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Intestinal digestibility of long-chain fatty acids in lactating dairy cows: A meta-analysis and meta-regression

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ABSTRACT

The objective of this analysis was to examine the intestinal digestibility of individual long-chain fatty acids (FA) in lactating dairy cows. Available data were collated from 15 publications containing 61 treatments, which reported total and individual FA duodenal flows and calculations of intestinal digestibility. All studies involved lactating dairy cows, and estimates of digestibility were based on measurements either between the duodenum and ileum (18 treatments) or between the duodenum and feces (43 treatments). Fatty acid digestibility was calculated for C16:0, C18:0, C18:1 (*cis* and *trans* isomers), C18:2, and C18:3. Digestibility of C18:0 was lower than for C18:1 and C18:3, with no difference in digestibility between saturated FA (C16:0 and C18:0). We weighted the studies by the reciprocal of the variance to generate best-fit equations to predict individual FA digestibility based on duodenal flow of FA and dietary independent variables. The flow of C18:0 negatively affected the digestibility of C18:0 and was also included in the best-fit equations for all other 18-carbon FA using duodenal flow characteristics. The type of fat supplemented had an effect on digestibility of individual FA, with whole seeds having reduced digestibility. Our meta-analysis results showed minimal differences in the digestibility of individual FA. However, C18:0 flow through the duodenum had a negative effect on the digestibility of several individual FA, with the largest negative effect on C18:0 digestibility. The mechanisms that reduce C18:0 absorption at high concentrations are unknown and warrant further investigation.
Key words: fatty acid, digestibility, meta-analysis

INTRODUCTION

Digestion and metabolism of FA in ruminants has gained interest from both a research and industry perspective due to several factors. First, dietary FA supplements have been used to increase the ME density of rations in lactating dairy cattle (Jenkins and Jenny, 1989; Chilliard, 1993). Depending on stage of lactation and energy balance, an increase in ME density could increase milk production, milk fat yield, and body reserves as long as dietary FA supplements do not reduce DMI or negatively affect the digestibility of other nutrients. Second, increased recognition of the bioactive properties of specific FA has led to increased interest in fat supplementation in ruminant diets. For example, supplemented n-3 FA improved reproductive performance in early lactation animals (Abayasekara and Wathes, 1999; Ambrose et al., 2006) and C16:0 supplementation improved milk fat yield compared with C18:0 supplementation (Rico et al., 2014b). Third, basal diets can vary dramatically in FA profile and content; therefore, research on FA digestion and metabolism is important even when no supplemental fat is included in diets. The ability to understand and model FA digestibility will be useful for diet formulation strategies and provide information for optimal FA supplementation.

Metabolism of FA begins in the rumen through the processes of hydrolysis and biohydrogenation. Hydrolysis occurs when triglycerides and glycolipids are converted into glycerides and FA by microbial lipases (Jenkins, 1993). Unsaturated FA, which are toxic to certain rumen microbes, undergo biohydrogenation to form saturated FA (Jenkins et al., 2008; Maia et al., 2010). Because of these changes in the rumen, feed-to-feces digestibility estimates for individual FA, appropriate for nonruminants, are not applicable for ruminants. The FA available for absorption in the small intestine are similar to those leaving the rumen (Moore and Christie, 1984). This consists of approximately 80 to 90% free FA with the remainder components of microbial phospholipids plus small amounts of dietary-derived triglycerides and glycolipids, which are hydrolyzed by intestinal and pancreatic lipases (Doreau and Ferlay, 1994). The low pH of the digesta entering the duodenum and the high concentration of taurocholic acid in bile promote the solubility of FA (Harrison and

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Leat, 1975). Pancreatic and bile secretions are added to the digesta in the duodenum, and are responsible for solubilizing FA (Bauchart, 1993). Pancreatic and bile secretions are at an apparent steady state in ruminants and not subject to large fluctuations dependent on meal composition (Noble, 1981). Most absorption of FA occurs in the jejunum; therefore, to accurately measure the digestibility of individual FA, duodenal flows of FA are needed to determine the total amount of each FA available to the ruminant. Fatty acids may also become biohydrogenated in the large intestine (Pantoja et al., 1996), which may result in an overprediction of apparent unsaturated FA digestibility and an underprediction of saturated FA digestibility. Therefore, differences may be present in digestibility estimates when digesta samples are collected from the ileum compared with feces.

Previous reports have indicated that the digestibility of saturated FA decreases with increasing chain length and unsaturation increases digestibility of FA (Steele and Moore, 1968; Andrews and Lewis, 1970). Digestibility of FA might decrease as more fat is included in the diet (Palmquist, 1991; Weisbjerg et al., 1992). Specifically, the reduction in digestibility as fat is included in diets has been linked to the lower digestibility of C18:0 (Weisbjerg et al., 1992). Based on previous reports of differences in long-chain FA digestibility and the importance of correctly modeling FA to understand the metabolism of FA in dairy cows, our objective was to perform a meta-analysis to determine apparent intestinal digestibility of individual long-chain FA in lactating dairy cattle. Secondarily, our objective was to use meta-regression to evaluate whether digestibility estimates of individual FA differed dependent on specific individual FA, FA concentration, and other potential biological drivers.

MATERIALS AND METHODS

Our initial selection criteria for inclusion into the data set were studies that reported individual FA digestibility measurements in lactating dairy cows using duodenally cannulated cows. We collected data from 20 studies representing 80 treatment means that were published in peer-reviewed journals. Five studies were removed because no estimates of variation were reported; an estimate of variation is required to properly weight the studies (Borenstein et al., 2009). Of the remaining 15 studies with 62 treatments, one treatment was removed because it contained saturated triglycerides as partially hydrogenated tallow (Pantoja et al., 1996), which has been previously reported as poorly digested in ruminants (Elliott et al., 1996; Weiss and Wyatt, 2004). The 61 remaining treatment means included 46 containing supplemental fat and 16 containing no supplemental fat source. Table 1 provides information on the individual studies and treatments used in the data set. Treatments were separated into categories based on supplemental fat type; control diets (no supplemental fat added) and diets supplemented with animal-vegetable fat, calcium-salts of FA, tallow, vegetable oil, seed meal, whole seeds, and other.

Comprehensive Meta-Analysis v 2.0 software was used to analyze the data (Biostat, Englewood, NJ). Apparent digestibility estimates were obtained using a MIXED model, which accounted for variation both within and among studies. Studies were weighted based on the inverse of the sum of both the within and among study variance. Digestibility of C18:0 was used as the comparison with all other FA because of equal saturation compared with C16:0 and equal chain length compared with C18:1, C18:2, and C18:3. If digestibility estimates were reported for individual isomers of unsaturated FA, a weighted average of digestibility based on flow through the duodenum was used. For example, if both *cis* and *trans* isomers of C18:1 were reported, we combined the data to represent a single value for C18:1 digestibility.

Our data set included digestibility estimates from both ileal and fecal collections. Using fecal digestion does not account for biohydrogenation and possible synthesis of FA from microbes that could occur in the large intestine. Only 4 studies with 18 treatment comparisons used ileally cannulated cows to measure FA digestibility in the small intestine. Therefore, we further examined if site of collection affected digestibility estimates for individual FA by evaluating studies that used similar methods of collection together.

Figures of study-adjusted values for digestibility of FA were developed based on SAS code described by St-Pierre (2001). Including the random effect of study in the model accounts for variation among studies and improves the accuracy of equations produced.

Meta-regression was used to determine dietary variables or measurements taken from the duodenum that influence digestibility estimates using JMP version 10.0.2 (SAS Institute Inc., Cary, NC). Studies were weighted by the inverse of the standard error squared (St-Pierre, 2001; Borenstein et al., 2009). In studies from which the standard error was less than half of the mean standard error, the standard error was set to half of the mean standard error across all studies to prevent over weighting (Firkins et al., 2001). The original model including all variables for duodenal flow was