THE PORTAL TRANSPORT OF ABSORBED FATTY ACIDS*

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Earlier reports have shown that absorbed C¹⁴-labeled stearic (1), palmitic (2), and pentadecanoic (3) acids can be recovered, almost quantitatively, in intestinal or thoracic duct lymph. In the case of myristic acid, however, the highest recovery in lymph was about 80, and the lowest about 60 per cent of the absorbed C¹⁴. Still lower values (15 to 55 per cent) were observed with lauric acid, and, when decanoic acid was studied, the recoveries in lymph did not exceed 20 per cent of the amount absorbed (1). The above findings were taken to indicate that the major portion of absorbed shorter chain fatty acids is transported from the intestine via the portal pathway.

These earlier findings were obtained with rats in which cannulae had been inserted into either the thoracic duct or intestinal lacteals. In the present study, we investigated fatty acid absorption in normal rats that were not subjected to operative manipulations. It is shown that when C¹⁴-labeled palmitic acid is fed the ratio of plasma fatty acid-C¹⁴ of the portal vein to that of the inferior vena cava is about unity, whereas in similar experiments with C¹⁴-labeled decanoic acid, the ratio exceeds unity. These results with intact rats are thus in agreement with the concept that long chain, saturated fatty acids are transported primarily, if not solely, via lymph, whereas short chain fatty acids enter by way of the portal system.

EXPERIMENTAL

Treatment of Animals—Male rats of the Long-Evans strain, which had been fasted from 18 to 20 hours, were fed by stomach tube 0.5 cc. of corn oil containing 20 mg. of either palmitic acid-1-C¹⁴ (4) or decanoic acid-1-C¹⁴ (1). The mixture was brought to body temperature before its administration. From 30 to 190 minutes after the intubation the rats were anesthetized with ether, and their abdominal walls were opened by a mid-

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line incision. The rats were then exsanguinated by the simultaneous withdrawal, into heparinized syringes, of nearly equal volumes of blood from the portal vein and the inferior vena cava. About 4 cc. of whole blood were obtained from each site. Plasma was analyzed for fatty acid-C\textsuperscript{14} as described below.

**Analytical Procedures; Plasma**—Plasma was slowly delivered into 20 volumes of 3:1 alcohol-ether, which was swirled constantly during the procedure. The mixture was then refluxed for 2 hours at 55° and filtered through Whatman No. 1 paper into an Erlenmeyer flask equipped with a small side arm. The precipitate on the filter paper was washed four times with ethyl ether. To the combined extract and washings was added 0.5 cc. of 45 per cent KOH. The volume of this mixture was reduced to about 1 cc. on a steam bath, a procedure that required about 4 hours. About 20 cc. of ethyl ether were then added, and the contents slowly acidified with H\textsubscript{2}SO\textsubscript{4}. The ethyl ether was decanted, and the aqueous residue was reextracted three times with ethyl ether. The C\textsuperscript{14} content of the ethyl ether extract was then determined. In the experiments with palmitic acid-1-C\textsuperscript{14}, this determination was done by the direct fat mount technique of Entenman et al. (5). In the decanoic acid-1-C\textsuperscript{14} experiments, the C\textsuperscript{14}

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### Table I

<table>
<thead>
<tr>
<th>Rat No.</th>
<th>Weight (gm.)</th>
<th>Absorption period (min.)</th>
<th>Per cent of administered C\textsuperscript{14} absorbed*</th>
<th>Fatty acid-C\textsuperscript{14} per cc. plasma obtained from Portal vein (P. v.)</th>
<th>Fatty acid-C\textsuperscript{14} per cc. plasma obtained from Inferior vena cava (I. v. c.)</th>
<th>P. v. fatty acid-C\textsuperscript{14}</th>
<th>I. v. c. fatty acid-C\textsuperscript{14}</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>285</td>
<td>30</td>
<td>14</td>
<td>4.0 \times 10^2</td>
<td>4.0 \times 10^2</td>
<td>1.0</td>
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<tr>
<td>2</td>
<td>285</td>
<td>60</td>
<td>15</td>
<td>7.3 \times 10^2</td>
<td>7.5 \times 10^2</td>
<td>0.97</td>
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<tr>
<td>3</td>
<td>335</td>
<td>60</td>
<td>58</td>
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<td>2.0 \times 10^2</td>
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<tr>
<td>4†</td>
<td>260</td>
<td>90</td>
<td>29</td>
<td>1.7 \times 10^2</td>
<td>1.6 \times 10^2</td>
<td>1.1</td>
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<tr>
<td>5†</td>
<td>282</td>
<td>100</td>
<td>42</td>
<td>3.2 \times 10^2</td>
<td>3.5 \times 10^3</td>
<td>0.91</td>
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<tr>
<td>6</td>
<td>290</td>
<td>150</td>
<td>50</td>
<td>2.6 \times 10^2</td>
<td>2.4 \times 10^3</td>
<td>1.1</td>
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<tr>
<td>7</td>
<td>300</td>
<td>180</td>
<td>61</td>
<td>2.0 \times 10^2</td>
<td>2.1 \times 10^3</td>
<td>0.95</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>300</td>
<td>190</td>
<td>49</td>
<td>6.1 \times 10^2</td>
<td>5.3 \times 10^4</td>
<td>1.2</td>
<td></td>
</tr>
</tbody>
</table>

* Refers to the difference between the administered C\textsuperscript{14} and the fatty acid-C\textsuperscript{14} recovered from the gastrointestinal tract (i.e. wall and contents).
† Received 10 mg. of labeled palmitic acid in 0.25 cc. of corn oil.

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through Whatman No. 1 paper into an Erlenmeyer flask equipped with a small side arm. The precipitate on the filter paper was washed four times with ethyl ether. To the combined extract and washings was added 0.5 cc. of 45 per cent KOH. The volume of this mixture was reduced to about 1 cc. on a steam bath, a procedure that required about 4 hours. About 20 cc. of ethyl ether were then added, and the contents slowly acidified with H\textsubscript{2}SO\textsubscript{4}. The ethyl ether was decanted, and the aqueous residue was reextracted three times with ethyl ether. The C\textsuperscript{14} content of the ethyl ether extract was then determined. In the experiments with palmitic acid-1-C\textsuperscript{14}, this determination was done by the direct fat mount technique of Entenman et al. (5). In the decanoic acid-1-C\textsuperscript{14} experiments, the C\textsuperscript{14}
content of the ethyl ether extract was measured by mounting the sodium salts of the fatty acids directly on aluminum plates, as described elsewhere (1).

Gastrointestinal Tract—The entire gastrointestinal tract (i.e. wall and contents), from cardiac sphincter to anus, was excised, thoroughly ground, its lipides extracted, and the C\textsubscript{14} content of the ether extract determined as described above. The values so obtained were used to calculate the extent of absorption of the administered fatty acid-C\textsubscript{14}.

Results

\textit{Palmitic Acid-1-C\textsubscript{14}}—Table I records the results on eight rats fed labeled palmitic acid. From 14 to 61 per cent of the administered C\textsubscript{14} was absorbed in 30 to 190 minutes. At the end of the absorption period, the fatty acid-C\textsubscript{14} content of portal vein and inferior vena cava plasma was determined. The fatty acid-C\textsubscript{14} concentration in the portal vein plasma was 0.9 to 1.2 times that in inferior vena cava plasma.

\textit{Decanoic Acid-1-C\textsubscript{14}}—The results obtained with eleven rats are recorded in Table II. The experimental periods ranged from 30 to 170 minutes, and the absorption of the fatty acid-C\textsubscript{14} during these periods ranged from 37 to 99 per cent. In the majority of cases the values for the ratio of fatty acid-C\textsubscript{14} in portal vein plasma to that in the inferior vena cava plasma exceeded 2.2.\textsuperscript{1}

Comment

In the present study we used normal rats that were not subjected to any operative manipulation for comparing the concentration of plasma fatty acid-C\textsubscript{14} of the portal vein with that of the inferior vena cava at early intervals after the enteral administration of either decanoic acid-C\textsubscript{14} or palmitic acid-C\textsubscript{14}. Following the feeding of decanoic acid-C\textsubscript{14}, the ratio of plasma fatty acid-C\textsubscript{14} in the portal vein to that of the inferior vena cava was significantly greater than unity. Indeed, in one of the 30 minute experiments, the fatty acid-C\textsubscript{14} concentration in portal vein plasma was about 10 times that in the inferior vena cava. These ratios are consistent with the view that short chain fatty acids are transported from their site of absorption primarily via blood.

But at no time did the ratio exceed 1.2 when labeled palmitic acid was fed, and in seven such experiments the ratio was 1.1 or lower. A ratio slightly above unity, such as the value of 1.2 observed in Rat 8, might indicate that some of the absorbed palmitic acid entered the portal blood.

\textsuperscript{1} When sodium decanoate-1-C\textsubscript{14} was injected intravenously and the fatty acid-C\textsubscript{14} content of portal vein plasma and inferior vena cava plasma determined 3 minutes later, this ratio was found to be unity.
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directly, but the possibility that the palmitic acid first entered lymph and
then reached the portal blood by way of lymphatic-venous anastomoses
cannot be ruled out. Those findings with palmitic acid C\textsuperscript{14} are in agree-
ment with those reported by Glenn et al. (6) and by Winter and Crandall (7)
in dogs fed olive oil, and support our earlier demonstration that lymph is
the major, if not the exclusive, pathway for transport of long chain, satu-
rated fatty acids (1-3).

Table II

| Fatty Acid-C\textsuperscript{14} Content of Plasma Obtained from Portal Vein and Inferior Vena Cava Following Feeding of Decanoic Acid-C\textsuperscript{14} |
|---|---|---|---|---|---|
| Decanoic acid labeled in the carboxyl position with C\textsuperscript{14} was administered. Each rat received by stomach tube about 20 mg. of the labeled acid in 0.5 cc. of corn oil at body temperature. All C\textsuperscript{14} values are corrected to an administered dose of 2 \times 10\textsuperscript{4}. |

<table>
<thead>
<tr>
<th>Rat No.</th>
<th>Weight</th>
<th>Absorption period</th>
<th>Per cent of administered C\textsuperscript{14} absorbed\textsuperscript{*}</th>
<th>Fatty acid-C\textsuperscript{14} per cc. plasma obtained from</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>gm.</td>
<td>min.</td>
<td></td>
<td>Portal vein (P. v.)</td>
<td>Inferior vena cava (I. v. c.)</td>
<td>P. v. fatty acid-C\textsuperscript{14}</td>
</tr>
<tr>
<td>10</td>
<td>300</td>
<td>30</td>
<td>52</td>
<td>3.1 \times 10\textsuperscript{4}</td>
<td>3.2 \times 10\textsuperscript{4}</td>
<td>9.7</td>
</tr>
<tr>
<td>11†</td>
<td>300</td>
<td>30</td>
<td>37</td>
<td>1.7 \times 10\textsuperscript{4}</td>
<td>7.4 \times 10\textsuperscript{4}</td>
<td>2.3</td>
</tr>
<tr>
<td>12†</td>
<td>300</td>
<td>35</td>
<td>56</td>
<td>2.0 \times 10\textsuperscript{4}</td>
<td>8.3 \times 10\textsuperscript{4}</td>
<td>2.4</td>
</tr>
<tr>
<td>13</td>
<td>305</td>
<td>65</td>
<td>41</td>
<td>2.2 \times 10\textsuperscript{4}</td>
<td>1.4 \times 10\textsuperscript{4}</td>
<td>1.6</td>
</tr>
<tr>
<td>14</td>
<td>360</td>
<td>70</td>
<td>60</td>
<td>4.3 \times 10\textsuperscript{4}</td>
<td>5.8 \times 10\textsuperscript{4}</td>
<td>7.4</td>
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<tr>
<td>15</td>
<td>280</td>
<td>120</td>
<td>87</td>
<td>3.1 \times 10\textsuperscript{4}</td>
<td>1.6 \times 10\textsuperscript{4}</td>
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</tr>
<tr>
<td>16</td>
<td>200</td>
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<td>2.6 \times 10\textsuperscript{4}</td>
<td>1.3</td>
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<td>17</td>
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<td>135</td>
<td>89</td>
<td>5.1 \times 10\textsuperscript{4}</td>
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<td>1.4</td>
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<tr>
<td>18</td>
<td>220</td>
<td>135</td>
<td>77</td>
<td>6.4 \times 10\textsuperscript{4}</td>
<td>2.8 \times 10\textsuperscript{4}</td>
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<tr>
<td>19</td>
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<td>140</td>
<td>78</td>
<td>1.1 \times 10\textsuperscript{4}</td>
<td>4.1 \times 10\textsuperscript{4}</td>
<td>2.7</td>
</tr>
<tr>
<td>20</td>
<td>230</td>
<td>170</td>
<td>87</td>
<td>1.1 \times 10\textsuperscript{4}</td>
<td>8.2 \times 10\textsuperscript{4}</td>
<td>1.3</td>
</tr>
</tbody>
</table>

\textsuperscript{*} Refers to the difference between the administered C\textsuperscript{14} and the fatty acid-C\textsuperscript{14} recovered from the gastrointestinal tract (i.e. wall and contents).

\textsuperscript{†} Received 16 mg. of labeled decanoic acid in 0.4 cc. of corn oil.

Summary

1. Following the administration of decanoic acid-1-C\textsuperscript{14} and palmitic acid-
1-C\textsuperscript{14} to rats, the concentration of fatty acid-C\textsuperscript{14} was measured in the plasma
of the portal vein and in that of the inferior vena cava.

2. The ratio of fatty acid-C\textsuperscript{14} in the portal vein plasma to that in the
inferior vena cava plasma in eleven rats fed the decanoic acid ranged from
1.3 to 9.7. In six of the rats the ratio was above 2.2.

3. In eight rats fed the palmitic acid, the ratio did not exceed 1.2, and
in seven of them the ratio was 1.1 or lower.
4. These findings are consistent with the view that short chain fatty acids are transported mainly by the portal pathway, and long chain, saturated fatty acids via lymph.

BIBLIOGRAPHY

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