A Proposed Unified Mechanism for the Reduction of Human Breast Cancer Risk by the Hormones of Pregnancy

Herbert I. Jacobson,1,2 Nicole Lemanski,1 Anu Agarwal,1 Amithi Narendran,3 Kelvin E. Turner II,3 James A. Bennett1 and Thomas T. Andersen3

Abstract Parity in women is associated with reduced lifetime risk of breast cancer, and hormones of pregnancy (estrogen E, progesterone P, human chorionic gonadotropin; hCG) are implicated. Parity also reduces mammary cancer risk in carcinogen-exposed rats, and administering pregnancy hormones to these animals is similarly effective. Because pregnancy hormones are also able to stimulate cancer growth, we proposed to resolve this dichotomy by determining whether administered pregnancy hormones elicit the cancer-inhibiting agent α-fetoprotein (AFP) from the liver, which would implicate AFP as a proximal effector of hormonal anticancer activity. Accordingly, we treated groups of nitrosomethylurea-exposed rats with saline, E3, E2 + P, E3 + P, hCG, or allowed them to experience pregnancy, then monitored mammary cancer incidence and serum levels of AFP over time. Each hormone treatment reduced mammary cancer incidence and elevated serum AFP levels. To challenge human tissues, human HepG2 liver cells in culture were treated with the same hormonal agents. Each hormone regimen increased the levels of AFP in the culture medium. Medium containing AFP elicited by hCG inhibited the E2-stimulated proliferation of cultured human MCF7 breast cancer cells, whereas hCG alone did not inhibit their growth. Furthermore, antibodies to AFP neutralized the growth-inhibiting effect of AFP-containing HepG2 medium. We conclude that in the treatment of carcinogen-exposed rats with the hormones of pregnancy, and by inference in women who have experienced pregnancy, that AFP is a proximal agent that inhibits mammary gland cancer.

An often-cited statistic notes that 180,000 women will be diagnosed with breast cancer each year in this country. It is also well known that parity has a profound effect on risk of acquiring breast cancer (1–3). Women who are parous when they are young have one-third to one-half the lifetime risk of acquiring breast cancer compared with nulliparous women (4). This observation has served as a provocative clue for researchers seeking modalities for the reduction of breast cancer risk. It has been reasoned that something in the serum of pregnant women must be an effector of the reduction in risk, and agents recognized as probable effectors are the steroidal estrogens (E2 or E3; refs. 5, 6), progesterone (P; refs. 5, 6), and human chorionic gonadotropin (hCG; refs. 7, 8). Additionally, α-fetoprotein (AFP) has been postulated to be the risk-reducing agent (9, 10).

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conditions which are associated with a reduction in breast cancer risk below that found with normal singleton pregnancy. Moreover, Richardson et al. (20, 21) have reported that parity-associated protection from breast cancer is directly proportional to a woman’s blood level of AFP during her pregnancy. Consistent with this line of thinking are laboratory studies which have shown that mammary cancer growth is inhibited by the direct addition of AFP to mammary cancer cells growing in culture or in rodents (19, 22–26). Noting that the concentrations of test substances such as E3, E2, P, or hCG administered in published prevention trials were quite high, we hypothesize that those test substances may be effective cancer preventers by virtue of their ability to elicit AFP secretion from the nonpregnant rat liver, rather than by having a direct effect on the mammary gland. Furthermore, we hypothesize that AFP, through its direct inhibition of breast cancer growth, is a key proximal agent by which the reduction in breast cancer risk is obtained. We tested this hypothesis by repeating the hormone treatments (E2, E3, P, and hCG) that were reported to be effective at reducing rat mammary cancer, in the same experimental configuration used by the previous researchers, and measured cancer incidence as well as serum AFP levels in these carcinogen-exposed, hormone-treated animals. Furthermore, as a surrogate for human liver, we examined the ability of these hormones to elicit AFP from human liver cells in culture. We report here that these hormone treatments do, in fact, lead to the production of AFP, that hormone-elicited AFP directly inhibits the growth of human breast cancer cells in culture, and that antibody to AFP specifically blocks the anti-breast cancer activity of hormone-elicited AFP. A preliminary report of this work has been published (27).

Materials and Methods

Animals

Female Sprague-Dawley rats were obtained from Taconic Farms at 34 d of age and were placed immediately on a controlled diet (Agway Pro-Lab 2000; Agway Corporation), allowed free access to food and water, and maintained on a 12-h light-dark cycle at a constant temperature (22°C) for the duration of the study. All procedures involving animals were reviewed and approved by the Albany Medical College Institutional Animal Care and Use Committee.

Carcinogen exposure

There were 30 rats in each experimental group (unless otherwise specified) to assure a 95% probability of detecting a difference between groups (ratios) of 40%, which was the difference seen for pregnancy (5, 15). MNU was obtained from the National Cancer Institute carcinogen repository (MRI, Inc.) and was dissolved in sterile physiologic saline, (1% w/v), buffered to pH 5.0 with 3% acetic acid. At 50 d of age, rats were randomized and a single injection of MNU, 50 mg/kg body weight, was administered into the jugular vein. Treatment with hormones occurred during the time period beginning 10 to 21 d after MNU exposure and continued so that the same start date and treatment durations as were used by the earlier workers were reproduced in the experiments reported herein. For tumor detection and monitoring tumor growth, animals were palpated twice weekly, starting at day 30 (after MNU exposure) and continuing for at least 102 d. Tumor incidence is reported as the number (or percentage) of rats in a group that experienced at least one tumor, whereas multiplicity is the average number of tumors per rat. The dimensions of each tumor were determined by noninvasive measurement with a caliper, and tumor volume was estimated as an ellipsoid of revolution $V = \frac{\pi}{6} d^2 D$, where $d$ and $D$ are the respective short and long diameters. For each group, mean tumor volume was calculated.

Hormone treatments

Each hormone treatment followed the doses and schedules specified in the publications being replicated, and therefore, differ from one another in modest ways. In every case, we used MNU, although in some of the previous investigations, DMBA was used (7, 8, 13, 17, 18). E3 + P. Following the procedures of Grubbs et al. (5), who used MNU as the carcinogen, 10 d after carcinogen administration, 30 female rats received 20 μg of E2 (Sigma Aldrich) plus 4 mg of P dissolved in sesame oil, daily, by s.c. injection (0.2 mL), for 40 d. E3 + P. Following the procedures of Rajkumar et al. (6), who used MNU, 13 d after carcinogen administration, 30 female rats received two individual subcutaneous Silastic capsules (0.078 in. ID × 0.125 in. OD, 2 cm long; Dow Corning) one packed with 30 mg of E2 and another packed with 30 mg of P (Sigma Aldrich). Each Silastic capsule was implanted s.c. dorsally, on either side of the upper spine while animals were under isoflurane anesthesia. Implants were left in place for 21 d to mimic pregnancy, and removed after 21 d.

E3 + P. Following the procedures of Rajkumar et al. (6), who used MNU, 13 d after carcinogen administration, 30 female rats received a subcutaneous Silastic capsule packed with 30 mg of E2 (Sigma Aldrich). All Silastic capsules were implanted s.c. dorsally while animals were under isoflurane anesthesia. Implants were left in place for 21 d to mimic pregnancy, and were then removed.

hCG. Similar to the procedures of Russo et al. (8) who used DMBA, 21 d after MNU administration, 30 female rats received an s.c. injection of 100 IU of hCG (Sigma Aldrich) reconstituted with deionized water (pH 7.2), daily, for 60 d.

Pregnancy. Following the procedures of Grubbs et al. (15), 10 d following carcinogen administration, 30 female rats were introduced to males (three females per male). Females stayed with males for 7 d, after which they were removed and separated into individual cages. Between 21 and 23 d later, 19 females bore litters and were allowed to breast-feed for 15 d. Females that did not become pregnant were excluded from the study.

Controls. The no-treatment group consisted of 30 female rats exposed to MNU without subsequent treatment, and experienced the maximal number of tumors over the course of the ensuing 4 mo. A group of animals that was not exposed to MNU developed no tumors during the course of the study.

Blood samples

Blood was drawn from animals in each of the six groups of rats at four time points: bleed 1 was prior to the first dose of treatment (for pregnancy, on the 4th day females were housed with males), bleed 2 occurred at the midpoint of the treatment regimens, whereas bleed 3 was on the last day of the treatment regimen. Bleed 4 occurred 7 d following the termination of the treatment regimen, or, for the pregnant group, 7 d postpartum. These bleeding times are indicated in Fig. 1. Control animals were bled 30, 40, and 50 d after MNU administration. While rats were anesthetized under 3% isoflurane, 1 mL blood samples were drawn from the tail vein with a 25-gauge needle and transferred to glass centrifuge tubes and allowed to clot at room temperature. Serum drawn from each sample was spun thrice (1,500 rpm, for 10 min) after which supernatant was collected and stored at −80°C until used for AFP measurement. No animal had more than one blood draw.

Measurement of hormone-elicited rat AFP in rat serum

Detection of AFP in rat sera was done by Western blot analysis using a standard curve based on AFP found in rat amniotic fluid. Amniotic fluid was drawn from the amniotic sacs of 15-d pregnant Sprague-Dawley rats, centrifuged thrice at 2,500 rpm for 5 min to clarify, and then diluted to various protein concentrations with PBS.
and subjected to electrophoresis on a 10% Tris-HCl agarose gel. Amniotic fluid AFP was detected as described below.

Preparation of the serum samples included a 1:60 dilution with distilled water, and then resuspension in electrophoresis sample preparation buffer. Samples were boiled for 6 min. A Bradford assay was used to determine the protein concentration of each sample (including amniotic fluid). Each sample (20 μL) was applied to a 10% polyacrylamide gel. Following electrophoresis, proteins were transferred to a polyvinylidene difluoride membrane using a semidry transfer cell. Membranes were blocked with 5% milk in 0.1% Tween TBS for 1 h at room temperature, then incubated overnight at 4°C in goat polyclonal anti-rat AFP conjugated to horseradish peroxidase (Santa Cruz Biotechnology). The polyvinylidene difluoride membrane was then washed four times in Tween TBS at room temperature and incubated for 5 min in Western Lightning reagent (PerkinElmer), a 1:1 mixture of luminal and oxidizing agent (enhanced chemiluminescence reagent). Film was exposed to polyvinylidene difluoride membranes and developed to reveal bands representing AFP. Quantification of AFP in rat sera was through densitometry measurements using ImageQuant Densitometry software. Densitometry measurements for various samples were compared with that of amniotic fluid, which is reported to be 1 mg/mL immediately prior to parturition (28).

**Measurement of hormone-elicited human AFP in HepG2 supernatants**

HepG2 cells (10^5 cells/well) were maintained and grown as a monolayer in αMEM (Life Technologies, Inc.) supplemented with 5% serum (40% bovine calf serum, 60% fetal bovine serum), penicillin G (100 units/mL), and streptomycin (100 μg/mL) in 24-well culture plates in triplicate. Cells were changed to serum-free medium when confluent and medium was changed every 3 d (19). For treatments with hormones, E3, E3 + P, E2 + P, or P (Sigma) was dissolved in 95% ethanol, diluted in buffer and brought to 10^{-8} mol/L in the cell culture dish; final ethanol concentration in each well was 0.095%.
hCG (Sigma; 10,000 IU/vial) was dissolved in sterile deionized wa-
ter and used at a final concentration of 10^{-8} mol/L. Control cells
were grown in serum-free medium alone (corrected for ethanol con-
centration where appropriate). Hormone-treated cells in serum-free
medium were administered hormones daily for 21 d. Medium con-
taining AFP was removed every 3 d and replaced with fresh serum-
free medium and hormones. The collected media containing secreted
AFP was stored at –20°C to prevent AFP degradation, and subse-
quently assessed for human AFP using a Beckman-Coulter Access
in the Clinical Chemistry Laboratories of the Albany Medical Center
Hospital.

Addition of AFP-containing HepG2 supernatant to
MCF-7 cells

To obtain sufficient quantities of human AFP for the treatment of
MCF-7 cells, HepG2 cells were grown in multiple T25 flasks at 2 × 10^6
cells per flask in 4 mL of the maintenance medium described
above, for 7 d until confluent. The media were then changed to se-
rum-free media (a 3:1 mix of MEMs and Waymouth’s MB752/1 me-
dium containing 1.5%, antibiotic-antimyotic, 2 mmol/L l-glutamine,
and 30 mmol/L sodium selenite). Cells were treated with 10^{-9} mol/L
of hCG daily, and supernatants were collected and pooled from the
flasks every 3rd day and replenished with fresh serum-free medium
up to 24 d. Cell debris was removed from supernatants by centrifu-
gation at 1,500 rpm for 10 min at 4°C. For AFP neutralization experi-
ments, (1.0 mL) was incubated with 40 μg
μg
μg
of monoclonal anti-human AFP antibody or isotype control (R&D Sys-
tems, Inc.), rocked for 1 h at room temperature followed by incubat-
ing with 100 μL of Protein A/G beads for another hour. The beads
were spun down at 2,500 rpm for 10 min and the AFP-depleted
supernatants were sterile-filtered for use in the treatment of MCF-7
cells.

Human MCF-7 breast cancer cells (American Type Culture Col-
collection) were grown in maintenance medium (DMEM with high
glucose supplemented with 5% fetal bovine serum, 1% antibiotic-
antimyotic, and 10 ng/mL bovine insulin). For the cell prolifera-
tion assay, MCF-7 cells were grown in estrogen-depleted medium
(EFM: phenol red–free DMEM, 10% dextran/charcoal-stripped bo-
vine calf serum, and antibiotics as above) for 24 h and plated at
1.2 × 10^5 cells per well in 24-well collagen IV–coated plates (BD
Biosciences) in 1 mL of EFM. Cells in four to six replicate wells
were used for each treatment condition. Medium was changed ev-
every other day to fresh EFM during treatment.

MCF-7 cells were treated the day following plating with either su-
pernatant from the HepG2 cells that had been treated with 10^{-9} mol/L
of hCG, this supernatant neutralized with anti-AFP (or isotype con-
trol), or hCG alone (10^{-9} mol/L). Untreated or neutralized superna-
tants from the HepG2 cells (100 μL) or hCG alone was added to MCF-7
cells in 1 mL of EFM, incubated for 1 h and followed by the
addition of E2 in 10 μL for a final E2 concentration of 10^{-10} mol/L. The
no-treatment control group and E2 alone control group of cells were
treated with an equal volume of serum-free medium. Cells were trea-
ted for 7 d with media changes every other day and quantitated on
the 8th day. Cells were trypsinized with 300 μL of 0.25% trypsin-
0.53 mmol/L EDTA, allowed to detach, scraped, and collected into
glass tubes. Wells were rinsed with an equal volume of EFM and
the cells pooled. Cells were mixed well and viable cell number was
quantitated using MTT assay (29).

Statistics

The level of cancer chemopreventive activity provided by each
hormone treatment was analyzed by comparing the incidence
(number of rats bearing tumors) in the treatment group with that of
the MNU-only control using Fisher’s exact test. For cell prolifera-
tion data, Dunnett’s test was used. In either test, P < 0.05 was
considered significant.

Results

Five groups of carcinogen-exposed rats were treated with
different hormonal regimens, whereas a sixth group received
no additional treatments. The outcomes in terms of mammary
cancer appearance are shown in Fig. 1A-E. In each panel, the
upper curve shows cancer appearance in the positive control
cancer appearance in animals treated with either E2 + P (A), E3 + P (B),
E3 alone (C), hCG (D), or pregnancy (E). In each case, the reduction of mammary
cancer incidence was similar to that reported by earlier workers
(5-8). Table 1 indicates that the decreased incidence is statisti-
cally significant (compared with controls) for each treatment,

<table>
<thead>
<tr>
<th>Treatment</th>
<th>No. of rats</th>
<th>Treatment dose</th>
<th>Treatment route</th>
<th>Treatment start date (days post-MNU)</th>
<th>Treatment duration (days)</th>
<th>Incidence in this study, % (P)*</th>
<th>Incidence reported by others, % (reference)</th>
<th>Tumors per group</th>
<th>Mean no. of tumors per rat</th>
<th>Mean tumor volume (mm)$^3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>30</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>68</td>
<td>—</td>
<td>38</td>
<td>1.23</td>
<td>3,504</td>
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<tr>
<td>E2 + P</td>
<td>30</td>
<td>20 μg E2 + 4 mg P</td>
<td>s.c. injection</td>
<td>10</td>
<td>40</td>
<td>26 (P = 0.004)</td>
<td>20 (5)</td>
<td>10</td>
<td>0.33</td>
<td>2,199</td>
</tr>
<tr>
<td>E3 + P</td>
<td>30</td>
<td>30 mg E3 + 30 mg P</td>
<td>Silastic implant</td>
<td>13</td>
<td>21</td>
<td>30 (P = 0.008)</td>
<td>25 (6)</td>
<td>8</td>
<td>0.27</td>
<td>880</td>
</tr>
<tr>
<td>E3</td>
<td>30</td>
<td>30 mg E3</td>
<td>Silastic implant</td>
<td>13</td>
<td>21</td>
<td>42 (P = 0.041)</td>
<td>64 (6)</td>
<td>24</td>
<td>0.8</td>
<td>955</td>
</tr>
<tr>
<td>hCG</td>
<td>30</td>
<td>100 IU hCG</td>
<td>i.p. injection</td>
<td>21</td>
<td>60</td>
<td>33 (P = 0.001)</td>
<td>45 (8)</td>
<td>12</td>
<td>0.4</td>
<td>763</td>
</tr>
<tr>
<td>Pregnancy</td>
<td>19</td>
<td>—</td>
<td>—</td>
<td>10</td>
<td>21$^2$</td>
<td>44 (P = 0.058)</td>
<td>45 (15)</td>
<td>28$^5$</td>
<td>0.93</td>
<td>2,649</td>
</tr>
</tbody>
</table>

*For difference from MNU control.

†Sum of all tumor volumes in a group/total number of animals in a group.

‡Normal gestation period in rats.

§Normalized for group size of 30 animals.

that incidence reduction in this study is comparable to that in the studies being replicated, that multiplicity was decreased by each treatment, and that tumor volume was decreased by each of these treatments.

Serum from animals in the prevention study was harvested immediately prior to regimen initiation (bleed 1), at the midpoint of each regimen (bleed 2), and again (from different animals) at the end of the treatment regimen (bleed 3). Additionally, animals were bled 1 week after the end of the treatment regimen (bleed 4). Rat AFP levels in these serum samples were estimated using Western blot analysis based on a standard curve using rat amniotic fluid AFP (Fig. 2A). A typical gel showing AFP bands in bleed 2 sera from the different treatment regimens is shown in Fig. 2B. Each of the regimens resulted in an increase in serum AFP levels during treatment. The extent of AFP increase varied among treatment regimens. The kinetics of increase and the intragroup and intergroup variability were thoroughly evaluated by measuring AFP band mean densitometry among five replicate animals in a group treated with steroid hormones (E₃ + P) and in the group treated with hCG (Fig. 2C). These two groups were chosen because they showed a very consistent decrease in mammary cancer incidence over time (Fig. 1B and D). As shown in Fig. 2C, prolonged treatment with hCG resulted in a significant increase in
serum AFP levels during treatment and levels were still increased 1 week following treatment cessation. In the group treated with E3 + P, serum AFP levels were significantly increased by midtreatment (bleed 2) but returned to pretreatment levels by the end of treatment and remained there 1 week posttreatment.

To evaluate the effect of hormones on human liver cells, HepG2 cells were incubated with either E2, E2 + P, hCG, or P alone, and human AFP released into the cell culture medium was quantified. Figure 3 indicates that treatment with E2, E2 + P, or hCG led to sustained elevated levels of human AFP in the medium, whereas treatment with P alone did not stimulate AFP production. Levels were elevated as early as day 3 after hormone addition, reached a maximum by 6 days, and remained elevated throughout the 21 days of the experiment.

To assess whether human AFP elicited from HepG2 cells could inhibit breast cancer cell growth in culture, supernatants from HepG2 cells that had been treated with hCG were added to cultures of MCF-7 human breast cancer cells growing in culture. As shown in Fig. 4, the AFP-containing supernatant significantly inhibited the estrogen-stimulated growth of these human breast cancer cells. The basal growth of these cells (cells in the absence of E2) was not inhibited by this supernatant. A key finding is that treatment of the HepG2 supernatant with antibody to AFP neutralized the growth-inhibitory activity of the supernatants, whereas treatment of these supernatants with isotype control did not neutralize their growth-inhibitory activity (Fig. 4). Treatment of MCF-7 cells with 10^{-7} mol/L of hCG alone (which was the concentration of hCG used to elicit AFP into the HepG2 supernatants) did not inhibit constitutive growth of MCF-7 cells or the E2-induced proliferation of these cells (Fig. 4). Interestingly, addition of HepG2 supernatants treated with anti-AFP (Fig. 4), or the addition of anti-AFP alone (data not shown) to MCF-7 cells actually stimulated the E2-induced growth of these cells.

**Discussion**

Pregnancy reduces breast cancer risk in women (4) and in rats (15). These observations led several independent investigators (5–8) to propose and then show that administering the hormones of pregnancy (E3, E2, or hCG) leads to reduced breast cancer incidence in rats exposed to carcinogens. We have confirmed this observation and show here that the hormones of pregnancy alone are sufficient to induce elevated AFP levels in nonpregnant adult rat serum and in cultures of human liver cells. We note here the well-established finding that pregnancy leads to elevated serum levels of AFP in women (30) and in rats (28), that this leads to reduced breast cancer incidence (9, 15, 20). AFP inhibits cancer growth directly, whereas the hormones of pregnancy do not. Taking all of these data together, it is logical to conclude that AFP is a key mediator through which the pregnancy-induced, or hormone-induced, reduction in breast cancer is realized. Capturing this oncostatic property in analogues of AFP could lead to a rational process for the treatment and prevention of breast cancer. These concepts are discussed below.

We show that treatment of nonpregnant, carcinogen-exposed rats with the hormones of pregnancy leads to a reduction in mammary cancer incidence compared with animals exposed only to carcinogen. Our experimental design called for repetition of the prevention studies done earlier (5–8), with the only significant difference being that some groups (7, 8, 18) have used DMBA, whereas we and others used MNU as the carcinogen in all cases. The incidence of mammary cancers (number of rats that had one or more tumors), the multiplicity of tumors (number of tumors per rat), and tumor burden (assessed as volume), were lower in the hormone-treated groups than in the carcinogen-only group and were very similar, in each instance, to that reported in the earlier studies (Table 1). It is difficult to compare latency (time to appearance of tumors after treatment with carcinogen) across publications because DMBA results in a different latency period than does MNU, but in our study, latency was prolonged for each treatment group except pregnancy.

It may be that the pharmacologic levels and the chronic administration of hormones used in this study, as well as in other studies (5–8), resulted in a generalized liver distress that increased the levels of AFP. Drug-induced liver distress that has increased the level of AFP has been reported (31). Drug-induced liver distress that has reduced the incidence of mammary cancer has also been reported (32–34). Unfortunately, AFP levels were not measured in these later studies.

It may be questioned whether the cancer prevention experiments in rats constitute a rational extension of the phenomenon occurring in human breast cancer. Because there were no experimental means to elicit AFP from human liver,
we undertook a more practical alternative, specifically, a challenge of cultured HepG2 human liver cells with these same hormones. With challenges of E3, E2 + P, or hCG, the level of human AFP found in culture medium was sustained at significantly elevated levels over the basal level secreted by untreated cells. A significant negative control observation was that P alone did not elicit AFP from human liver cells. It is also known that P alone fails to protect rats against carcinogen-induced mammary cancer (35).

To assess whether hormone-elicited AFP is sufficient to attenuate cancer, we used the culture medium of hCG-stimulated HepG2 cells to influence the proliferation and response of MCF-7 human breast cancer cells. We avoided the use of steroid stimulation so as to preclude any trophic effects of steroids on the MCF-7 cells. In other work (36–39), as well as in this report, we have shown that E2 stimulates the growth of MCF-7 and T47D cells; it certainly does not inhibit proliferation. As shown clearly in Fig. 4, the culture medium of hCG-stimulated HepG2 cells is sufficient to inhibit E2-induced proliferation of MCF-7 cancer cells. When the HepG2 medium was stripped of human AFP, the medium no longer inhibited the growth of the cancer cells, and in fact, led to an overgrowth of cells, suggesting that AFP is a proximal agent of cancer inhibition and that its removal might lead to accentuated breast cancer growth. AFP operates via a membrane-associated AFP receptor which is expressed by MCF-7 cells and by other malignancies (40). Interestingly, MCF-7 cells also produce AFP (41), the ligand for that receptor, suggesting that these cells might be experiencing some restriction in growth through AFP-mediated autocrine inhibition of estrogen responsiveness. AFP removal by anti-AFP may have released the cells from this restriction which may have led to the accentuated tumor growth seen under the conditions of anti-AFP treatment of MCF-7 cells. hCG alone did not inhibit E2-induced proliferation of these cells, indicating that hCG is not the proximal agent of cancer inhibition. Neither did it stimulate proliferation.

The ability of AFP in the culture media of HepG2 cells to inhibit proliferation of MCF-7 cells is consistent with earlier reports using different systems. Sonnenschein et al. (22) elegantly showed the ability of transplanted AFP-secreting hepatomas to inhibit the growth of mammary cancers growing in rats. Using a heterologous system, we showed that human AFP could stop the growth of human breast cancers growing as xenografts in immune-deficient mice (19), and in a homologous system, that rodent AFP could stop the growth of MTW9A mammary cancers in rats (42).

Based on these data and epidemiologic data described below, we postulate that AFP is a key pregnancy-associated molecule that leads to a reduction of breast cancer incidence later in life. In 1989, Jacobson and Janerich (10) proposed that AFP in the serum of pregnant women may be the mediator of the reduction in lifetime breast cancer risk that is associated with early term pregnancy. The pregnancy-associated epidemiologic data became particularly compelling in suggesting a role for AFP in reducing breast cancer risk when it was found that a twin pregnancy, in which AFP levels are almost twice those in singleton pregnancies, afforded greater breast cancer risk reduction when compared with that obtained after a singleton pregnancy (9). Then, Richardson et al. (20) also reported a direct correlation within a single cohort of women, between the level of AFP during pregnancy and subsequent reduction in breast cancer risk, further linking AFP to risk reduction. Jacobson et al. (10) further hypothesized that during pregnancy, the transient relaxation of immune competence that is believed to play a role in averting fetal rejection permits some subclinical estrogen-responsive tumors to progress into active growth, a state in which estrogen is necessary to sustain tumor viability. The newly emerging tumors immediately encounter an environment (high concentration of AFP) that blocks their responsiveness to...
estrogen, and those cells that are estrogen-dependent die, which is consistent with the reported antiestrogenic activity of AFP. Emergent tumors that are autonomous of estrogen would survive and grow to clinical diagnosis. In rat studies reported by Grubbs et al. (16), in the rat studies reported here, and in women (2), pregnancy leads to an early increase, followed by an overall later decrease, in mammary cancer incidence (Fig. 1E). The outcome of the pregnancy is thus a short-term, modestly increased risk for early diagnosis of autonomous cancer, and clearance from the breast tissue of much of its future potential for estrogen-dependent malignant disease, which would account for the overall decrease in breast cancer incidence in parous women. This putative anti-breast cancer effect of AFP is consistent with the results of the study reported herein.

Other theories have been put forth to explain the parity-associated reduction in breast cancer incidence, and there may be a multifactorial basis underpinning the pregnancy-associated protection, but what is particularly appealing about the unifying AFP hypothesis is that it presents an obvious pharmacologic strategy for harnessing this anti-breast cancer potential and translating it to the clinic. Chronic administration of an AFP-like agent may decrease tumor incidence, growth rate, or detection, thus constituting prevention. Whereas chronic administration of a protein (AFP) may be impractical and may have additional unwanted biological activities, the administration of a smaller, safe active-site mimic of the protein would be preferable. An analogue of the active site of AFP, termed AFPep, has been developed and may be such an agent in that it has been shown to inhibit the growth of breast cancer cells and prevent the development of carcinogen-induced rat mammary cancers (14, 36, 37, 43). AFPep is a very well-tolerated agent and is active after oral administration, properties that are necessary for a chemoprevention strategy (14, 36, 37). Molecules that mimic E2, E2, or hCG would seem less desirable as preventive agents because these hormones are also known to stimulate breast cancer growth. Thus, although AFP may have evolved for other purposes, its presence in nature may be reducing breast cancer incidence and mining its active site may lead to a novel agent that will be useful for the chemoprevention of breast cancer.

Disclosure of Potential Conflicts of Interest
No potential conflicts of interest were disclosed.

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