ABSTRACT

Six lactating Holstein cows were used in a replicated 3 x 3 Latin square design to determine the effects of medium-chain triglyceride supplementation on milk fatty acid composition and plasma energy metabolites. Treatments were no supplemental triglyceride, 500 ml of odd-carbon, medium-chain triglyceride (fatty acid composition: 100% pelargonic acid), or 500 ml of even-carbon, medium-chain triglyceride (fatty acid composition: 65% caproic acid, 35% capric acid) added daily to a total mixed ration. Medium-chain triglyceride supplementation did not affect ruminal molar proportions of acetate or propionate but slightly increased the molar proportion of butyrate. Even-carbon and odd-carbon, medium-chain triglycerides reduced DM intake by 1.7 and 1.3 kg/d, respectively, but did not affect milk yield or milk protein percentage. Cows that did not receive supplemental triglyceride produced milk with 3.29% fat. Milk fat concentration was increased by even-carbon, medium-chain triglyceride supplementation relative to odd-carbon, medium-chain triglyceride supplementation (3.44 vs. 2.99%). Although changes in milk fatty acid composition were observed, they were minor and mostly unexplained. Feeding even-carbon, medium-chain triglycerides caused slight increases in plasma glucose and nonesterified fatty acid concentrations, but plasma β-hydroxybutyrate concentration was not affected by treatments.

INTRODUCTION

Recently, there has been interest in supplementing human diets with medium-chain length fatty acids (MCFA; C6:0 to C12:0) in the form of triglycerides. Medium-chain triglycerides (MCT) fed to rats are hypocholesterolemic, probably as a result of reduced cholesterol absorption from the intestine and reduced hepatic cholesterol synthesis (1). If dietary MCT are hypocholesterolemic in humans, increasing MCT in bovine milk may be desirable.

In contrast to long-chain fatty acids (LCFA, C14:0 to C20:0), which are absorbed via the lymphatic system as chylomicrons, MCFA are absorbed via the hepatic portal vein (1). Therefore, the efficiency of transfer of absorbed MCFA to milk may be low due to extensive oxidation in the liver. In rat liver, MCFA are more rapidly and extensively oxidized than LCFA because they are not activated to acyl-CoA derivatives in the cytosol (i.e., are not used for triglyceride, phospholipid, and cholesterol ester synthesis) and they rapidly cross mitochondrial membranes because transport is independent of carnitine acyl transferase-I (1). Supplemental even-carbon MCT (ECMCT) are ketogenic in rats because excessive acetyl-CoA generated from oxidation are directed toward synthesis of ketones (6, 20, 21). Odd-carbon MCT (OCMCT) are not ketogenic, presumably because propionyl-CoA generated from oxidation may provide substrate for TCA cycle activity and glucose synthesis (6, 14).

The objectives of this study were to determine whether C8:0, C9:0, or C10:0 content of milk could be increased by supplementing dairy cattle diets with MCT and what effects supple-
MENTATION WITH MCT HAS ON PLASMA ENERGY METABOLITES.

MATERIALS AND METHODS

Six lactating Holstein cows that averaged 39.5 kg milk/d (range: 35.4 to 44.5 kg/d) were used in a replicated 3 x 3 Latin square design, each period lasting 21 d. Cows were fed a basal diet consisting of 50% concentrate (43.4% ground ear corn, 37.4% wheat middlings, 16.2% corn gluten feed, and 3.0% vitamins and minerals, as-fed basis) and 50% alfalfa haylage (DM basis). Diets were fed twice daily at 1000 and 2200 h to provide a 5% weighback. Treatments consisted of the basal diet or basal diet supplemented with either ECMCT (65% C8:0 and 35% C10:0 fatty acids) or OCMCT (100% C9:0 fatty acid). Supplemental MCT were added at the rate of 300 ml/d during d 1 to 10 and 500 ml/d during d 11 to 21 of each period. One-half of the MCT allotment was mixed by hand with grain at each feeding prior to blending grain and forage into a total mixed ration.

Milk yield was recorded daily, and milk sampled from four consecutive milkings on d 20 and 21 of each period was analyzed separately for fat and protein by infrared analysis (Wisconsin DHIA, Appleton, WI). A portion of each of the four milk samples was composited, and following methyl ester formation (18), was analyzed for fatty acids (16) by gas-liquid chromatography using a column packed with GP 10% SP-2330 on 100/120 chromosorb WAW (Supelco, Inc., Bellefonte, PA).

Feed intake was measured daily. Feed samples were obtained during the last week of each period and orts were sampled during the final 2 d of each period. Feed and ort samples were placed in a forced air oven at 55°C for 48 h to determine DM content.

Ruminal fluid was collected via stomach tube at 1400 h on d 20 of each period. Samples were acidified to pH 2 to 3 with 50% H2SO4 (vol/vol) and centrifuged at 17,300 x g for 10 min. The supernatant was analyzed for ruminal VFA by gas-liquid chromatography (3) using a column packed with GP 10% SP-2330 on 100/120 chromosorb WAW (Supelco, Inc., Bellefonte, PA).

Blood was collected in heparinized vacutainers containing NaF (1.2 mg/ml blood) from the tail vein at 1300 h on d 20 and 21 of each period. Plasma obtained by centrifugation of blood (7000 x g for 10 min) was frozen until aliquots were analyzed for glucose (Sigma Chemical Co., St. Louis, MO), β-hydroxybutyrate (4), and nonesterified fatty acids (NEFA, Wako Pure Chemical Industries, Ltd., Osaka, Jpn).

Data were analyzed by ANOVA by the General Linear Model procedure using SAS (15). The model employed for analysis was: Yijkl = u + Si + Cj(Si) + Pk + T1 + eijkl where Yijkl is the dependant variable, u = overall mean of the population, Si = i th square, Cj = j th cow, Pk = k th period, T1 = I th treatment, and eijkl = random residual. Single df orthogonal contrasts were: control versus MCT and ECMCT versus OCMCT. Effects were considered significantly different if P<.05 and tendencies if P>.05 and <.15.

RESULTS AND DISCUSSION

Molar percentage butyrate tended to increase during MCT supplementation (Table 1) and was the only ruminal VFA affected by treatments. This is in contrast to previous studies (5, 11) that demonstrated a reduction in the molar percentage butyrate during feeding of LCFA in free or esterified form. Reduced protozoa] num bers have been associated with reductions in butyrate during fat supplementation (11, 19). Effects of MCT on microbial populations or the nature and extent of MCT metabolism in the rumen are unknown.

Dry matter intake (Table 2) was significantly decreased by supplementation with MCT as part of a total mixed ration. Reductions in DM intake resulting from feeding oil previously have been observed (9, 11) and may result from poor acceptability of the ration, adverse effects of fat on ruminal fermentation and fiber digestion, feedback regulation to maintain constant energy intake, or a combination of these factors. Because molar proportions of ruminal VFA were relatively similar across treatments, palatability of fat may have been the major factor reducing intake.

Milk yield and milk protein concentration (Table 2) were not affected by treatment. Milk fat concentration and yield were significantly less during OCMCT supplementation relative to ECMCT supplementation. The OCMCT po-
TABLE 1. Ruminal volatile fatty acids in cows fed medium-chain triglycerides.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Control</th>
<th>ECMCT</th>
<th>OCMCT</th>
<th>SE</th>
<th>Significant effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acetate, %</td>
<td>59.4</td>
<td>55.9</td>
<td>56.3</td>
<td>2.7</td>
<td>NS</td>
</tr>
<tr>
<td>Propionate, %</td>
<td>23.9</td>
<td>26.0</td>
<td>25.1</td>
<td>2.4</td>
<td>NS</td>
</tr>
<tr>
<td>Butyrate, %</td>
<td>9.5</td>
<td>11.1</td>
<td>12.2</td>
<td>.8</td>
<td>Control&gt;MCT</td>
</tr>
<tr>
<td>Valerate, %</td>
<td>3.0</td>
<td>2.8</td>
<td>2.5</td>
<td>.4</td>
<td>NS</td>
</tr>
<tr>
<td>Isobutyrate, %</td>
<td>1.4</td>
<td>1.4</td>
<td>1.2</td>
<td>.2</td>
<td>NS</td>
</tr>
<tr>
<td>Isovalerate, %</td>
<td>2.8</td>
<td>2.7</td>
<td>2.5</td>
<td>.4</td>
<td>NS</td>
</tr>
<tr>
<td>Acetate:propionate</td>
<td>2.9</td>
<td>2.2</td>
<td>2.6</td>
<td>.5</td>
<td>NS</td>
</tr>
</tbody>
</table>

1Control = No fat supplementation; ECMCT = supplementation of 300 ml/d even-carbon, medium-chain triglyceride (65% C8, 35% C10) during d 1 to 10 and 500 ml/d during d 11 to 21; OCMCT = supplementation of 300 ml/d odd-carbon, medium-chain triglyceride (100% C9) during d 1 to 10 and 500 ml/d during d 11 to 21.

2Moles per 100 mol of total VFA.

3NS = No significant differences (P>.15).

4MCT = Combined effects of ECMCT and OCMCT treatments.

TABLE 2. Dry matter intake, milk production, and milk composition by cows fed medium-chain triglycerides.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Control</th>
<th>ECMCT</th>
<th>OCMCT</th>
<th>SE</th>
<th>Significant effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>DM, Intake, kg/d</td>
<td>29.3</td>
<td>27.6</td>
<td>28.0</td>
<td>.5</td>
<td>Control&gt;MCT</td>
</tr>
<tr>
<td>Milk, kg/d</td>
<td>36.2</td>
<td>35.1</td>
<td>35.9</td>
<td>.5</td>
<td>NS</td>
</tr>
<tr>
<td>Milk fat, %</td>
<td>3.29</td>
<td>3.44</td>
<td>2.99</td>
<td>.14</td>
<td>ECMCT&gt;OCMCT</td>
</tr>
<tr>
<td>Milk protein, %</td>
<td>3.20</td>
<td>3.23</td>
<td>3.20</td>
<td>.06</td>
<td>NS</td>
</tr>
<tr>
<td>Milk fat, kg/d</td>
<td>1.19</td>
<td>1.20</td>
<td>1.07</td>
<td>.04</td>
<td>ECMCT&gt;OCMCT</td>
</tr>
<tr>
<td>Milk protein, kg/d</td>
<td>1.16</td>
<td>1.13</td>
<td>1.15</td>
<td>.01</td>
<td>Control&gt;MCT</td>
</tr>
<tr>
<td>3.5% FCM, kg/d</td>
<td>35.0</td>
<td>34.6</td>
<td>32.9</td>
<td>.6</td>
<td>Control&gt;MCT</td>
</tr>
</tbody>
</table>

1Control = No fat supplementation; ECMCT = supplementation of 300 ml/d even-carbon medium-chain triglyceride (65% C8, 35% C10) during d 1 to 10 and 500 ml/d during d 11 to 21; OCMCT = supplementation of 300 ml/d odd-carbon, medium-chain triglyceride (100% C9) during d 1 to 10 and 500 ml/d during d 11 to 21.

2NS = No significant differences (P>.15).

3MCT = Combined effects of ECMCT and OCMCT treatments.

Journal of Dairy Science Vol. 72, No. 8, 1989
TABLE 3. Plasma glucose, \( \beta \)-hydroxybutyrate, and nonesterified fatty acids in cows fed medium-chain triglycerides.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Control</th>
<th>ECMCT</th>
<th>OCMCT</th>
<th>SE</th>
<th>Significant effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glucose, mg/dl</td>
<td>60.9</td>
<td>61.0</td>
<td>59.0</td>
<td>.9</td>
<td>ECMCT&gt;OCMCT ( P = .14 )</td>
</tr>
<tr>
<td>( \beta )-Hydroxybutyrate, mg/dl</td>
<td>8.4</td>
<td>10.3</td>
<td>9.1</td>
<td>.8</td>
<td>NS (^2)</td>
</tr>
<tr>
<td>Nonesterified fatty acid, ( \mu )g/L</td>
<td>184</td>
<td>205</td>
<td>188</td>
<td>7</td>
<td>ECMCT&gt;OCMCT ( P = .11 )</td>
</tr>
</tbody>
</table>

\(^1\)Control = No fat supplementation; ECMCT = supplementation of 300 ml/d even-carbon, medium-chain triglyceride (65% \( C_8 \), 35% \( C_{10} \)) during d 1 to 10 and 500 ml/d during d 11 to 21; OCMCT = supplementation of 300 ml/d odd-carbon, medium-chain triglyceride (100% \( C \)) during d 1 to 10 and 500 ml/d during d 11 to 21.

\(^2\)NS = No significant differences \( (P > .15) \).
TABLE 4. Fatty acid composition of milk fat from cows fed medium-chain triglycerides.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Control</th>
<th>ECMCT</th>
<th>OCMCT</th>
<th>SE</th>
<th>Significant effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>C4:0</td>
<td>2</td>
<td>.2</td>
<td>.1</td>
<td>.1</td>
<td>NS</td>
</tr>
<tr>
<td>C6:0</td>
<td>1.0</td>
<td>1.4</td>
<td>.6</td>
<td>.4</td>
<td>NS</td>
</tr>
<tr>
<td>C8:0</td>
<td>2.1</td>
<td>2.6</td>
<td>1.5</td>
<td>.4</td>
<td>ECMCT&gt;OCMCT (P = .07)</td>
</tr>
<tr>
<td>C9:0</td>
<td>&lt;.1</td>
<td>.1</td>
<td>.4</td>
<td>&lt;.1</td>
<td>ECMCT&lt;OCMCT (P = .01)</td>
</tr>
<tr>
<td>C10:0</td>
<td>5.4</td>
<td>7.9</td>
<td>5.6</td>
<td>1.2</td>
<td>NS</td>
</tr>
<tr>
<td>C12:0</td>
<td>6.6</td>
<td>8.4</td>
<td>6.7</td>
<td>.9</td>
<td>NS</td>
</tr>
<tr>
<td>C14:0</td>
<td>15.9</td>
<td>18.4</td>
<td>17.1</td>
<td>.7</td>
<td>Control&lt;MCT (P = .08)</td>
</tr>
<tr>
<td>C16:0</td>
<td>30.5</td>
<td>25.7</td>
<td>30.0</td>
<td>2.8</td>
<td>NS</td>
</tr>
<tr>
<td>C16:1</td>
<td>3.4</td>
<td>2.5</td>
<td>2.7</td>
<td>.7</td>
<td>NS</td>
</tr>
<tr>
<td>C18:0</td>
<td>11.6</td>
<td>12.1</td>
<td>9.7</td>
<td>1.2</td>
<td>NS</td>
</tr>
<tr>
<td>C18:1</td>
<td>21.6</td>
<td>18.3</td>
<td>23.1</td>
<td>1.7</td>
<td>ECMCT&lt;OCMCT (P = .08)</td>
</tr>
<tr>
<td>C18:2</td>
<td>2.6</td>
<td>2.3</td>
<td>2.6</td>
<td>.4</td>
<td>NS</td>
</tr>
</tbody>
</table>

1Control = No fat supplementation; ECMCT = supplementation of 300 ml/d even-carbon, medium-chain triglyceride (65% C8, 35% C10) during d 1 to 10 and 500 ml/d during d 11 to 21; OCMCT = supplementation of 300 ml/d odd-carbon, medium-chain triglyceride (100% C9) during d 1 to 10 and 500 ml/d during d 11 to 21.

2Grams per 100 g C4:0 + C6:0 + C8:0 + C9:0 + C10:0 + C11:0 + C12:0 + C13:0 + C14:0 + C16:0 + C16:1 + C18:0 + C18:1 + C18:2.

3NS = No significant differences (P > .15).

4MCT = Combined effects of ECMCT and OCMCT treatments.

Fatty acids), might be expected to be metabolized to a lesser degree by the liver and be more available for mammary uptake. Rats with portal cavalcav shunts and fed MCT had dramatically higher MCFA concentrations in adipose tissue relative to intact rats fed control or MCT-supplemented diets (22). Similarly, neonatal rats fed triglycerides containing LCFA showed faster weight gains, larger fat pads, and larger and more adipocytes than animals fed MCT (7). Presumably these differences were related to extensive hepatic oxidation of MCT fatty acids, enhanced thermogenesis, and lessened energy efficiency (7). Kronfeld et al. (8) suggested MCFA may be ketogenic when fed to lactating cows. In our study, MCT supplementation did not significantly increase plasma β-hydroxybutyrate concentration (Table 3). Supplementation of ECMCT has resulted in ketonemia in laboratory animals (20, 21). However, amount of MCT fed (typically 30% or more of dietary energy as fat) was considerably greater in these trials than in our trial. Feeding MCT as part of a total mixed ration and the relatively continuous flow of digesta from the rumen may result in a continuous delivery of MCFA to the liver, which may minimize the likelihood of excessive hepatic ketone production and increases in blood ketone concentration. Concentration of nonesterified fatty acids tended to increase during ECMCT treatment relative to OCMCT and control treatments. These differences were relatively small and apparently insufficient to induce ketonemia via increased fatty acid uptake, fatty acid oxidation, and subsequent ketone production.

Feeding OCMCT to rodents avoids the increases in plasma ketone concentration typically observed during ECMCT supplementation (6, 14). This may be due to the generation of propionyl-CoA during oxidation of odd-carbon MCFA, which may supply substrate for increased tricarboxylic acid cycle activity, facilitate complete oxidation of acetyl-CoA, or pro-
MEDIUM-CHAIN TRIGLYCERIDE SUPPLEMENTATION

vide precursors for glucose synthesis. The OCMCT supplementation of rat diets alleviates the hypoglycemic effect of feeding ECMCT (6) and results in similar (6) or slightly higher (14) plasma glucose concentrations when compared with LCFA (corn oil) supplementation. In our study, there was a tendency toward an increase in plasma glucose concentration during supplementation of ECMCT relative to OCMCT; however, differences between treatments were small and probably not biologically significant.

Addition of 500 ml/d MCT to a total mixed ration did not substantially increase MCFA content of milk. This was probably due to substantial oxidation of MCFA by the liver, but plasma β-hydroxybutyrate concentrations did not increase as a result. However, the possibility of ruminal catabolism or extensive fecal excretion of MCFA cannot be dismissed. Odd-carbon MCT addition did not reduce ketone concentration or increase plasma glucose concentration, indicating they were not an antiketogenic fat supplement.

ACKNOWLEDGMENTS

The work was supported by Wisconsin Agricultural Experiment Station Project 2937. Appreciation is expressed to Peter J. Riley of Capital City Products (Columbus, OH) for providing the medium-chain triglycerides.

REFERENCES


Journal of Dairy Science Vol. 72, No. 8, 1989