

CONCEPTS IN FAT AND FATTY ACID DIGESTION IN RUMINANTS

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INTRODUCTION

Fat and fatty acid metabolism and digestion in ruminants is of considerable interest at the present time, both to scientists and the agricultural industry. The subject has received renewed interest for a number of reasons; first, the use of dietary fat supplements has increased, and will continue to do so, as nutritionists strive to increase the energy density of diets to meet requirements of the high producing dairy cow, and second, we now recognize that fatty acids, both of dietary and rumen origin, can have specific and potent effects on ruminant metabolism and human health. Increased interest in these areas, and recent improvements in analytical procedures have led to recent efforts to include lipid metabolism in models of ruminant digestion, and if done properly this may potentially be useful in diet formulations and decision making processes and recommendations. Considering the increased interest in ruminant lipid metabolism the purpose of this review is to provide an overview of the biological processes involved in the metabolism of fatty acids in the rumen and the subsequent absorption of fatty acids in the small intestine. To aid our discussion we will refer to a data set that we have recently put together which will allow us to highlight key changes that occur during rumen metabolism and the subsequent digestibility of fatty acids.

LIPID DIGESTION DATA SET

In order to aid our interpretation of ruminant lipid digestion we have collated the available data from lactating dairy cow studies. All of these studies were published in the scientific literature, and to our knowledge represent all available data. The data set includes 20 trials in which total and individual fatty acid intakes and duodenal (or omasal) flows were measured, 14 of which had calculations of intestinal digestibility of individual fatty acids. Table 1 provides a descriptive summary of these investigations. All studies involved lactating dairy cows, and estimates of digestibility were based on measurements either between the duodenum and ileum or between the duodenum and feces. Studies based on whole tract disappearance of lipid were not used because they do not account for the extensive shift in fatty acid composition that occurs in the rumen. A key development in recent years has been the

improvement in analytical procedures which has revealed the complex pattern of fatty acids that are produced in the rumen and incorporated into ruminant meat and milk fat. It is important to note that the current data set varies in the use of analytical methods that identify specific fatty acids and thus all 18:1 fatty acids are grouped together; for intake this will primarily be oleic acid (*cis*-9 18:1), but following rumen metabolism, this will consist predominantly of a number of *trans* 18:1 fatty acids and a lesser amount of *cis* 18:1 fatty acids. Furthermore, it has been assumed, unless otherwise specified in the publication, that data reported for 18:2 and 18:3 refer to linoleic (*cis*-9, *cis*-12 18:2) and linolenic (*cis*-9, *cis*-12, *cis*-15 18:3) acids, respectively.

RUMEN LIPID METABOLISM

An extensive metabolism of lipids occurs in the rumen and this has a major impact on the profile of fatty acids available for absorption and tissue utilization. In respect to lipid metabolism, the two major processes that occur in the rumen are hydrolysis of ester linkages in lipids and the biohydrogenation of unsaturated fatty acids (Figure 1). Hydrolysis of dietary lipids is predominantly due to rumen bacteria with little evidence for a significant role by rumen protozoa and fungi, or salivary and plant lipases. Although the extent of hydrolysis is generally high (>85%), a number of factors that affect the rate and extent of hydrolysis have been identified. For example, the extent of hydrolysis is reduced as the dietary level of fat is increased or when factors such as low rumen pH and ionophores inhibit the activity and growth of bacteria (see reviews by Doreau et al., 1997 and Harfoot and Hazlewood, 1997).

Due to the toxic nature of unsaturated fatty acids to many rumen bacteria, biohydrogenation of these fatty acids is the second major transformation that dietary lipids can undergo in the rumen. It requires a free fatty acid to proceed, and as a consequence rates are always less than those of hydrolysis, though factors that affect hydrolysis also impact biohydrogenation. Most biohydrogenation (>80%) occurs in association with the fine food particles, and this has been attributed to extracellular enzymes of bacteria either associated with the feed or free in suspension (Harfoot and Hazlewood, 1997). Numerous *in vitro* and *in vivo* studies have elucidated the major pathways of ruminal biohydrogenation; classical pathways were established using pure cultures of rumen organisms, and the bacteria involved in biohydrogenation have been classified into two groups, A and B, based on their metabolic pathways (Kemp and Lander, 1984). To obtain complete biohydrogenation of polyunsaturated fatty acids (PUFA), bacteria from both groups are generally required. Although Group A contains many bacteria that can hydrogenate PUFA to *trans* 18:1 fatty acids, only a few species characterized as Group B can hydrogenate a *trans* 18:1 fatty acid to stearic acid (Harfoot and Hazlewood, 1997). This feature of biohydrogenation explains why increased feeding of PUFA simultaneously causes an increase in the rumen concentration of monounsaturated fatty acids and a decrease in the concentration of saturated fatty acids.

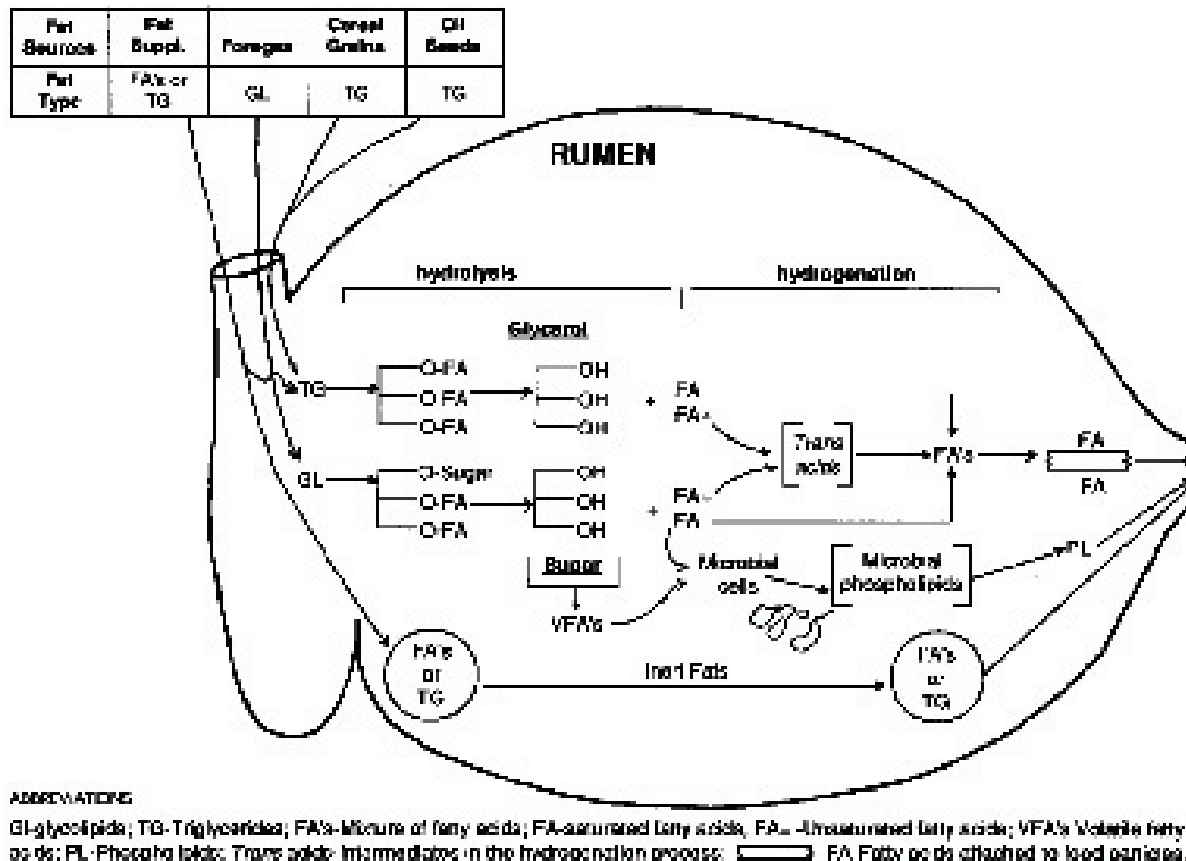
In general, the rates of rumen biohydrogenation of fatty acids are typically faster with increasing unsaturation, and, as shown in Table 1, for most diets linoleic acid and linolenic

Table 1. Descriptive statistics of the lipid metabolism and digestion data set involving lactating dairy cows¹.

Variable	n2	5th Percentile	95th Percentile	Mean
Fatty Acid Intake(g/day)				
Total	80	315	1293	865
C16:0	76	47	351	170
C18:0	80	8	130	52
³ C18:1	80	56	532	229
C18:2	80	92	524	272
C18:3	75	29	138	77
Rumen Biohydrogenation (%)				
C18:2	80	62	93	79
C18:3	75	70	97	86
Duodenal Fatty Acid Flow (g/day)				
Total	80	341	1444	858
C16:0	76	54	307	161
C18:0	75	113	675	397
C18:1	75	44	375	162
C18:2	80	10	165	56
C18:3	75	1	25	9
Small Intestine Digestibility (% of flow to duodenum)				
Total	70	58	86	74
C16:0	70	63	85	75
C18:0	70	46	87	72
C18:1	65	63	91	80
C18:2	70	61	92	78
C18:3	57	62	87	77
Small Intestine Absorption (g/day)				
Total	70	246	1102	628
C16:0	70	42	228	123
C18:0	65	103	458	282
C18:1	65	26	327	128
C18:2	70	9	116	45
C18:3	57	2	18	7

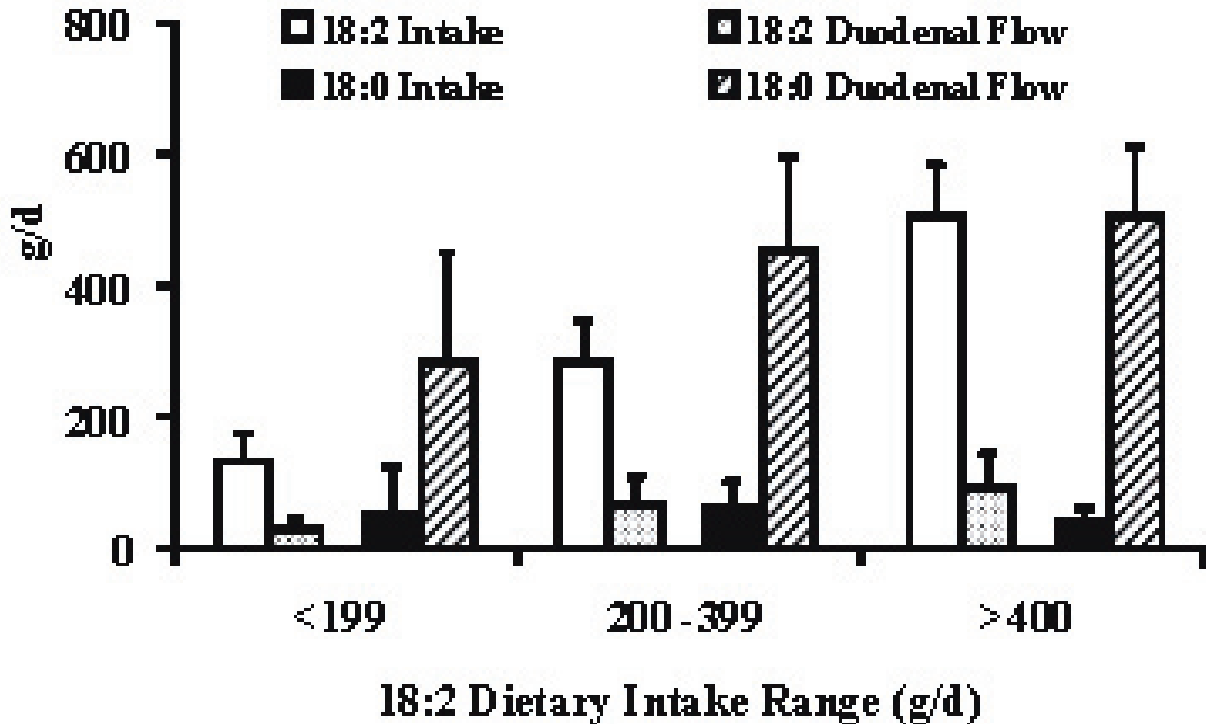
¹All data were taken or calculated from experiments reported in 20 independent studies (Bauchart et al., 1987; Murphy et al., 1987; Klusmeyer and Clark, 1991; Wu et al., 1991; Weisbjerg et al., 1992; Ferlay et al., 1993; Wonsil et al., 1994; Tice et al., 1994; Pantoja et al., 1996; Enjalbert et al., 1997; Pires et al., 1997; Kalscheur et al., 1997a; Kalscheur et al., 1997b; Christensen et al., 1998; Avila et al., 2000; Loor et al., 2002; Shingfield et al., 2003; Lundy et al., 2004; Loor et al., 2004; Loor et al., 2005). ²Total number of treatments within the data set contributing to each variable. ³Includes all 18:1 fatty acid isomers. For intake this is predominately oleic acid, but in the duodenal flow this consists of a range of trans 18:1 fatty acids and some oleic acid.

Figure 1. Lipid metabolism in the rumen. Reproduced from Davis (1990).



acid are hydrogenated to the extent of 70-95% and 85-100%, respectively. These data are in agreement with the review by Doreau and Ferlay (1994) that was based on data from all ruminant species. Therefore, the extensive metabolism of dietary unsaturated fatty acids in the rumen results in stearic acid being the major fatty acid entering the duodenum (Table 1). Figure 2 illustrates this based on linoleic acid intake (separated into tertiles) and compares changes in intake and duodenal flow (i.e., rumen output) of linoleic and stearic acids. Linoleic acid is typically the most common fatty acid present in diets in US dairy cows and the intake varies widely; however, only a fraction of the linoleic acid consumed (mean 272 g/d) is actually available for absorption (mean duodenal flow 56 g/d; Table 1). On the other hand, typically very little stearic acid (18:0) is consumed (mean 52 g/d), but we see a reciprocal increase in stearic acid flow to the duodenum (mean 397 g/d) as a result of it being the end product of biohydrogenation of all 18-carbon PUFA (Table 1). In this data set, there were several studies where over 500 g/d of stearic acid was measured leaving the rumen and available for absorption.

Figure 2. Relationship for linoleic acid (18:2) and stearic acid (18:0) intake and duodenal flow. Data are separated into tertiles based on 18:2 dietary intake. Data obtained from the references listed in Table 1.



As analytical techniques have improved, we have gained an appreciation of the complex pattern of fatty acids that are produced during rumen biohydrogenation and subsequently incorporated into milk fat. Table 2 illustrates the range of positional and geometric isomers of *trans* 18:1 and conjugated linoleic acids (CLA) identified in milk and dairy products. The established major pathways of biohydrogenation describe the formation of *trans*-11 18:1 and *cis*-9, *trans*-11 CLA, but do not account for the occurrence of other fatty acid intermediates identified in rumen digesta and milk fat. The extent to which the various pathways of biohydrogenation are associated with specific enzymes and species of bacteria or represent a lack of specificity of the enzymes involved in biohydrogenation is unknown. The production of specific biohydrogenation intermediates in the rumen is an area of increasing interest because of the recognition that individual fatty acids can have specific and potent effects on ruminant metabolism and human health. For example, both *trans*-11 18:1 and *cis*-9, *trans*-11 CLA present in milk fat have been shown to have anticarcinogenic and antiatherogenic properties in animal models of human health (Bauman et al., 2005a), while the role of *trans*-10, *cis*-12 CLA as a regulator of milk fat synthesis in dairy cows was the subject of our paper at this meeting last year (Bauman et al., 2005b). For further information on the biology of

hydrolysis and biohydrogenation, and the effects of diet on these processes, the reader is referred to a recent review of ours (Palmquist et al., 2005) as well as the classic review by Harfoot and Hazlewood (1997).

Table 2. Range of positional and geometric isomers of trans 18:1 and conjugated linoleic acids (CLA) in milk and dairy products (adapted from Lock and Bauman, 2004).

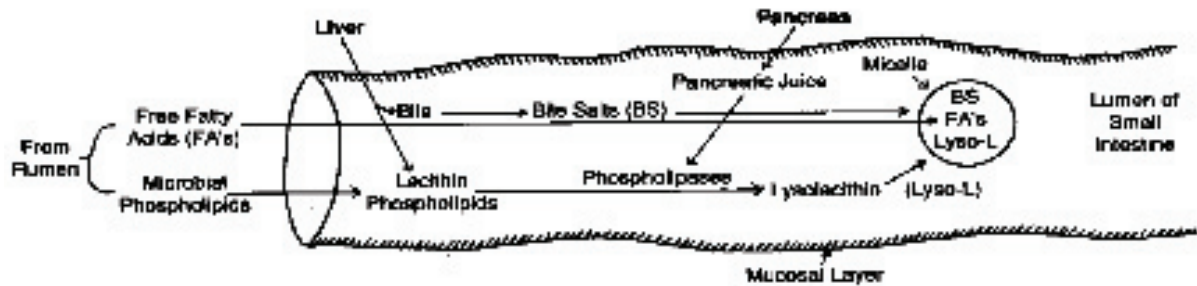
<i>Trans 18:1</i>		<i>Conjugated Linoleic Acids</i>	
Isomer	% of total trans 18:1 isomers	Isomer	% of total CLA isomers
<i>trans</i> -4	0.3–2.3	<i>trans</i> -7, <i>cis</i> -9	1.2–8.9
<i>trans</i> -5	<0.1–1.4	<i>trans</i> -7, <i>trans</i> -9	<0.1–2.4
<i>trans</i> -6–8	0.5–11.3	<i>trans</i> -8, <i>cis</i> -10	<0.1–1.5
<i>trans</i> -9	3.0–18.2	<i>trans</i> -8, <i>trans</i> -10	0.2–0.4
<i>trans</i> -10	3.4–29.8	<i>cis</i> -9, <i>trans</i> -11	72.6–91.2
<i>trans</i> -11	24.5–74.9	<i>trans</i> -9, <i>trans</i> -11	0.8–2.9
<i>trans</i> -12	1.9–17.6	<i>trans</i> -10, <i>cis</i> -12	<0.1–1.5
<i>trans</i> -13 + 14	<0.1–23.1	<i>trans</i> -10, <i>trans</i> -12	0.3–1.3
<i>trans</i> -15	3.3–11.1	<i>cis</i> -11, <i>trans</i> -13	0.2–4.7
<i>trans</i> -16	1.7–12.5	<i>trans</i> -11, <i>cis</i> -13	0.1–8.0
		<i>trans</i> -11, <i>trans</i> -13	0.3–4.2
		<i>cis</i> -12, <i>trans</i> -14	<0.01–0.8
		<i>trans</i> -12, <i>trans</i> -14	0.3–2.8
		<i>cis</i> - <i>cis</i> isomers	0.1–4.8

FATTY ACID ABSORPTION

Fatty acid absorption occurs predominantly in the jejunum region of the small intestine. Prior to reaching the jejunum, two secretions, bile and pancreatic juice, are added to the digesta in the duodenum. Before fatty acid absorption can occur, it is necessary for the lipid material absorbed onto the feed particles to be solubilized into the aqueous environment. In ruminants, as in all species, micelle formation is the key to this process and, therefore, key to efficient fatty acid absorption (Davis, 1990). The important feature of micellar solutions is their ability to dissolve (solubilize) water-insoluble fatty acids by incorporating appropriately shaped and charged molecules either into the core or the outer sheath of the complex that comprises the micellar matrix (Freeman, 1984). In ruminants, both the bile and

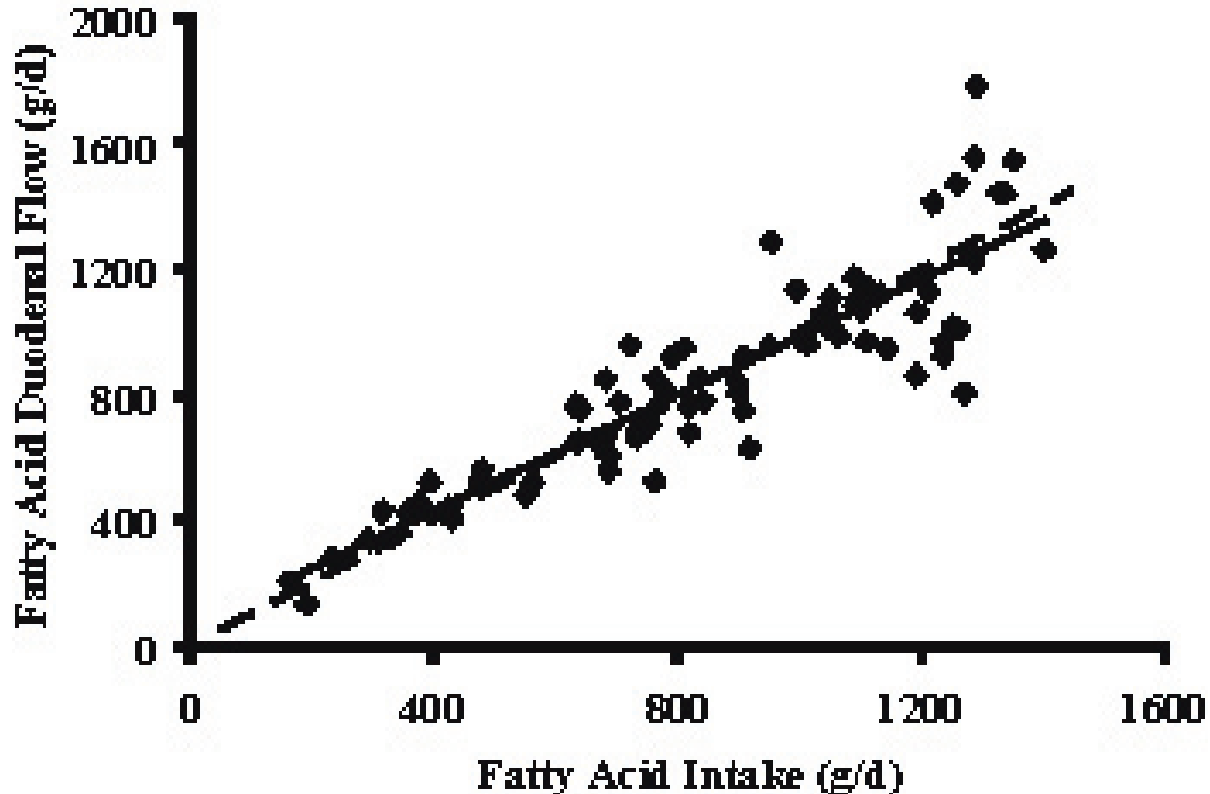
pancreatic secretions are required for this process; bile supplies bile salts and lecithin, and pancreatic juice provides the enzyme to convert lecithin to lysolecithin and the bicarbonate to raise the pH. Lysolecithin, together with bile salts, desorb the fatty acids from feed particles and bacteria, allowing the formation of the micelle (Figure 3). The critical role of lysolecithin and bile salts in this process is illustrated in studies with sheep where fatty acid absorption was virtually abolished when bile secretion into the duodenum was blocked (Moore and Christie, 1984). Once micelles are formed they facilitate transfer of water-insoluble lipids across the unstirred water layer of intestinal epithelial cells of the jejunum, where the fatty acids and lysolecithin are absorbed. Within the intestinal epithelial cells the fatty acids are re-esterified into triglycerides and then packaged into chylomicrons for transport in lymph to the blood.

Figure 3. Fat digestion in the small intestine of ruminants. Reproduced from Davis (1990).



Since there is no significant absorption or modification of long and medium chain fatty acids in the omasum or abomasum, the lipid material available for absorption in the small intestine is similar to that leaving the rumen (Moore and Christie, 1984). This lipid material consists of approximately 80-90% free fatty acids attached to feed particles; the remaining lipid components are microbial phospholipids plus small amounts of triglycerides and glycolipids from residual feed material, which are hydrolyzed by intestinal and pancreatic lipases (Doreau and Ferlay, 1994). Despite the dramatic changes that occur in the rumen, rumen out-flow of total fatty acids is very similar to dietary intake of fatty acids; this is true across a wide range of diets with different fatty acid intakes (Figure 4). In some instances the total amount of fatty acids entering the duodenum can exceed fatty acid intake and this most often occurs when lipid intake is low, e.g., with high forage-based diets. In this case the increase is a result of bacterial lipid synthesis in the rumen. However, the contribution of microbial lipids is extremely variable as a result of the associative effects of different diets on microbial synthesis (Noble, 1981). As can be seen in Figure 4, an accurate determination of fatty acid intake will allow for a reasonable approximation of duodenal flow of total fatty acids,

Figure 4. Relationship between dietary fatty acid intake (X-axis) and fatty acid duodenal flow (Y-axis). Data obtained from the references listed in Table 1. The dashed line shows a 1:1 relationship between intake and duodenal flow. Regression equation (solid line) is $y = 0.93x + 60$; $R^2 = 0.80$



although it must be remembered that the profile of this lipid material is vastly different (Table 1). However, it is important to note that accurate determination of fatty acid intake can present some challenges, often due to the overestimation of total fatty acid content of forages and the difficulty in obtaining complete recovery of highly saturated fat supplements (see review by Palmquist and Jenkins, 2003).

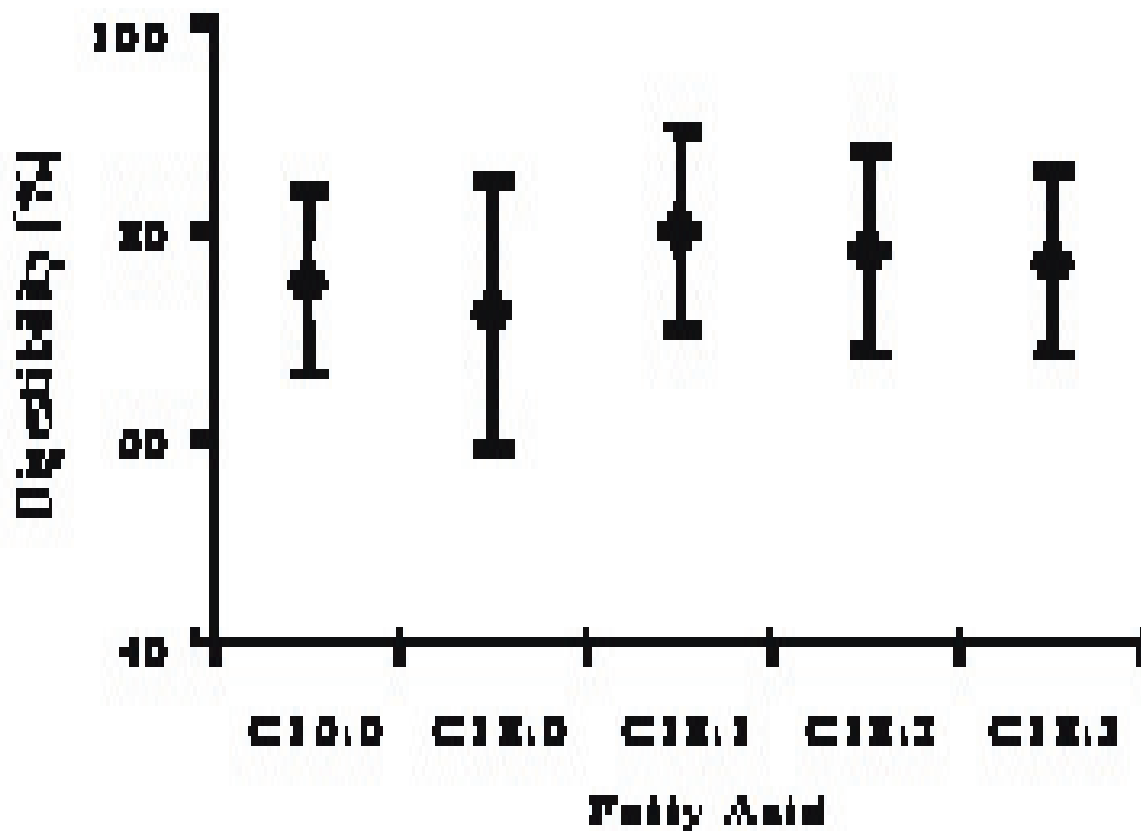
In our data set, fatty acid absorption was relatively constant with no significant decline when fatty acid duodenal flow was high. Total fatty acid digestibility averaged 74% resulting in a mean absorption of 628 g/d (Table 1). The range (95% confidence interval) for total fatty acid digestibility and total fatty acid absorption was 58-86% and 247-1102 g/d, respectively (Table 1). These data are in agreement with Doreau and Ferlay (1994) who carried out an extensive review of the literature in all ruminant species and reported values for fatty acid digestibility ranging from 55 to 92%; again this range was not related to fatty acid

intake. Of particular interest is whether differences exist in the digestibility of individual fatty acids. Specifically, there is disagreement regarding the digestibility of stearic acid in dairy cows and whether its digestibility differs substantially from other fatty acids. In general, the ability of ruminants to absorb fatty acids is much higher than that of non-ruminants (Noble, 1981). In non-ruminants there is a wide divergence in the digestibility of fatty acids (Freeman, 1984) with the digestibility of individual fatty acids decreasing when chain length increases, and increasing as the number of double bonds increases (Lessire et al., 1992). In particular, free palmitic and stearic acids are poorly absorbed in non-ruminants (Noble, 1981). However, as illustrated in Figure 5 (mean values $\pm$ SD), although similar patterns are observed in ruminants, relative differences in the digestibility of individual fatty acids are modest; mean digestibilities for 16:0, 18:0, 18:1, 18:2, 18:3 were 75, 72, 80, 78, and 77%, respectively (Table 1). These data are in agreement with the review of Doreau and Ferley (1994) which reported that mean digestibilities were 77, 85, 83 and 76% for 18 carbon fatty acids with zero, one, two and three double bonds, respectively. With recent improvements in analytical techniques, differences in the digestibility of individual fatty acids and fatty acid isomers can be more thoroughly examined, but application in feeding systems still requires accurate information on the profile of fatty acids leaving the rumen.

Figure 5 also illustrates the considerable variation in the digestibility of individual fatty acids across studies. The overall conclusion is that differences in digestibility among individual fatty acids contribute very little to the extensive variation reported in the literature (range $\sim$ 60 to 90%; Table 1). Rather, the majority of this variation reflects differences among individual experiments, and thus relates to experimental approaches and analytical techniques, as well as differences in diets and specific feed components. Table 1 also illustrates the daily amount of individual fatty acids absorbed across the data set. As emphasized earlier, stearic acid is the predominant fatty acid in the digesta and consequently is the major contributor to total absorbed fatty acids. Therefore, any discrimination against the absorption of stearic acid relative to the other fatty acids may be hardly noticeable since this is the predominant component in the digesta and more is absorbed than of any other fatty acid (Noble, 1981). Consequently, the composition of absorbed fatty acids is close to the composition of fatty acids entering the duodenum.

There are a number of reasons that may explain the highly efficient absorption of saturated fatty acids in ruminants compared to non-ruminants. In particular, the manner of presentation of lipids in the digesta of the small intestine together with the environment in which the lipid material exists differs markedly in ruminants and non-ruminants (Noble, 1981). In ruminants, there is a slow and continuous release of relatively small amounts of fatty acids into the duodenum with the majority of this lipid material in the free fatty acid form (80-90%), in contrast to non-ruminants where the majority is esterified (>90%). Also, the degree of neutralization of the acid digesta as it passes through the duodenum of the ruminant is significantly less than it is in non-ruminants, a consequence of the low concentration and rate of secretion of bicarbonate in ruminant pancreatic secretions (Lock et al., 2005; Moore and Christie, 1984).

Figure 5. Comparison of individual fatty acid digestibilities in lactating dairy cows. Values represent means $\pm$ SD for the data obtained from the references listed in Table 1.



From our review of the literature it is evident that the ruminant has evolved a number of key differences and features in fatty acid absorption compared with non-ruminants that allow for efficient absorption of fatty acids under the prevailing conditions. First, ruminant bile is characterized by an excess of taurine-conjugated bile acids compared to glycine-conjugated bile acids; in the majority of herbivores, glycine-conjugated bile acids predominate, but in the mature ruminant taurine-conjugates exceed glycine-conjugates by approximately 3:1 (Noble, 1981). This is of significance because under the acidic conditions of the ruminant upper-small intestine taurine-conjugated bile acids remain in a partially ionized condition and in the micellar phase where they are able to effect solubilization of fatty acids (Noble, 1981). Even at pH 2.5 taurine-conjugated bile acids remain soluble and partly ionized, while glycine-conjugated bile acids are insoluble in much less acidic conditions (pH 4.5) and unable to effect solubilization (Moore and Christie, 1984). Second, there are significant differences between ruminants and non-ruminants in the source of amphiphile or ‘swelling agent’, which promotes micelle formation. In ruminants lysolecithin is the amphiphile involved in micelle formation, whereas in non-ruminants, monoglycerides

plus bile salts interact with the fatty acids to form the micelle (Davis, 1990). Monoglycerides, short-chain saturated fatty acids, unsaturated fatty acids, and phospholipids are able to infiltrate and increase the size (swell) of the bile salt micelle, in particular increasing the capacity of its hydrophobic core. This is significant as non-polar solutes (i.e., long-chain saturated fatty acids) have non-amphiphilic characteristics and must be solubilized in the hydrophobic interior of the mixed micelle (Freeman, 1984); therefore, increasing the capacity of the micelle's hydrophobic core significantly enhances the solubility of long-chain saturated fatty acids with a consequent improvement in their absorption. Freeman (1969) examined the amphiphilic properties of polar lipid solutes and found that lysolecithin had a pronounced effect on the micellar solubility of stearic acid (Table 3). In fact, lysolecithin's ability to increase the solubility of stearic acid is ~2-fold greater than that of other amphiphiles, including oleic acid which has been quoted recently as having important amphiphilic properties when fed as a Ca-salt to ruminants (Moate et al., 2004; Block et al., 2005). Lysolecithin was, furthermore, the only amphiphile examined which was shown to significantly increase the distribution of stearic acid into the micellar phase and away from the particulate phase (Table 3). Considering that most fatty acids leaving the rumen are saturated and the predominant fatty acid is stearic acid, perhaps it is not surprising that the ruminant has evolved such an efficient system involving lysolecithin for solubilizing this fatty acid.

Table 3. Amphiphilic properties of some polar lipids. Adapted from Freeman (1969) and Freeman (1984).

Amphiphile	Amphiphilic Index ¹	Increase or decrease (%) in Km/o of stearic acid ²
Oleic Acid	0.138	-11
Monoglyceride (1-Mono-olein)	0.138	+37
Linoleic Acid	0.154	—
Lauric Acid	0.164	—
Lysolecithin	0.280	+115

¹The amphiphilic index is defined as the increase in stearic acid solubility in bile salt solution per unit increase in amphiphilic concentration.

²Distribution coefficient describing the distribution of stearic acid between the particulate oil phase and the micellar phase; a positive (+) value indicates that an amphiphile increases the distribution of stearic acid into the micellar phase, which would favor absorption.

Before formulating any rigid rules with regard to the digestibility of individual fatty acids there are a number of factors that should be taken into account. First, the majority of studies investigating individual fatty acid digestibility use data calculated by difference between duodenal and fecal samples. An often overlooked consideration is the rate and extent of fatty acid biohydrogenation in the large intestine which would result in an over-prediction of unsaturated fatty acid digestibility and an under-prediction of saturated fatty acid digestibility. Biohydrogenation in the large intestine may be small in quantity, but the

amount of unsaturated fatty acids reaching the lower tract is also small, so the error could be significant. Unfortunately, there are only very limited data available in which sampling from the duodenum and ileum was carried out, thereby avoiding this bias. Second, the extent of oxidation of unsaturated fatty acids during storage and sample preparation should be considered, which would also bias results. Lastly, following the secretion of bile and pancreatic juices into the duodenum there is a significant influx of both free and esterified unsaturated fatty acids into the lipid material in the small intestine (Noble, 1981). There are limited data on the quantitative significance of this influx in dairy cows, but again this may bias results regarding individual fatty acid digestibility. Moreover, this influx of unsaturated fatty acids is important in further facilitating micelle formation and absorption of saturated fatty acids. Bearing these considerations in mind, differences observed in the digestibility of individual fatty acids in the current data set are minor.

Finally, many of the treatments in the current data set used lipid supplements of various types. A key question, therefore, is whether different lipid supplements significantly alter fatty acid digestibility. Based on the consistency of the data showing little or no difference in the absorption of individual fatty acids, there is no reason to believe that different fat supplements will markedly affect overall fatty acid digestibility. An exception to this statement is that there is sufficient evidence to indicate that saturated triglyceride supplements made from hydrogenated animal fats are poorly digested (e.g., Pantoja et al., 1996), which is probably not related to the amount fed but rather the physical nature of the product limiting ruminal hydrolysis resulting in increased duodenal flow of triglyceride.

SUMMARY

The digestion and metabolism of dietary fats and fatty acids in ruminants is complex and in this paper we have provided an overview of the biology of these processes as well as summarizing the available literature from lactating dairy cows. There is an extensive metabolism of dietary unsaturated fatty acids in the rumen resulting in the lipid material leaving the rumen consisting primarily of free fatty acids that are highly saturated. Although lipid hydrolysis and classical pathways of fatty acid biohydrogenation are well established, analytical improvements have revealed the complexity of lipid metabolism in the rumen. Clearly, many pathways of biohydrogenation exist and many factors related to diet and rumen environment affect this process. As a consequence, there are numerous fatty acid intermediates produced during rumen biohydrogenation; recent research has established that some of these unique fatty acids are signaling molecules that regulate metabolic processes in the cow and others can have beneficial health effects when consumed in dairy products.

Before intestinal absorption can take place the fatty acids must be released from their intimate association with the particulate matter of the digesta. This is overcome by solubilization of the fatty acids into the aqueous environment with micelle formation key to this process. Ruminants have evolved a number of key differences and features in fatty acid absorption compared with non-ruminants that allow for efficient absorption of fatty acids

and these include differences in both bile salt composition and the amphiphile involved in micelle formation as well as the slow and continuous release of relatively small amounts of fatty acids into the duodenum. Consequently, in general, the ability of ruminants to absorb fatty acids, particularly saturated fatty acids, is much higher than that of non-ruminants. The available data from studies with lactating dairy cows indicate that relative differences in the digestibility of individual fatty acids are modest, and contribute very little to the extensive variation reported in the literature. Rather, this variation likely reflects differences in diets, specific feed components and methodology among individual experiments. Therefore, with the exception of saturated triglyceride supplements, there is no reason to believe that different fat supplements will markedly affect overall fatty acid digestibility.

Our review of the available literature is in its early stages and further analysis of the current data set are planned which will include the use of meta-analytic techniques (St-Pierre, 2001; Ipharraguerre & Clark, 2005), and a thorough examination of the effects of different fat supplements on fatty acid digestibility using both the current data set and a data set using the available literature from studies in which total tract lipid digestibility has been reported for diets containing different fat supplements. Obviously, our knowledge of lipid digestion and metabolism is rapidly advancing and the opportunity and challenge is to effectively apply this knowledge in the feeding and management of today's high producing dairy cows.

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