMEN METABOLISM AND DIGESTIBILITY IN SHEEP

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Ronald Alexander Clarke

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ABSTRACT

EFFECTS OF DIETARY FATTY ACIDS UPON RUMEN METABOLISM AND DIGESTIBILITY IN SHEEP

BY

RONALD ALEXANDER CLARKE

Two metabolism experiments were conducted with sheep to study effects of increasing dietary levels of unsaturated fatty acid upon utilization of various ration components. Four rumen fistulated sheep were used, and each experiment was conducted according to a 4 X 4 Latin square design involving 4 sheep, 4 rations and 4 periods. Each period was of 18 days duration consisting of 10 days for adjustment and an 8 day collection period. Rumen, fecal, and blood samples were collected at specific intervals. In both experiments the treatments were made up by varying the proportions of methyl stearate, oleic, and linoleic acids in the basal ration.

Apparent digestion coefficients for energy, nitrogen, fibre, dry matter, ether extract and crude fat were not significantly affected when increasing levels of unsaturated fatty acids were fed. Although ether extract and crude fat digestibilities were not directly affected by treatment, distinct qualitative changes in rumen and fecal

saturated fatty acid levels were observed. Ruminal fatty acids showed a higher degree of saturation than comparable dietary fatty acids. These qualitative changes were in accordance with high levels of saturated fecal fatty acids observed in the unsaturated fatty acid treatments. The results, in general, suggest that hydrogenation of C-18 polyethnoid fatty acids was occurring within the rumen.

Synthesis of palmitic and oleic acids appeared to occur within the rumen. Rate of synthesis may have been influenced by ruminal levels of these acids which in turn were affected by dietary levels.

Fat digestibilities decreased 11 - 19 digestion units when fecal soap excretion was taken into account. The fatty acids making up these soaps appeared to differ with treatment. Fecal stearate excretion in the form of soaps from the unsaturated fatty acid treatments was about 110% higher than fecal stearate excretion in the saturated fatty acid treatment.

The relative proportions of serum fatty acids were not affected by dietary fatty acids.

No significant differences were observed among treatments in total ruminal VFA concentrations, or was any definite trend deliniated indicating that degree of ration fatty acid unsaturation affected total VFA concentration in

the rumen. In general, as dietary unsaturated fatty acids were increased, the proportions of propionic acid increased and butyric acid decreased.

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INTRODUCTION

Recent uses of inedible fats and oils in animal feeds have provided a stimulus for the elucidation of fatty acid utilization in ruminants. Considerable experimental information is available with respect to fatty acid utilization in monogastrics; this is not the case for ruminants, however. Extrapolation of monogastric data to ruminants is not possible because of inherent differences between monogastrics and ruminants in fatty acid metabolism. The proportions of fatty acids received in the diet of monogastric animals remains relatively constant until subsequent absorption. Ruminants, on the other hand, are capable of changing the proportions of fatty acids in the diet through hydrogenation of unsaturated fatty acids within the rumen, thereby presenting a more saturated mixture of fatty acids for subsequent absorption. If one assumes that metabolism of fatty acids (post-ruminal) is comparable to that of monogastrics, then rumen hydrogenation could have a detrimental effect on digestibility. Young and Garrett (40) have showed in the chick that palmitate and stearate were poorly digested as opposed to their unsaturated analogues. They also found that digestibilities of these acids were significantly improved by the addition of oleic and linoleic

acids to the ration.

The addition of fats or oils to ruminant rations has been shown to affect the digestibility of cellulose, protein, dry matter and organic matter. In addition, cellulose digestibility has been shown to be affected by different fatty acids in the ration. Davison and Wood (13) observed a significant difference in cellulose digestion when oleic acid was compared with stearic acid in a feeding trial. Digestion of cellulose was poorer in rations containing oleic acid.

There is a definite lack of knowledge concerning effects of different dietary fatty acids upon the utilization of such ration components as cellulose, protein, energy, fat and individual fatty acids in ruminants. The present experiments were conducted to determine effects of feeding various proportions of fatty acids (saturated and unsaturated) upon ration utilization and rumen fatty acid metabolism in lambs. The parameters investigated include the following: ration, ruminal and fecal levels of fatty acids; apparent digestibilities of crude fat, ether extract, energy, fibre, dry matter, and nitrogen; and serum fatty acid and rumen volatile fatty acid levels. The fatty acid composition of protozoa was also determined.

LITERATURE REVIEW

Some Factors Affecting Fatty Acid Utilization in Monogastrics

Young and Garrett (40) reported that various dietary components can influence the utilization of fatty acids in the chick. They showed that absorption of fatty acid mixtures high in saturated fatty acids can be improved by antibiotic treatments, and suggested that the effect may be mediated through the elimination of undesirable intestinal microflora. In another experiment the ration levels of crude protein, carbohydrate source, and the ratio of saturated to unsaturated fatty acids in the diet were shown to influence fatty acid absorption. When the level of crude protein was increased from 24 to 28%, an improvement in the apparent digestion of fatty acids from beef tallow was observed. Also, a significant improvement in beef tallow digestibility occurred when corn was used as the principal source of carbohydrate as compared to glucose. This carbohydrate effect was not observed in a later experiment and therefore could not be considered a consistant variable. Young and Garrett (40) also found that by increasing the amount of ration oleic and/or linoleic acids in relation to palmitic acid, a marked increase in the digestibility of palmitic acid occurred. Oleic acid was more efficient in this regard than linoleic acid.

Stearic acid, when fed alone, was digested to the extent of 14%. By the addition of palmitic acid (12% palmitic and 7% stearic in diet), the digestibility of stearic acid was reduced to 2%. When oleic acid was added to this mixture, an improvement in digestibility occurred; however, it was not as high as when oleic acid was added to palmitic acid alone. When linoleic acid was fed with oleic plus a mixture of the above two saturated fatty acids, the highest digestion of the saturated fatty acids was observed. Similar aspects of fatty acid metabolism were investigated by Renner and Hill (29). They determined the digestibility of palmitic and stearic acids with increasing levels of unsaturated fatty acids in chick diets. Animal tallow, containing 50% unsaturated fatty acids, lard containing 60% unsaturated fatty acids, and soybean oil containing 76% unsaturated fatty acids were used in the rations. There were substantial increases in palmitic and stearic acid digestibilities with increasing levels of ration unsaturated fatty acids.

The mechanism by which oleic acid facilitates absorption of saturated fatty acids is not clear. Langworth and Holmes (23) suggested that micelles made up of bile salts, mono-olein and/or oleic acid are formed in the lumen of the intestinal tract. These micelles have the ability

to enhance the emulsification of saturated fatty acids, and presumably make them more available for absorption. Young and Garrett (40) suggested that improved absorption of saturated fatty acids in the presence of oleic acid may be due to a preferential synthesis of mono-olein in the brush border of the mucosal cells and that this mono-glyceride acts as an acceptor of saturated fatty acids to form di- and triglycerides. This hypothesis was supported by the observations of Clark and Hubscher (10) where under in vitro conditions more 1-C^{14} palmitic acid was combined with mono-olein than with monolaurin or monopalmitin. Senior and Isselbacher (32) observed no difference between either the 9 or 8 isomers of monopalmitin or mono-olein in their ability to act as acceptors for palmityl Co-A to form diglycerides in vitro.

Renner and Hill (30) have shown that chicks fed palmitic acid in a mixture with triolein showed a stepwise improvement in palmitic acid digestion when the palmitic acid to triolein ratio was decreased from 3 to 1. In this case, it would appear that pancreatic lipase hydrolysed the triolein to oleic acid and mono-olein, and the mono-olein moiety could enhance the formation of more readily absorbed micelles as well as acting as an acceptor for palmitic acid in the formation of triglycerides.

The carbon chain length and degree of unsaturation of fatty acids can affect their digestibility. Carrol (7) showed that short chained fatty acids (up to C 10) are completely digested in the rat and that further increases in chain length resulted in a progressive decrease in digestibility. Accordingly, the digestibilities were relatively poor for C 18 and higher saturated fatty acids. The monounsaturated analogues were better digested but showed the same digestibility trend with increasing chain length. Presence of a double bond near the middle of the chain was found to be equivalent, in terms of digestibility, to shortening the chain length by six carbon atoms.

Fat digestibilities have been correlated with the melting points of some natural fats. Crockett and Duel (12) showed that margarine, Crisco, prime steam lard, and bland lard have high digestibility values in the rat and compare favorably with natural fats and oils which have melting points below 50°C. However, when lard was more hydrogenated (melting over a range of 55 - 61°C), there was a marked drop in digestibility when compared to fats of lower melting points. This could be expected since a higher melting point indicates a higher level of fatty acid saturation.

Melting point of fats, when used for the estimation of digestibility of a natural fat, has proven to be

inadequate. The melting point does not accurately reflect the species of fatty acids, however, since natural fats melt over a temperature range which is dependent upon the distribution of fatty acids among the glycerides. Some effects of saturated fatty acid distribution among glyceride molecules on fat digestibility were investigated by Mattson (24). He found that when the saturated fatty acids were distributed evenly among the glyceride molecules, digestibilities were significantly higher than when saturated fatty acids were distributed in a manner such that a portion of the triglycerides were made up entirely of saturated fatty acids. Mattson (24) concluded that fat digestibility was inversely proportional to content of simple triglycerides made up of saturated fatty acids having a chain length of 18 carbon atoms or more. This observation by Mattson could be partly explained by the fact that no unsaturated fatty acids were present within the triglyceride moiety, which would be capable of facilitating fatty acid absorption (23).

Several investigators have noted significant amounts of ether insoluble fatty acids (possibly caused by the complexing of the fatty acid anion with calcium, potassium etc. to form soaps) in the feces of monogastrics and ruminants. Duel et al. (14) determined rapeseed and cottonseed oil digestibilities in humans. They estimated the

fecal excretion of neutral fats, fatty acids and soaps. Cottonseed oil was digested to the extent of 96.5% vs. 99.0% for rapeseed oil. This difference in digestibility was due to significantly higher fecal soap excretion in the cottonseed oil treatment. These workers suggested that calcium ions may have had a greater depressing effect on the fatty acids of cottonseed oil than the fatty acids of rapeseed oil. Cheng et al. (8) designed an experiment to determine effects of including calcium and magnesium in diets relatively rich in natural fats, synthetic triglycerides, or fatty acids, upon fecal soap excretion. They found that the presence of calcium and magnesium in the diet did not change the digestibility of fat with melting points lower than 50°C. This observation helps to explain the high fat digestibilities reported by Crockett and Duel (12) in diets containing high levels of calcium and magnesium, sincetheir fats had melting points under 50°C. The removal of calcium and magnesium from the diet markedly increased digestibility of fats with melting points above 50°C (Cheng et al., 8). In the diet containing calcium and magnesium, trilaurin was digested to the extent of 70.5% whereas in the absence of these divalent rations, the value was 97.3%. Corresponding coefficients of digestibility for trimyristin under these divergent dietary conditions were 37.3 and 76.6%, respectively,

while with tristearin the values were 10.6 and 18.9%. Smaller additions of calcium and magnesium to the trilaurin diet resulted in less depression in digestibility. These data confirmed earlier observations by Boyd et al. (3) in which the depressing effect of ration calcium on fat digestion was related to fatty acid composition of the diet.

The uptake of fatty acids by intestinal mucosal cells appears to be influenced by soap formation. If penetration of fatty acids into mucosal cells occurs on the basis of lipid solubility, as suggested by Johnston and Borgstrom (22), then the presence of fatty acids in the non-ionized state (salts exist as ions in an acid media) should facilitate uptake. Hofman and Borgstrom (21) determined the pK of fatty acids in micellar solutions to be 6.5. In subsequent experiments in which the uptake of fatty acids in micellar solutions by intestinal slices was measured, they found that fatty acids were present predominantly in the non-ionized form.

Fatty Acid Metabolism in the Rumen

Conditions exist within the rumen whereby unsaturated fatty acids can be hydrogenated to their more saturated analogues. This phenomenon was first shown by Reiser (27) who incubated linseed oil in vitro with sheep rumen contents