The *Escherichia coli* glycine transport system and its role in the regulation of the glycine cleavage enzyme system

Angela C. Ghrist and George V. Stauffer

Author for correspondence: George V. Stauffer. Tel: +1 319 335 7791. Fax: +1 319 335 9006.

An *Escherichia coli* K12 mutant defective in both serine biosynthesis (serA) and glycine transport (cycA) was found to exhibit a glycine cleavage negative (GCV-) phenotype, i.e. was unable to use glycine as a serine source. While [2-\textsuperscript{14}C]glycine uptake and induction of a *gcvT::lacZ* fusion were greatly reduced in a cycA mutant compared to the wild-type, both strains exhibited parallel increases in uptake and induction with increasing exogenous glycine concentrations. A plasmid carrying the wild-type cyc region complemented the GCV- phenotype and restored both glycine uptake and glycine-inducible *gcvT::lacZ* expression. Wild-type and cycA strains grown in the presence of either a glycine-containing tripeptide or threonine, which can be degraded internally into glycine, exhibited similar induction of the *gcvT::lacZ* fusion. However, when a gcv mutation, which causes glycine to accumulate within the cell, was introduced into the cycA strain, there was increased induction of the *gcvT::lacZ* fusion, but induction was less than that observed in a gcv cycA+ strain. It is proposed that cyc serves primarily in the regulation of gcv by transporting glycine into the cell, which endogenously induces gcv expression. However, the possibility of some form of exogenous regulation of gcv, mediated by the cyc-encoded glycine transport system, exists.

**Keywords:** *Escherichia coli*, glycine transport, glycine cleavage, *gcv*, *cyc*

**INTRODUCTION**

The biosynthesis of glycine and one-carbon (C\textsubscript{1}) units is of central physiological importance. Glycine is used in both protein and purine biosynthesis and C\textsubscript{1} units are needed for the biosynthesis of methionine, thymine, purines, and numerous methylated products (Stauffer, 1986). In enteric bacteria, serine hydroxymethyltransferase, the *glyA* gene product, catalyses the conversion of serine to glycine and 5,10-methylenetetrahydrofolate (Mudd & Cantoni, 1964; Pizer, 1965). This reaction is the cell's primary source of glycine and C\textsubscript{1} units. A second pathway for C\textsubscript{1} biosynthesis involves the cleavage of glycine to CO\textsubscript{2}, NH\textsubscript{3} and 5,10-methylenetetrahydrofolate by the glycine cleavage (GCV) enzyme system (Sagers & Gunsalus, 1961; Kikuchi, 1973). In balancing the cell's requirements for glycine and C\textsubscript{1} units, GlyA and the GCV enzyme system serve important roles in cellular metabolism.

Although regulation of the *glyA* gene has been studied extensively (Stauffer, 1986), the regulation of *gcv* is only just beginning to be understood. The *gcvT*, *gcvH* and *gcvP* genes encoding the GCV enzyme system are known to form an operon that maps at minute 62.5 on the *Escherichia coli* chromosome (Stauffer et al., 1986, 1991, 1993). The system has been shown to be inducible in the presence of exogenous glycine (Meedel & Pizer, 1974; Wilson et al., 1993a) and repressed in the presence of exogenous purines (Wilson et al., 1993b). To date, three proteins, Lrp, PurR and GcvA, have been shown to be involved in the regulation of *gcv*. Lrp, or leucine-responsive regulatory protein, is a global regulatory protein involved in the control of transcription of numerous genes relating to amino acid metabolism and is required for normal induction of *gcv* (Lin et al., 1992). PurR, or purine repressor protein, has been shown to repress the transcription of the purine biosynthetic genes (Kiistrup et al., 1989; Rolfs & Zalkin, 1988), *glyA* (Steiert et al., 1990), and *gcv* (Wilson et al., 1993b) in the presence of purines. Finally, GcvA has been shown to serve as an activator of *gcv* in the presence of exogenous glycine and as a repressor...
Transport systems frequently play important roles in the regulation of gene expression (Epstein, 1983). In most cases, transport systems play a role in endogenous gene regulation by transporting effector molecules into the cell, where they are sensed by soluble or membrane-bound regulatory proteins. In other instances, membrane-spanning transport systems may exogenously regulate gene expression by producing an intracellular regulatory signal in response to the presence of extracellular effector molecules. Sensing an exogenous effector is one way of regulating gene expression by a compound in the medium when that compound is also a metabolic intermediate always present in the cell.

The E. coli glycine transport system (Cyc) has been shown to transport glycine, d-alanine, d-serine, and the antibiotic d-cycloserine (Wargel et al., 1970; Cosloy, 1973). Mutations in cyc result in d-cycloserine resistance and have been found to reduce the uptake of [2-14C]glycine by more than 90% as compared to the wild-type (Wargel et al., 1970; Cosloy, 1973; Robbins & Oxender, 1973). It has been shown that this system is not inducible, but rather appears to be formed constitutively (Cosloy, 1973). Also designated dag, cyc has most recently been mapped to minute 956 on the E. coli chromosome map (Bachmann, 1990).

In this study, the role of cyc in the regulation of gcv was investigated. The results suggest that cyc serves primarily in the induction of gcv by increasing endogenous glycine. However, the results do not rule out the possibility that cyc may also play a role in some form of exogenous induction of gcv.

**METHODS**

**Bacterial strains and plasmids.** All bacterial strains used in this study are E. coli K-12 derivatives and are described in Table 1. Plasmids were constructed during this study and are described in the text.

**Growth conditions.** The glucose minimal (GM) medium used was the Vogel & Bonner (1956) minimal salts medium supplemented with 0.4% glucose. The complex medium used was Luria broth (Miller, 1972). Agar was added at 1.5% (w/v) to make solid medium. Amino acids, antibiotics and other supplements were added at the following concentrations, unless otherwise stated: leucine, isoleucine, threonine and phenylalanine, 50 μg ml⁻¹; serine, 200 μg ml⁻¹; glycine, 300 μg ml⁻¹; thiamin, 1 μg ml⁻¹; tetracycline (Te), 10 μg ml⁻¹; kanamycin (Km), 20 μg ml⁻¹; chloramphenicol (Cm), 300 μg ml⁻¹; d-cycloserine, 40 μg ml⁻¹. GM medium was always supplemented with phenylalanine and thiamin since most strains carry the pheA905 and thi mutations. When serine was added to the medium, isoleucine was also added to overcome serine sensitivity (Uzan & Danchin, 1978).

All λ lysogens carry the cI857 mutation resulting in a temperature sensitive repressor and were grown at 30 °C. Lysogens were tested for a single copy of bacteriophage by infection with λ cI9017 (Shimada et al., 1972). All other strains were grown at 37 °C.

**P1 transductions.** The use of P1 cml clr-100 phage for transductions was as described by Miller (1972).

**β-Galactosidase enzyme assays.** These were performed according to Miller (1972), using the chloroform/SDS lysis procedure. Activities are expressed in Miller units.

**Measurement of [2-14C]glycine uptake.** Overnight cultures grown in GM medium containing appropriate supplements and antibiotics were diluted 1:100 (10 ml final volume) in the same medium, grown to an optical density of 0.4 at 600 nm, resuspended in 0.6 ml cold 0.4% GM medium, and the OD600 of 0.1 ml of each culture was determined spectrophotometrically. Cm was added to the remaining 0.5 ml cells, and each tube placed on ice until all cultures had been harvested.

To begin the uptake assay, each tube containing 0.5 ml cells was incubated for 5 min at 30 °C. To each tube, [2-14C]glycine [0.0125 μCi μg⁻¹ (2.96 MBq μg⁻¹); 800 μg ml⁻¹] and 0.4% GM medium were added in amounts necessary to achieve the desired glycine concentration (final volume 2 ml) and incubation at 30 °C continued. At the desired time, a 0.2 ml sample was taken and placed in a microcentrifuge tube containing 1 ml 0.4% GM medium + 50 mM unlabeled glycine warmed to 30 °C, centrifuged for 45 s and the supernatant removed. The pellet
was resuspended in 1 ml 1 × minimal salts and centrifuged again for 1 min. The supernatant was removed and the sample placed on ice until all samples had been collected. Samples were resuspended in 12 ml scintillation cocktail and radioactivity was measured using a Beckman scintillation counter.

**DNA manipulations.** Isolation of phage DNA, restriction enzyme digestion, ligation, plasmid isolation and transformation were performed as described by Sambrook et al. (1989).

**Materials.** Restriction enzymes and other DNA modifying enzymes were from BRL or New England Biolabs. [2-14C]Glycine was obtained from New England Nuclear. All other chemicals were purchased from standard commercial sources.

**RESULTS**

**Construction and analysis of a new class of GCV– mutants**

Mutants blocked simultaneously in the serine biosynthetic pathway and the GCV pathway are unable to use glycine as a serine source (the GCV– phenotype) (Plamann et al., 1983). Therefore, it is reasonable to hypothesize that a mutant blocked simultaneously in both serine biosynthesis and glycine transport might also display the GCV– phenotype. To test this hypothesis, a serA cycA double mutant was constructed by transducing the cycA mutation from GS780 (cycA30::Tn10) into the serA strain GS958 (serA25) with P1 cml cir-100 phage. Transductants were selected on LB plates supplemented with Tc and TcR transductants were spotted on a series of GM plates containing serine, glycine, or serine and d-cycloserine. After overnight incubation (approximately 16 h), all TcR transductants were capable of growing when supplemented with serine and d-cycloserine. After overnight incubation (approximately 16 h), all TcR transductants were capable of growing when supplemented with serine and d-cycloserine, confirming that they had acquired the cycA30::Tn10 mutation conferring d-cyclosereine resistance. In addition, all transductants displayed the GCV– phenotype, i.e. they exhibited normal growth when supplemented with serine, but extremely weak growth when supplemented with glycine. One such transductant was retained and designated GS988.

It should be noted that with continued incubation (approximately 24 h), the transductants eventually displayed growth on GM plates supplemented with glycine. This growth may have been due in part to the high concentration of glycine used (300 µg ml−1). When GS988 colonies were spotted on GM plates with a lower concentration of glycine (15 µg ml−1), they failed to show growth after 72 h incubation. These observations suggest that glycine is entering the cell, but at a rate which is insufficient for normal growth.

**The effects of a cycA mutation on glycine uptake and induction of gcv**

It was initially observed that a cycA mutant defective in glycine transport still exhibited approximately 50% of the normal level of glycine-mediated induction when grown in the presence of glycine (300 µg ml−1) (data not shown). Thus, it was possible that the gcv system was exogenously induced by glycine. We tested this possibility and the possible role of cyc in the regulation of gcv. The lysogen GS162(agree T::lacZ) carries an in-frame fusion of the gcvT gene to lacZ (Stauffer et al., 1993). In this fusion, β-galactosidase synthesis is under the control of the gcv regulatory region. GS162(agree T::lacZ) was transduced with P1 cml cir-100 phage grown on GS780 (cycA30::Tn10). Transductants were selected on LB plates supplemented with Tc, and TcR transductants were spotted on GM plates containing d-cycloserine. All transductants were resistant to d-cycloserine. One transductant was retained and designated GS990 (agree T::lacZ).

To confirm that GS990 (agree T::lacZ) was defective in glycine transport, the uptake of [2-14C]glycine at 10, 25, 50, 100 and 300 µg glycine ml−1 was measured, with GS162 (agree T::lacZ) serving as an isogenic control. As illustrated in Fig. 1, glycine uptake was greatly reduced in GS990 (agree T::lacZ) at all concentrations assayed. The greatest reduction (83%) occurred at the lowest concentration assayed (10 µg ml−1). With increasing concentrations of glycine, both strains exhibited roughly parallel increases in glycine uptake, most likely due to additional routes of entry thought to exist at high concentrations of glycine (>10−4 M) (Robbins & Oxender, 1973).

If gcv expression is regulated solely by endogenous glycine, then the reduction in glycine uptake in GS990 (agree T:: lacZ) should lead to a similar reduction in gcvT::lacZ expression. To test this, GS162 (agree T::lacZ) and GS990 (agree T::lacZ) were grown in GM medium supplemented with 0, 10, 25, 50, 100 and 300 µg glycine ml−1 and assayed for β-galactosidase activity. Both strains exhibited increasing β-galactosidase activity with increasing glycine concentrations (Fig. 1). In both strains, this increase in activity was roughly paralleled by an increase in glycine uptake, suggesting that the amount of endogenous glycine is directly or indirectly responsible for induction of gcv.

**Induction of gcv by a glycine-containing tripeptide**

To provide further evidence that gcv is induced endogenously by glycine, wild-type and cyc strains were grown in the presence of a glycine-containing tripeptide and assayed for β-galactosidase activity. Small oligopeptides are transported into the cell via transport systems which function independently of those which transport free amino acids (Payne & Gilvarg, 1978). Once inside the cell, these oligopeptides are then hydrolysed into free amino acids by intracellular peptidases (Payne & Gilvarg, 1978). Since the oligopeptide transport systems in wild-type and cyc strains should be functional, growth in media supplemented with a glycine-containing tripeptide should lead to similar internal glycine concentrations, and thus similar levels of gcv expression. Strains GS958 (serA) and GS988 (serA cycA) were spotted onto GM plates supplemented with either glycine or the glycine-containing tripeptide glycine-glycine-phenylalanine. After incuba-
A. C. GHRIST and G. V. STAUFFER

**Table 2. β-Galactosidase activities of the wild-type (cyc<sup>*</sup>) strain and a cyc mutant carrying the λgcvT::lacZ phage**

<table>
<thead>
<tr>
<th>Lysogen</th>
<th>β-Galactosidase activity* (Miller units)</th>
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<tbody>
<tr>
<td></td>
<td>GM</td>
</tr>
<tr>
<td>GS162 (cyc&lt;sup&gt;*&lt;/sup&gt;)</td>
<td>172</td>
</tr>
<tr>
<td></td>
<td>171</td>
</tr>
<tr>
<td>GS990 (cyc)</td>
<td>165</td>
</tr>
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<td></td>
<td>174</td>
</tr>
</tbody>
</table>

*Cells were grown in GM medium with or without leucine and with or without threonine at the indicated concentrations. All results are means from at least two separate trials in which each sample was determined in triplicate. All standard deviations were within 12% of the mean.

bound glycine was significantly less than that exhibited in the presence of an equimolar amount of free glycine.

**Induction of gcv by threonine**

Another means of increasing internal glycine independent of cyc<sup>*</sup> is to grow cells in the presence of threonine. Threonine enters the cell via a transport system distinct from that which transports glycine (Robbins & Oxender, 1973; Templeton & Savagean, 1974). Inside the cell, threonine may then be degraded to glycine and acetyl coenzyme A by threonine dehydrogenase, encoded by tdb, and α-amino-β-ketobutyrate lyase (Newman et al., 1976; Potter et al., 1977). This pathway has been shown to provide an alternative route for glycine biosynthesis (Ravnikar & Sommerville, 1987). The conversion of threonine to glycine can be increased by the addition of leucine, as leucine has been shown to relieve hrp-mediated repression of tdb (Rex et al., 1991). Leucine alone has been shown to have no effect on gcv expression (Lin et al., 1992).

If gcv is induced by endogenous glycine, then wild-type and cyc<sup>A</sup> strains should have similar levels of induction when grown in the presence of either threonine or threonine and leucine. GS162(<i>lacZ</i>) (wild-type) and GS990(<i>lacZ</i>) (cyc<sup>A</sup>) were grown in GM medium either with or without leucine and either with or without low (15 µg ml<sup>-1</sup>) and high (50 µg ml<sup>-1</sup>) levels of threonine and assayed for β-galactosidase activity. As shown in Table 2, the wild-type and cyc<sup>A</sup> lysogens were not induced in the presence of leucine alone. Both lysogens displayed similar induction by threonine (15 µg ml<sup>-1</sup>) in the presence or absence of leucine. When threonine was used at 50 µg ml<sup>-1</sup>, induction of gcv was higher in both lysogens, although induction was significantly lower in the cyc<sup>A</sup> lysogen compared to the wild-type. In addition, the presence of leucine and threonine resulted in slightly higher levels of induction in both lysogens.
Table 3. β-Galactosidase activities of wild-type, gcv and cyc strains carrying the λgcvT::lacZ phage

<table>
<thead>
<tr>
<th>Lysogen</th>
<th>Relevant genotype</th>
<th>β-Galactosidase activity* (Miller units)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>GM</td>
</tr>
<tr>
<td>GS162</td>
<td>(gcv' cycA')</td>
<td>202</td>
</tr>
<tr>
<td>GS936</td>
<td>(gcv cycA')</td>
<td>1645</td>
</tr>
<tr>
<td>GS990</td>
<td>(gcv' cycA)</td>
<td>184</td>
</tr>
<tr>
<td>GS989</td>
<td>(gcv cycA)</td>
<td>1140</td>
</tr>
</tbody>
</table>

*Cells were grown in GM medium with or without glycine (300 μg ml⁻¹). All results are means from at least two separate trials in which each sample was determined in triplicate. All standard deviations were within 8% of the mean.

gcvT::lacZ expression in a gcv cycA double mutant

Lysogen GS936(λgcvT::lacZ) is a gcv mutant. This strain exhibits a high level of induction of a gcvT::lacZ fusion as measured by β-galactosidase activity, even in the absence of exogenous glycine (Table 3). This is presumably due to the accumulation of glycine within the cell, since GS936(λgcvT::lacZ) secretes glycine, as evidenced by its ability to feed a glycine auxotroph (data not shown).

Transformation of this strain with a plasmid carrying a functional GCV enzyme system returned the induction of β-galactosidase synthesis to wild-type levels (data not shown).

If the induction of gcv is due solely to internal glycine, then a gcv cycA double mutant should have levels of induction similar to those observed in a gcv mutant, as internal glycine levels should be essentially the same. To test this hypothesis, a gcv cycA double mutant was constructed by transducing GS936(λgcvT::lacZ) (gcv) with P1 cml clr-100 phage grown on GS780 (cycA30::Tn10). Transductants were selected on LB plates supplemented with Tc and TcR transductants were then spotted on GM plates supplemented with d-cycloserine. One d-cycloserine-resistant transductant was retained and designated GS989(λgcvT::lacZ). This strain secreted glycine at a level similar to that observed in GS936(λgcvT::lacZ), as measured by its ability to feed a glycine auxotroph (data not shown).

Table 3 shows β-galactosidase activities for GS162(λgcvT::lacZ) (wild-type), GS990(λgcvT::lacZ) (cycA), GS936(λgcvT::lacZ) (gcv), and GS989(λgcvT::lacZ) (cycA gcv) grown in GM medium with and without glycine. β-Galactosidase activity was greater in GS989(λgcvT::lacZ) than it was in GS990(λgcvT::lacZ) in both uninduced and glycine-induced cultures, presumably due to a higher endogenous glycine concentration. However, β-galactosidase activities in strain GS989(λgcvT::lacZ) were still significantly lower than those in strain GS936(λgcvT::lacZ) in both uninduced and induced cultures.

Cloning cyc

The glycine transport system was cloned using the ‘Miniset’ of specialized transducing bacteriophages described by Kohara et al. (1987). In brief, a series of bacteriophages containing E. coli DNA covering the known map position of ced were spotted on a lawn of GS988 (serA gcA) growing on GM plates containing glycine (25 μg ml⁻¹). Since GS988 is unable to transport sufficient glycine for growth, only those cells containing a functional transport system from the λ bacteriophage should be able to grow. One such bacteriophage, 7E9, complemented the GCV⁻ phenotype. DNA was prepared from this phage and digested with BamHI. The 17 kb insert was isolated and ligated into the BamHI site of the single-copy plasmid pGS225, a PDF41 derivative (Kahn et al., 1979) containing a Tn5::kan gene (Berg et al., 1975). This new plasmid was designated pGS260.

The ability of pGS260 to complement a GCV⁻ phenotype was tested by transforming strain GS988. Transformants were selected on LB plates supplemented with Km and Tc. When the transformants were spotted on GM plates supplemented with glycine, pGS260 was able to complement the GCV⁻ phenotype.

To confirm that pGS260 was capable of restoring normal glycine transport, the uptake of [2-¹⁴C]glycine was measured for GS162(λgcvT::lacZ) (wild-type) and GS990(λgcvT::lacZ) (cycA) transformed with pGS260; the untransformed strains served as controls. GS990(λgcvT::lacZ) transformed with pGS260 displayed near normal glycine transport (Fig. 3), and GS162(λgcvT::lacZ) transformed with pGS260 exhibited glycine uptake greater than that observed in the untransformed strain, suggesting that pGS260 carries the y-encoded glycine transport system.
Induction of gcv in wild-type and cyc strains transformed with pGS260

Plasmid pGS260 was used to transform lysogens GS162(\(\lambda\text{gcvt}::\text{lacZ}\)) (wild-type), GS990(\(\lambda\text{gcvt}::\text{lacZ}\) (\(\text{yc}\)), and GS989(\(\lambda\text{gcvt}::\text{lacZ}\) (\(\text{gcv}\)). Transformants were then grown in GM medium with or without glycine and assayed for \(\beta\)-galactosidase activity. As shown in Table 4, pGS260 complemented the \(\text{yc}\) mutation in lysogen GS990(\(\lambda\text{gcvt}::\text{lacZ}\)), increasing the induction of \(\text{gcvt}::\text{lacZ}\) by glycine to the level found in GS162(\(\lambda\text{gcvt}::\text{lacZ}\)) (see Table 3). The plasmid was also able to complement the \(\text{yc}\) mutation in GS989(\(\lambda\text{gcvt}::\text{lacZ}\)), increasing the induction of \(\text{gcvt}::\text{lacZ}\) in the absence of glycine to that observed in GS936(\(\lambda\text{gcvt}::\text{lacZ}\)) (see Table 3). In addition, introducing an additional copy of \(\text{yc}\) via pGS260 into GS162(\(\lambda\text{gcvt}::\text{lacZ}\)) increased the induction of \(\text{gcvt}::\text{lacZ}\) by glycine over that observed when only a single copy of \(\text{yc}\) was present (see Table 3), suggesting that at least part of the increased induction of \(\text{gcvt}::\text{lacZ}\) by glycine in the transformed strain results from an increase in glycine transport.

**Table 4. \(\beta\)-Galactosidase activities of wild-type, gcv and cyc strains carrying the \(\lambda\text{gcvt}::\text{lacZ}\) phage and transformed with pGS260**

<table>
<thead>
<tr>
<th>Strain</th>
<th>Relevant genotype</th>
<th>(\beta)-Galactosidase activity* (Miller units)</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td>GM</td>
</tr>
<tr>
<td>GS162(pGS260)</td>
<td>(\text{gcv}^+\text{yc}^-/\text{yc}^-)</td>
<td>166</td>
</tr>
<tr>
<td>GS990(pGS260)</td>
<td>(\text{gcv}^+\text{yc}^-/\text{yc}^-)</td>
<td>178</td>
</tr>
<tr>
<td>GS989(pGS260)</td>
<td>(\text{gcv}^+\text{yc}/\text{yc}^-)</td>
<td>1645</td>
</tr>
</tbody>
</table>

* Cells were grown in GM medium with or without glycine (300 \(\mu\text{g ml}^{-1}\)). All results are means from at least two separate trials in which each sample was determined in triplicate. All standard deviations were within 12% of the mean.

Discussion

The glycine transport system appears to serve primarily in the regulation of \(\text{gcvt}\) by transporting glycine into the cell, where endogenous induction of \(\text{gcvt}\) expression occurs. In many ways, this regulation is similar to the endogenous regulation of proline oxidase (\(\text{put}A\)), a proline degradation enzyme, by the proline transport system (\(\text{put}P\)) (Ratzkin et al., 1978). In this system, proline is transported into the cell by the \(\text{put}P\) transport system, where it then induces both \(\text{put}P\) and \(\text{put}A\). A \(\text{put}P\) mutant, which lacks proline oxidase activity in the uninduced state, secretes proline, suggesting that a functional proline transport system is required to maintain internal proline pools. Mutants blocked simultaneously in proline biosynthesis and proline transport grow very poorly, even when supplied with high concentrations of proline. This is similar to the inability of a \(\text{ser}A\) \(\text{cyc}A\) mutant to use glycine as a glycine/serine source. A \(\text{put}P\) mutant grown in the presence of proline exhibits as much as a 99% reduction in proline uptake compared to the wild-type, yet still exhibits a slight induction of both \(\text{put}P\) and \(\text{put}A\), presumably due to diffusion, residual transport or secondary transport of proline into the cell. This is similar to the ability of glycine to induce \(\text{gcvt}\) in a \(\text{yc}\) mutant, even though glycine uptake is greatly reduced.

Despite similarities to the \(\text{put}\) system, several observations leave open the possibility that part of the induction signal is exogenous. When wild-type and \(\text{put}P\) strains were grown in the presence of a proline-containing dipeptide, induction of \(\text{put}P\) and \(\text{put}A\) was the same in both strains and was not significantly different from that observed when the wild-type strain was grown in the presence of free proline (Ratzkin et al., 1978). When wild-type and \(\text{yc}\) strains were grown in the presence of a glycine-containing tripeptide, induction of \(\text{gcvt}\) was the same in both strains (Fig. 2). However, this induction was significantly less than that observed when the wild-type strain was grown in an equimolar amount of free glycine. This difference in induction may be due to an exogenous induction signal by glycine, which would be absent in the case of induction by peptide-bound glycine. Another explanation is that peptide-bound glycine is transported less efficiently than free glycine or that the conversion of tripeptide to free glycine is limiting. It is also possible that free glycine is able to induce \(\text{gcvt}\) more efficiently than peptide-bound glycine due to an association of the glycine transport system with Gcv or GcvA.

Another observation which may indicate partial exogenous induction is that \(\text{gcvt}\) mutants excrete glycine into the growth medium, presumably an indication that internal glycine pools are saturated. However, expression of \(\text{gcvt}\) was significantly elevated in a \(\text{gcvt}\) \(\text{ye}^+\) strain compared to the wild-type \(\text{gcvt}\) mutant, even though internal glycine concentration equal to that of the \(\text{gcvt}\) strain. It is also possible that, in the case of the \(\text{gcvt}\) strain, glycine secreted into the growth medium induces \(\text{gcvt}\) exogenously. If exogenous induction occurs, it appears to require a functional glycine transport system.

Our results also show that threonine induces the \(\text{gcvt}\) operon (Table 2). This is most likely an indirect effect caused by the conversion of threonine to glycine (Ravnikar & Sommerville, 1987). This conclusion is supported by the increase in induction observed when both leucine and threonine were added to the growth medium (Table 2). Leucine has previously been shown to increase the conversion of threonine to glycine (Rex et al., 1991). It should be noted that threonine supplementation results in lower levels of \(\text{gcvt}::\text{lacZ}\) expression in the \(\text{yc}\) mutant than in the \(\text{yc}^-\) strain. This may again be due to the inability of the \(\text{yc}\) mutant to maintain a high internal glycine concentration. Another possibility is that the wild-type glycine transport system is also capable of the nonspecific transport of threonine when threonine is present at high concentrations.
The cloned \( E. coli \) glycine transport system will allow us to investigate in more detail the possibility of both endogenous and exogenous induction of the GCV enzyme system, and the role that the cytoplasmic glycine transport system plays in gev induction.

**ACKNOWLEDGEMENTS**

This investigation was supported by Public Health Service grant GM26878 from the National Institute of General Medical Sciences.

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Received 22 April 1994; revised 3 August 1994; accepted 24 August 1994.