Cylooxygenase-2 Expression in Human Breast Cancers and Adjacent Ductal Carcinoma in Situ

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ABSTRACT

Cyclooxygenase-2 (COX-2) is an inducible enzyme that converts arachidonic acid to prostaglandins. Overexpression of the COX-2 gene in mammary glands of transgenic mice was sufficient to induce tumorigenesis. We analyzed COX-2 expression in human breast cancers (and breast cancer cell lines) and adjacent ductal carcinoma in situ (DCIS) as well as its association with HER2/neu and clinicopathological variables. Archival primary breast carcinomas (n = 57), adjacent DCIS (n = 14) and DCIS alone (n = 2) were analyzed for COX-2 and HER2 expression by immunohistochemistry using specific monoclonal antibodies. An immunohistochemical scoring system was used. HER2 gene amplification had been analyzed previously by fluorescence in situ hybridization (n = 20). Histology of carcinomas included infiltrating ductal (n = 44), lobular (n = 2), and other (n = 7). Frozen breast cancers and adjacent normal tissue pairs (n = 9) were analyzed for COX-2 mRNA by reverse transcription-PCR. COX-2 and HER2 expression were also analyzed in human breast cancer cell lines (MCF-7, MCF-7/HER2, SK-BR-3, and MDA-MB-231) by immunoblotting. Cytoplasmic COX-2 expression was detected at an intermediate or high level in epithelial cells in 18 of 42 (43%) invasive breast cancers and in 10 of 16 (63%) cases of DCIS. Normal-appearing breast epithelia expressed COX-2 in 81% of cases and was generally focal and of similar or decreased intensity relative to adjacent neoplastic epithelia. COX-2 mRNA was detected in all samples analyzed by reverse transcription-PCR and was increased in eight of nine breast cancers relative to paired normal tissue. In archival tumors, no significant correlation was found between COX-2 and HER2 expression/amplification and clinicopathological variables. COX-2 expression was induced in MCF-7 cells stably transfected with HER2, in contrast to parental MCF-7 cells, and was detected in MDA-MB-231, but not SK-BR-3 cells. COX-2 is frequently overexpressed in invasive breast cancers and in adjacent DCIS and, thus, may be an early event in mammary tumorigenesis. Forced HER2 expression in MCF-7 cells was shown to up-regulate COX-2, although no association was found in human tumors. Our results suggest that nonsteroidal anti-inflammatory drugs and selective COX-2 inhibitors may be useful in the chemoprevention and therapy of human breast cancer.

INTRODUCTION

Elevated levels of PGF\textsubscript{2α} have been detected in cultured human breast cancer cells as well as in invasive human breast cancers (1–4) and are associated with negative hormone receptor status and increased metastatic potential (1). COX enzymes catalyze the conversion of arachidonic acid to PGs and related eicosanoids. Two isoforms of the COX gene have been identified, which encode for constitutively expressed COX-1 and inducible COX-2 (5).

COX-2 is an intermediate response gene that encodes a 71-kDa protein which is up-regulated at sites of inflammation (6) and in some epithelial cancers, including human colon (7, 8), gastric (9), esophageal (10, 11), and lung (12) adenocarcinomas. Increases in COX-2 and PG production were induced by viral and Ras-mediated transformation of mammary epithelial cells (13). Elevated levels of COX-2 mRNA and protein have been reported in breast cancer cell lines (1), and limited and conflicting data exist regarding the frequency of COX-2 expression in human breast cancers. Using RT-PCR, Parrett et al. (14) detected COX-2 expression in all 13 breast cancers examined in contrast to normal human breast tissue. Soslow et al. (15) reported that 7 of 17 invasive breast cancers expressed COX-2 proteins. In contrast, Hwang et al. (16) detected COX-2 protein by immunoblot analysis in only 2 of 44 human breast cancer specimens.

In a transgenic mouse model, overexpression of COX-2 in mammary epithelial cells resulted in the development of mammary tumors, indicating that COX-2 was sufficient to induce mammary tumorigenesis (17). The importance of COX-2 in intestinal tumorigenesis was shown by mating COX-2 knockout mice to A\textsuperscript{+}\textsuperscript{-}Min mice, which resulted in a dramatic reduction in the number of intestinal polyps in double knockouts (18). The effect of selective COX-2 inhibitors on mammary carcinogenesis has been reported. Treatment with celecoxib significantly delayed mammary tumor development in DMBA-treated rats and was found to be more effective than the COX inhibitor ibuprofen (19). Furthermore, nimesulide was shown to significantly reduce tumor size, multiplicity, and to a lesser extent, incidence in experimental mammary tumors (20). The effect of celecoxib on established breast cancer was also studied in a study in which rats were maintained for 4 months after DMBA treatment and subsequently fed celecoxib or control for 6 weeks (21). Mean tumor volume was decreased by 32% in the treatment group, but increased dramatically (518%) in controls.

Adenocarcinoma of the breast is the most common cancer in women in the United States and is second only to lung cancer as a cause of cancer-related mortality (22). Epidemiological studies suggest that regular intake of NSAIDs may protect against breast cancer (23–25). In a case-control study, a 40% reduction in breast cancer incidence was observed in women who reported daily intake of aspirin, ibuprofen, or other NSAIDs for at least 5 years (24). In a Canadian study of 5882 women, regular intake of NSAIDs for 2–5 years was associated with a 24% reduction in invasive breast cancer (25). The Nurses Health Study, however, found no difference in aspirin intake among women who developed breast cancer and those who did not (26). Regular and prolonged intake of NSAIDs is associated with a 40–50% reduction in colorectal cancer incidence (23, 27, 28) and also reduces mortality related to this disease (29). NSAIDs inhibit COX enzymes and are potent chemopreventive agents against colon (30–32) and some mammary carcinoma models. In this regard, indomethacin (33–35) and ibuprofen (36, 37) were both found to reduce the incidence of DMBA-induced mammary tumors in rats. In 2-aminoo-1-methyl-6-phenylimidazopyridine- and N-methyl-N-nitrosourea-induced breast cancer models, aspirin (38) and flurbiprofen (39) were shown to reduce mammary tumorigenesis. In other studies, however, indomethacin (40) and piroxicam (41) failed to exert a

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3 The abbreviations used are: PG, prostaglandin; COX, cyclooxygenase; RT-PCR, reverse transcription-PCR; DMBA, dimethylbenz[a]anthracene; NSAID, nonsteroidal anti-inflammatory drug; DCIS, ductal carcinoma in situ; IHC, immunohistochemistry; MAB, monoclonal antibody.
Materials and Methods

Tissue Samples. We analyzed a nonconsecutive series of primary human breast carcinomas (n = 57), adjacent DCIS (n = 14) or DCIS alone (n = 2), and normal-appearing breast epithelia (n = 41) that were obtained from the surgical pathology laboratory at The University of Texas M. D. Anderson Cancer Center. Tissue specimens were formalin fixed, paraffin embedded, and represented different tumor stages [stage 1 (n = 15), stage 2 (n = 24), stage 3 (n = 12), stage 4 (n = 1), or unknown (n = 3)], according to the TNM classification (45). Consecutive 4-μm tissue sections were cut from paraffin blocks and placed on polylysine-coated slides for IHC analysis. An additional nine pairs of frozen, invasive breast cancer and normal tissue samples were obtained from the Institutional Tissue Bank.

Tumor Cell Lines. We analyzed the human breast adenocarcinoma cell lines MDA-MB-231, SK-BR-3, MCF-7, and MCF-7/HER2. MCF-7 cells had been stably transfected with the HER2 cDNA (gift from Dr. Mien Chi Hung, University of Texas M. D. Anderson Cancer Center). The HCA-7 colorectal carcinoma cell line was obtained from Dr. S. Kirkland (Imperial Cancer Research Fund, London, United Kingdom), and the HCT116 colon cancer cell line was from the American Type Culture Collection (Rockville, MD). All cells were grown in DMEM:F-12 (Life Technologies, Inc., Frederick, MD) supplemented with heat-inactivated 10% FCS and 10 units/ml penicillin and streptomycin. Cultured cells were maintained in a humidified environment at 37°C and 94% air/5% CO2.

IHC. Slides were deparaffinized, and endogenous peroxidase activity was blocked by incubation in 3% H2O2 in methanol for 30 min at room temperature. Sections were then microwaved in PBS (pH 7.4) for 4 min for antigen retrieval. Immunoreactivity was detected by an immunoperoxidase method (Vectastain Elite ABC; Vector Laboratories, Burlingame, CA). Nonspecific binding was blocked with avidin then biotin (Vector) for 15 min each. The primary antibody was applied for 30 min at room temperature. Slides were rinsed in PBS, the biotinylated secondary IgG antibody was applied for 30 min at room temperature. Slides were rinsed in PBS, and avidin conjugated to horseradish peroxidase (ABC reagent) was applied for 45 min at room temperature. The chromogen 3,3'-diaminobenzidine (Research Genetics, Huntsville, AL) was subsequently added, and the color reaction was observed with light microscopy. The reaction was stopped by immersing slides in deionized water; slides were then counterstained with hematoxylin and mounted.

As a control for nonspecific staining, a COX-2-specific blocking peptide (Cayman Chemical) derived from the human COX-2 cDNA sequence was mixed with the COX-2 MAb and applied to sections. In all cases, immunoreactivity was completely suppressed. As a negative control, the primary MAb was omitted and PBS was applied, with all other steps of the procedure included. The HCA-7 colon cancer cell line was used as a positive control for COX-2.

For HER2 immunostaining, a modification of the procedure used for COX-2 was used. Antigen retrieval was performed by microwave treatment of slides in citrate buffer (pH 6.0) for 4 min on the high setting and an additional 6 min at lower power. Slides were incubated with a monoclonal anti-c-erbB-2/HER2 antibody (clone e2-4001+B5; Neomarkers, Fremont, CA) at a 1:200 dilution. A series of breast cancers were stained with this MAB, and the results were compared with those same cases stained with another anti-c-erbB-2/HER2 MAb (Oncogene Science, Manhasset, NY). Identical results were found (data not shown). A human breast cancer with HER2 overexpression and amplification was included with all slide runs. Additional controls included SK-BR-3 and MDA-MB-231 cells. Negative control slides omitted the primary antibody but included all other steps of the procedure.

HIC Scoring. For COX-2, weighted score was computed that represented the product of percentage of tumor cell positivity and intensity, as described previously (46). Percent tumor cell positivity was categorized as follows: 0, <5%; 1, 5–25%; 2, 26–50%; 3, 51–75%, and 4, >75%. Staining intensity was graded as absent (0), weak (1+), medium (2+), or strong (3+). The intensity of the invasive tumor and of DCIS (when it existed on the same slide) were determined separately. On the basis of weighted scores, expression was categorized as negative or low (0–4), intermediate (5–8), or high (9–12). Localization of HER2 staining was described as cytoplasmic or membranous. Cases considered positive for HER2 had membranous staining in at least 10% of tumor cells and intensity scored as 0–3+. Before the study specimens were scored, representative sections displaying each of the four staining intensities were reviewed by two examiners.

Immunoblotting. Frozen tissue samples were homogenized in Tris-HCl buffer (pH 7.4) containing 0.5% NP40 and protease inhibitors (Boehringer Mannheim, Indianapolis, IN). Cultured cell lines were processed according to standard procedures, and a cell lysate was prepared. Protein extraction was performed on tissue and cell lysates, and the protein concentration was determined in soluble supernatants in each sample. We then loaded 40 μg of protein per lane onto a SDS-polyacrylamide gel, and proteins were then transferred onto an Immobilon membrane (Millipore, Bedford, MA). Membranes were blocked with 5% nonfat dry milk. Blots were incubated overnight at 4°C with MAB against COX-2 (Cayman Chemical) at a dilution of 1:1000 and actin (Oncogene Science, Uniondale, NY). The level of protein expression was measured with the enhanced chemiluminescence detection system (Amersham, Arlington Heights, IL) according to the manufacturer’s instructions. Actin levels were analyzed as controls for protein loading.

RT-PCR. Total RNA was extracted and purified from human breast tumors and paired normal tissues using the RNeasy mini Kit (Qiagen, Valencia, CA) according to the manufacturer’s instructions. Total RNA (1 μg) was converted to cDNA by Superscript II reverse transcriptase (Life Technologies, Inc., Rockville, MD) in a total reaction volume of 20 μl. The cDNA was PCR-amplified with AmpliTaq DNA polymerase (Perkin-Elmer/Applied Biosystems, Foster City, CA). Relative expression of COX-2 mRNA was analyzed using quantitative multiplex RT-PCR with β-actin as an internal control. The reaction mixture contained 1 unit of Hotstart polymerase (Qiagen, Mannheim, Indianapolis, IN). Forward (F) 5′-GGGCAATCATCAG-3′ (386-bp product); for β-actin, (F) 5′-GGGATCCATCAGC-3′ (386-bp product); for β-actin, (F) 5′-TCATTGCTATC-3′ (540-bp product). The reaction was performed according to the following program: 15 min at 94°C for activating the polymerase, 38 cycles (28 cycles for β-actin) at 94°C for 30 s for denaturation, 1 min at 61°C for annealing, and extension for 1 min at 72°C, followed by an additional extension step at 72°C for 7 min. The PCR products were run on a 2.0% agarose gel and then stained with 0.5 μg/ml ethidium bromide. Stained bands on the gel were visualized under UV light and then photographed.

Results

Patient Characteristics. We evaluated archival tissue specimens from 57 women with invasive breast cancer, as shown in Table 1. Age...
at diagnosis ranged from 25 to 78 years (median age, 47 year), and 36 (63%) women were less than age 50. Eighty percent of the tumors were infiltrating ductal adenocarcinomas. Adjacent DCIS was found in 13 of the 57 cases. Two patients had exclusively DCIS and no invasive cancer. Patient characteristics, including tumor stage, nuclear grade, hormonal receptor status, and preoperative treatment history, are outlined in Table 1. At a median follow-up of 19 months (range, 1–86 months), all but two patients were alive.

**COX-2 Immunoreactivity.** Cytoplasmic COX-2 expression was detected at an intermediate or high level by a semiquantitative IHC method in neoplastic epithelial cells in 18 of 42 (43%) primary breast cancers (Table 2). Negative or low-level staining for COX-2 was observed in 57% of these invasive tumors. COX-2 was detected at an intermediate or high level in 10 of 16 (62.5%) cases of DCIS adjacent to cancer. The two cases of DCIS alone showed an intermediate level of COX-2. COX-2 staining was granular and localized to the tumor cytoplasm (Fig. 1). COX-2 expression was less heterogeneous in DCIS cases than in invasive cancers. Within the same tissue sections, COX-2 expression in invasive breast tumors and adjacent DCIS were highly correlated (P = 0.019). COX-2 was expressed in benign ductular epithelial cells adjacent to tumor in 81% of cases (Table 2). Staining in normal-appearing epithelia was often focal and of similar or reduced intensity relative to neoplastic epithilia. Stromal staining for COX-2 in fibroblasts and other interstitial cells was infrequently detected. Specificity of staining was confirmed by use of a COX-2 sequence-specific blocking peptide that completely suppressed staining in all cases.

**COX-2 mRNA by RT-PCR.** COX-2 mRNA expression was analyzed in paired tumor and normal tissue specimens from breast cancer patients (n = 9), using COX-2 specific primers and RT-PCR. As shown in Fig. 2, COX-2 was detected in tumor and normal breast tissue from all nine patients. The level of COX-2 mRNA in tumors was shown to exceed that in normal tissues in eight of these paired specimens from the same patients.

**HER2/neu Expression and Gene Amplification.** HER2 was analyzed by IHC in all breast cancer cases. Membranous staining of 3+ intensity was detected in 17 of 55 (31%) invasive breast cancers (Fig. 1E), and was 2+ in 4 and 1+ in 5 cases. Results for HER2 gene amplification by FISH were available on 20 cases. Five of 7 (72%) tumors with 3+ membranous staining and all 2+ tumors (n = 4) were amplified. HER2 gene amplification was not found in the cases that stained 1+ or were negative for HER2. A significant correlation was observed between membranal HER2 staining and gene amplification (P = 0.003). Cytoplasmic HER2 staining was detected in 15 of 55 (27%) cancers; 23 (42%) cases were negative for HER2. Cytoplasmic staining was granular, and the intensity was 2+ or 3+. HER2 was not amplified in these cytoplasmic or the negative cases.

**Association of COX-2 with Clinicopathological Variables.** COX-2 protein expression in invasive breast cancers or adjacent DCIS did not significantly correlate with any of the clinicopathological variables examined, including hormonal status. No difference in the frequency of COX-2 expression was found in tumors from patients receiving neoadjuvant therapy (n = 16) versus untreated patients (P = 0.16). No association was found between COX-2 and HER2 immunostaining or gene amplification.

**COX-2 in Breast Carcinoma Cell Lines.** Human breast cancer cell lines (SK-BR-3, MDA-MB-231, and MCF-7) were analyzed for COX-2 and HER2 expression by immunoblotting. We studied the estrogen-dependent, poorly invasive, and nonmetastatic MCF-7 cell line (47) and the estrogen-independent, highly invasive, and metastatic MDA-MB-231 cell line (48). SK-BR-3 cells are less invasive and estrogen dependent (49). SK-BR-3 and MCF-7 cells were found to lack COX-2 proteins, and MDA-MB-231 cells displayed a low level of COX-2 (Fig. 3, A and B). To determine whether HER2 can regulate the expression of COX-2, we analyzed MCF-7 cells stably transfected with the HER2. cDNA MCF-7/HER2 transfectants were found to express COX-2 in contrast to parental cells, suggesting induction of COX-2 by HER2 (Fig. 3B). As shown previously, SK-BR-3 cells overexpressed HER2 in the cellular membrane (Fig. 1F) and displayed HER2 amplification (Fig. 3A; Ref. 49). MDA-MB-231 cells expressed a low level of HER2 proteins (Ref. 48; Fig. 3A). The HCA-7 colorectal cancer cell line is known to constitutively express COX-2 and was used as a positive control (50). The COX-2-negative HCT116 colon cancer cell line (8) were used as a negative control for COX-2 protein expression. HCA-7 cells were found to overexpress COX-2 and HER2 proteins (Fig. 3A). HCT116 cells lacked COX-2 but expressed HER2 proteins (Fig. 3A). Immunostaining of these cell lines was concordant with immunoblotting results (data not shown). Neither HCA-7 nor HCT116 cells had HER2 amplification (Fig. 3A).

**DISCUSSION**

We detected frequent expression of COX-2 in epithelial cells of human breast adenocarcinomas and adjacent DCIS, which may ac-

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**Table 1. Clinicopathological variables in human breast neoplasms.**

<table>
<thead>
<tr>
<th>Variable</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clinical stage</td>
<td></td>
</tr>
<tr>
<td>0 (DCIS)</td>
<td>2</td>
</tr>
<tr>
<td>I</td>
<td>15</td>
</tr>
<tr>
<td>II A, B</td>
<td>24</td>
</tr>
<tr>
<td>III</td>
<td>12</td>
</tr>
<tr>
<td>IV</td>
<td>1</td>
</tr>
<tr>
<td>Neoadjuvant treatment</td>
<td></td>
</tr>
<tr>
<td>Chemotherapy ± hormonal</td>
<td>16</td>
</tr>
<tr>
<td>None</td>
<td>41</td>
</tr>
<tr>
<td>Nuclear grade</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>7</td>
</tr>
<tr>
<td>2</td>
<td>22</td>
</tr>
<tr>
<td>3</td>
<td>25</td>
</tr>
<tr>
<td>Lymphovascular invasion</td>
<td></td>
</tr>
<tr>
<td>No</td>
<td>28</td>
</tr>
<tr>
<td>Yes</td>
<td>19</td>
</tr>
<tr>
<td>Histology</td>
<td></td>
</tr>
<tr>
<td>Ductal</td>
<td>44</td>
</tr>
<tr>
<td>Lobular</td>
<td>2</td>
</tr>
<tr>
<td>DCIS*</td>
<td>16</td>
</tr>
<tr>
<td>Other</td>
<td>7</td>
</tr>
<tr>
<td>Estrogen receptor</td>
<td></td>
</tr>
<tr>
<td>Positive</td>
<td>36</td>
</tr>
<tr>
<td>Negative</td>
<td>13</td>
</tr>
<tr>
<td>ND*</td>
<td>8</td>
</tr>
<tr>
<td>Progesterone receptor</td>
<td></td>
</tr>
<tr>
<td>Positive</td>
<td>26</td>
</tr>
<tr>
<td>Negative</td>
<td>22</td>
</tr>
<tr>
<td>ND*</td>
<td>9</td>
</tr>
</tbody>
</table>

* Includes stage 0 and DCIS adjacent to invasive cancer.
** Includes DCIS alone (n = 2).

**Table 2. Analysis of COX-2** expression by IHC in human breast tissues.**

<table>
<thead>
<tr>
<th>Variable</th>
<th>n (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Invasive cancer (n = 42)</td>
<td></td>
</tr>
<tr>
<td>Negative or low</td>
<td>24 (57)</td>
</tr>
<tr>
<td>Intermediate</td>
<td>8 (19)</td>
</tr>
<tr>
<td>High</td>
<td>10 (24)</td>
</tr>
<tr>
<td>DCIS (n = 16)</td>
<td></td>
</tr>
<tr>
<td>Negative or low</td>
<td>6 (37)</td>
</tr>
<tr>
<td>Intermediate*</td>
<td>8 (50)</td>
</tr>
<tr>
<td>High</td>
<td>2 (13)</td>
</tr>
<tr>
<td>Normal epithelium (n = 48)</td>
<td></td>
</tr>
<tr>
<td>Negative</td>
<td>9</td>
</tr>
<tr>
<td>Positive</td>
<td>39 (81)</td>
</tr>
</tbody>
</table>

* COX-2 expression was categorized based on weighted scores (product of staining intensity and percentage of tumor cell positivity).
** Includes DCIS alone (n = 2).
count for the elevated levels of PGs, including PGE_2, found in these tumors. We report the largest series to date using a semiquantitative IHC approach. We found that COX-2 is expressed at intermediate or high levels in 43% of human breast carcinomas and in 62.5% of DCIS. The higher frequency of COX-2 in DCIS versus invasive cancer suggests that up-regulation of COX-2 is a relatively early event in mammary carcinogenesis. Given that DCIS was adjacent to invasive tumor in all but two cases (which expressed COX-2), further study of COX-2 in patients with DCIS alone is warranted. Our findings in breast neoplasms differ from those reported in human colorectal adenomas, where COX-2 was detected at a reduced frequency relative to invasive cancers (7, 8). COX-2 staining was detected in normal-appearing breast epithelium in 81% of cases and was often focal and of similar or reduced intensity relative to tumor. Despite frequent expression of COX-2 in normal epithelia from breast cancer cases, COX-2 mRNA in eight of nine tumors, was increased in eight of nine tumors relative to paired normal tissues from the same patients.

COX-2 expression was unrelated to the clinicopathological variables examined, including clinical stage and hormonal status. Given data indicating that activation of the HER2/HER3 pathways in colon cancer cell lines can induce COX-2 mRNA and protein as well as PGE_2 biosynthesis (44), we compared the expression of COX-2 and HER2 in breast cancers by IHC. No association between COX-2 and HER2 expression or amplification was found; however, COX-2 is regulated by multiple factors, including cytokines, growth factors, and tumor promoters; consequently, a direct relationship between COX-2 and HER2 may not be readily observed. In addition, HER2 can undergo posttranslational modification, i.e., tyrosine phosphorylation, resulting in its activation. Therefore, the level of HER2 expression may not correlate with activity and its ability to induce COX-2. Use of an anti-HER-2 antibody may allow further examination of the relationship between HER-2 and COX-2.

Fig. 1. A and B, COX-2 staining is detected in the cytoplasm of tumor cells within DCIS. Normal breast ductular epithelium (dotted arrow) shows reduced intensity of COX-2 staining relative to DCIS (solid arrow). C, invasive breast carcinoma lacking COX-2 staining. D, infiltrating ductal adenocarcinoma of the breast with a high level of COX-2 expression. E, membranous HER2 staining (3+) in an infiltrating ductal breast carcinoma. F, SK-BR-3 breast cancer cells overexpress HER2 in the cell membrane in contrast to MDA-MB-231 cells (inset).

Forced expression of HER2 in MCF-7 cells, which lack endogenous COX-2 proteins, resulted in low-level COX-2 expression, indicating that COX-2 can be induced by HER2. HCA-7 colon cancer cells, which constitutively express COX-2 (50), were found to over-express HER2. Growth of these cells in culture has been shown to be inhibited by anti-HER2 antibodies and celecoxib, as were HCA-7 xenografts grown in nude mice (50). Furthermore, inhibition of HER2/HER3 signaling by an anti-HER3 antibody decreased both HER2/HER3 heterodimerization and COX-2 expression (44). Taken
PGE2 levels are involved in breast carcinogenesis and that NSAIDs can induce apoptosis in colon carcinoma cell lines (52). NSAIDs have been shown to inhibit breast and intestinal tumors in animal models, and the selective COX-2 inhibitor celecoxib has been shown to significantly reduce the number of polyps in patients with colorectal familial adenomatous polyposis (53). Taken together, inhibition of COX-2 by NSAIDs may be an important mechanism-based strategy for the prevention and treatment of human breast cancer.

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