Metabolism of Basic Amino Acids in Pseudomonas putida

TRANSPORT OF LYSINE, ORNITHINE, AND ARGinine*

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SUMMARY

Uptake of lysine, arginine, and ornithine by Pseudomonas putida P2 involves at least three transport systems. A lysine-inducible, general basic amino acid system (Km = 7.3 × 10⁻⁶ M; Vmax = 128 nmoles per min per mg for L-lysine) transports all three amino acids and is inhibited by the D or l isomers of all three amino acids (Miller, D. L., and Rodwell, V. W. (1971) J. Biol. Chem. 246, 1765) and by the next higher and lower homologs of L-arginine. Transport of L-arginine by the general system (Km = 4.8 × 10⁻⁷ M; Vmax = 0.7 nmoles per min per mg) is inhibited by the same compounds that inhibit L-lysine transport. A second system transports L-lysine (Km = 4.1 × 10⁻⁷ M; Vmax = 25 nmoles per min per mg) and L-ornithine (Km = 1.3 × 10⁻⁷ M; Vmax = 100 nmoles per min per mg) and is inhibited by D- or L-lysine, D- or L-ornithine, and by D-arginine, but not by L-arginine nor by other amino acids. L-Arginine and L-ornithine accumulate at ratios of intracellular to extracellular amino acid concentration of 750 to 18,000, respectively, suggesting that transport is an active process. Transport of L-arginine by cells grown on L-arginine occurs via a low Km, L-arginine-specific system (Km = 5.2 × 10⁻⁷ M; Vmax = 11 nmoles per min per mg). Transport, which is not inhibited by any substrate analog tested, is linear for at least 7 min, is abolished by CN⁻ or N₃⁻, and generates ratios of internal to external arginine as high as 3500.

Pseudomonas putida P2 (ATCC 25571) can utilize a variety of amino acids including lysine, arginine, and ornithine as sole sources of carbon and nitrogen. We have previously described the pathways for catabolism of lysine (1) and arginine (2) in this organism and the presence in cultures grown on L-lysine of a general basic amino acid transport system (3) which transports lysine, ornithine, and arginine with Km values of greater than 10⁻⁶ M. We report here the presence, in cells grown on L-lysine, of an additional transport system for basic amino acids. L-Lysine-grown cells also possess a low Km system for L-lysine (Km = 4.1 × 10⁻⁷ M) and L-ornithine (Km = 1.3 × 10⁻⁷ M). Cultures grown on L-arginine appear to lack the general basic amino acid transport system but are induced for a low Km system specific for L-arginine (Km = 3.2 × 10⁻⁸ M).

MATERIALS AND METHODS

L-[U-¹⁴C]Arginine and L-[U-¹⁴C]ornithine were from New England Nuclear Corp. and L-[U-¹⁴C]lysine was from Calbiochem. L-Arginase (L-arginine amidinohydrolase, EC 3.5.3.1) was from Sigma. ɑ-N-Methyl-L-arginine and ɑ-arginine amidase were from Fox Chemical Co. All other amino acids and amines were from previously listed commercial sources (l-3). ɑ-N-Methyl-L-arginine, L-homoarginine, and D-arginine were purified by descending paper chromatography in butanol-glacial acetic acid-H₂O 120:30:50 (v/v) and L-arginine amide was purified by electrophoresis at pH 6.4 prior to use.

Electrophoresis—Conditions for isolation of amino acids by electrophoresis at pH 6.4 were as previously described (2, 3).

Organism and Growth Conditions—P. putida P2 (ATCC 25571) was grown as previously described (1-3) with either 35 mm L-lysine, 25 mm L-arginine, or 25 mm L-malate plus 2.5 mm ammonium sulfate as the sole source of carbon and nitrogen.

Measurement of Transport—Transport of amino acids was measured in a manner similar to that described previously (3). Data for L-lysine and L-ornithine transport were obtained with cell suspensions at final concentrations of 10 and 20 μg, dry weight, per ml, respectively. Data at low (0.65 to 0.4 μM) and at high (12 μM) L-arginine concentration were obtained with cell suspensions at final concentrations of 10 and 100 μg, dry weight, per ml, respectively. Cells harvested in midexponential phase growth (100 to 120 Klett units) by centrifugation for 10 min at 6000 × g were resuspended in 150 ml of ionic medium (4), centrifuged again, and finally resuspended in ionic medium (4) at a concentration of 130, 12.5, or 2.5 μg, dry weight, per ml. The cell suspension, chilled to and maintained at 4°C, retained full transport activity for at least 8 hours. Chilled cell suspensions were first incubated by shaking at 30° for 9 min prior to use. This preliminary incubation is necessary to obtain reproducible rates of transport (3). After incubation, the cell suspension was transferred to a tube containing radioactive amino acid at the concentrations specified in table and figure legends. When transport of L-lysine, L-ornithine, or low (0.05 to 0.40 μM) concentrations of L-arginine was studied, 0.8 ml of cell suspension was added to 0.2 ml of L-arginine, L-lysine, or L-ornithine solu-
Transport of L-Arginine by General Basic Amino Acid System—Previous study of the general basic amino acid transport system present in cells grown on L-lysine established that L-lysine, L-arginine, and L-ornithine are actively transported and that transport of L-lysine is inhibited by D-lysine, D- or L-arginine, and D- or L-ornithine (3). Transport of 12.4 \mu M L-arginine by cells grown on L-lysine also is inhibited by D-arginine, D- or L-lysine, D- or L-ornithine, and by the next higher and lower homologs of L-arginine, but not by \( \alpha-N \)-methyl-L-arginine or by \( \alpha-N \)-methyl-L-ornithine (Table I). Guanidinoacetate, \( \beta \)-guanidinoacetate, \( \gamma \)-guanidinobutyrate, \( \alpha \)-amino-\( n \)-caproate, agmatine, L-canavanine, D- or L-glutamate, L-glutamine, glycine, L-histidine, D- or L-isoleucine, D- or L-phenylalanine, L-proline, D- or L-threonine, and L-valine were without inhibitory effect. Transport of 12.4 \mu M L-arginine by cells grown on L-lysine thus appears to occur via the general basic amino acid transport system responsible for transport of similar concentrations of L-lysine. The \( K_m \) for transport of L-arginine is 4.8 \times 10^{-6} \text{ M} and \( V_{\text{max}} \) is 67 nmoles per min per mg (Fig. 1). Transport of 12.4 \mu M L-arginine is optimal at 36° (Fig. 2) and at pH 7.0 (Fig. 3).

Transport of L-Lysine—Our previous data for transport of L-lysine by lysine-grown cells was obtained primarily at a relatively high (8.5 \mu M) concentration of L-lysine (3). Investigation of the transport of lower concentrations of L-lysine (0.034 to 0.66 \mu M) revealed a low \( K_m \) (4.1 \times 10^{-7} \text{ M}) system with a \( V_{\text{max}} \) of 25 nmoles per min per mg (Fig. 4). We next studied the ability of lysine-grown cells to accumulate lysine. Lysine-grown cells, 10 \mu g per ml, were permitted to accumulate L-[\text{U-\text{13C}}]lysine, present initially at 0.20 \mu M concentration, for 15 sec and intracellular lysine was isolated and described previously (3). The intracellular lysine concentration exceeded the initial extracellular concentration by 750-fold. Transport of L-lysine by this low \( K_m \) system thus appears to be active. Transport of L-lysine by the low \( K_m \) system is inhibited by D-lysine, D- or L-ornithine, and to a lesser extent by D-arginine, but is not inhibited by L-arginine or other amino acids tested (Table II). This result contrasts with the specificity of the high \( K_m \) system which is inhibited by the D or L isomers of all three amino acids (3) and by the next higher and lower homologs of L-arginine.1

\[ \text{L-arginine amide} \]

\[ \text{Relative transport rate} \]

| Addition                  | Lysine-grown cells with molar ratio of addition to L-arginine of | Arginine-grown cells with molar ratio of addition to L-arginine of | 2 | 10 | 10 | 70 |
|--------------------------|---------------------------------------------------------------|-----------------------------------------------------------------|---|---|---|---|
| None                     | 100                                                          | 100                                                             | 100 | 100 | 100 | 100 |
| D-Arginine               | 36                                                           | 21                                                             | 99  | 92  | 92  | 92  |
| L-Homoarginine           | 56                                                           | 36                                                             | 100 | 95  | 95  | 95  |
| L-\( \alpha \)-Amino-\( \gamma \)-guanidinobutyrate   | 83                                                           | 32                                                             | 103 | 89  | 89  | 89  |
| L-Lysine                 | 36                                                           | 23                                                             | 95  | 97  | 97  | 97  |
| D-Lysine                 | 24                                                           | 21                                                             | 96  | 96  | 96  | 96  |
| L-Ornithine              | 21                                                           | 18                                                             | 92  | 92  | 92  | 92  |
| D-Ornithine              | 20                                                           | 17                                                             | 105 | 95  | 95  | 95  |
| \( \alpha \)-N-Methyl-L-arginine | 98                                                            | 88\( ^a \)                                                         | 94  | 94  | 94  | 94  |
| L-Arginine amide         |                                                              | 105\( ^a \)                                                      | 117 | 117 | 117 | 117 |

\( ^a \) Molar ratio of addition to L-arginine of 18.

Results

Transport of Basic Amino Acids by Cells Grown on L-Lysine

Transport of L-Arginine by General Basic Amino Acid System—Previous study of the general basic amino acid transport system present in cells grown on L-lysine established that L-lysine, L-arginine, and L-ornithine are actively transported and that transport of L-lysine is inhibited by D-lysine, D- or L-arginine, and D- or L-ornithine (3). Transport of 12.4 \mu M L-arginine by cells grown on L-lysine also is inhibited by D-arginine, D- or L-lysine, D- or L-ornithine, and by the next higher and lower homologs of L-arginine, but not by \( \alpha-N \)-methyl-L-arginine or by L-arginine amide (Table I). Guanidinoacetate, \( \beta \)-guanidinoacetate, \( \gamma \)-guanidinobutyrate, \( \alpha \)-amino-\( n \)-caproate, agmatine, L-canavanine, D- or L-glutamate, L-glutamine, glycine, L-histidine, D- or L-isoleucine, D- or L-phenylalanine, L-proline, D- or L-threonine, and L-valine were without inhibitory effect. Transport of 12.4 \mu M L-arginine by cells grown on L-lysine thus appears to occur via the general basic amino acid transport system responsible for transport of similar concentrations of L-lysine. The \( K_m \) for transport of L-arginine is 4.8 \times 10^{-6} \text{ M} and \( V_{\text{max}} \) is 67 nmoles per min per mg (Fig. 1). Transport of 12.4 \mu M L-arginine is optimal at 36° (Fig. 2) and at pH 7.0 (Fig. 3).

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\[ \text{L-arginine amide} \]
Transport of L-Ornithine—We have previously shown that L-ornithine at concentrations of about 10 μM is actively transported by the general basic amino acid transport system of lysine-grown cells (3). When transport of 0.06 to 1.1 μM L-ornithine was investigated, evidence was obtained for a low $K_m$ ($1.3 \times 10^{-6}$ M).

**Table II**

| Addition                  | Relative rate of transport of L-Lysine with molar ratio of addition to L-lysine of | Relative rate of transport of L-Ornithine with molar ratio of addition to L-ornithine of |
|---------------------------|-----------------------------------------------------------------------------------|-----------------------------------------------------------------------------------|
| None                      | 100                                                                                 | 100                                                                                 |
| L-Lysine                  | 100                                                                                 | 100                                                                                 |
| L-Ornithine               | 90                                                                                  | 87                                                                                  |
| L-Homoarginine            | 80                                                                                  | 87                                                                                  |
| L-α-Amino-γ-guanidino-    | butyrate                                                                           | 80                                                                                  | 87                                                                                  |
| Glycine                   | 90                                                                                  | 87                                                                                  | 80                                                                                  |
| L-Histidine               | 90                                                                                  | 87                                                                                  | 80                                                                                  |

Fig. 2. Effect of temperature on the rate of L-arginine transport. Transport was measured in the usual manner except that the buffer used for prior incubation, incubation and washing was ionic medium at the indicated temperature. Shown are: transport of 12.4 μM L-arginine by lysine-grown cells, 100 μg per ml (●——●), and transport of 0.36 μM (O——O) and of 12.4 μM (●——●) L-arginine by arginine-grown cells, 10 and 100 μg per ml, respectively. Transport rates are expressed relative to that observed at the optimum temperature for each experiment.

Fig. 3. Effect of pH on the rate of L-arginine transport. Transport was measured in the usual manner except that the buffer used for prior incubation, incubation, and washing was ionic medium adjusted to the indicated pH by addition of HCl or NaOH. Shown are: transport of 12.4 μM L-arginine by lysine-grown cells, 100 μg per ml (●——●), and transport of 0.34 μM (O——O), and of 12.4 μM (●——●) L-arginine by arginine-grown cells, 10 and 100 μg per ml, respectively. Transport rates are expressed relative to that observed at pH 7.0 for each experiment.

Fig. 4. Double reciprocal plot of the concentration dependence of L-lysine transport by cells grown on L-lysine. The initial external L-lysine concentrations were varied from 0.034 to 0.06 μM. Transport was measured at a final cell concentration of 10 μg cells per ml.
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FIG. 5. Transport of L-ornithine and competitive inhibition of L-ornithine transport by n-arginine and by D- and L-lysine. Transport of 0.06 to 1.5 μM L-ornithine by lysine-grown cells, 20 μg per ml, was measured in the absence of lysine (○—○), in the presence of 4.6 μM n-arginine (■—■), 4.6 μM L-lysine (□—□), and of 0.90 μM n-lysine (△—△).

FIG. 6. Time course of L-arginine uptake. Previously incubated suspensions of arginine-grown cells, 10 μg per ml, were exposed to 0.87 μM L-[U-14C]arginine (1.08 × 10^6 cpm). The total quantity of radioactivity taken up, expressed as nanomoles of L-arginine per mg of cells, was calculated from aliquots removed at the indicated times.

The pattern of inhibition of L-ornithine transport resembled that for inhibition of transport of L-lysine by the low K_m system. D-lysine, D-ornithine, and to a lesser extent D-arginine and L-lysine, but neither L-arginine nor any other amino acid tested inhibited L-ornithine transport (Table II). D-Lysine (K_i = 2.6 × 10^{-3} M) is a more effective competitive inhibitor of L-ornithine transport than is L-lysine (K_i = 3.9 × 10^{-4} M) or D-arginine (K_i = 4.8 × 10^{-4} M) (Fig. 5).

Transport of L-arginine by cells grown on L-arginine

Active transport of L-arginine—The time course for uptake of the radioactivity of L-[U-14C]arginine by cultures grown on L-arginine is linear for at least 7 min (Fig. 6) and transport is virtually abolished by incubation of cells with 17 mM KCN or NaN_3 prior to assay. The ratio of internal to external arginine concentration exceeded unity at all concentrations studied (0.055 to 4.40 μM) and exceeded 1000 at low concentrations of external arginine. A portion of the accumulated intracellular arginine was shown to be at least 77% the L isomer by conversion to L-ornithine by treatment with L-arginase (Table III). Transport of L-arginine by arginine-grown cells thus appears to be an active process. The data of Table III also suggest that the size of the internal arginine pool is essentially independent of the external L-arginine concentration.

Kinetic Parameters for Transport of L-arginine—The initial rate of L-arginine transport by cells grown on L-arginine was studied at various concentrations of L-arginine (Fig. 1). K_m was 5.2 × 10^{-3} M and V_max was 11 nanomoles per min per mg.

Effect of Temperature and of pH—Transport of 0.34 μM L-arginine, studied from 10–50°C, is optimal at 30°C (Fig. 2) and at pH 7.0 (Fig. 3).

Induction of L-arginine-specific Transport System—The ability
of cells grown on malate plus ammonia and exposed to L-arginine to transport L-arginine begins to rise after 4 hours and then increases rapidly (Fig. 7). The transport rate at 14 hours was 9.6 nmoles per min per mg or 9.6 times that of uninduced, malate-grown cells.

**Specificity of L-Arginine Transport**—The ability of lysine, ornithine, and structural analogs of L-arginine to inhibit transport of 0.04 to 0.07 μM L-arginine was tested. Transport of L-arginine is unaffected by even a 70-fold molar excess of D-arginine, D- or L-lysine, or D- or L-ornithine. The next higher and lower methylene homologs of L-arginine, α-N-methyl-L-arginine, and L-arginine amide also are without inhibitory effect (Table I).

![Graph](http://www.jbc.org/Downloaded from)

**Fig. 7.** Induction of the ability to transport L-arginine. The experiment was performed in a manner analogous to those described previously (2, 3). Cells grown on 25 mM dL-malate plus 2.5 mM ammonium sulfate were collected by centrifugation, washed, resuspended in 80 ml of ionic medium, and divided equally among eight 2% liter Fernbach flasks. These were shaken 10 min at 30°. To seven flasks, 8.5 ml of 750 mM L-arginine were added. Shaking was continued, and cells harvested at the indicated times after addition of arginine were washed once in ionic medium and resuspended for measurement of transport. Transport of 0.31 μM L-[U-14C]arginine (1.96 x 10^6 cpm) was studied at a cell concentration of 10 μg per ml.

**Table IV**

| Substrates | General amino acid transport system (present in lysine-grown cells) | Diarnino acid transport system (present in lysine-grown cells) | L-Arginine-specific transport system (present in arginine-grown cells) |
|-----------|---------------------------------------------------------------|---------------------------------------------------------------|------------------------------------------------------------------|
| L-Lysine  | (Km = 7.3 x 10^-7 M; Vmax = 5.2 x 10^6)                      | L-Lysine (Km = 4.1 x 10^-7 M; Vmax = 5.2 x 10^6)             | L-Arginine (Km = 5.2 x 10^-7 M; Vmax = 11^6)                      |
| D- or L-Arginine | D-Arginine (Km = 4.8 x 10^-7 M; Vmax = 67^6)            | D-Arginine (Km = 1.3 x 10^-7 M; Vmax = 100^6)               | None                                                             |
| D- or L-Ornithine | L-Ornithine (Km = 25^6)                                   | D-Ornithine (Km = 1.3 x 10^-7 M; Vmax = 100^6)              |                                                                  |
| L-Homoarginine | L-Homoarginine (Km = 25^6)                                 | L-Homoarginine (Km = 1.3 x 10^-7 M; Vmax = 100^6)          |                                                                  |
| L-α-Amino-γ-guanidobutyrate | L-α-Amino-γ-guanidobutyrate | L-α-Amino-γ-guanidobutyrate |                                                               |

5.5 μM L-Ornithine also is transported (3).

Expressed as nanomoles per min per mg of cells, dry weight.

**DISCUSSION**

In *P. putida*, the basic amino acids lysine, ornithine, and arginine are transported by at least three systems (Table IV). One is a general system with relatively high Km values and broad specificity. The other two systems have lower Km values and narrower substrate specificities.

We previously reported that *P. putida* grown on L-lysine is induced for transport of lysine, ornithine, and arginine and that all three amino acids appear to be transported by the same general system. Transport of L-lysine by this general system is inhibited by the D and L isomers of all three basic amino acids (3) and by the next higher and lower homologs of L-arginine. The transport of L-arginine by lysine-grown cells can also occur via this general system is suggested by the similarities in Km values and by the ability of D- or L-lysine, D- or L-ornithine, and D-arginine, and the next higher and lower homologs of L-arginine to inhibit both L-lysine and L-arginine transport (Table IV). The other transport system of *P. putida* grown on L-lysine appears to involve active transport since it is dependent on energy production and catalyzes accumulation of amino acids against a concentration gradient. This system, termed the diarnino acid system, transport L-lysine and its next lower homolog, L-ornithine. The D and L isomers of lysine, ornithine, and D- but not L-arginine, or the next higher or lower homologs of L-arginine, inhibit transport of both L-lysine and L-arginine. Both L-lysine and L-ornithine appear to be transported either by the same system or by systems with one or more common components. This interpretation is suggested by the similarities in Km values and by inhibition by the same substrate analogs...
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The third transport system, present in arginine-grown cells, has the lowest \( K_m \) and appears to be absolutely specific for active transport of L-arginine.

The \( K_m \) values for transport by all three systems fall within the range reported for transport of amino acids by other bacteria. While the \( V_{\text{max}} \) values range from equivalent to far in excess of those reported elsewhere, \( P. \) putida, unlike most bacteria, utilizes transported amino acids not only for protein biosynthesis but also for production of ATP and of all amphibolic intermediates.

The most striking difference between the three transport systems is their substrate specificity, which ranges from relatively broad to absolutely specific (Table IV). The absolute specificity of the L-arginine-specific system is suggested by the failure of any guanidino compound tested, including D-arginine and the next higher and lower homologs of L-arginine, to significantly inhibit L-arginine transport. Other amino acids also are without inhibitory effect. The diamino acid transport system exhibits intermediate specificity. L-Lysine and its next lower homolog L-ornithine both are transported, and the D isomers of lysine and ornithine and D-arginine inhibit transport of either L-amino acid. Inhibition data suggest that D-lysine, D-ornithine, and D-arginine also may be transported by the diamino acid transport system. The effect of substrate analog inhibitors on transport of L-arginine by the general system, taken together with data reported previously for inhibition of transport of L-lysine (3), permits assessment of the specificity of the general amino acid transport system. Transporsted substrates appear to possess the following minimal structure.

\[
\begin{align*}
R & \\
\text{NH}_2^+ & \\
(OH)_{3-3} & \\
\text{CHNH}_2^+ & \\
\text{COO}^- & 
\end{align*}
\]

The unsubstituted carboxyl is required (agmatine and L-arginine amide do not inhibit) as also an unsubstituted \( \alpha \)-amino group (guanidinoacetate, \( \beta \)-guanidinopropionate, \( \gamma \)-guanidinobutyrate, \( N-\alpha \text{-acetyl-L-lysine} \) (3) and \( N-\text{N\text{-methyl-L-arginine}} \) do not inhibit) although the configuration about the \( \alpha \) carbon atom may be either D or L (D-lysine, D-ornithine, and D-arginine inhibit). A positively charged group is required distal to the carboxyl group (\( \alpha \)-amino-\( \alpha \)-caproate does not inhibit) and this must be either a free amino group (\( N-\text{\alpha \text{-acetyl-L-lysine}} \) (3) does not inhibit) or a guanidino group. The number of methylene carbon atoms separating the \( \alpha \)-amino group from the terminal nitrogen may range from 3 to 5 (L-ornithine, L-lysine, and L-arginine are transported; L-\( \alpha \)-amino-\( \gamma \)-guanidinobutyrate and L-homoarginine inhibit), but the terminal methylene carbon may not be replaced by an oxygen atom (while L-homoarginine inhibits, L-canavanine does not).

An analogy may be drawn between transport of basic amino acids by \( P. \) putida and of L-lysine, L-ornithine, and L-arginine by \( E. \) coli K-12, which also is mediated by three distinct transport systems (6). Both organisms possess a low \( K_m \) system specific for L-arginine transport \((K_m = 2.6 \times 10^{-4} \text{ M} \ (E. \) coli) and \( 5.2 \times 10^{-8} \text{ M} \ (P. \) putida)), and substrate analogs are not inhibitors of L-arginine transport. \( E. \) coli also possesses a general basic amino acid transport system which, in contrast to that of \( P. \) putida (3), is not inhibited by the D isomers of the transported amino acids. Finally, while \( P. \) putida possesses a diamino acid transport system, \( E. \) coli possesses an L-lysine-specific system for which no analogy was detected in \( P. \) putida.

REFERENCES

1. Miller, D. L., and Rodwell, V. W. (1971) J. Biol. Chem. 246, 2758-2764
2. Miller, D. L., and Rodwell, V. W. (1971) J. Biol. Chem. 246, 5033-5038
3. Miller, D. L., and Rodwell, V. W. (1971) J. Biol. Chem. 246, 1765-1771
4. Baginsky, M. L., and Rodwell, V. W. (1966) J. Bacteriol. 92, 424-432
5. Smith, I. (1958) Chromatographic techniques, p. 73, Interscience Publications, Inc., New York
6. Rosen, B. P. (1971) J. Biol. Chem. 246, 3633-3662
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