THE SYNTHESIS OF THE ISOMERS OF CYSTATHIONINE
AND A STUDY OF THEIR AVAILABILITY IN SULFUR
METABOLISM

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Considerable experimental evidence has accumulated indicating that
cystathionine is an intermediate in the conversion of methionine to cystine
(1–5). The following report describes the synthesis of the isomers of
cystathionine and the testing of their ability to replace the sulfur-contain-
ing amino acids in the diet of the young rat.

The name cystathionine was suggested for the thio ether, S-(l-β-amino-
β-carboxyethyl)-l-homocysteine (4). Since the present report is concerned
with the four possible stereoisomers of the molecule, it is convenient to
provide a stereochemical designation for the compounds. Since the isomer
referred to above is related only to the natural amino acids and since it is
dextrorotatory, it seems appropriate to designate it further as l(+)-
cystathionine. According to this system S-(d-β-amino-β-carboxyethyl)-
d-homocysteine, the optical isomer of l(+)—cystathionine, would be
designated d(−)—cystathionine. The remaining two isomers are diastereoiso-
mers of the first pair, and the name, allocystathionine, is suggested for them.
Each of the allocystathionines is related to both the l- and d-amino acid
series, but only one of the allocystathionines can yield l-cysteine on simple
cleavage. Because biological interest in the compound has centered
chiefly around its ability to serve as a precursor of cysteine, the cysteine-
like moiety of the molecule is suggested as the stereochemical reference
point. Thus, levorotatory S-(l-β-amino-β-carboxyethyl)-d-homocysteine,
containing an l-cysteine moiety, may be designated l(−)—allocystathionine.
Dextrorotatory S-(d-β-amino-β-carboxyethyl)-l-homocysteine, which simi-
larly contains a d-cysteine moiety, may be designated d(+)—allocystathio-
nine. The relationship between the four isomers is shown in the accom-
panying structures.

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36 ISOMERS OF CYSTATHIONINE

COOH
H₂N—C—H
H—C—H
H—C—H
H—C—H
S
H—C—H
H—C—H
H—C—H
H₂N—C—H
COOH

$\text{I(+)-cystathionine}$

COOH
H—C—NH₂
H—C—H
H—C—H
H—C—H
S
H—C—H
H—C—H
H—C—H
H₂N—C—H
COOH

$\text{d(-)-cystathionine}$

COOH
H—C—NH₁
H—C—H
H—C—H
H—C—H
S
H—C—H
H—C—H
H—C—H
H₂N—C—H
COOH

$\text{l(-)-Allocystathionine}$

COOH
H—C—NH₁
H—C—H
H—C—H
H—C—H
S
H—C—H
H—C—H
H—C—H
H₂N—C—H
COOH

$\text{d(+)-Allocystathionine}$

EXPERIMENTAL

$\text{S-Benzylhomocysteine}$ was resolved and converted to the optically active isomers of homocystine (6). These homocystine isomers served as precursors of the homocysteines used in the formation of the cystathionine isomers. Serine was resolved by the method of Fischer and Jacobs (7) and converted to the optically active isomers of $\alpha$-amino-$\beta$-chloropropionic acid, according to the directions of Fischer and Raske (8). Condensation of the respective isomers of homocysteine and $\alpha$-amino-$\beta$-chloropropionic acid was carried out in the manner used to synthesize $\text{l(+)-cystathionine}$ (2). Separation of the cystathionines from the accompanying homocystine was accomplished by recrystallization from a cyanide solution, according to the method originally devised by Brown and du Vigneaud for the separation of lanthionine from contamination with cystine (9).

$\text{d-Cystathionine}$—15.3 gm. of $\text{d-homocystine}$, $[\alpha]_D^{22} = -79.6^\circ$, were reduced in liquid ammonia with metallic sodium, according to the directions of du Vigneaud and Patterson (6). On completion of the reduction, the flask was removed from the cooling bath and the ammonia was allowed to evaporate. When ammonia no longer issued, the flask was evacuated for 1 hour at water pump pressure and filled with nitrogen. 50 cc. of oxygen-free water were added, and the flask was evacuated again to remove excess ammonia and refilled with nitrogen. As in the earlier synthesis of the mixed isomers of cystathionine (10), the homocysteine was used without isolation.

17.9 gm. of methyl $\text{d-\alpha-amino-\beta-chloropropionate}$ hydrochloride were hydrolyzed by heating to 100° with 180 cc. of 20 per cent HCl. The clear solution which resulted was evaporated under reduced pressure,
redissolved in water, and evaporated again. A thick mush of crystals resulted, and this was dissolved in 25 cc. of oxygen-free water.

The flask containing the homocysteine was equipped with a stirrer and immersed in a water bath kept at approximately 60°. The solution of \( \alpha \)-amino-\( \beta \)-chloropropionic acid hydrochloride was added portionwise during a period of 2 hours. When the reaction mixture became acid to phenolphthalein paper, a few pellets of solid KOH were added. After the last addition of \( \alpha \)-amino-\( \beta \)-chloropropionic acid, the flask was allowed to remain in the water bath from 9 to 10 hours. At the end of this time, 200 cc. of oxygen-free water were added to dissolve the precipitated salt, and the pH of the solution was adjusted to pH 6.0 with concentrated HCl. The flask was filled with nitrogen and allowed to stand in the refrigerator overnight.

The resulting precipitate was separated and suspended in 300 cc. of water. 25 cc. of concentrated HCl were added. The resultant dark colored solution was clarified by filtration through a layer of Darco and neutralized to pH 6.0 with concentrated NH\(_4\)OH. The crystalline precipitate was filtered and washed with water. The dried product weighed 11.2 gm. A sample showed a strong sodium cyanide-nitroprusside test for disulfide.

To separate the \( d(–) \)-cystathionine from homocystine, the above product was suspended in 200 cc. of water and dissolved by the addition of concentrated NH\(_4\)OH. The solution was filtered, and to the filtrate 0.5 gm. of NaCN was added. After 30 minutes the solution was neutralized to pH 6.0 with glacial acetic acid; crystallization occurred spontaneously. The crystals were collected by filtration and the cyanide treatment was repeated. After the final recrystallization, 9.2 gm. of product were obtained. A sample of this product showed a faint cyanide-nitroprusside test. Analysis of a portion of it for homocystine by the Kassell and Brand modification (11) of the Folin-Marenzi method (12) showed the presence of less than 1 per cent of homocystine. A 1 per cent solution of the compound in 1 N HCl possessed a rotation of [\( \alpha \)]\(_D\) \( = -23.5^\circ \) which compares favorably with the value of [\( \alpha \)]\(_D\) \( = +23.7^\circ \) for \( l(+) \)-cystathionine (2).

\[
\text{C}_9\text{H}_4\text{O}_4\text{N}_2\text{S. Calculated. } N \, 12.60, \, S \, 14.42
\]

\[
\text{222.3 Found. } \quad \text{“} \, 12.80, \, \text{“} \, 14.89
\]

**Dibenzoyl-d-cystathionine**—200 mg. of \( d(–) \)-cystathionine were suspended in 10 cc. of water in a 50 cc. ground glass-stoppered flask and dissolved by the addition of NaOH. The flask was shaken in an ice bath and 0.35 cc. of benzoyl chloride was added in three portions. Each addition was followed by vigorous shaking until the odor of benzoyl chloride disap-
ISOMERS OF CYSTATHIONINE

peared. The reaction mixture was kept alkaline to phenolphthalein by the addition of more alkali. After the last addition of benzoyl chloride, the reaction mixture was allowed to stand at room temperature for 1 hour and then was made acid to Congo red paper by the addition of concentrated HCl. An oily precipitate separated which soon solidified. After the flask had been cooled in the refrigerator overnight, the solid mass was separated by filtration and washed with water.

The product was dissolved in 50 cc. of 70 per cent alcohol, heated, and the hot solution was filtered through a layer of Darco. The clear filtrate was evaporated in vacuo until crystals appeared. After the flask was cooled overnight, the crystalline precipitate was filtered, washed with 5 cc. of cold 70 per cent alcohol, and dried at 80°. This dibenzoyl-d-cystathionine melted1 at 232-234°. The melting point recorded for dibenzoyl-l-cystathionine is 229° (2).

\[
\text{C}_{18}\text{H}_{16}\text{O}_{4}\text{N}_{2}\text{S. Calculated. N 6.51, S 7.45} \\
480.5 \quad \text{Found. } \quad " 6.74, " 7.27
\]

\((-\)-Allocystathionine—This isomer was synthesized from 15.3 gm. of \(d\)-homocystine, \([\alpha]_D^{22} = -79.6°\), and 17.9 gm. of methyl \(l\)-alpha-amino-\(\beta\)-chloropropionate hydrochloride. The product obtained from this coupling reaction was suspended in 300 cc. of water and dissolved by the addition of concentrated HCl. After clarification by filtering through a layer of Darco, the solution was neutralized to pH 6.0. After 24 hours in the cold room, the crystalline precipitate was collected. The product was washed with water and dried at 80°. A yield of 12.6 gm. was obtained. This product showed a strong cyanide-nitroprusside test.

The product was recrystallized three times by precipitation from an alkaline cyanide solution, as described above for \(d\)(-)-cystathionine. This treatment yielded 3 gm. of product which still showed a positive cyanide-nitroprusside test, but analysis for homocystine showed the presence of less than 1 per cent of homocystine. A 1 per cent solution of the \((-\)-)allocystathionine in 1 N HCl possessed a rotation of \([\alpha]_D^{21} = -25.0°\).

\[
\text{C}_{17}\text{H}_{18}\text{O}_{4}\text{N}_{2}\text{S. Calculated. N 12.60, S 14.42} \\
222.3 \quad \text{Found. } \quad " 12.03, " 14.68
\]

\(l\)(-)-Allo-cystathionine—This derivative was prepared from 200 mg. of \((-\)-)allocystathionine by the procedure described for dibenzoyl-\(d\)-cystathionine. The recrystallized product melted at 186-187°.

\[
\text{C}_{18}\text{H}_{16}\text{O}_{4}\text{N}_{2}\text{S. Calculated. N 6.61, S 7.45} \\
480.5 \quad \text{Found. } \quad " 6.55, " 7.68
\]

1 All melting points are corrected capillary melting points.
$d(+)-$Allocystathionine—This isomer was synthesized from 15.3 gm. of $l$-homocystine, $[\alpha]_D^{22} = +74.0^\circ$, and 17.9 gm. of methyl $d$-$\alpha$-amino-$\beta$-chloropropionate hydrochloride. The product was treated as described previously and, after three precipitations from alkaline cyanide, 4 gm. of product were obtained which were shown to contain less than 1 per cent of homocystine by analysis. A 1 per cent solution of the $d(+)$-allocystathionine in 1 $\text{N} \text{HCl}$ possessed a rotation of $[\alpha]_D^{21} = +24.5^\circ$.

$$\text{C}_7\text{H}_{14}\text{O}_2\text{N}_2\text{S}. \quad \text{Calculated. N 12.60, S 14.42}$$

$$\text{Dibenzoyl-$d$-allocystathionine—This derivative was prepared from 200 mg. of } d(+)-\text{allocystathionine according to the procedure described for dibenzoyl-$d$-cystathionine. After two recrystallizations from 70 per cent alcohol, the product melted at 189^\circ$.}

$$\text{C}_{27}\text{H}_{22}\text{O}_8\text{N}_2\text{S}. \quad \text{Calculated. N 6.51, S 7.45}$$

**Feeding Experiments**

For the study of the availability of the isomers of cystathionine for the replacement of cystine in the diet of the growing white rat, the diet was the same as that used with $l(+)$-cystathionine (2). Supplementation of this diet with either cystine or $l(+)\text{-cystathionine had been shown to permit growth (2). The protein nitrogen of the diet was supplied by a mixture of pure amino acids patterned after the amino acid mixture of Rose and Rice (13). The diet had the following composition: amino acid mixture (exclusive of the sulfur-containing amino acids) 21.3, sucrose 44.7, Crisco 30.0 (including fat-soluble vitamin supplement), and salt mixture (Osborne and Mendel (14)) 4.0 parts, respectively.

The sulfur-containing amino acids were added to the amino acid mixture and an equal weight of sucrose was omitted from the diet. The fat-soluble vitamins were furnished in a corn oil solution, 4 cc. of which were added to the fat component of 1 kilo of diet. The source and quantities of these vitamins have been described previously (15). 0.5 cc. of a solution containing the water-soluble vitamins was fed twice daily. 1 cc. of this solution contained 20 $\gamma$ of thiamine chloride, 20 $\gamma$ of riboflavin, 20 $\gamma$ of nicotinic acid, 20 $\gamma$ of pyridoxine hydrochloride, 200 $\gamma$ of calcium $dl$-pantothenate, 5 mg. of inositol, and 25 mg. of choline chloride. The diets and water were allowed ad libitum, and the animals were weighed every 4 days.

For the basal diet in the experiments recorded in Table I and Fig. 1 methionine was added to form 0.2 per cent of the diet. This amount of methionine was such that growth was not permitted on the basal diet, but
when sufficient cystine was added growth would result. The cystathionine isomers and cystine were added to the basal diet in amounts indicated in Table I. The growth curves for the animals used in these experiments are shown in Fig. 1. The daily food consumption is given in Table I.

**Table I**

*Food Consumption of Rats Fed Cystathionines in Place of Cystine*

<table>
<thead>
<tr>
<th>Rat No. and sex</th>
<th>Supplement to basal diet</th>
<th>Experimental period</th>
<th>Average daily food consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>1435 ♀</td>
<td>None</td>
<td>10 days</td>
<td>2.7 gms.</td>
</tr>
<tr>
<td>1436 ♀</td>
<td>0.74% l-(−)-allocystathionine</td>
<td>20 days</td>
<td>5.5 gms.</td>
</tr>
<tr>
<td></td>
<td>None</td>
<td>7 days</td>
<td>4.3 gms.</td>
</tr>
<tr>
<td>1440 ♀</td>
<td>0.74% l-(−)-allocystathionine</td>
<td>20 days</td>
<td>5.8 gms.</td>
</tr>
<tr>
<td>1441 ♀</td>
<td>0.74% d(+) allocystathionine</td>
<td>7 days</td>
<td>4.0 gms.</td>
</tr>
<tr>
<td>1442 ♀</td>
<td>None</td>
<td>20 days</td>
<td>2.9 gms.</td>
</tr>
<tr>
<td>1443 ♀</td>
<td>0.74% d(+)-allocystathionine</td>
<td>2 days</td>
<td>2 *</td>
</tr>
<tr>
<td>1437 ♀</td>
<td>None</td>
<td>20 days</td>
<td>5.1 gms.</td>
</tr>
<tr>
<td>1439 ♀</td>
<td>0.74% d(−)-cystathionine</td>
<td>7 days</td>
<td>4.9 gms.</td>
</tr>
<tr>
<td>1441 ♀</td>
<td>None</td>
<td>20 days</td>
<td>4.2 gms.</td>
</tr>
<tr>
<td>1439 ♀</td>
<td>0.74% d(−)-cystathionine</td>
<td>7 days</td>
<td>4.9 gms.</td>
</tr>
<tr>
<td>1439 ♀</td>
<td>0.74% l(+)-cystathionine</td>
<td>20 days</td>
<td>3.8 gms.</td>
</tr>
<tr>
<td>1442 ♀</td>
<td>0.74% d(-)-cystathionine</td>
<td>7 days</td>
<td>4.2 gms.</td>
</tr>
<tr>
<td>1438 ♀</td>
<td>None</td>
<td>20 days</td>
<td>5.4 gms.</td>
</tr>
<tr>
<td>1441 ♀</td>
<td>0.4% l-cystine</td>
<td>10 days</td>
<td>6.1 gms.</td>
</tr>
<tr>
<td>1438 ♀</td>
<td>0.4% l-cystine</td>
<td>7 days</td>
<td>2.8 gms.</td>
</tr>
<tr>
<td></td>
<td>None</td>
<td>17 days</td>
<td>3.7 gms.</td>
</tr>
<tr>
<td>1439 ♀</td>
<td>0.4% l-cystine</td>
<td>20 days</td>
<td>5.6 gms.</td>
</tr>
<tr>
<td></td>
<td>None</td>
<td>7 days</td>
<td>6.1 gms.</td>
</tr>
<tr>
<td>1438 ♀</td>
<td>0.4% l-cystine</td>
<td>37 days</td>
<td>4.7 gms.</td>
</tr>
</tbody>
</table>

* The animal died 2 days after being placed on the basal diet. The food consumption was negligible.

The curves in Fig. 1 show that the addition of 0.4 per cent of cystine to the basal diet made it adequate for growth. In agreement with the results of earlier experiments, substitution of an equivalent quantity (0.74 per cent) of l(+)-cystathionine permitted growth approximately equal to that obtained with a cystine supplement. Of the other stereoisomers of
cystathionine, only one supported growth in place of cystine. A supplement of 0.74 per cent of $l(-)$-allocystathionine gave growth at a rate comparable to that of an equivalent amount of cystine or $l(+)\text{-cystathionine}$. The parallel growth curves of Rats 1435, 1436, and 1441 suggest that $l(-)$-allocystathionine can support growth as well as an equivalent quantity of cystine. Supplementation of the basal diet with either
d(−)-cystathionine or d(+)-allocystathionine resulted in no better growth than that of the control animal.

### Table II

*Food Consumption of Rats Fed l(−)-Allocystathionine in Place of Methionine*

<table>
<thead>
<tr>
<th>Rat No. and sex*</th>
<th>Supplement to basal diet†</th>
<th>Experimental period</th>
<th>Average daily food consumption</th>
<th>Remarks on feeding†</th>
</tr>
</thead>
<tbody>
<tr>
<td>1508 ♀</td>
<td>Choline</td>
<td>5</td>
<td>3.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.46% dl-homocystine + choline</td>
<td>17</td>
<td>6.7</td>
<td></td>
</tr>
<tr>
<td>2607 ♀</td>
<td>Choline</td>
<td>4</td>
<td>3.3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.46% dl-homocystine + choline</td>
<td>15</td>
<td>4.9</td>
<td></td>
</tr>
<tr>
<td>1510 ♀</td>
<td>Choline</td>
<td>5</td>
<td>2.6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.74% l(−)-allocystathionine + choline</td>
<td>18</td>
<td>4.9</td>
<td></td>
</tr>
<tr>
<td>2608 ♀</td>
<td>Choline</td>
<td>4</td>
<td>2.3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.74% l(−)-allocystathionine + choline</td>
<td>15</td>
<td>4.2</td>
<td></td>
</tr>
<tr>
<td>2609 ♀</td>
<td>Choline</td>
<td>4</td>
<td>2.8</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.74% l(−)-allocystathionine + choline</td>
<td>15</td>
<td>4.5</td>
<td></td>
</tr>
<tr>
<td>1511 ♀</td>
<td>None</td>
<td>5</td>
<td>3.2</td>
<td></td>
</tr>
<tr>
<td>2611 ♀</td>
<td>Choline</td>
<td>4</td>
<td>3.4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.74% l(−)-allocystathionine</td>
<td>10</td>
<td>4.4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.74% l(−)-allocystathionine</td>
<td>5</td>
<td>0.8</td>
<td></td>
</tr>
<tr>
<td>2610 ♀</td>
<td>Choline</td>
<td>4</td>
<td>2.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.74% l(−)-allocystathionine</td>
<td>7</td>
<td>4.6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.74% l(−)-allocystathionine</td>
<td>4</td>
<td>0.8</td>
<td></td>
</tr>
<tr>
<td>2606 ♀</td>
<td>Choline</td>
<td>4</td>
<td>2.8</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.46% dl-homocystine</td>
<td>10</td>
<td>4.6</td>
<td>Restricted</td>
</tr>
<tr>
<td></td>
<td>0.46% dl-homocystine</td>
<td>5</td>
<td>2.1</td>
<td></td>
</tr>
<tr>
<td>2605 ♀</td>
<td>Choline</td>
<td>19</td>
<td>3.0</td>
<td></td>
</tr>
</tbody>
</table>

*Rats 1508 to 1511 inclusive were purchased from the Rockland Farms; Rats 2605 to 2611 inclusive were litter mates from our colony.
† Data in this column note the presence or absence of 25 mg. of choline chloride (per day) in the vitamin supplement.
‡ Unless otherwise noted, feeding was *ad libitum.*

Cleavage of *l*(−)-allocystathionine to *l*-cysteine would offer a simple explanation of its ability to support growth in place of cystine. However, subsequent studies *in vitro* showed that the cleavage of *l*(−)-allocystathionine by liver tissue presumably yielded d-homocysteine. Since

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* Anslow, W. P., Jr., and du Vigneaud, V., unpublished data.
Fig. 2. Growth curves for rats fed L(-)-allocystathionine in place of methionine. The number and sex of the animals are indicated at the extreme left; the initial and final weights are in parentheses. The dietary supplement is noted along the curves; the arrows indicate the times at which the diet was changed. The basal diet contains 0.4 per cent cystine.

d-homocystine can support growth in place of cystine (16), cleavage to homocysteine is the more probable explanation of the ability of L(-)-allocystathionine to support growth. If L(-)-allocystathionine is cleaved
to $d$-homocysteine in the intact animal, then $l(-)$-allocystathionine supplemented with adequate dietary choline might be expected to support growth in place of methionine.

To test the latter hypothesis, a series of rats was placed on a basal diet containing 0.4 per cent cystine but no methionine, a diet used to test the same hypothesis in the case of $l(\pm)$-cystathionine (2), under which conditions $l(\pm)$-cystathionine did not support growth. The diet had the same composition as the one used above except with respect to the sulfur-containing amino acids. $dl$-Homocystine or $l(-)$-allocystathionine was added to this diet in the amounts indicated in Table II. Growth curves for this series of animals are shown in Fig. 2.

Supplementation of the basal diet with $dl$-homocystine made the diet adequate for growth. Supplementation with an equivalent quantity of $l(-)$-allocystathionine likewise brought about growth, but not to so great an extent as did the $dl$-homocystine supplement. Data in Table II show that the food consumption of animals fed the $l(-)$-allocystathionine ranges from 4.4 to 4.9 gm. per day, whereas the food consumption of animals fed homocystine was approximately 6.7 gm. per day. When the intake of Rat 2607 (receiving the homocystine supplement) was restricted to 4.9 gm. per day, the rate of growth of this animal was comparable to that of the animal fed $l(-)$-allocystathionine.

When the choline was removed from the vitamin supplement, Rats 1511, 2611, and 2606 grew for a short time. However, all the rats began to lose weight precipitously from the 7th to the 10th day of the choline-free diet. Palpation indicated enlarged kidneys in Rat 2610 on the 12th day, in Rat 2611 on the 16th day, and in Rat 2606 on the 18th day. At autopsy gross examination of these three animals showed large mottled kidneys in Rat 2606, and marked enlargement and hyperemia in Rats 2610 and 2611. Enlarged kidneys were not felt in Rat 1511 and growth was resumed when choline was again included in the vitamin supplement.

**SUMMARY**

The three previously uncharacterized isomers of cystathionine have been synthesized and characterized. A stereochemical nomenclature for these compounds is suggested.

On a cystine-free, methionine-restricted diet, $l(-)$-allocystathionine is able to support growth in the young rat, behaving in this respect like $l(\pm)$-cystathionine. However, on a diet adequate with respect to cystine but deficient in methionine, $l(-)$-allocystathionine supports growth in the young rat when fed together with choline, in contrast to the behavior of $l(\pm)$-cystathionine under these conditions.
d(−)-Cystathionine and d(+).allocystathionine do not support growth on a cystine-free, methionine-restricted diet.

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BIBLIOGRAPHY

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