Effects of the Antiestrogens Tamoxifen, Toremifene, and ICI 182,780 on Endometrial Cancer Growth

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Background: Tamoxifen has been shown to promote the growth of human endometrial tumors implanted in athymic mice, and it has been associated with a twofold to threefold increase in endometrial cancer. Toremifene, a chlorinated derivative of tamoxifen, and ICI 182,780, a pure antiestrogen, are two new antiestrogens being developed for the treatment of breast cancer. The effects of these drugs on endometrial cancer are currently unknown. Our objective was to evaluate the effects of toremifene and ICI 182,780 on the growth of human endometrial cancer in athymic mice. Methods: Athymic, ovariectomized mice were implanted with human endometrial tumors and treated with estrogen, tamoxifen, or the new antiestrogens. Results: The effects of tamoxifen and toremifene on the growth of either tamoxifen-stimulated or tamoxifen-naive endometrial tumors in athymic mice were not substantially different. ICI 182,780 inhibited the growth of tamoxifen-stimulated endometrial cancer, in both the presence and the absence of estrogen. Conclusions: Toremifene and tamoxifen produce identical effects in our endometrial cancer models. Therefore, it is possible that toremifene, like tamoxifen, may be associated with an increased incidence of endometrial cancer. In contrast, ICI 182,780 inhibited tamoxifen-stimulated endometrial cancer, both in the presence and in the absence of estrogen, suggesting that this drug may be safe with regard to the endometrium, even if it is used following tamoxifen, and that it may not result in an increased incidence of endometrial cancer. Indeed, it is even possible that ICI 182,780 may prove useful as an adjuvant agent in early stage endometrial cancer. [J Natl Cancer Inst 1998;90:1552–8]

In 1988, we demonstrated that the antiestrogen tamoxifen exhibited target site-specific actions in breast and endometrial cancers (1). Athymic mice were co-transplanted with the estrogen-responsive breast tumor, MCF-7, and the estrogen receptor (ER)-positive endometrial carcinoma, EnCa101. Treatment with estradiol and tamoxifen demonstrated that the antiestrogen completely inhibited the estrogen-stimulated growth of the breast tumor but stimulated growth of the endometrial carcinoma (1). From these observations, we concluded that women who were being treated with long-term adjuvant tamoxifen therapy should be screened for pre-existing endometrial carcinoma, which is known to be present in five times as many women as is detected clinically (2). Although tamoxifen had proven benefits in breast cancer at that time (3), we suggested that pre-existing endometrial cancer would not be controlled (1). Our finding of the target site-specific actions of tamoxifen was subsequently demonstrated in patients. Since the original clinical report by Fornander et al. (4) in 1989 showing that tamoxifen significantly decreased the incidence of contralateral breast cancer but increased the incidence of endometrial cancer, the topic of the association between tamoxifen and endometrial carcinoma has been a subject of intense investigation and some controversy. Recently, we surveyed the world literature to determine the extent of the problem and to survey gynecologic recommendations based on current knowledge (5). It is clear that tamoxifen causes a twofold to threefold increase in the incidence of endometrial cancer (5). This increase translates to about two to three cases per thousand postmenopausal patients per annum. The disease is the same stage and grade as endometrial cancer in the general population (5). As a result of the rarity of detection, no special gynecologic monitoring, other than routine annual checkups and the follow-up of suspicious spotting and bleeding, has been recommended (6). Indeed, the International Agency for Research on Cancer (IARC), an agency of the World Health Organization, recently stated that no patient should stop taking tamoxifen because of concerns about the risk of endometrial cancer and that the benefits of tamoxifen use far outweigh any risks (7).

Concerns about the uterine safety of tamoxifen have naturally provoked a search for agents that might control the growth of both breast and endometrial carcinomas. Toremifene (Fig. 1), a chlorinated derivative of tamoxifen, has shown promise in the treatment of advanced breast cancer in postmenopausal women (8–10). The drug has been evaluated at numerous doses, ranging from 60 mg daily to 260 mg daily in postmenopausal women, and the general consensus is that responses, particularly in ER-positive breast cancer, are equivalent to those seen with tamoxifen at doses of 20 or 40 mg daily in postmenopausal women (11). Based on its clinical and toxicologic profiles, toremifene at a dose of 60 mg daily has been approved by the U.S. Food and Drug Administration for the treatment of advanced breast cancer in postmenopausal women.

ICI 182,780 (Fig. 1) is an example of a pure antiestrogen, which, like tamoxifen, acts through the ER but has no demonstrated estrogen agonist effects. ICI 182,780 inhibits tamoxifen-
that had been treated with estrogen (1-cm estrogen capsule given every 6 weeks) and had not been exposed to tamoxifen for at least three passages. These estrogen-stimulated tumors are more responsive to estrogen for growth. Pieces of tumor (1 mm³) were implanted bilaterally with a trochar into the mammary fat pads.

The mice were divided into groups of five or 10 and were treated with estrogen, antiestrogens, or the vehicle. Silastic estradiol capsules were made as described previously (17), implanted subcutaneously, and replaced after 6–8 weeks of treatment. Estrogen capsules were either 1 cm or 0.3 cm in length.

Tamoxifen and toremifene were each suspended in a solution of 90% CMC (1% carboxymethylcellulose in double-distilled water) and 10% PEG 400/Tween 80 (99.5% polyethylene glycol 400 and 0.5% Tween 80). Tamoxifen was administered orally, i.e., by mouth, at a dose of 0.5 mg per mouse daily for 5 days each week. Toremifene was administered orally at a dose of 0.5, 1.5, or 5 mg per animal. ICI 182,780 was dissolved in ethanol and administered in peanut oil (following the evaporation of ethanol under N₂) to a final concentration of 50 mg/mL. ICI 182,780 was injected subcutaneously at a dose of 5 mg (0.1 mL peanut oil) per animal each week.

The tumors were measured weekly with calipers. The cross-sectional area was determined by use of the following formula: length × breadth/4 × π.

All procedures involving animals were approved by the Animal Care and Use Committee of Northwestern University.

Quantitation of Antiestrogens

The mice were killed, their livers, hearts, and uteri were harvested, and serum was obtained by decapitation. Serum samples (150 μL) were deproteinized with equal volumes of 100% acetonitrile, followed by centrifugation (Model J2 HC; Beckman Instruments, Westbury, NY) at 21 200g for 5 minutes at 0°C. Supernatant layers were transferred to vials. Samples were stored at −80°C. Tissue samples (15 mg) were homogenized in 2% acetic acid in methanol (vol/vol) and centrifuged at 502g for 10 minutes at room temperature, and the supernatant layer was transferred to a glass tube and dried under N₂ at 37°C. The precipitates were re-extracted with 100% acetonitrile and centrifuged at 502g for 5 minutes at room temperature, and the organic layer was combined with the methanolic extract and then redried. Dried samples were reconstituted in their respective mobile phases for the high-performance liquid chromatography (HPLC) assay (Waters Corporation, Milford, MA) of toremifene and tamoxifen (18). Samples were derivatized after separation by an in-column in-line photochemical reaction, and the highly fluorescent phenanthrene derivatives were quantified by fluorescence detection. Toremifene and metabolites were separated by using the Prodigy 5-ODS3 column (Phenomenex, Torrance, CA) (0.1% diethylamino [DEA] [Fisher Chemicals, Fairlawn, NJ] in 57% acetonitrile [HPLC grade; Fisher Chemicals] in H₂O for 15 minutes and 0.1% DEA in 76% acetonitrile in H₂O at 0.1 mL/minute for 40 minutes) (19). Tamofoxen and metabolites were separated by column switching to a coupled analytical column (Rex column 5 μ-CN; Regis Chemicals, Morton Grove, IL) and eluted by reversed phase ion exchange in 34% acetonitrile and 66% of 20 M potassium dibasic phosphate (HPLC grade; J. T. Baker, Phillipsburg, NJ) (pH 3.1) at 1.2 mL/ minute. Both assays were conducted on Hitachi HPLC systems (Hitachi Instruments, Inc., San Jose, CA) (20).

Quantitation of Estrogen

Estradiol levels were assayed in mouse serum by use of a time-resolved immunofluorescence procedure (Delphia assay; Wallac, Gaithersburg, MD). Mouse serum gives responses parallel to those of the reference preparation up to a concentration of 1300 pg/mL; thereafter, the serum responses are blunted. The intra-assay coefficient of variation was 5.2%. All samples were measured in a single assay.

Statistical Methods

Differences in the mean tumor area between the treatment and control groups were measured by analysis of variance followed by unequal Student’s t test, performed at the last week of each experiment. Significance is reported as two-sided P values.

RESULTS

Preliminary data demonstrated that parent toremifene levels are low at 24 hours (Table 1), and we have observed that 4-hydroxylation is the major route of toremifene metabolism.
Table 1. Levels of toremifene in tissues from mice killed 6 or 24 hours after final dosing*

<table>
<thead>
<tr>
<th>Tissue</th>
<th>Time, h</th>
<th>6</th>
<th>24</th>
</tr>
</thead>
<tbody>
<tr>
<td>Serum, ng/mL</td>
<td></td>
<td>795 ± 359†</td>
<td>58 ± 39†</td>
</tr>
<tr>
<td>Tumor, μg/g</td>
<td></td>
<td>11.1 ± 2.1†</td>
<td>2.3 ± 1.0†</td>
</tr>
<tr>
<td>Heart, μg/g</td>
<td></td>
<td>6.1 ± 3.3†</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Liver, μg/g</td>
<td></td>
<td>13.0 ± 8.0†</td>
<td>&lt;1</td>
</tr>
</tbody>
</table>

*Athymic mice (n = 10) were treated with toremifene at 1.5 mg (60 mg/kg) daily for 9 weeks. Levels of toremifene were measured 6 and 24 hours after final dosing (five mice per time point).
†Values = mean ± standard deviation.

(mean serum levels ± standard deviation for 4-hydroxy derivative at 6 hours = 2879 ± 1647 ng/mL) in athymic mice (data not shown).

To characterize the relative metabolism of tamoxifen and toremifene, we performed an experiment in which athymic, ovariectomized mice without tumors were treated with tamoxifen at a dose of 0.5 mg or 1.5 mg daily or toremifene at a dose of 0.5 mg or 1.5 mg daily for 3 weeks. Based on our preliminary data, drug levels in serum were measured 4 or 8 hours after final dosing. At both doses, serum levels of toremifene were higher than those of tamoxifen, and the major route of metabolism for both drugs (particularly toremifene) in mice appears to be 4-hydroxylation (Table 2). Results for both the 0.5-mg and the 1.5-mg doses are shown in Table 2.

At the 0.5-mg doses, parent toremifene levels were significantly higher at 4 hours (P < .02) but not at 8 hours (P = .25), compared with parent tamoxifen levels. Levels of the 4-hydroxy metabolite were significantly higher for toremifene than for tamoxifen at 4 hours (P = .002) and at 8 hours (P = .001). There was no significant difference in levels of N-desmethyl metabolites between tamoxifen and toremifene at 4 hours (P = .17) and at 8 hours (P = .12).

At the 1.5-mg dose, there was no significant difference between parent levels of tamoxifen and toremifene at 4 hours (P = .27) and at 8 hours (P = .8). Levels of the 4-hydroxytoremifene were significantly higher at 4 hours (P = .02) but not at 8 hours (P = .15), compared with those of tamoxifen. P values were calculated by analysis of variance followed by unpaired Student’s t tests.

To confirm that the 1-cm and 0.3-cm estrogen capsules resulted in levels of estradiol approximating premenopausal and postmenopausal levels, we performed a separate experiment in which athymic, ovariectomized mice without tumors were untreated or were implanted with 1-cm or 0.3-cm estradiol capsules for 2 weeks (Fig. 2). Mean estradiol levels ± standard errors were 379.5 ± 101.2 pg/mL and 83.8 ± 34.6 pg/mL for the 1-cm and 0.3-cm capsules, respectively (Fig. 2). The 1-cm capsule produces serum estradiol levels approximating those in premenopausal women, which vary throughout the menstrual cycle, between 150 pg/mL and 350 pg/mL (21). The 0.3-cm capsule results in levels similar to those in postmenopausal women, in whom the majority of circulating estrogen is in the form of estrone, which is secreted at an average of 35 μg/day to 40 μg/day (22). Although these levels are much higher than physiologic estrogen levels in mice, we wanted to provide levels similar to levels in premenopausal and postmenopausal women because the tumors implanted were of human origin.

For the evaluation of the impact of estradiol and toremifene on the growth of a tamoxifen-stimulated endometrial tumor, mice were treated with vehicle, with estrogen (1-cm capsule), with tamoxifen at a dose of 0.5 mg daily, or with toremifene at a dose of 0.5 mg, 1.5 mg, or 5 mg daily. A broad range of toremifene doses was used to cover the range used clinically relative to tamoxifen, i.e., three to 10 times the dose of tamoxifen.

There was no significant difference between tamoxifen and toremifene (at all three doses) on tumor growth at 9 weeks (P = .438) (Fig. 3). Both antiestrogens stimulated tumor growth compared with that in the untreated animals (P<.05) but to a lesser extent than estrogen (P = .02) (Fig. 3).

We had observed that toremifene produces higher serum levels than tamoxifen in mice that had not been implanted with tumors (Table 2). It was, therefore, possible that lower serum...
levels of toremifene may be associated with less tumor growth than lower serum levels of tamoxifen. To examine this possibility further, we performed an experiment in which athymic mice were implanted with tamoxifen-stimulated/estrogen-responsive endometrial tumors and treated daily with tamoxifen at a dose of either 0.5 mg or 1.5 mg. The tumor area was measured weekly, and serum levels of tamoxifen and metabolites were assayed 4 hours after the last dosing (Table 3). We were surprised to observe that the 1.5-mg dose resulted in less tumor growth than the 0.5-mg dose, despite higher serum levels (Table 3).

To evaluate the action of tamoxifen or toremifene on the growth of tamoxifen-naive/estrogen-responsive endometrial tumors, we treated the mice with vehicle, with estrogen (1-cm capsule), with tamoxifen (0.5 mg daily), or with toremifene (1.5 mg daily). A ratio of 1 : 3 of tamoxifen to toremifene was chosen because clinical trials have demonstrated that 60 mg of toremifene is equivalent in efficacy to 20 mg of tamoxifen (9). There was no significant difference in tumor growth between tamoxifen and toremifene after 9 weeks of treatment (two-sided \(P = .09\) for tamoxifen; two-sided \(P = .06\) for toremifene) (Fig. 4). Finally, mice (five per group) were implanted with tamoxifen-stimulated/estrogen-responsive endometrial tumors. The mice were treated with vehicle, with postmenopausal levels of estrogen (provided by a 0.3-cm estrogen capsule), or with ICI 182,780 at a dose of 5 mg weekly, with and without estrogen (0.3-cm capsule). As can be seen in Fig. 5, estrogen significantly stimulated tumor growth compared with control at 10 weeks. However, ICI 182,780 inhibited tumor growth in the presence of estrogen compared with control (Fig. 5), and ICI 182,780 when given alone did not stimulate tumor growth.

**DISCUSSION**

Tamoxifen is an effective therapy approved for all stages of breast cancer. Toremifene, or chlorotamoxifen, shows efficacy in the treatment of endocrine therapy-naive, postmenopausal patients with advanced disease (9); however, it demonstrates cross-resistance with tamoxifen, even when high doses (as high as 10 times the dose of tamoxifen) are administered (23).

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**Table 3.** Tumor growth and serum levels of tamoxifen and metabolites in mice receiving 0.5-mg or 1.5-mg doses per animal per day for 7 weeks*

<table>
<thead>
<tr>
<th>Dose, mg</th>
<th>Tumor area, cm²†</th>
<th>Tamoxifen, ng/mL</th>
<th>N-Desmethyltamoxifen, ng/mL</th>
<th>4-Hydroxytamoxifen, ng/mL</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>1.1 ± 0.9</td>
<td>50.9 ± 23</td>
<td>27.6 ± 13.8</td>
<td>64.4 ± 50.4</td>
</tr>
<tr>
<td>1.5</td>
<td>0.6 ± 0.7</td>
<td>334.3 ± 60.7</td>
<td>337.7 ± 74.9</td>
<td>477.8 ± 127.9</td>
</tr>
</tbody>
</table>

*Athymic mice (n = 10) were treated with tamoxifen at a dose of 0.5 mg per animal (20 mg/kg) or 1.5 mg per animal (60 mg/kg) daily. The tumor area at 7 weeks and levels of tamoxifen and metabolites, 4 hours after final dosing, are shown.

†Values = means ± standard deviation.
Tamoxifen and toremifene clearly have cross-resistance for EnCa101 growth. We chose a broad range of oral doses of toremifene to ensure that the large doses that have been used clinically were not, in fact, inhibitory for endometrial cancer (9,26). Equivalent, three times, and 10 times the daily dose of tamoxifen all supported the growth of the EnCa101 tumors; however, in all cases, growth was not as rapid as that observed with estradiol. Clearly, the known estrogen-like properties of toremifene (27) in animals translate to estrogen-like effects to support the accelerated growth of pre-existing endometrial cancer.

Much has been made of a potential link between DNA adduct formation and the carcinogenesis of high doses of tamoxifen in rat liver and the potential for carcinogenesis in humans (28–30). Toremifene has not been demonstrated to form DNA adducts in rat liver (14), and it was thought, therefore, that it would be less likely than tamoxifen to result in an increased risk for endometrial cancer. Our data suggest that this theory is not the case and that toremifene stimulates endometrial tumor growth in athymic mice to the same extent as tamoxifen.

However, there is little evidence for a link between liver tumorigenesis in rats and endometrial cancer in women with tamoxifen. First, extensive investigations of human metabolism and adduct formation have demonstrated that there are fundamental differences between rats and humans (31). Second, studies of DNA adduct formation with tamoxifen in human liver (32) and human uterus (33) have been negative, although an intriguing study from Scandinavia (34) suggests uterine adduct formation during tamoxifen therapy. Obviously, on the face of it, this theory would seem to be of concern, but it is inconsistent with the known genesis of human cancer. If the DNA adduct hypothesis is correct, endometrial cancer would be predicted to occur after several years of tamoxifen exposure. Initiation and promotion of human cancer may require even a decade. However, this is inconsistent with the facts. Nearly all tamoxifen-associated endometrial cancers occur within the first 5 years of exposure, and half of them are detected after fewer than 2 years of treatment. We have suggested that this is consistent with the activation and detection of pre-existing disease (5). The model would be that estrogen-induced endometrial cancer undergoes clonal selection during tamoxifen or toremifene treatment and is subsequently detected on follow-up of gynecologic symptoms. In addition, a recent report (35) noted similar chromosome changes and gene rearrangements in tamoxifen-associated and control polyps. If tamoxifen is a carcinogen and if endometrial hyperplasia and polyps are part of a stepwise process resulting in cancer, tamoxifen-associated polyps should have genomic abnormalities different from those of polyps occurring in patients not receiving tamoxifen (35). Our data suggest that any woman exposed to tamoxifen, who had a pre-existing endometrial cancer, would have continued growth of disease during toremifene treatment. This theory is consistent with the similar estrogen-like effects of tamoxifen and toremifene on the human uterus (36).

In contrast, ICI 182,780 inhibited tamoxifen-stimulated endometrial growth in the presence of postmenopausal levels of estradiol, and, when administered alone, it did not increase the growth of endometrial cancer. This observation suggests that, even in patients with pre-existing endometrial cancer that has...
been stimulated to grow with tamoxifen, ICI 182,780 would be safe and would inhibit further endometrial tumor growth. ICI 182,780 is not cross-resistant with tamoxifen. Studies show that ICI 182,780 has no estrogenic actions on the rodent uterus (37) or on the primate uterus (38), and preliminary screening of women who are treated for advanced breast cancer has not demonstrated uterine hypertrophy (13). There is every indication that ICI 182,780 will control growth of both breast cancer and endometrial cancer in patients.

In summary, toremifene appears to have identical effects as tamoxifen on the growth of endometrial tumors in athymic mice. This observation suggests that, in humans, toremifene will support the growth of pre-existent endometrial cancer. In addition, if toremifene is ever used as an adjuvant agent, we would anticipate an increase in the detection of endometrial cancer similar to that seen with tamoxifen. In contrast, ICI 182,780 inhibits endometrial cancer, both in the presence and in the absence of estrogen, suggesting that it will prevent further tumor growth in patients with tamoxifen-stimulated endometrial cancer. ICI 182,780 should not be associated with an increase in endometrial cancer and could even be considered in the treatment of endometrial cancer.

REFERENCES

(36) Tomas E, Kauppila A, Blanco G, Apaja-Sarkkinen M, Laatikainen T. Com-


NOTES

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