Induction of Ornithine Decarboxylase Activity in Mouse Urinary Bladder by L-Tryptophan and Some of Its Metabolites

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ABSTRACT

The responses of female noninbred mouse urinary bladder ornithine decarboxylase (EC 4.1.1.17) (ODC) and S-adenosyl-L-methionine decarboxylase (EC 4.1.1.50) (SAMD) activities to L-tryptophan feeding and to topical intraurethral administration of L-tryptophan and some of its urinary metabolites were studied. Mice fed a diet containing 1% L-tryptophan demonstrated significant increases in vesical ODC and SAMD activities as early as 2 weeks after the commencement of the diet. By the end of the third week, ODC and SAMD activities reached peak values of 7- and 3-fold, respectively, significantly greater than the control levels (p < 0.05 and p < 0.01, respectively). Then, enzyme activities gradually decreased but remained at levels significantly higher than those of the control mice until the end of the sixth week when the study was terminated. Topical application by urethral catheter of some urinary tryptophan metabolites was followed by a rapid, transient induction of urinary bladder ODC activity within 5 hr. Statistically significant differences between vehicle controls and xanthurenic acid (p < 0.01), DL-kyurenine (p < 0.01), L-kyurenine (p < 0.01), anthranilic acid (p < 0.01), and quinaldic acid (p < 0.05) were observed. However, no significant differences were seen with L-tryptophan, 3-hydroxy-DL-kyurenine, the 8-methyl ether of xanthurenic acid, or D-kyurenine or with 3-hydroxyanthranilic, kyurenine, quinolinic, picolinic, and nicotinic acids. Bladder SAMD was not elevated significantly by most of these directly applied tryptophan metabolites. ODC inducibility by active compounds was followed by mucosal hyperplasia within 7 days. These data suggest that certain L-tryptophan metabolites may be involved in two-stage urinary bladder carcinogenesis in a manner similar to that shown to occur in murine skin tumor systems by other chemicals.

INTRODUCTION

The urinary bladder epithelium is susceptible to a wide variety of chemical carcinogens (4–6, 11, 12, 31, 32). L-Tryptophan, an essential amino acid, is extensively metabolized (Chart 1), resulting in urinary excretion of several metabolites, some of which have demonstrated urinary bladder carcinogenic activities in experimental systems (4–6, 9). A relationship between elevated urinary tryptophan metabolite levels and bladder cancer in humans was proposed (3, 4, 32, 40). Recent data (11, 12, 16, 21, 34) suggest that tryptophan or its urinary metabolites may be cocarcinogens or promoters of bladder neoplasia. We first proposed (4–6, 9, 40) that bladder carcinogenesis was a multifactorial process that might involve stages of induction and promotion analogous to those of skin tumorigenesis (1, 39). This proposal has been confirmed and extended by others (11, 12, 16, 17, 21).

Evidence that polyamines and the enzymes responsible for their biosynthesis play a significant role in carcinogenesis, tumor promotion, and cellular hyperplasia has been presented (1, 19, 28, 35, 39). Data have been presented that ODC5 induction by 12-O-tetradecanoylphorbol-13-acetate in mouse skin, although not sufficient (20, 27), is an important component of the mechanism of tumor promotion by 12-O-tetradecanoylphorbol-13-acetate (1, 28, 38). ODC induction also was reported to occur in carcinogenesis of liver (30, 36), lung (13), and colon (37), as well as urinary bladder (22). Single topical and i. u. administration of the vesical carcinogens FANFT and ANFT resulted in early, exaggerated ODC activity in rodent urinary bladders (22). We report here the induction of mouse urinary bladder ODC and SAMD activities following systemic administration of L-tryptophan and following i. u. administration of some tryptophan metabolites.

MATERIALS AND METHODS

Chemicals. The following chemicals were purchased: reagent grade dimethyl sulfoxide and L-tryptophan (Aldrich Chemical Co., Milwaukee, Wis.); anthranilic acid and 3-hydroxyanthranilic acid (Sigma Chemical Co., St. Louis, Mo.); ANFT (Saber Laboratories, Morton Grove, Ill.); α-[1-14C]ornithine hydrochloride (specific activity, 52.5 mCi/mmol) and S-adenosyl-L-[carboxyl-14C]methionine (specific activity, 52.3 mCi/mmol) (New England Nuclear, Boston, Mass.). The tryptophan metabolites nicotinic acid; picolinic acid; quinolinic acid; kynurenic acid; D-, L-, and DL-kyurenine; 3-hydroxy-DL-kyurenine; the 8-methyl ether of xanthurenic acid; and xanthurenic acid were generously provided by Dr. R. R. Brown (University of Wisconsin Clinical Cancer Center, Madison, Wis.). Chemical identity and purity of all test compounds were checked by melting point, IR and UV absorption spectrophotometry, and paper and high-performance liquid chromatography (3).

Animals and Treatment. Female noninbred Swiss albino mice (Sprague-Dawley, Madison, Wis.), 12 to 14 weeks old, received pelleted diet (Wayne Lab Blox; Allied Mills, Inc., Chicago, Ill.) and water ad libitum and were killed between 1 and 3 p.m. in order to avoid circadian rhythm variations.

For the 6-week feeding trial with L-tryptophan, the following protocol was used: L-Tryptophan (50 g; 1% w/w) was mixed mechanically with...
40 g of anhydrous dextrose and 4910 g of ground diet and was stored in a refrigerator at 4–10° until used (15). This diet was fed to 180 mice for 0 to 6 weeks. Forty control mice were fed unmedicated ground diet for 0 to 6 weeks. Mice were weighed at the start of the study and when killed. Food consumption was determined at weekly intervals. Eight groups (3 mice/group) of L-tryptophan-treated mice were killed at weekly intervals; 4 groups (3 mice/group) of control animals were killed at the start of the study and at the end of the third and sixth weeks. For histological study, 6 mice fed the L-tryptophan-containing diet and 3 mice fed unmedicated ground diet were killed at weekly intervals. Urinary bladders were appropriately inflated with and fixed in 10% buffered formalin, and sections were stained with hematoxylin and eosin as described previously (15, 37).

Chemicals applied by i. u. instillations directly into the vesical lumen were solubilized in an appropriate solvent (Table 1), diluted with distilled water to the final indicated solvent percentage, and administered in a volume of 0.10 ml as described previously (22). For histological study, 3 or 6 mice were killed at 3, 5, 7, 10, 12, 24, 48, 120, and 168 hr after instillation of tryptophan metabolites.

**Tissue Preparation and Enzyme Assays.** Mice were killed at predetermined times by cervical dislocation. Whole bladders from 3 mice were pooled, homogenized, and centrifuged, and ODC and SAMD activities and protein content of the soluble bladder extracts were determined by methods described previously (22).

## RESULTS

**Effects of L-Tryptophan Feeding on Urinary Bladder ODC and SAMD Activities.** No significant differences in diet consumption and growth rates were found between experimental and control groups. The daily dose of L-tryptophan in the experimental group was about 50 mg/mouse. Urinary bladder ODC (Chart 2A) and SAMD (Chart 2B) activities, measured at

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Chemical</th>
<th>Dose (µmol)</th>
<th>Groups</th>
<th>ODC (pmol CO₂/30 min/mg protein)</th>
<th>Groups</th>
<th>SAMD (pmol CO₂/30 min/mg protein)</th>
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<tbody>
<tr>
<td>1</td>
<td>L-Tryptophan</td>
<td>1.0</td>
<td>4</td>
<td>29 ± 8*</td>
<td>4</td>
<td>45 ± 3*</td>
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<td>Xanthurenic acid</td>
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<td>7</td>
<td>158 ± 20*</td>
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<td>52 ± 8</td>
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<td>L-Kynurenine</td>
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<td>144 ± 29*</td>
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<td>63 ± 11</td>
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<td>138 ± 20*</td>
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<td>60 ± 10</td>
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<td>Quinolic acid</td>
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<td>6</td>
<td>117 ± 23*</td>
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<td>82 ± 16</td>
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<td>3-Hydroxy-DL-kynurenine</td>
<td>1.0</td>
<td>8</td>
<td>95 ± 16</td>
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<td>63 ± 13</td>
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<td>Quinolinic acid</td>
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<td>90 ± 13</td>
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<td>3-Hydroxyanthranilic acid</td>
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<td>11</td>
<td>77 ± 16</td>
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<td>74 ± 14</td>
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<td>42 ± 4</td>
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<td>Picolinic acid</td>
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<td>ANFT (positive control)</td>
<td>0.46</td>
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<td>Vehicle control (10% dimethyl sulfoxide)</td>
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<td>46 ± 12</td>
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<td>8-Methyl ether of xanthurenic acid</td>
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<td>77 ± 8*</td>
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<td>61 ± 11</td>
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<td>56 ± 7*</td>
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<td>77 ± 17</td>
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<tr>
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<td>D-Kynurenine</td>
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<td>32 ± 7</td>
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<td>58 ± 10</td>
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<td>32 ± 5</td>
<td>5</td>
<td>62 ± 9</td>
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</table>

* Mean ± S.E. for duplicate assay.
* p < 0.01.
* 0.05 > p > 0.01.
* A few drops of 7.16 N NH₄OH diluted with 2 × 10⁻² M phosphate buffer (pH 7.4).
Following the instillation of 1 umol of xanthurenic acid, urinary bladder ODC and SAMD activities on mouse urinary bladder were measured. Following the instillation of xanthurenic acid, DL-kynurenine, quinolinic acid, 3-hydroxyanthranilic acid, kynurenine acid, and the 8-methyl ether of xanthurenic acid stimulated neither ODC nor SAMD activities to significant levels. Nicotinic acid and picolinic acid did not induce ODC activity but significantly stimulated SAMD activity.

**Effects of Tryptophan Metabolites on Urinary Bladder Morphology.** Following tryptophan metabolite or vehicle treatment, some bladders showed mucosal hyperemia, congestion, and focal hemorrhage as early as 3 hr, but these changes were not observed consistently with any treatment. By 24 hr following i.u. treatment with xanthurenic acid, DL-kynurenine, L-kynurenine, anthranilic acid, or quinaldic acid, the urothelial cells demonstrated positional irregularity and crowding, and by 48 hr mitotic figures were frequently observed. By 7 days, mild, multifocal hyperplasia appeared as the epithelial mucosa became 4 to 5 cells thick. This hyperplastic effect of the tested tryptophan metabolites was parallel to their ODC inducibility.

**DISCUSSION**

Since the report of Dunning et al. (14) that added dietary tryptophan enhanced the rat bladder carcinogenicity of 2-acetylaminofluorene, a number of studies have been conducted in an effort to ascertain if the essential amino acid L-tryptophan or its urinary metabolites are bladder carcinogens (3–9). Several of these metabolites exhibited bladder oncogenicity when tested by the intravesical pellet implantation technique (4, 9), although the systemic administration of tryptophan or some of its metabolites did not induce bladder cancer (4, 21, 25, 29, 34). Recent studies (11, 12, 16, 21, 34) suggested that tryptophan or its urinary metabolites might be cocarcinogens or promoters of bladder neoplasia. Promoting activity of dietary DL-tryptophan for the bladder was demonstrated in rats (12) and dogs (34) following initiation by FANFT or arylamines, respectively. Dietary L-tryptophan was shown to promote bladder tumor formation in mice (21) and rats (16) following initiation by FANFT. It also significantly increased the labeling and hyperplastic indices of mouse bladder urothelium (21).
Although the initiation-promotion concept was developed from tumorigenicity investigations with mouse skin, recent studies have suggested that tumor promotion may be operative in some other organs including the urinary bladder (4–6, 9, 11, 12, 16, 17, 21, 34). Several properties of initiation and promotion have been characterized experimentally in the murine skin cancer model (1, 28, 39). Most initiating agents are mutagenic in various short-term in vitro assays, whereas promoting agents are not necessarily mutagenic or have only weak mutagenic activity. Promoting agents usually have the ability to induce hyperplasia of target tissues without initiation, but this alteration does not progress toward cancer formation unless the tissues first have been treated with initiating agents. Tryptophan and several of its metabolites were not mutagenic by the Ames test (2). However, focal hyperplasia or cellular proliferation following tryptophan feeding was reported in mice (21), rats (25), and dogs (33).

We now have demonstrated that mouse urinary bladder ODC and SAMD activities were stimulated by feeding L-tryptophan, the method generally selected for experimental induction of bladder neoplasia by this chemical (12, 16, 21, 25, 34), that direct application of several tryptophan metabolites to the mouse urinary bladder led to a rapid, transient induction of urinary bladder ODC activity within 5 hr, and that the metabolites which activated ODC also induced a hyperplastic reaction of the urothelium following their topical application. Xanthurenic acid, DL-kynurenine, L-kynurenine, antranilic acid, and quinaldic acid showed significant increases of bladder ODC activity; all these compounds except antranilic acid were active carcinogens by the bladder pellet implantation technique (4, 9). Conversely, L-tryptophan or D-kynurenine, 3-hydroxy- DL-kynurenine, and 3-hydroxyxanthanilic acid, kynurenine, quinolinic, picolinic, and nicotinic acids failed to induce mouse bladder ODC activity; of these latter tryptophan metabolites, only 3-hydroxy-DL-kynurenine and 3-hydroxyxanthanilic acid displayed bladder carcinogenicity (4, 9). The in vitro induction of ODC activity in rat urinary bladder carcinoma cells by 3-hydroxyxanthanilic acid was recently reported (18). The relationship of this observation (18) utilizing an in vitro rat neoplastic cell system to the in vivo study of nonneoplastic mouse urothelial cell responses reported here remains to be determined. Previous studies demonstrated that, by the methods of i.v. administration used, L-tryptophan (26), 3-hydroxy-L-kynurenine, 3-hydroxyxanthanilic acid (8), or the 8-methyl ether of xanthurenic acid (7) easily traversed the bladder wall and thus entered the tissues first have been treated with initiating agents. Tryptophan and several of its metabolites were not mutagenic by the Ames test (2). However, focal hyperplasia or cellular proliferation following tryptophan feeding was reported in mice (21), rats (25), and dogs (33).

Acknowledgments

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References

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