THE AMINO ACIDS OF HUMAN SWEAT

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(Received for publication, August 6, 1946)

We have previously described microbiological procedures for the determination of amino acids in blood plasma (1, 2). These methods are now applied to sweat and certain experiments are carried out with the view of investigating amino acid secretion by the sweat glands. The amounts of ten individual amino acids in sweat are reported for the first time.

EXPERIMENTAL

Methods

The microbiological methods used were those described previously by Hier and Bergeim (1, 2) and by Hier et al. (3), except that threonine was determined with Streptococcus faecalis according to Stokes et al. (4), since more consistent results were obtained with this organism than with Lactobacillus arabinosus as previously used. However, we have found no difference in values when Streptococcus faecalis or Lactobacillus delbrückii was substituted for Lactobacillus casei (used for arginine, phenylalanine, and tyrosine), Lactobacillus arabinosus (used for leucine, isoleucine, valine, and tryptophane), or Leuconostoc mesenteroides (used for lysine and histidine).

The subjects used in all experiments were male medical and dental students ranging from 20 to 30 years of age. Unless otherwise stated in Tables I to VI, all subjects had a shower or bath no longer than 2 hours previous to the collection of the sweat sample. This was a precaution against variable accumulation of amino acids on the skin by evaporation. Specimens of sweat were collected by encasing the nude subjects in a rubber bag as far as their necks and seating them in a heat cabinet. Incandescent lamps furnished sufficient heat to obtain 100 to 200 cc. of sweat in 20 to 30 minutes. The collected sweat was then filtered through a medium porosity Berkefeld filter to remove dirt and débris. 10 cc. of this filtrate were diluted to 50 cc. for assay. 1 cc. of basal medium diluted to a final volume of 2 cc. with the sample and water was used in all cases.

Normal Values—In Tables I and II, data are shown for normal subjects with slight variations in preparation of subjects, volume of collection, and after ingestion of tyrosine and histidine. In this series the first and second sweat samples for each subject were collected on different days. There

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does not appear to be any effect of diet upon the amounts of amino acids in the sweat since there is no consistent trend shown in Subjects 1, 2, 3, 4, or 5, depending upon whether samples were collected before or after eating. Furthermore, the ingestion of 20 gm. of \( l(-) \)-tyrosine caused only a slight increase in the tyrosine content of sweat from Subject 7, which is well within the normal range. Similarly the ingestion of 20 gm. of \( l(-) \)-histidine hydrochloride in Subjects 8 and 9 caused no increase in the histidine content of the sweat.

### TABLE I

**Free Amino Acid Composition of Sweat from Normal Human Subjects Collected after Slightly Varying Preparation of Subjects and Volume of Collection**

The amino acid values are reported in micrograms per cc.

<table>
<thead>
<tr>
<th>Amino acid</th>
<th>Subject 1</th>
<th>Subject 2</th>
<th>Subject 3</th>
<th>Subject 4</th>
<th>Subject 5</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A.m.; no lunch</td>
<td>P.m.; after lunch</td>
<td>P.m.; after lunch</td>
<td>P.m.; no lunch</td>
<td>P.m.; after lunch</td>
</tr>
<tr>
<td>Arginine</td>
<td>170.0</td>
<td>171.0</td>
<td>92.5</td>
<td>60.5</td>
<td>139.0</td>
</tr>
<tr>
<td>Histidine</td>
<td>140.0</td>
<td>69.0</td>
<td>46.5</td>
<td>42.5</td>
<td>92.5</td>
</tr>
<tr>
<td>Isoleucine</td>
<td>37.3</td>
<td>22.0</td>
<td>21.3</td>
<td>16.3</td>
<td>16.5</td>
</tr>
<tr>
<td>Leucine</td>
<td>37.5</td>
<td>33.3</td>
<td>20.8</td>
<td>21.3</td>
<td>19.8</td>
</tr>
<tr>
<td>Lysine</td>
<td>33.8</td>
<td>25.1</td>
<td>21.1</td>
<td>20.8</td>
<td>22.7</td>
</tr>
<tr>
<td>Phenylalanine</td>
<td>34.7</td>
<td>21.5</td>
<td>17.5</td>
<td>17.0</td>
<td>19.3</td>
</tr>
<tr>
<td>Threonine</td>
<td>71.8</td>
<td>65.7</td>
<td>50.0</td>
<td>21.3</td>
<td>70.0</td>
</tr>
<tr>
<td>Tryptophane</td>
<td>16.0</td>
<td>12.0</td>
<td>7.5</td>
<td>8.5</td>
<td>10.0</td>
</tr>
<tr>
<td>Tyrosine</td>
<td>25.0</td>
<td>32.5</td>
<td>13.2</td>
<td>18.0</td>
<td>27.5</td>
</tr>
<tr>
<td>Valine</td>
<td>43.5</td>
<td>31.0</td>
<td>24.0</td>
<td>24.0</td>
<td>26.3</td>
</tr>
</tbody>
</table>

Total: 609.6 483.1 314.4 250.2 443.6 494.8 508.4 483.1 473.7

<table>
<thead>
<tr>
<th></th>
<th>75.0</th>
<th>54.0</th>
<th>80.0</th>
<th>70.0</th>
<th>185.0</th>
<th>160.0</th>
<th>92.0</th>
<th>160.0</th>
<th>25.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume, cc</td>
<td>0.25</td>
<td>0.22</td>
<td>0.44</td>
<td>0.43</td>
<td>0.37</td>
<td>0.39</td>
<td>0.82</td>
<td>0.90</td>
<td></td>
</tr>
<tr>
<td>NaCl, %</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Subject 6 demonstrates that there is considerable accumulation of amino acids on the skin due to evaporation. This subject did not bathe for 2 days previous to the first collection and all the amino acids are markedly higher than the normal for all subjects, as well as higher than was obtained with the same subject in a later collection after a shower in the usual manner.

From the data in Tables I and II it may also be seen that there is neither negative nor positive correlation between the volume of sweat and the amount of amino acids present. This, of course, may not be true if larger volumes of sweat are collected. In our data the maximum variation in volume is from 25 to 240 cc. of sweat.

**Variation in Single Subject**—The data in Table III demonstrate the variation in amounts of amino acids in sweat which occurs in the same subject
Table II
Free Amino Acid Composition of Sweat from Normal Human Subjects Collected after Slightly Varying Preparation of Subjects, Volume of Collection, and after Large Doses of Tyrosine and Histidine

The amino acid values are reported in micrograms per cc.

<table>
<thead>
<tr>
<th>Amino acid</th>
<th>Subject 6</th>
<th>Subject 7</th>
<th>Subject 8</th>
<th>Subject 9</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>P.m.;</td>
<td>P.m.;</td>
<td>P.m.;</td>
<td>P.m.;</td>
</tr>
<tr>
<td></td>
<td>2 days;</td>
<td>after</td>
<td>20 gm.</td>
<td>after</td>
</tr>
<tr>
<td></td>
<td>, no</td>
<td>lunch</td>
<td>tyrosine</td>
<td>lunch</td>
</tr>
<tr>
<td></td>
<td>shower</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arginine</td>
<td>315.0</td>
<td>141.0</td>
<td>130.5</td>
<td>191.0</td>
</tr>
<tr>
<td>Histidine</td>
<td>210.0</td>
<td>46.5</td>
<td>62.5</td>
<td>66.0</td>
</tr>
<tr>
<td>Isoleucine</td>
<td>52.0</td>
<td>22.5</td>
<td>16.0</td>
<td>20.4</td>
</tr>
<tr>
<td>Leucine</td>
<td>57.3</td>
<td>21.0</td>
<td>30.3</td>
<td>29.5</td>
</tr>
<tr>
<td>Lysine</td>
<td>45.5</td>
<td>17.0</td>
<td>26.8</td>
<td>20.5</td>
</tr>
<tr>
<td>Phenylalanine</td>
<td>38.0</td>
<td>13.0</td>
<td>15.5</td>
<td>25.5</td>
</tr>
<tr>
<td>Threonine</td>
<td>155.0</td>
<td>55.3</td>
<td>45.5</td>
<td>77.3</td>
</tr>
<tr>
<td>Tryptophane</td>
<td>27.5</td>
<td>9.0</td>
<td>9.8</td>
<td>11.0</td>
</tr>
<tr>
<td>Tyrosine</td>
<td>76.0</td>
<td>27.5</td>
<td>24.0</td>
<td>44.5</td>
</tr>
<tr>
<td>Valine</td>
<td>63.3</td>
<td>23.0</td>
<td>30.3</td>
<td>33.3</td>
</tr>
<tr>
<td>Total</td>
<td>1039.6</td>
<td>375.8</td>
<td>391.2</td>
<td>519.0</td>
</tr>
<tr>
<td>Volume, cc.</td>
<td>85.0</td>
<td>95.0</td>
<td>240.0</td>
<td>80.0</td>
</tr>
<tr>
<td>NaCl, %</td>
<td>0.71</td>
<td>0.52</td>
<td>0.39</td>
<td>0.38</td>
</tr>
</tbody>
</table>

Table III
Variation in Amino Acid Composition of Sweat Obtained from Same Subject (No. 10) over Period of 3 Months (Volumes 80 to 150 Cc.)

The amino acid values are supported in micrograms per cc.

<table>
<thead>
<tr>
<th>Date of collection</th>
<th>Arginine</th>
<th>Histidine</th>
<th>Isoleucine</th>
<th>Leucine</th>
<th>Lysine</th>
<th>Phenylalanine</th>
<th>Threonine</th>
<th>Tryptophane</th>
<th>Tyrosine</th>
<th>Valine</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1946</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jan. 15</td>
<td>170.0</td>
<td>89.0</td>
<td>25.9</td>
<td>27.5</td>
<td>19.2</td>
<td>20.0</td>
<td>64.0</td>
<td>10.0</td>
<td>17.0</td>
<td>31.0</td>
<td>479.6</td>
</tr>
<tr>
<td>&quot; 22</td>
<td>128.0</td>
<td>86.0</td>
<td>23.4</td>
<td>25.0</td>
<td>21.2</td>
<td>17.5</td>
<td>59.0</td>
<td>16.0</td>
<td>21.0</td>
<td>26.0</td>
<td>421.1</td>
</tr>
<tr>
<td>&quot; 28</td>
<td>99.5</td>
<td>85.0</td>
<td>14.3</td>
<td>14.8</td>
<td>15.0</td>
<td>21.3</td>
<td>54.0</td>
<td>25.5</td>
<td>28.5</td>
<td>22.5</td>
<td>380.4</td>
</tr>
<tr>
<td>Feb. 5</td>
<td>190.0</td>
<td>74.5</td>
<td>14.3</td>
<td>20.0</td>
<td>16.5</td>
<td>18.8</td>
<td>51.3</td>
<td>17.5</td>
<td>29.5</td>
<td>22.8</td>
<td>455.2</td>
</tr>
<tr>
<td>&quot; 14†</td>
<td>76.5</td>
<td>52.5</td>
<td>13.3</td>
<td>9.8</td>
<td>12.3</td>
<td>12.0</td>
<td>29.0</td>
<td>9.0</td>
<td>25.0</td>
<td>30.3</td>
<td>269.7</td>
</tr>
<tr>
<td>&quot; 14‡</td>
<td>105.0</td>
<td>55.5</td>
<td>22.0</td>
<td>14.5</td>
<td>13.3</td>
<td>17.7</td>
<td>37.5</td>
<td>10.5</td>
<td>26.5</td>
<td>31.5</td>
<td>334.0</td>
</tr>
<tr>
<td>Apr. 7</td>
<td>119.0</td>
<td>63.5</td>
<td>14.3</td>
<td>16.0</td>
<td>17.3</td>
<td>18.0</td>
<td>52.5</td>
<td>9.5</td>
<td>34.0</td>
<td>23.3</td>
<td>367.4</td>
</tr>
</tbody>
</table>

* Before lunch.
† 2 hours after lunch.
‡ 2 hours after 25 gm. of histidine hydrochloride.

when a series of collections is made over a prolonged period. Seven collections were made within a period of 3 months. In Table IV the means
and standard errors calculated from the data in Table III for Subject 10 are compared with the normal values. These normal values include all of the subjects in Tables I and II except the first sample for Subject 6. They also include the sweat values in Table V. In the case of arginine, isoleucine, leucine, and lysine, the variation is of the same order of magnitude for the single subject as compared to all the subjects, while there is greater variation for the single subject in the case of tryptophane and less variation for histidine, phenylalanine, threonine, tyrosine, and valine.

Table III also shows that diet or previous ingestion of 20 gm. of L(-)-histidine hydrochloride has no effect on amino acid composition of sweat in this subject.

Table IV

Range of Free Amino Acids in Sweat from Nine Normal Subjects Compared to That of Seven Sweat Collections from One Subject and to Normal Human Plasma

The mean and standard deviation are given in micrograms per cc.

<table>
<thead>
<tr>
<th>Amino acid</th>
<th>Subject 10; data from Table III</th>
<th>Normal subjects; Tables I and II</th>
<th>Normal human plasma (cf. (1))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arginine</td>
<td>126.6 ± 37.0</td>
<td>135.8 ± 39.2</td>
<td>23.2 ± 6.4</td>
</tr>
<tr>
<td>Histidine</td>
<td>72.3 ± 4.4</td>
<td>80.2 ± 9.7</td>
<td>14.2 ± 2.4</td>
</tr>
<tr>
<td>Isoleucine</td>
<td>17.5 ± 5.0</td>
<td>22.7 ± 6.6</td>
<td>16.6 ± 3.4</td>
</tr>
<tr>
<td>Leucine</td>
<td>18.2 ± 5.9</td>
<td>26.9 ± 7.7</td>
<td>20.3 ± 3.6</td>
</tr>
<tr>
<td>Lysine</td>
<td>16.4 ± 2.9</td>
<td>22.6 ± 4.5</td>
<td>29.7 ± 4.6</td>
</tr>
<tr>
<td>Phenylalanine</td>
<td>17.9 ± 2.7</td>
<td>21.9 ± 6.3</td>
<td>14.0 ± 3.5</td>
</tr>
<tr>
<td>Threonine</td>
<td>49.6 ± 11.4</td>
<td>53.8 ± 18.4</td>
<td>20.8 ± 4.9</td>
</tr>
<tr>
<td>Tryptophane</td>
<td>14.9 ± 5.3</td>
<td>11.2 ± 3.3</td>
<td>11.1 ± 2.3</td>
</tr>
<tr>
<td>Tyrosine</td>
<td>25.9 ± 5.4</td>
<td>31.5 ± 9.5</td>
<td>15.0 ± 4.2</td>
</tr>
<tr>
<td>Valine</td>
<td>28.8 ± 3.6</td>
<td>29.6 ± 7.5</td>
<td>28.9 ± 3.7</td>
</tr>
</tbody>
</table>

Amino Acids of Sweat Compared to Plasma—It may also be seen from Table IV that the mean values for isoleucine, leucine, lysine, phenylalanine, tryptophane, and valine are of the same order of magnitude in sweat and plasma. However, arginine and histidine are approximately 6 times higher in sweat than in plasma, while threonine and tyrosine are about 2 times higher in sweat.

To study this problem further one of us (S. W. H.) ingested 25 gm. of L(-)-tyrosine and L(-)-histidine hydrochloride after having simultaneous blood, sweat, and urine samples taken. 2 hours later sweat, urine, and blood samples were again taken. It is evident from Table V that again the arginine and histidine content of the sweat is markedly higher than that of the blood plasma, while the threonine and tyrosine content of sweat is slightly higher than that of plasma. Furthermore, although the level of histidine and tyrosine rose significantly in the blood and spilled over into the urine as a result of the large dose of ingested amino acids, there was no such change in the sweat.
TABLE V
Effect of Ingestion of Large Amounts of \( l^-\)-Histidine Hydrochloride (25 Gm.) and \( l^-\)-Tyrosine (25 Gm.) on Free Amino Acid Composition of Sweat, Blood Plasma, and Urine

The amino acid values are reported in micrograms per cc.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Arginine</th>
<th>Histidine</th>
<th>Isoleucine</th>
<th>Leucine</th>
<th>Lysine</th>
<th>Phenylalanine</th>
<th>Threonine</th>
<th>Tyrosine</th>
<th>Valine</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sweat 1; before ingestion of</td>
<td>92.0</td>
<td>100.0</td>
<td>14.3</td>
<td>12.5</td>
<td>18.2</td>
<td>16.3</td>
<td>35.0</td>
<td>6.0</td>
<td>17.0</td>
<td>339.3</td>
</tr>
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<td>amino acids</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sweat 2; after ingestion of</td>
<td>77.0</td>
<td>82.5</td>
<td>10.8</td>
<td>11.3</td>
<td>14.4</td>
<td>14.0</td>
<td>25.8</td>
<td>6.5</td>
<td>13.5</td>
<td>283.3</td>
</tr>
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<td>amino acids</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plasma 1; before ingestion of</td>
<td>31.8</td>
<td>19.5</td>
<td>8.0</td>
<td>21.5</td>
<td>26.7</td>
<td>13.2</td>
<td>18.9</td>
<td>12.9</td>
<td>17.4</td>
<td>25.5</td>
</tr>
<tr>
<td>amino acids</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plasma 2; after ingestion of</td>
<td>42.0</td>
<td>555.0</td>
<td>10.0</td>
<td>16.7</td>
<td>34.2</td>
<td>21.1</td>
<td>27.0</td>
<td>10.8</td>
<td>55.2</td>
<td>25.5</td>
</tr>
<tr>
<td>amino acids</td>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Urine 1; before ingestion of</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>amino acids</td>
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<td></td>
<td></td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>Urine 2; during ingestion of</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>amino acids</td>
<td>160.0</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Urine 3; after ingestion of</td>
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<td></td>
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</tr>
</tbody>
</table>

TABLE VI
Effect of Ingestion of Large Amounts of \( l^-\)-Tyrosine (25 Gm.), dl-Isoleucine (25 Gm.), and dl-Threonine (25 Gm.) on Amino Acid Composition of Sweat and Blood Plasma

The amino acid values are reported in micrograms per cc.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Arginine</th>
<th>Histidine</th>
<th>Isoleucine</th>
<th>Leucine</th>
<th>Lysine</th>
<th>Phenylalanine</th>
<th>Threonine</th>
<th>Tyrosine</th>
<th>Valine</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sweat 1; before ingestion of</td>
<td>104.0</td>
<td>59.5</td>
<td>17.3</td>
<td>19.5</td>
<td>11.3</td>
<td>19.5</td>
<td>35.0</td>
<td>9.0</td>
<td>23.0</td>
<td>15.3</td>
</tr>
<tr>
<td>amino acids</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td>27.8</td>
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<td>38.3</td>
<td>9.5</td>
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<td>14.4</td>
<td>15.3</td>
<td>20.3</td>
<td>22.5</td>
<td>21.3</td>
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<td>5.7</td>
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<td>171.0</td>
<td>7.7</td>
<td>15.9</td>
<td>22.8</td>
<td>99.9</td>
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The influence of 25 gm. of \( l^-\)-tyrosine, 25 gm. of \( dl^-\)-isoleucine, and 25 gm. of \( dl^-\)-threonine was similarly studied in a second experiment on the same subject, as shown in Table VI. Again, while the blood level of these
amino acids rose significantly, there was no effect on the composition of the sweat. Here also the arginine, histidine, threonine, and tyrosine concentrations are higher in the sweat than in the plasma, while the other amino acids are present in about the same concentration in plasma and sweat.

**DISCUSSION**

Our results show that the amino acids secreted in the sweat are independent of the effect of diet or food ingestion since no difference in composition is found in sweat taken from subjects in a fasting state or after eating. Furthermore, the level of the amino acids in sweat is independent of the variations in the blood. Ingestion of large amounts of amino acids which causes a marked rise in the blood level is without effect on the sweat amino acids. This must mean that the amino acids do not appear in the sweat merely by filtration from the blood. This is further shown by the fact that arginine and histidine are markedly higher and threonine and tyrosine are slightly higher in sweat than in plasma, while the other amino acids studied are present in approximately the same order of magnitude in both fluids. The high arginine content of sweat is particularly interesting in view of the findings of Talbert et al. (5) that the urea nitrogen of sweat is about 4 or 5 times that of blood. Arginine may be involved in the formation of this urea by the sweat gland.

These results are consistent with the findings of other observers that there is not a very good correlation between blood and sweat levels of other substances. The glucose (6) content of sweat is considerably lower than that of the blood, while lactic acid (7) is about 20 times higher in sweat than in blood. According to Talbert (8), using a rather unreliable method, the amino nitrogen of sweat is slightly lower than that of blood. Alcohol when ingested appears in the blood and sweat in the same concentrations (9). Johnson et al. (10) recently have shown that the sweat chloride concentration is lower than that of serum, and that there is no apparent correlation between the level of serum and sweat chlorides.

The variation in the amino acid composition of sweat samples taken from one individual over a period of time appears to be approximately equivalent to the variation occurring within the normal population for arginine, isoleucine, leucine, and lysine. Less variation occurs with histidine, phenylalanine, threonine, tyrosine, and valine in the individual than in the population. In our subject the tryptophane content of the sweat was more variable than that of the population.

The amount of amino acids lost in the sweat is not strikingly significant in the economy of amino acids by the body. In our subjects the sweat contained about 0.44 mg. per cc. of the ten amino acids studied. Under average conditions of temperature and humidity, the amount of sweat is about
500 cc. per day. This would represent a loss of about 220 mg. per day of the ten amino acids. Even with excessive sweating in warm weather with active work when 3 liters of sweat may be formed, only 1.3 gm. of these amino acids would be lost.

SUMMARY

The microbiological determination of ten free amino acids in normal sweat is reported. These are found as follows in micrograms per cc.: arginine 135.8 ± 39.2, histidine 80.2 ± 9.7, isoleucine 22.7 ± 6.6, leucine 20.9 ± 7.7, lysine 22.6 ± 4.5, phenylalanine 21.9 ± 6.3, threonine 53.8 ± 18.4, tryptophane 11.2 ± 3.3, tyrosine 31.5 ± 9.5, and valine 29.6 ± 7.5. It is found that the marked increases in the free amino acid content of the plasma due to ingestion of large amounts of single amino acids are without effect on the amino acid content of the sweat. Similarly, food ingestion does not appear to have any effect. Furthermore, the arginine and histidine content particularly, and the threonine and tyrosine content of sweat to a lesser extent, is higher in sweat than in blood plasma, while the other amino acids are present in about the same amounts. These observations indicate that the amino acids do not appear in sweat merely as a result of filtration from the blood plasma. The loss of amino acids in the sweat does not appear to be of much importance in the economy of amino acids by the body.

BIBLIOGRAPHY
