Inhibition of the Soluble and the Tumor Cell Receptor-bound Plasmin by Urinary Trypsin Inhibitor and Subsequent Effects on Tumor Cell Invasion and Metastasis

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ABSTRACT

The present study was undertaken to determine whether highly purified human urinary trypsin inhibitor (UTI) efficiently inhibits the soluble and the tumor cell receptor-bound plasmin. The ability of plasmin inhibitors to regulate invasion by tumor cells which express membrane-associated plasmin was also examined. UTI and two other plasmin inhibitors (α2-antiplasmin and α2-macroglobulin) were used. α2AP and α2M, as well as UTI, rapidly inactivate the soluble plasmin that is not bound to cells. Experiments were performed in vitro using cultures of ovarian cancer HOC-I cells and gestational choriocarcinoma SMT-ccl cells. HOC-I and SMT-ccl cells had plasminogen on their cell surface, and the plasmin activity was detected on their cell surface enzymologically and immunologically. Receptor-bound plasmin reacted effectively with UTI and was directly inactivated by UTI. In contrast, receptor-bound plasmin was not inhibited by α2AP and α2M. Using a modified Boyden chamber and an artificial basement membrane, Matrigel, it was found that UTI, but not α2AP or α2M, can inhibit HOC-I and SMT-ccl cells invasion in vitro. Furthermore, in the experimental lung metastasis model, UTI inhibited the formation of lung metastasis by Lewis lung carcinoma cells. The inhibition of tumor cell invasion was not due to direct antitumor effects of UTI. These results suggest that inhibition of receptor-bound plasmin by UTI is associated with significantly reduced tumor cell invasiveness in vitro and with a decreased number of metastasis in vivo.

INTRODUCTION

The serine-protease plasmin plays an important role in fibrinolysis, cell migration, tissue remodeling, angiogenesis, tumor invasion, and formation of metastasis (1, 2). A high affinity lysine-binding site located in the first three Kringle domains is important for the interaction of plasminogen with fibrin and α2AP (3). In solution, native glutamic acid-plasminogen is only poorly activated to plasmin, which in plasma is very rapidly inactivated by α2AP, but in the presence of fibrin, plasminogen activation is very rapid and the plasmin formed is protected from inactivation. It has also been reported that cell surface receptor-bound plasmin is protected from inhibition by α2AP and α2M (4).

The acid-labile ITI, which is a serine-protease inhibitor present in human serum and plasma, is the precursor of UTI. Hochstrasser et al. (5, 6) were the first to describe a physiological UTI (HI-30) which had an apparent molecular mass of 34 kDa estimated by gel chromatography. The characterization of complementary DNAs clearly indicates that ITI is a complex protein composed of several distinct polypeptide chains, two heavy chains and one light chain, probably corresponding to a precursor of UTI. UTI and ITI derivatives are assumed to be produced in vivo by limited proteolysis of ITI in the NH2-terminal region of the polypeptide chain. UTI is composed of two tandem Kunitz-type domains connected with a small peptide. The amino acid sequences surrounding the reactive sites of the Kunitz-type domains in the inhibitory parts of UTI had already been reported (7–10). Although UTI inhibits trypsin, chymotrypsin, plasmin, and human leukocyte elastase, as well as cathepsin B and H, little is known about its physiological function (11). UTI has been shown to increase in several disease states including inflammation and cancer (11). This compound is at present clinically prescribed for treatment of acute pancreatitis and hemorrhagic shock in Japan.

The reaction of cell surface receptor-bound plasmin with some plasmin inhibitors (α2AP, α2M, and UTI) has not yet been compared. Recently, we found that a synthetic peptide which represents the amino acid sequences within Domain II of UTI inhibits plasmin activity. In addition, treatment with UTI or with this peptide inhibits tumor cell invasion in vitro. These observations indicate that inhibition of plasmin specifically reduces the invasion of the tumor cells (12).

This study was undertaken to determine whether UTI efficiently inhibits the soluble and the tumor cell surface receptor-bound plasmin. We have also investigated the effects of UTI and other plasmin inhibitors on tumor cell invasion in vitro using a reconstituted basement membrane assay and formation of metastasis in vivo using an experimental lung metastasis model.

MATERIALS AND METHODS

Cells and Culture. The ovarian cancer cell line HOC-I was established from a recurrent human ovarian endometrioid carcinoma (13), and the choriocarcinoma cell line SMT-ccl was established from a pulmonary metastatic region of human gestational choriocarcinoma (14). The murine 3LL xenograft, selected for its high lung colonization potential, was kindly provided by Chugai Pharmaceutical Co., Tokyo, Japan. The tumor was maintained by serial s.c. transplantation in C57BL/6 or C57BL × DBA/2 F1 mice. The 3LL cells were maintained as adherent monolayers (in plastic dishes) in Eagle’s minimal essential medium supplemented with 10% fetal bovine serum, sodium pyruvate, nonessential amino acids, L-glutamine, and vitamins (Gibco, Grand Island, NY) at 37°C in a humidified incubator with 5% CO2 in air. HOC-I and SMT-ccl cells were maintained under an atmosphere of 5% CO2 in RPMI 1640 (Nissui, Tokyo, Japan) medium supplemented with 10% heat-inactivated fetal calf serum (Gibco). These cells were grown to confluence in 75-cm2 tissue culture flasks (Falcon) washed three times with PBS containing 2% (w/v) BSA (Iwai, Tokyo, Japan), and then harvested after a brief treatment with 0.25% trypsin (Sigma Chemical Co., St. Louis, MO). The cell viability was determined by trypan blue dye exclusion prior to use.

Animals. Specific-pathogen-free female C57BL/6 mice, 6–8 weeks old, were purchased from Charles River Japan, Inc. (Kanagawa, Japan). The care and use of the animals were in accordance with the Institution’s guidelines.

Antibodies and Plasmin Inhibitors. The antibodies used were anti-rabbit polyclonal antibody against human plasminogen (Cosmo Bio, Kyoto, Japan) and anti-rabbit polyclonal antibody against UTI (supplied by Mochida Pharmaceutical Co., Tokyo, Japan). Aprotinin, a nonspecific inhibitor for serine protease, was a gift from Bayer Werk, Frankfurt, Germany. All other reagents were of analytical grade. Glutamic acid-plasminogen and plasmin was purchased from KabiVitrum, Stockholm, Sweden.

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2 To whom requests for reprints should be addressed.

3 The abbreviations used are: α2AP, α2-antiplasmin; α2M, α2-macroglobulin; ITI, inter-α-trypsin inhibitor; UTI, urinary trypsin inhibitor; 3LL, Lewis lung carcinoma; PBS, phosphate-buffered saline; BSA, bovine serum albumin; DIP-plasmin, diisopropylphosphoryl-plasmin; ElA, enzyme immunoassay; sPA, urokinase-type plasminogen activator.

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DIP-plasmin was prepared by incubating plasmin twice with 10 mM diisopropylphosphorofluoridate (1 h, 23°C). Excess diisopropylphosphorofluoridate was removed by dialysis against PBS (4). α₂AP was purchased (Athens Research) or purified according to the procedure of Wiman et al. (3), and α₂M was purchased (Cosmo Bio, Kyoto). A highly purified preparation of UTI (specific activity, 2,330 units/mg soluble protein, with a molecular mass of 67,000 Da) was kindly supplied by Mochida Pharmaceutical Co. The covalent structure of the polypeptide chain of the physiological inhibitor UTI (HI-30) was determined to be identical to that described elsewhere (16, 17).  

Binding of Biotinylated Plasminogen and DIP-Plasmin. Glutamic acid-plasminogen and DIP-plasmin were biotinylated according to the method of Gussenhoven et al. (15), using N-hydroxysuccinimidyl/biotinimidoacrylate (Sigma).  

HOC-I and SMT-ccl cells were grown to confluence in 96-well microtiter plates (Costar, Cambridge, MA), washed twice with cold PBS containing 2% BSA, and then were treated with biotinylated plasminogen or biotinylated DIP-plasmin (10 μM, 4 h, 4°C). A 10 μM concentration of plasminogen is enough to saturate cell surface plasminogen binding sites (data not shown; see Ref. 4). After the cells were washed twice with PBS-0.2% BSA, specifically bound biotinylated plasminogen (or DIP-plasmin) was detected with avidin-peroxidase (0.4 μg/ml; 1 h, 23°C; Dako, Copenhagen, Denmark). The reactions with 3,3′,5,5′-tetramethylbenzidine (AMRESCO, Inc.), were terminated, and each well was measured at 450 nm (A₄₅₀) in an ELISA reader (Model 2550; Bio-Rad, Richmond, CA) (16, 17).  

In addition, the specific binding of biotinylated plasminogen (or DIP-plasmin) to cells pretreated with 6AHA was determined to detect the amount of total plasminogen-binding sites on their surface (18). Endogenous plasminogen (or DIP-plasmin) was displaced by incubating the cells with 0.1 M 6AHA (30 min, 23°C) followed by thorough washing with PBS-0.1% BSA. The cells were then incubated with biotinylated plasminogen or DIP-plasmin (10 μM, 4 h, 4°C). After they were washed twice with PBS-0.1% BSA, the total binding sites were determined as described above. A time course study (0–5 h, 4°C) was carried out to assess biotinylated plasminogen binding to the cells.  

Tumor cells grown to confluence in microtiter plates were incubated with 5 μM biotinylated plasminogen in the presence of increasing concentrations of either unlabeled plasminogen (0–10 μM) or DIP-plasmin (0–10 μM) at 4°C for 4 h, and binding was measured as described above. All samples were assayed at least in triplicate.  

Enzyme-linked Immunosorbent Assay. HOC-I and SMT-ccl cells were grown to confluence in 96-well microtiter plates, washed with PBS-2% BSA, and then allowed to react with antibody against plasminogen (100 ng, 16 h, 4°C). Nonspecific binding was ascertained in reactions using rabbit immunoglobulin as the control. Antibody specifically bound to plasminogen was detected with biotin-conjugated second antibody (1.5 μg/ml; Dako; 1 h, 23°C), followed by the addition of avidin-peroxidase (0.4 μg/ml; 1 h, 23°C). The reactions with tetramethylbenzidine were terminated and the A₄₅₀ of each well was measured in an ELISA reader (16, 17). Furthermore, some of these cells were treated with PBS-0.1% BSA containing 10 μM plasminogen (4 h, 4°C). After the cells were washed, antibody specifically bound to plasminogen, which saturated all surface binding sites, was determined as described above.  

Enzyme Assay. A chromogenic assay for plasmin activity was carried out. Cell suspension (150 μl; 1 × 10⁶ cells/ml complete medium) was added to 96-well microtiter plates (Costar, Cambridge, MA), washed twice with cold PBS containing 2% BSA, and then were treated with various concentrations of plasmin inhibitors (0–50 μM, 200 μM/mouse) for 7 days immediately after tumor cell inoculation. Twenty-one days after the inoculation of tumor cells, mice were sacrificed and the lungs were removed, washed in water, and fixed in Bouin’s solution. The lung tumor colonies were counted under a dissecting microscope. The data were analyzed for significance by Student’s t test or nonparametric test.  

RESULTS  

Immunological and Enzymological Determination of Plasminogen on the Surface of Tumor Cells. Membrane-localized plasminogen was detected by cell enzyme-linked immunosorbent assay using a plasminogen-specific antibody (Table 1). The concentration of plasminogen-related antigen associated with SMT-ccl cells was approximately 3 times higher than that found in HOC-I cells, although the data are expressed as the number of cells on the bottom surface of the filter at a randomly chosen area (17).  

Table 1 Immunological determination of plasminogen on the surface of tumor cells by cell enzyme-linked immunosorbent assay

<table>
<thead>
<tr>
<th>Treatment</th>
<th>HOC-I</th>
<th>SMT-ccl</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>0.08 ± 0.02b</td>
<td>0.21 ± 0.09</td>
</tr>
<tr>
<td>After saturation</td>
<td>0.24 ± 0.06</td>
<td>0.65 ± 0.13</td>
</tr>
<tr>
<td>6AHA treatment</td>
<td>&lt;0.01</td>
<td>0.02 ± 0.01</td>
</tr>
<tr>
<td>6AHA treatment + saturation</td>
<td>0.20 ± 0.07</td>
<td>0.57 ± 0.17</td>
</tr>
</tbody>
</table>

* Tumor cells were washed with cold PBS-2% BSA.  
* Mean ± SD (absorbance unit) of absorbance at 450 nm of assays using 1 × 10⁶ cells and carried out in triplicate.  
* The cells were incubated with 10 μM plasminogen (4 h, 4°C).  
* The cells were treated with 0.1 M 6AHA to displace endogenous plasminogen (30 min, 23°C).  
* Again, the cells were treated with PBS-0.1% BSA containing 10 μM plasminogen (4 h, 4°C).
drastically following a 6AHA treatment. The cells treated with 6AHA acquire the property of binding plasminogen.

We next performed binding studies on these cells using biotinylated plasminogen or biotinylated DIP-plasmin. Binding of biotinylated plasminogen to the cells occurred in a dose-dependent and saturable manner. Specific binding reached saturation at approximately 5 μM (Fig. 1). Total plasminogen binding was measured following treatment with 6AHA to remove endogenous plasminogen from cellular binding sites. Specific binding increased after treatment with 6AHA. Biotinylated plasminogen was able to bind to the cell-associated binding proteins uncovered by treatment with 6AHA. Similar results were obtained with respect to binding of biotinylated DIP-plasmin to the cells (data not shown).

In addition, experiments were performed to determine whether either plasminogen or DIP-plasmin could compete with biotinylated plasminogen for binding to these tumor cells. Biotinylated plasminogen (5 μM) was inhibited in a dose-dependent manner by unlabeled plasminogen or DIP-plasmin, and these competitors had similar abilities to inhibit biotinylated plasminogen binding to these cells. The concentration of unlabeled plasminogen or DIP-plasmin producing 50% inhibition of biotinylated plasminogen binding to the cells were similar (approximately 3 μM; data not shown). These results indicate that these cells express functional plasminogen binding proteins that are partially occupied by ligands.

For a quantitative assay of plasmin activity on the surface of tumor cells, we applied S-2251, a chromogenic synthetic substrate, to the cells adhered to the microtiter plates (Fig. 2). HOC-I cells alone were capable of degrading S-2251 to some extent. Note that SMT-ccl cells showed higher levels of plasmin activity than HOC-I cells. In addition, the murine tumor cell line 3LL was also able to degrade S-2251.

Inhibition of the Soluble and the Tumor Cell Receptor-bound Plasmin by Plasmin Inhibitors. The inhibition of soluble plasmin by plasmin inhibitors was investigated using chromogenic assays. The relative enzyme activities obtained when plasmin (20 nM) was titrated with UTI (0.4 μM), α2AP (0.4 μM), or α2M (0.4 μM) are shown in Fig. 3. As expected, more than 90% of the plasmin activity in solution was inhibited by α2AP within 10 min at 23°C. Titration of plasmin with UTI or α2M revealed that each of them inhibits plasmin at a slower rate. Thus, α2AP proved to be more efficient than UTI and α2M when plasmin is in solution.

The reaction of SMT-ccl cell-associated plasmin with α2AP and α2M at 23°C was extremely slow compared with the solution phase reaction, demonstrating that receptor-bound plasmin is highly protected from inhibition by α2AP and α2M. In contrast, UTI has the ability to inhibit the tumor cell-associated plasmin. Titration of the soluble and the receptor-bound plasmin with UTI revealed that 5 μM UTI inhibits cell-associated plasmin with essentially the same affinity as the solution phase plasmin in our assay system (Fig. 3). Similar results were obtained with HOC-I and 3LL cell surface plasmin (data not shown). These results indicate that UTI inhibits the cell-associated human plasmin and mouse plasmin-like activity.

The caseinolytic activity of SMT-ccl cells in the presence or absence of plasmin inhibitors is shown in Fig. 4. This was significantly suppressed in the presence of UTI, which confirmed the results of the amidolytic assays described above.

Effect of Plasmin Inhibitors on Tumor Cell Invasion. uPA and plasmin appear to be essential to the invasion process of HOC-I and SMT-ccl cells in vitro (17). Inhibition of HOC-I cell invasion in vitro was observed after treatment with specific inhibitors and antibodies for uPA and plasmin (17). These cells express both cell-associated plasmin(ogen) and functional uPA receptors that are partially occupied by ligands. SMT-ccl cells, which express 3-fold levels of cell-associated plasmin activity (by amidolytic assay; see Fig. 2), showed approximately 2-fold increase in their invasive potential (Table 2).

Experiments with UTI in the in vitro invasion assay showed a statistically significant and dose-dependent inhibition of SMT-ccl cells. α2AP and
or a2M was admixed with tumor cells (30 min, 23°C) and the mix appeared at day 7 after tumor cell inoculation. These inhibitors did not affect the local tumor growth. The results of a representative experiment are shown in Table 3. a2AP and a2M did not lead to decreased numbers of lung tumor colonies even at the highest concentrations used. In contrast, the average number of pulmonary nodules formed was significantly lower in mice treated with UTI. UTI showed a statistically significant and dose-dependent inhibition of tumor cell metastasis.

DISCUSSION

The increased invasive potential of tumor cells is correlated with tumor cell-associated proteolytic activity (uPA, plasmin, cathepsin B, cathepsin D, and collagenase) (1, 2, 26), which leads to degradation of the tumor stroma and the basement membranes. In general, tumor cells express cell surface-associated uPA and plasmin activities and the inhibition of these activities by specific antibodies and proteinase inhibitors leads to a decrease in the invasive potential of tumor cells (27–33). However, it is difficult to use antibodies for cancer therapy in humans.

It has been indicated that receptor-bound plasmin is protected from inhibition by a2AP and a2M (4). However, when the concentration of a2AP approximates or exceeds that present in plasma (1.0 μM), receptor-bound plasmin is inactivated by direct reaction with a2AP at the cell surface as well as after dissociation. These data demonstrate that the plasmin receptor provides a mechanism for the expression of enzyme activity even in the presence of consistently high concentrations of a2AP and a2M.

In the present study, we compared the reaction of tumor cell-associated plasmin with highly purified plasmin inhibitors (UTI, a2AP, and a2M) with that of solution phase plasmin. Besides, we used the above mentioned plasmin inhibitors to investigate the role of cell-associated plasmin activity in tumor cell invasion and metastasis. We used two human tumor cell lines, ovarian cancer HOC-I and choriocarcinoma SMT-ccl cells, and one murine tumor cell line, Lewis lung carcinoma cells. a2AP and a2M rapidly inactivated soluble plasmin but not receptor-bound plasmin. In contrast, UTI inhibited both types of plasmin. As expected, UTI but not a2AP or a2M inhibited tumor cell invasion of basement membranes in vitro and was associated with a decreased number of lung tumor colonies in vivo. This inhibition was dose dependent and nontoxic, and correlated well with the ability of UTI to inhibit cell-associated plasmin activity. Furthermore, we concluded that the mode of action of inhibitors is not associated with an inhibition of tumor cell chemotaxis or of cell

<table>
<thead>
<tr>
<th>Plasmin inhibitor</th>
<th>Concentration (μM)</th>
<th>HOC-I</th>
<th>SMT-ccl</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td></td>
<td>24 ± 11</td>
<td>56 ± 15</td>
</tr>
<tr>
<td>UTI</td>
<td>0.05</td>
<td>22 ± 20</td>
<td>26 ± 13</td>
</tr>
<tr>
<td></td>
<td>0.5</td>
<td>16 ± 8</td>
<td>21 ± 12</td>
</tr>
<tr>
<td></td>
<td>5.0</td>
<td>25 ± 5</td>
<td>9 ± 1</td>
</tr>
<tr>
<td>α2AP</td>
<td>0.25</td>
<td>29 ± 14</td>
<td>65 ± 24</td>
</tr>
<tr>
<td></td>
<td>2.5</td>
<td>32 ± 19</td>
<td>45 ± 23</td>
</tr>
<tr>
<td></td>
<td>25</td>
<td>23 ± 21</td>
<td>50 ± 13</td>
</tr>
<tr>
<td>α2A</td>
<td>0.25</td>
<td>25 ± 24</td>
<td>53 ± 11</td>
</tr>
<tr>
<td></td>
<td>2.5</td>
<td>21 ± 16</td>
<td>62 ± 13</td>
</tr>
<tr>
<td></td>
<td>25</td>
<td>24 ± 11</td>
<td>53 ± 21</td>
</tr>
</tbody>
</table>

* P < 0.05 compared to control.
* P < 0.01 compared to control.

α2M (up to 25 μM), however, showed no significant inhibitory effects. Similar results were obtained with UTI, α2AP, and α2M on in vitro invasion of HOC-I cells and 3LL cells, indicating that α2AP and α2M have no significant inhibitory effects. These results indicate that only UTI, not α2AP or α2M, plays an important role in the inhibition of tumor cell invasion. The chemotactic response of the cells was also tested to determine if the inhibition of cell invasion induced by plasmin inhibitors was due to an inhibition of this response. HOC-I, SMT-ccl, and 3LL cells showed a good chemotactic migration in the presence of each of the plasmin inhibitors (data not shown). Plasmin inhibitors had no effects on tumor cell chemotaxis. Moreover, the effects of these inhibitors on cell attachment were also examined. Under optimal conditions, more than 80% of these cells remained attached to the well after washing. No inhibition of attachment of HOC-I, SMT-ccl, and 3LL cells to Matrigel or fibronectin was seen after treatment with plasmin inhibitors (data not shown).

Effects of Plasmin Inhibitors on the Experimental Metastasis.

We examined the effects of plasmin inhibitors on the experimental pulmonary metastasis by systemic injection of 3LL cells. UTI, α2AP, or α2M was admixed with tumor cells (30 min, 23°C) and the mixtures were injected i.v. into C57BL/6 mice. The visible tumors have appeared at day 7 after tumor cell inoculation. These inhibitors did not affect the local tumor growth. The results of a representative experiment are shown in Table 3. α2AP and α2M did not lead to decreased numbers of lung tumor colonies even at the highest concentrations used. In contrast, the average number of pulmonary nodules formed was significantly lower in mice treated with UTI. UTI showed a statistically significant and dose-dependent inhibition of tumor cell metastasis.

Table 3 Inhibition by plasmin inhibitors of pulmonary metastasis of Lewis lung carcinoma cells in the in vivo C57BL/6 mouse model

<table>
<thead>
<tr>
<th>Plasmin inhibitor</th>
<th>n</th>
<th>Concentration (μM)</th>
<th>No. of tumor nodules in the lung</th>
<th>Range</th>
<th>Rate of inhibition (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>9</td>
<td></td>
<td>64 ± 52.7</td>
<td>21–200</td>
<td>13</td>
</tr>
<tr>
<td>UTI</td>
<td>9</td>
<td>0.5</td>
<td>53.7 ± 30.0</td>
<td>12–125</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>5.0</td>
<td>36.9 ± 24.4*</td>
<td>0–69</td>
<td>43</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>50</td>
<td>11.0 ± 13.9b</td>
<td>0–30</td>
<td>83</td>
</tr>
<tr>
<td>α2AP</td>
<td>7</td>
<td>5.0</td>
<td>54.0 ± 49.5</td>
<td>25–159</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>5.0</td>
<td>45.5 ± 48.2</td>
<td>16–200</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>50</td>
<td>58.1 ± 34.1</td>
<td>16–180</td>
<td>0</td>
</tr>
<tr>
<td>α2M</td>
<td>9</td>
<td>0.5</td>
<td>26.9 ± 17.7</td>
<td>11–105</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>5.0</td>
<td>21.7 ± 25.8</td>
<td>13–85</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>50</td>
<td>31.1 ± 18.3</td>
<td>12–74</td>
<td>0</td>
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</table>

* P < 0.05 compared to control.
* P < 0.01 compared to control.
attachment to fibronectin, a component in basement membranes. The amino acid sequence of UTI, which is derived from limited proteolysis of UTI, includes two Kunitz-type domains connected with a small peptide (5–11). The amino acid sequences surrounding the reactive sites of the Kunitz-type domains in the inhibitory parts of UTI are Gly–Pro–Cys–Met–Gly–Met–Thr for elastase inhibition and Gly–Pro–Cys–Arg–Ala–Phe–Ile for trypsin/plasmin inhibition, respectively (5–11). Furthermore, UTI and its related fragment, which contains a plasmin-inhibiting domain (composed of 15 amino acid sequences including Gly–Pro–Cys–Arg–Ala–Phe–Ile), significantly inhibit tumor cell invasion in a dose-dependent manner in an in vitro reconstituted basement membrane assay.4

The surface-bound proteinases, uPA and plasmin, would create more favorable conditions for localized proteolysis (34–36). This enhancing effect of uPA/plasmin may be due to proteolysis in critical sites of contact between tumor cells and substratum, or to increased interaction between the enzyme and the substrate as a result of higher local enzyme concentration, or because receptor-bound plasmin is protected from inhibition by serum inhibitors. The role that plasmin plays in tumor invasion has been clearly demonstrated by previous studies (30, 35). Pretreatment of murine B16 melanoma cells with plasmin resulted in a 200–300% increase in the number of pulmonary metastasis at plasmin concentrations above 1 ng/ml (30). Migonetti et al. (35) reported that the uPA/plasmin system plays an important role in amnion invasion by B16 melanoma cells. To prevent invasion, plasmin inhibition must occur when the enzyme is adsorbed on the substrate, a situation in which a2AP may be much less active than when plasmin and the inhibitor are in the soluble phase (35).

The human amnion basement membrane is impermeable to molecules larger than 60 kDa (35). This is smaller than the native UTI molecule (67 kDa). We speculate that UTI-derived fragments can enter sites of contact between cancer cells and reconstituted basement membranes, and if so, the receptor-bound plasmin could be inhibited by UTI fragments. Thus, the inhibitory effect of UTI supports the possibility that the blocking of cell invasion exerted by UTI is due to inhibition of cancer cell receptor-bound plasmin by small UTI fragments which contain reactive site for plasmin and may be generated from the native UTI molecule by tumor cell-derived limited proteolysis.

Our results support the hypothesis that proteolysis of extracellular matrix components by cell-associated plasmin activity may be a critical step during the process of tumor cell invasion and metastasis. The present study strongly argues for a role of cell-associated plasmin in facilitating in vitro and in vivo tumor cell invasion. Pretreatment of 3LL cells with UTI caused a decrease of their invasive potential in vitro. Furthermore, 3LL cells treated with UTI showed a suppression of cell-associated plasmin activity that correlated well with a decrease in their ability to colonize the lung. The conclusion drawn from this study is that cell-associated plasmin may be important in the late steps of metastatic migration (extravasation) because the cells were directly injected into the blood stream in the present metastasis assay. However, these experiments do not eliminate roles for plasmin in the initial steps (intrasavation) of the metastatic process or in both the early and late steps of the migration process. The exact reasons for the efficient inhibition of cancer cell invasion and metastasis by the UTI molecule remain to be explored.

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4 Unpublished data.


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