Effects of Duodenal Infusions of Palmitic, Stearic, or Oleic Acids on Milk Composition and Physical Properties of Butter

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ABSTRACT

Four dairy cows fitted with a duodenal cannula were used in a 4 × 4 Latin square design to investigate the effects of daily duodenal infusion of 500 g of fatty acids (containing mainly C16:0, C18:0, or cis-C18:1) on fecal concentrations of fatty acids, fatty acid profiles of milk fat, and solid fat content of butter. Fecal concentrations of C16:0 and especially of C18:0 were increased by duodenal infusion. Infusion with C16:0 increased the proportion of C16:0 in milk fat and delayed softening of butter when the temperature rose. Infusion with C18:0 resulted only in a slight increase of C18:0 proportion in milk fat and did not significantly affect solid fat in butter between −10 and 30°C. With the infusion of cis-C18:1, the proportion of cis-C18:1 in milk fat was more than twice that of control, to the detriment of C16:0. Butter contained low proportion of solid fat, even at low temperatures. Increasing C16:0 or cis-C18:1 in milk fatty acid via duodenal infusion can be used to study their specific effects on butter characteristics, but, because of a low transfer from infusion to milk, this method is less efficient with C18:0.

(Key words: fatty acids, duodenal infusion, milk composition, butter)

Abbreviation key: C = control infusion, FA = fatty acids, O = oleic acid infusion, P = palmitic acid infusion, S = stearic acid infusion.

INTRODUCTION

The fatty acid (FA) profile of cow’s milk fat can be modified through the diet. Such manipulations can enhance butter spreadability (3, 12) or dietetic characteristics by increasing cis-C18:1 and decreasing C16:0 (21). However, because of ruminal biohydrogenation of unsaturated FA, changes in the FA composition of milk fat when dietary lipids are used may not reflect the composition of dietary fat. For experimental purposes, dietary fat can be added via abomasal (9, 10) or duodenal (8, 14) infusion to overcome the effects of ruminal digestion. Besides, mammary uptake of arterial FA and mammary de novo synthesis of FA can be affected by interactions between FA (2, 11, 17, 18), so that the interpretation of the effects of dietary or postruminal addition of usual fat sources, which are blends of several FA, can be difficult.

The objective of this study was to determine the effects of C16:0, C18:0 or cis-C18:1 on milk production, milk FA profile, and physical properties of butter. To avoid the effects of ruminal biohydrogenation or interaction between different FA, we used a continuous duodenal infusion of FA in a nearly pure form.

MATERIALS AND METHODS

Cows, Diets, Experimental Design, and Analytical Procedures

Four cows were used in a 4 × 4 Latin square design. They were fed a limited amount (18 kg of DM/d) twice daily, at 8:00 a.m. and 8:00 p.m., of a diet containing (DM basis) 59% forage, 40% concentrate, and 1% mineral-vitamin mix (Table 1). During each 10-d period, cows were infused duodenally with a control infusion containing no FA (C treatment), or with 500 g of FA mixtures (Henkel KGaA, D-40191 Düsseldorf) suspended in 2.5 L of water with 5 g of xanthan gum (Rhodigel E415, Rhône Poulenc, F-92545 Montrouge Cedex) and emulsified with 12.5 g of lecithin (L. Meyer France SA, BP 311, F-93153 Le Blanc Mesnil). On d 1 of each period, the amount infused was only 300 g of FA. These mixtures (Table 2) contained mainly C16:0 [palmitic acid infusion (P) treatment], C18:0 [stearic acid infusion (S) treatment], or cis-C18:1 [oleic acid infusion (O) treatment]. Detailed information on cows, diets, experimental design, and analytical procedures were described previously (11). Additionally, fecal samples...
were collected from d 9 to 10 between 8:00 a.m. and 8:00 p.m. and were stored at −20°C until analysis.

Milk from d 9 and 10 was used for butter manufacture. Every evening, cream was separated from the two daily milkings with a centrifugal separator (Elecrem model 147 077; F-44270 Machecoul) and stored overnight (12 h) at 4°C prior to butter manufacture. The next day, the cream was left at ambient temperature (18°C) until it reached 12°C and was immediately churned into butter in a laboratory drum churn (Menager Elba model 10; F-50100 Cherbourg). Buttermilk was washed from the butter with cold water (10°C), and excess moisture was removed by draining and working the butter manually for 10 min. Butter was stored at 4°C for 48 h. It was subsequently packed in a plastic container and frozen at −20°C until analysis. Butter samples were thermally analyzed with a differential scanning calorimeter (Perkin-Elmer model DSC 1; Norwalk, CT 06856, USA). The samples were held for 5 min at 70°C; the temperature was then reduced to −60°C at a rate of 5°C/min. After 2 min at this temperature the thermogram was recorded by heating at a rate of 5°C/min to 60°C. The proportion of liquid fat was determined via integration of the curve; we assumed identical enthalpies of fusion for all triglycerides. Solid fat was determined as 100 - liquid fat.

Calculation of Results and Statistical Analysis

Apparent transfer of infused FA from infusion to milk was calculated as (milk daily secretion with control infusion)/infused FA. Statistical validity of the differences among treatments was analyzed using SYSTAT (Version 5.03 for Windows, SYSTAT Inc., Evanston, IL). Treatments were compared by ANOVA, followed by the Tukey's pairwise comparison test (26). Regression was used to assess the relationship between milk FA proportions and solid fat percent in butter. Significance was taken at P < 0.05.

RESULTS AND DISCUSSION

Fecal Concentration of Fatty Acids

The fecal concentration of total and infused FA, except cis-C₁₈:₁, increased with duodenal infusion; treatment S resulted in the highest value (Table 3). These values suggest a high intestinal digestibility of infused cis-C₁₈:₁, a low digestibility of infused C₁₈:₀, and an intermediate digestibility of infused C₁₆:₀. The form of infused fat may have influenced their digestibility, because free FA flowing from the rumen are, in physiological conditions, adsorbed onto feed particles (4). In our experiment, delivery of FA emulsion directly to the duodenum may have impacted subsequent emulsification in the small intestine. Moreover, duodenal flows of C₁₆:₀ and C₁₈:₀ were very high in our trial with P and S treatment, because more than 460 g of C₁₆:₀ or C₁₈:₀ was added through the duodenal cannula to C₁₆:₀ or C₁₈:₀ from dietary origin, or to C₁₈:₀ resulting from ruminal biohydrogenation of dietary unsaturated C₁₈. Increase
of duodenal flow of C_{18:0} from 170 to about 400 g/d has been shown to decrease its digestibility from 73 to 45% and a low increase of duodenal flow of C_{16:0} from about 50 to 125 g/d decreased its digestibility from 78 to 71% (13). On the contrary, in the same experiment increasing duodenal flow of total C_{18:1} from 60 to 280 g/d did not modify its digestibility. Other trials have found intestinal digestibility of C_{18:0} close to 60% with diets resulting in C_{18:0} duodenal flows close to 600 g (24), and lack of modification of digestibility of FA after duodenal infusion of rapeseed oil, containing 60% cis-C_{18:1} (8). The lack of effect of duodenal flow of cis-C_{18:1} on its digestibility is probably due to the greater water solubility and ease of micelle formation of unsaturated FA (28). Moreover, a high ratio of saturated FA to unsaturated FA can decrease C_{18:0} digestibility (15). This ratio was higher with our S treatment than is usually observed when natural fats are added to the diet, because most of these natural fats contain more unsaturated than saturated FA, and incomplete ruminal biohydrogenation permits some unsaturated FA to enter the duodenum.

In our experiment, lecithin was added to the duodenal infusion as an emulsifier. However, positive effects of this lecithin on intestinal digestibility were difficult to assess. Lecithin has been shown to have very limited effects when added into the diet (29), possibly because of ruminal degradation. The consequences of postruminal lecithin supply have not been studied on digestibility, but only on milk production and composition (16).

Milk Production and Composition

Milk production and milk true protein content were not affected by infusion of FA (Table 4). Lack of effect of abomasal infusion of FA on milk protein output has previously been observed by Drackley et al. (10). Gagliostro and Chilliard (14) have previously shown a substantial decrease of milk protein content due to duodenal infusion of 1.1 kg of rapeseed oil. In their experiment, rations were given ad libitum, and oil infusion resulted in a 16% decrease in DMI, which can explain the decreased milk protein content. In our experiment, feed was offered in limited amounts and diet consumption was complete with all treatments.

Total FA in milk were significantly higher with P treatment compared with C treatment. The O treatment resulted in a nearly significant (P = 0.056) increase in FA content, whereas S treatment resulted in intermediate values, as compared with C. Abomasal infusion of 450 g of mostly saturated FA (mainly C_{16:0} and C_{18:0}) did not result in such an effect (9), but duodenal infusion of 1.1 kg of rapeseed oil has been reported to increase milk fat content (14). The quantitative effects of dietary fat addition on milk fat content are highly variable, because positive effects of dietary FA supply can be counteracted by negative effects of lipids on ruminal digestion (7) or by negative effects of trans-FA resulting from ruminal biohydrogenation of unsaturated FA (2, 27). In our experiment with duodenal infusion of FA, a negative effect on ruminal digestion could only have resulted from a lower DMI. Such a modification was not observed, so the higher milk fat secretion could logically be expected.

Duodenal infusion of nearly pure FA resulted in substantial modifications of the milk FA profile (Table 4) and daily milk FA output (Table 5). As expected, proportions and secretions of C_{16:0}, C_{18:0}, and cis-C_{18:1} were higher with P, S, and O treatments, respectively. This main effect, and the higher proportion of C_{18:2} observed with O treatment, can be attributed to arterial uptake of infused FA by the mammary gland (11, 25). The relative increase was greatest with O (+ 199 g of cis-C_{18:1} and + 26 g of C_{18:2}/kg of milk FA) and P (+ 229 g of C_{16:0}) treatments, and low with S treatment (+ 55 g of C_{18:0}). These differences were consistent with treatment differences in fecal FA.

Besides this direct effect of digestive supply, O treatment decreased C_{14:0} and C_{16:0} proportions. In vitro, Hansen and Knudsen (17, 18) showed with dispersed bovine mammary cells—that the addition of C_{18:0} or cis-C_{18:1} inhibits de novo synthesis of FA with 16 carbons or less, except C_{4:0}. These authors hypothesized that C_{18:0} or cis-C_{18:1} compete with newly synthesized short or medium chain acyl-CoA for esterification at the sn-2 and sn-3 positions of glycerol. In our experiment, no significant effect could be observed on FA with 6 to 12 carbons, and, probably due to its low digestibility, S treatment had no significant effect on C_{14:0} or C_{16:0} contents in milk fat. The effects of O treatment were also not significant on total daily outputs of C_{14:0} and C_{16:0}, because of high milk fat content. This suggests that the lowered proportion of these FA might be due both to a decreased synthesis and to a dilution effect.

Hansen and Knudsen (18) also observed that addition of C_{16:0} slightly decreased C_{14:0} and strongly increased C_{4:0} synthesis at all concentrations, increased C_{16:0} synthesis at low concentration but decreased C_{16:0} synthesis at high concentration. Our results are consistent with these in vitro observed modifications of C_{4:0} whose daily output was increased with P treatment, and with modifications of C_{14:0}. The decrease in C_{16:0} synthesis with high C_{16:0} supply could have limited the direct effect of P treatment on C_{16:0} concentration in milk fat.

Noble et al. (20) with dietary C_{18:0} showed that increase in milk total C_{18:1} proportion was 1.5 times the change in C_{18:0}. In our trial, the increase in cis-C_{18:1} was not significant with S treatment, was only half that
### Table 4. Milk production and composition of milk produced by cows duodenally infused with control suspension or suspensions enriched with fatty acids.

<table>
<thead>
<tr>
<th>Duodenal infusion&lt;sup&gt;1&lt;/sup&gt;</th>
<th>Control</th>
<th>Palmitic</th>
<th>Stearic</th>
<th>Oleic</th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Milk production, kg/d</td>
<td>23.2</td>
<td>25.1</td>
<td>24.5</td>
<td>21.3</td>
<td>0.8</td>
</tr>
<tr>
<td>True protein, %</td>
<td>2.89</td>
<td>2.97</td>
<td>2.98</td>
<td>2.91</td>
<td>0.05</td>
</tr>
<tr>
<td>Total fatty acids, %</td>
<td>3.57&lt;sup&gt;a&lt;/sup&gt;</td>
<td>4.55&lt;sup&gt;b&lt;/sup&gt;</td>
<td>4.09&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>4.48&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>0.55</td>
</tr>
<tr>
<td>Fatty acids, % by weight of total fatty acids</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C&lt;sub&gt;4:0&lt;/sub&gt;</td>
<td>3.83</td>
<td>4.76</td>
<td>4.78</td>
<td>4.42</td>
<td>0.29</td>
</tr>
<tr>
<td>C&lt;sub&gt;6:0&lt;/sub&gt;</td>
<td>2.10</td>
<td>2.05</td>
<td>2.25</td>
<td>1.99</td>
<td>0.08</td>
</tr>
<tr>
<td>C&lt;sub&gt;8:0&lt;/sub&gt;</td>
<td>1.20</td>
<td>1.06</td>
<td>1.22</td>
<td>1.08</td>
<td>0.07</td>
</tr>
<tr>
<td>C&lt;sub&gt;10:0&lt;/sub&gt;</td>
<td>1.75</td>
<td>2.03</td>
<td>2.47</td>
<td>2.25</td>
<td>0.18</td>
</tr>
<tr>
<td>C&lt;sub&gt;12:0&lt;/sub&gt;</td>
<td>3.51</td>
<td>2.36</td>
<td>2.88</td>
<td>2.66</td>
<td>0.28</td>
</tr>
<tr>
<td>C&lt;sub&gt;14:0&lt;/sub&gt;</td>
<td>11.69&lt;sup&gt;b&lt;/sup&gt;</td>
<td>8.65&lt;sup&gt;a&lt;/sup&gt;</td>
<td>10.37&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>8.93&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.44</td>
</tr>
<tr>
<td>C&lt;sub&gt;16:0&lt;/sub&gt;</td>
<td>35.54&lt;sup&gt;d&lt;/sup&gt;</td>
<td>46.21&lt;sup&gt;c&lt;/sup&gt;</td>
<td>32.41&lt;sup&gt;d&lt;/sup&gt;</td>
<td>23.29&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.35</td>
</tr>
<tr>
<td>C&lt;sub&gt;18:0&lt;/sub&gt;</td>
<td>8.33&lt;sup&gt;c&lt;/sup&gt;</td>
<td>7.48&lt;sup&gt;cd&lt;/sup&gt;</td>
<td>12.56&lt;sup&gt;c&lt;/sup&gt;</td>
<td>6.84</td>
<td>0.55</td>
</tr>
<tr>
<td><em>cis</em>-C&lt;sub&gt;18:1&lt;/sub&gt;</td>
<td>17.99&lt;sup&gt;c&lt;/sup&gt;</td>
<td>15.21&lt;sup&gt;c&lt;/sup&gt;</td>
<td>19.76&lt;sup&gt;c&lt;/sup&gt;</td>
<td>37.14&lt;sup&gt;d&lt;/sup&gt;</td>
<td>1.37</td>
</tr>
<tr>
<td><em>trans</em>-C&lt;sub&gt;18:1&lt;/sub&gt;</td>
<td>1.55</td>
<td>1.34</td>
<td>1.62</td>
<td>1.15</td>
<td>0.15</td>
</tr>
<tr>
<td>C&lt;sub&gt;18:2&lt;/sub&gt;</td>
<td>2.08</td>
<td>1.55</td>
<td>1.93</td>
<td>4.70</td>
<td>0.14</td>
</tr>
<tr>
<td>C&lt;sub&gt;18:3&lt;/sub&gt;</td>
<td>0.54</td>
<td>0.51</td>
<td>0.54</td>
<td>0.31</td>
<td>0.12</td>
</tr>
<tr>
<td>Total unsaturated C&lt;sub&gt;18&lt;/sub&gt;</td>
<td>22.16&lt;sup&gt;c&lt;/sup&gt;</td>
<td>18.64&lt;sup&gt;c&lt;/sup&gt;</td>
<td>23.84&lt;sup&gt;c&lt;/sup&gt;</td>
<td>43.30&lt;sup&gt;d&lt;/sup&gt;</td>
<td>1.59</td>
</tr>
<tr>
<td>Total C&lt;sub&gt;18&lt;/sub&gt;</td>
<td>30.49&lt;sup&gt;c&lt;/sup&gt;</td>
<td>26.12&lt;sup&gt;c&lt;/sup&gt;</td>
<td>36.40&lt;sup&gt;c&lt;/sup&gt;</td>
<td>50.14&lt;sup&gt;d&lt;/sup&gt;</td>
<td>1.91</td>
</tr>
</tbody>
</table>

<sup>a,b,c,d</sup>Means in the same row without a common superscript differ (a, b, P < 0.05; c, d, P < 0.01). Means in rows without superscripts do not differ (P > 0.05).

<sup>1</sup>Experimental duodenal infusions provided daily: no fatty acids (control infusion), about 490 g of C<sub>16:0</sub> (palmitic infusion), about 460 g of C<sub>18:0</sub> + 31 g of C<sub>16:0</sub> (stearic infusion), and about 400 g of *cis*-C<sub>18:1</sub> + 37 g of C<sub>18:2</sub> + 31 g of C<sub>16:0</sub> (oleic infusion).

### Table 5. Daily secretion and apparent transfer from infusion to milk of fatty acids by cows duodenally infused with control suspension or suspensions enriched with fatty acids.

<table>
<thead>
<tr>
<th>Duodenal infusion&lt;sup&gt;1&lt;/sup&gt;</th>
<th>Control</th>
<th>Palmitic</th>
<th>Stearic</th>
<th>Oleic</th>
<th>SEM</th>
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</thead>
<tbody>
<tr>
<td>Fatty acids secretion, g/d</td>
<td></td>
<td></td>
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<tr>
<td>C&lt;sub&gt;4:0&lt;/sub&gt;</td>
<td>31&lt;sup&gt;a&lt;/sup&gt;</td>
<td>54&lt;sup&gt;b&lt;/sup&gt;</td>
<td>48&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>43&lt;sup&gt;b&lt;/sup&gt;</td>
<td>4</td>
</tr>
<tr>
<td>C&lt;sub&gt;6:0&lt;/sub&gt;</td>
<td>17</td>
<td>23</td>
<td>22</td>
<td>19</td>
<td>2</td>
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<tr>
<td>C&lt;sub&gt;8:0&lt;/sub&gt;</td>
<td>10</td>
<td>12</td>
<td>12</td>
<td>10</td>
<td>1</td>
</tr>
<tr>
<td>C&lt;sub&gt;10:0&lt;/sub&gt;</td>
<td>22</td>
<td>23</td>
<td>24</td>
<td>21</td>
<td>2</td>
</tr>
<tr>
<td>C&lt;sub&gt;12:0&lt;/sub&gt;</td>
<td>28</td>
<td>27</td>
<td>28</td>
<td>25</td>
<td>3</td>
</tr>
<tr>
<td>C&lt;sub&gt;14:0&lt;/sub&gt;</td>
<td>95</td>
<td>97</td>
<td>102</td>
<td>84</td>
<td>8</td>
</tr>
<tr>
<td>C&lt;sub&gt;16:0&lt;/sub&gt;</td>
<td>290&lt;sup&gt;c&lt;/sup&gt;</td>
<td>519&lt;sup&gt;d&lt;/sup&gt;</td>
<td>321&lt;sup&gt;c&lt;/sup&gt;</td>
<td>219&lt;sup&gt;c&lt;/sup&gt;</td>
<td>25</td>
</tr>
<tr>
<td>C&lt;sub&gt;18:0&lt;/sub&gt;</td>
<td>70&lt;sup&gt;a&lt;/sup&gt;</td>
<td>84&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>125&lt;sup&gt;b&lt;/sup&gt;</td>
<td>66&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>9</td>
</tr>
<tr>
<td><em>cis</em>-C&lt;sub&gt;18:1&lt;/sub&gt;</td>
<td>147&lt;sup&gt;c&lt;/sup&gt;</td>
<td>170&lt;sup&gt;d&lt;/sup&gt;</td>
<td>196&lt;sup&gt;c&lt;/sup&gt;</td>
<td>346&lt;sup&gt;d&lt;/sup&gt;</td>
<td>15</td>
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<tr>
<td><em>trans</em>-C&lt;sub&gt;18:1&lt;/sub&gt;</td>
<td>13</td>
<td>15</td>
<td>16</td>
<td>11</td>
<td>2</td>
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<td>C&lt;sub&gt;18:2&lt;/sub&gt;</td>
<td>17&lt;sup&gt;c&lt;/sup&gt;</td>
<td>18&lt;sup&gt;d&lt;/sup&gt;</td>
<td>19&lt;sup&gt;d&lt;/sup&gt;</td>
<td>43</td>
<td>2</td>
</tr>
<tr>
<td>C&lt;sub&gt;18:3&lt;/sub&gt;</td>
<td>4</td>
<td>6</td>
<td>5</td>
<td>3</td>
<td>2</td>
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<tr>
<td>Total unsaturated C&lt;sub&gt;18&lt;/sub&gt;</td>
<td>181&lt;sup&gt;c&lt;/sup&gt;</td>
<td>209&lt;sup&gt;c&lt;/sup&gt;</td>
<td>236&lt;sup&gt;c&lt;/sup&gt;</td>
<td>403&lt;sup&gt;d&lt;/sup&gt;</td>
<td>20</td>
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<td>Total C&lt;sub&gt;18&lt;/sub&gt;</td>
<td>251&lt;sup&gt;c&lt;/sup&gt;</td>
<td>294&lt;sup&gt;c&lt;/sup&gt;</td>
<td>361&lt;sup&gt;cd&lt;/sup&gt;</td>
<td>469&lt;sup&gt;d&lt;/sup&gt;</td>
<td>27</td>
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<td>Apparent transfer&lt;sup&gt;2&lt;/sup&gt;, %</td>
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<td>Principal infused fatty acid</td>
<td></td>
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<tr>
<td>C&lt;sub&gt;18:0&lt;/sub&gt; + <em>cis</em>-C&lt;sub&gt;18:1&lt;/sub&gt;</td>
<td>46.7&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>12.0&lt;sup&gt;b&lt;/sup&gt;</td>
<td>49.7&lt;sup&gt;b&lt;/sup&gt;</td>
<td>7.4</td>
<td>4.4</td>
</tr>
<tr>
<td>C&lt;sub&gt;18:2&lt;/sub&gt;</td>
<td>22.7</td>
<td>71.8</td>
<td></td>
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<sup>a,b,c,d</sup>Means in the same row without a common superscript differ (a, b, P < 0.05; c, d, P < 0.01). Means in rows without superscripts do not differ (P > 0.05).

<sup>1</sup>Experimental duodenal infusions provided daily: no fatty acids (control infusion), about 490 g of C<sub>16:0</sub> (palmitic infusion), about 460 g of C<sub>18:0</sub> + 31 g of C<sub>16:0</sub> (stearic infusion), and about 400 g of *cis*-C<sub>18:1</sub> + 37 g of C<sub>18:2</sub> + 31 g of C<sub>16:0</sub> (oleic infusion).

<sup>2</sup>Calculated as (milk daily secretion with fatty acids infusion - milk daily secretion with control infusion) / infused fatty acid.
observed for C18:0 when considering milk proportion, and was identical when milk output was considered. However, these authors used Ayrshire cows; breed is known to influence the concentration of C18:0 and cis-C18:1 in milk fat (22).

Apparent transfer from duodenal infusion to milk output was high for C18:0 with P treatment and cis-C18:1 with O treatment, and low for C18:0 with S treatment (Table 5). Part of C16:0 in milk is synthesized in the mammary gland, and this synthesis can be affected by blood C16:0 supply (18), so that the apparent transfer of this FA is not meaningful biologically. Because C18:0 can be desaturated to cis-C18:1 in the duodenal mucosa (5) and in the mammary gland (1), we also calculated an apparent transfer of C18:0 for S treatment using milk secretion of both C18:0 and cis-C18:1. The value was about twice the value calculated with C18:0 only, which is consistent with the 50% mammary desaturation rate of C18:0 measured via arteriovenous differences in the same experiment (11). However, a very large variability among cows was observed.

Apparent transfer was 50% for cis-C18:1 and 72% for C18:0 in our experiment. Palmquist and Mattos (23) measured a 47% recovery of labeled C18:2 placed postruminally. LaCount et al. (19) reported values in the same range than ours for apparent transfer of total C18:1 (54%), but a lower value for C18:2 (52%).

Thermal Analysis of Butter

Solid fat contents of butterfat for a range of temperatures from -10 to 30°C are presented in Table 6. At all temperatures, butters from milk produced by cows receiving the O treatment had much lower solid fat content. This enhanced butter softness at refrigerator temperature, but above 12°C these butters oiled off.

Such physical properties of butterfat from O treatment could be expected from previous results, showing a strong linear relationship between liquid fat content at 6 or 14°C and the iodine index (12). The iodine index represents the degree of unsaturation of the fat, and in the present experiment, variations of this degree of unsaturation were mainly due to cis-C18:1. Figure 1 shows the relationship between milk fat concentration of cis-C18:1 and solid fat in butter at refrigerator temperature (6°C) and at room temperature (18°C). At 18°C, considering the concentration of C16:0 in milk fat slightly enhanced the relationship shown in Figure 1, with a significant coefficient for C16:0 in the multiple regression: [solid fat content at 18°C = 40.6 + 0.73 C16:0 - 1.14 cis-C18:1 (r² = 0.97 ; P < 0.001 ; n = 16)]. The effect of P infusion on solid fat was significant from 18°C, resulting in less oily butter at room temperature.

Treatment S produced butters with physical characteristics not significantly different from control butters, although the solid fat content tended to be lower at temperatures below 30°C. With this treatment, the increase in C18:0 tended to make the fat harder (6), but this effect may have been counteracted by the slight increase in cis-C18:1.

CONCLUSIONS

Duodenal infusion of nearly pure C16:0, C18:0, or cis-C18:1 mainly increased the incorporation of the infused fatty acids.
FA into milk fat. The desired FA profile of butter relative to assumed consumer cardiovascular risk was enhanced by O infusion and made worse by P infusion. The P infusion increased butter quality at room temperature, and O infusion increased softness at low temperature but resulted in oily butter at room temperature. Transfer of C18:0 from duodenum to milk may have been limited by low digestibility of S treatment, so that milk FA profile and butter softness were poorly affected by S treatment. Achieving an increase in cis-C18:1 proportion in milk fat will require protection of dietary cis-C18:1 from ruminal biohydrogenation or methods to improve intestinal digestibility of C18:0.

ACKNOWLEDGMENTS

The authors thank M.H. Quemener for thermal analysis of the butters.

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