Chemopreventive Efficacy of Naproxen and Nitric Oxide–naproxen in Rodent Models of Colon, Urinary Bladder, and Mammary Cancers

Vernon E. Steele,1 Chinthalapally V. Rao,2 Yuting Zhang,2 Jagan Patlolla,2 Daniel Boring,1 Levy Kopelovich,1 M. Margaret Juliana,3 Clinton J. Grubbs3 and Ronald A. Lubet1

Abstract Nonsteroidal anti-inflammatory drugs (NSAID) have been highly effective in preventing colon, urinary bladder, and skin cancer preclinically, and also in clinical trials of colon adenoma formation. However, certain NSAIDs cause gastrointestinal ulceration and may increase cardiovascular events. Naproxen seems to cause the lowest cardiovascular events of the common NSAIDs other than aspirin. Nitric oxide (NO)-naproxen was tested based on the finding that adding a NO group to NSAIDs may help alleviate GI toxicity. In the azoxymethane-induced rat colon aberrant crypt foci (ACF) model, naproxen administered at 200 and 400 ppm in the diet reduced mean ACFs in the colon by about 45% to 60%, respectively. NO-naproxen was likewise administered in the diet at roughly equimolar doses (300 and 600 ppm) and reduced total ACF by 20% to 40%, respectively. In the hydroxybutyl (butyl) nitrosamine rat urinary bladder cancer model, NO-naproxen was given at 183 or 550 ppm in the diet, and naproxen at 128 ppm. The NO-naproxen groups had 77% and 73% decreases, respectively, in the development of large urinary bladder tumors, whereas the 128 ppm naproxen group also showed a strong decrease (69%). If treatments were started 3 months after hydroxybutyl (butyl) nitrosamine, NO-naproxen (550 ppm) and naproxen (400 ppm) were also highly effective (86-94% decreases). In the methylnitrosourea-induced mammary cancer model in rats, NO-naproxen and naproxen showed nonsignificant inhibitions (12% and 24%) at 550 and 400 ppm, respectively. These data show that both naproxen and NO-naproxen are effective agents against urinary bladder and colon, but not mammary, carcinogenesis.

Perhaps the most strikingly positive group of agents tested to prevent colon, urinary bladder, and skin cancers in experimental animal models are the various specific and nonspecific cyclooxygenase (COX) inhibitors. It was shown over 20 years ago that nonspecific nonsteroidal anti-inflammatory drugs (NSAID) were highly effective in the azoxymethane (AOM)-induced rat colon cancer model and the hydroxybutyl (butyl) nitrosamine (OH-BBN)–induced rodent urinary bladder cancer model. Several years ago, our laboratories found that celecoxib, which preferentially inhibits COX-2 activity, was similarly effective in these models (1, 2). These latter findings helped validate COX-2 as a potential target for chemoprevention in a number of organs, including skin cancer (3–5). The studies also helped to support clinical trials in the prevention of colon adenomas and skin cancer (6).

Although the clinical chemoprevention results with celecoxib in the colon and skin seem promising, they must be balanced against the increase in cardiovascular (CV) problems associated with the selective COX-2 inhibitors (7). Although these CV problems are clearly associated with rofecoxib at its standard dose, major problems associated with the standard dose of celecoxib are less clear, although higher doses do yield an increase in CV events. Naproxen, which seems to have fewer CV effects than most NSAIDs, might prove to be an alternative. However, a second and more common side effect of NSAIDs is gastric bleeding, perhaps to a slightly lesser degree with specific COX-2 inhibitors. In an attempt to overcome this adverse effect, nitric oxide (NO)–linked derivatives have been synthesized with various NSAIDs (7, 8). It is clear, both in preclinical studies and in more limited human studies, that this class of agents does have gut-sparing effects (9–11). Our laboratories have reported that NO-aspirin is effective in preclinical models of colon cancer (12).

The three cancer models used in the present studies are relatively standard, and have been used by numerous investigators to screen for potential chemopreventive agents. The animals in the OH-BBN–induced urinary bladder cancer model...
develop large invasive tumors that show many of the gene and protein expression changes associated with invasive bladder cancer in humans (2). The rats in the methylnitrosourea (MNU)-induced mammary cancer model develop minimally invasive estrogen receptor–positive (ER+) mammary cancers that by array analysis appear similar to well-differentiated human estrogen receptor–positive breast cancer (13). This model has been shown to respond to a wide variety of potential chemopreventive agents including hormonal manipulations (selective estrogen receptor modulators, aromatase inhibitors, and ovariectomy) that significantly inhibit the development of human estrogen receptor–positive breast cancer. Additionally, the AOM-induced aberrant crypt foci (AOM-ACF) assay (which examines the development of aberrant crypts) was used because it was felt to be a precursor of colon cancer in rats (14). The ACF end point has been used to screen for a wide range of agents and has previously shown a high concordance with animal colon tumor assays. The drugs were administered either shortly after the last carcinogen treatment (AOM-ACFs, MNU-mammary) or in the OH-BBN bladder model both 2 weeks after the last OH-BBN treatment and 3 months later when precancerous lesions were already present.

It is now well recognized that NSAIDs and, more recently, COX-2 preferential inhibitors are highly effective in preventing the development of urinary bladder cancer in rodent models. Most of the earlier studies initiated treatment with the chemopreventive agents beginning with the first dose of carcinogen administration. We reported with celecoxib, however, that administration beginning after the final OH-BBN administration was equally effective, implying that most of the preventive effect of NSAIDs was later in cancer development (2). This later administration of NSAIDs both overcomes questions regarding alterations in OH-BBN metabolism and more closely parallels the timing of a likely clinical intervention where treatment will be initiated later in tumor progression. Our laboratories have used the late intervention protocol as a standard for testing this class of chemopreventive agents.

Materials and Methods

Reagents

Naproxen (Fig. 1) was obtained from Sigma and NO-naproxen was provided by the National Cancer Institute Division of Cancer Prevention. The carcinogen OH-BBN was purchased from TCI America, whereas MNU and AOM were purchased from Midwest Research Institute. Rats for the urinary bladder and mammary study were obtained from Harlan Sprague-Dawley, Inc. Rats for the colon studies were purchased from Harland Barrier. The diets were purchased either from Teklad (Harlan Teklad) or Bioserv, and tap water was provided ad libitum. Diets for colonic ACF assay were based on the modified AIN-76A containing 5% corn oil by weight (American Institute of Nutrition). Chemopreventive agents used in the colon model were premixed with a small quantity of casein and then blended into bulk diet using a Hobart Mixer. In the urinary bladder and mammary cancer studies, naproxen was mixed directly into the diet (Teklad mash diet), whereas NO-naproxen was premixed with ethanol, trioc-tanolin, and corn oil (12, 9, and 9 g/kg diet, respectively) to ensure a homogeneous mixture in the feed. Both control and experimental diets were prepared weekly and stored in a cold room. Agents content in the experimental diets were determined periodically in multiple samples taken from the top, middle, and bottom portions of individual diet preparations to verify uniform distribution. Rats were allowed ad libitum access to the respective diets.

Rat colon ACF model

Seven-week-old male Fischer-344 rats were randomized into groups (n = 18 rats/group) and fed AIN-76A control diet. At 8 wk of age, rats intended for carcinogen treatment were injected s.c. with AOM at a dose of 15 mg/kg BW once weekly for 2 wk, and those intended for vehicle treatment received an equal volume of normal saline. Three days after the second AOM treatment, groups of rats were fed either the control diet or experimental diet containing 200 or 400 ppm naproxen and 300 or 600 ppm NO-naproxen. These dietary regimens were continued until termination of the experiment, i.e., 8 wk after the second AOM treatment. Rats were sacrificed by CO2 euthanasia, and all organs were examined grossly. Colons were then evaluated for ACF. For this evaluation, they were opened lengthwise from the anus to the caecum, and then fixed flat with mucosa on the upper side between filter papers in 10% buffered formalin.

Quantification of ACF

Topographical analysis of the colonic mucosa was done according to Bird (14) and is routinely performed in our laboratory (15). After a minimum of 24 h, fixed colons were stained with 0.2% methylene blue solution for 5 to 10 min, placed mucosal side up on a microscopic slide, and viewed under a light microscope. The total number of ACF in the entire colon was determined in every 2-cm section of the colon, starting from the distal (taken as 0 cm) to the proximal end of the colon. Aberrant crypts were distinguished from the surrounding normal crypts by their increased size, increased distance from lamina basal surfaces of cells, and easily discernible pericryptal zone. The parameters used to assess the aberrant crypts were incidence and multiplicity. Aberrant crypt multiplicity was determined as the number of crypts in each focus and categorized as small (if less than four crypts/focus) or large (if containing four or more aberrant crypts/focus). ACF data are reported as mean ± SEM. Statistical differences between control and treated groups were evaluated using unpaired t test with Welch’s correction (to correct for unequal group variances). Differences between groups were considered significant at P < 0.05.

Rat urinary bladder model

The rat OH-BBN–induced urinary bladder model was performed as previously described (2, 16). Briefly, female Fischer 344 rats were obtained from Harlan Sprague-Dawley, Inc., at 4 wk of age. Beginning at 56 d of age, the rats were treated twice a week with 150 mg OH-BBN/gavage for 8 wk. There were 29 to 30 rats per group. During the studies, the rats were weighed once per week and palpated for bladder tumors biweekly. Diet supplementation with naproxen (400 or 128 ppm) or NO-naproxen (550 or 183 ppm) was initiated either 2 wk or 3 mo after the end of the OH-BBN treatments. The studies were terminated 7 or 8 mo after the last of the OH-BBN treatments. At necropsy, urinary bladders with lesions were excised and weighed. The
weights and the number of rats with large tumors (≥200 mg) were recorded as end points for cancer prevention. Histopathology of all large tumors showed that they were carcinomas. A bladder with no lesions would weigh ~80 to 90 mg. Statistical analysis of bladder weights were performed by the Wilcoxon rank test and the final incidence of large urinary bladder cancers were analyzed by the Fischer’s exact test (2, 16).

**Rat mammary model**

The MNU-induced rat mammary cancer model was performed as previously described (16). Female Sprague-Dawley rats were obtained at 4 wk of age from Harlan Sprague-Dawley, Inc. The carcinogen, MNU, was injected i.v. (75 mg/kg BW) via the jugular vein when the animals were 50 d of age. Each group had 15 rats. Following MNU, the rats were weighed 1x/wk and palpated 2x/wk for the development of mammary cancers. Because the tumors are close to the skin, they can be palpated by experienced technicians as early as 2 mm in size. All palpable tumors are recorded on a diagram of a rat in a logbook such that after histologic classification the latency period of the cancers can be determined. The incidence, multiplicity, and weight data in Table 2 reflect only cancers. The agents (400 ppm naproxen or 550 ppm NO-naproxen) were administered in the diet beginning 5 d after carcinogen treatment and continued until the end of the experiment (148 d after MNU). The mammary cancer incidence and multiplicity were analyzed using Logrank analysis and the Armitage test, respectively (17).

**Results**

**Inhibition of colon carcinogenesis in AOM treated rats**

In the AOM-induced rat colon ACF model, both naproxen and NO-naproxen were tested, at equimolar doses, and were shown to inhibit both the total number of ACF per colon and the number of multicrypt foci per colon (Figs. 2 and 3). These doses are, in fact, below the standard clinical dose of naproxen using standard animal/human scaling factors. In this assay, the parent compound (naproxen) seemed to be slightly more effective in inhibiting ACF than the NO-naproxen, but the differences were not significant. Naproxen at 200 and 400 ppm inhibited ACFs per colon by 40% and 60%, respectively, whereas NO-naproxen at 300 and 600 ppm inhibited 20% and 40%, respectively. If one considers only the larger multicrypt ACF, then the naproxen decreased larger ACFs by 55% (200 ppm) and 70% (400 ppm), and NO-naproxen reduced large ACFs by 30% (300 ppm) and 50% (600 ppm). Importantly, both agents showed dose-dependent suppression of AOM-induced rat colonic ACF formation.

**Inhibition of bladder cancer in OH-BBN–treated rats**

Both early and late intervention protocols were used to examine the cancer preventive efficacy of naproxen and NO-naproxen. When administration of the agents at equimolar doses was started early (or 2 weeks post-OH-BBN), reductions in the incidence of large urinary bladder cancers were reduced by 77% for NO-naproxen at 183 ppm, 73% for NO-naproxen at 550 ppm, and 69% for naproxen at 128 ppm when compared with the controls (Table 1). Thus, the results for NO-naproxen showed a slightly higher inhibition than the parent compound. The final body weights were not significantly changed for any experimental group. Subsequently, both naproxen and NO-naproxen were tested when treatment was initiated at 3 mo after the last OH-BBN treatment. Note that the naproxen dose was higher (400 ppm) than that used in the first study (128 ppm). We used two high equimolar doses for comparison in this later intervention study, since typically efficacy is lower with later treatments. At this time, all the animals had preinvasive lesions (mostly hyperplastic) and roughly 70% had small, established cancers. Animals were then followed to our normal end points of incidence of large tumors and final bladder weights. With the later treatment, naproxen (400 ppm) reduced large tumors 94% and the NO-naproxen (550 ppm) caused a 86% reduction (Table 1). A 54% and 58% reduction in mean urinary bladder weights was also observed in the naproxen and NO-naproxen groups, respectively. These data consistently showed little differential effect between naproxen and NO-naproxen with respect to efficacy in preventing bladder tumors.

**Inhibition of mammary cancer in MNU-treated rats**

Both naproxen and NO-naproxen showed a nonsignificant preventive effect on MNU-induced rat mammary cancers (Table 2). The final body weights were not significantly changed for any experimental group. Naproxen at 400 ppm in the diet reduced the mammary cancer incidence by 27%, whereas NO-naproxen at 550 ppm reduced the incidence only
13%. Neither reduction was significantly different from the controls. The average number of tumors/rat was reduced by 24% in the naproxen treated rats, whereas only a 12% reduction was seen in the NO-naproxen–treated rats (Fig. 4). Again, neither result was significantly different from control tumor multiplicity. The weight of the mammary tumors was statistically different from the controls in rats receiving NO-naproxen, although the biological significant is questionable in lieu of there being no effect on cancer incidence or multiplicity.

Discussion

In preclinical animal models, both a variety of NSAIDs and the COX-2 inhibitor celecoxib have been uniformly effective against carcinogen-induced colon and urinary bladder cancers (18–22). For a variety of reasons, including the fact that COX-2 is presumably a major chemopreventive target and that it might have fewer gastric effects, celecoxib progressed more rapidly than other NSAIDs to large-scale clinical trials. However, when examined in a large placebo-controlled trial at doses beyond those normally recommended, celecoxib increased the incidence of CV events starting ~18 months after the initiation of treatment (23). These results, and the even more striking results with rofecoxib, raised the possibility that most NSAIDs might increase CV incidents. At this time, it is felt that the nonspecific NSAID naproxen might have the least CV effects of any of the NSAIDs. Results of studies with naproxen have been mixed, with certain studies showing limited increases in CV risk relative to placebo and certain studies showing CV protection (24, 25). Nevertheless, it has consistently caused fewer CV effects than any of the other NSAIDs and may even be cardioprotective (26, 27). In addition, a recent American Gastroenterological Association panel has recommended the use of naproxen for persons of moderate CV risk based on the initial estimation that this agent might have fewer CV problems than other NSAIDs (27). This was

| Table 1. Weights of urinary bladders with OH-BBN induced lesions in Fischer-344 rats treated with naproxen and NO-naproxen |

<table>
<thead>
<tr>
<th>Treatment*</th>
<th>Mean final body weights (g)</th>
<th>Urinary bladder + lesions (mg)†</th>
<th>Number of large urinary bladder cancers‡</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agent started 2 wk post–OH-BBN</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NO-naproxen, 550 ppm in diet</td>
<td>232</td>
<td>186 ± 22 (71% ↓)§</td>
<td>7/30 (73% ↓)§</td>
</tr>
<tr>
<td>NO-naproxen, 183 ppm in diet</td>
<td>231</td>
<td>161 ± 11 (75% ↓)§</td>
<td>6/30 (77% ↓)§</td>
</tr>
<tr>
<td>Naproxen, 128 ppm in diet</td>
<td>225</td>
<td>217 ± 32 (66% ↓)§</td>
<td>8/30 (69% ↓)§</td>
</tr>
<tr>
<td>None</td>
<td>220</td>
<td>641 ± 104</td>
<td>25/29</td>
</tr>
<tr>
<td>Agent started 3 mo post–OH-BBN</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NO-naproxen, 550 ppm in diet</td>
<td>227</td>
<td>136 ± 7 (58% ↓)§</td>
<td>2/29 (86% ↓)§</td>
</tr>
<tr>
<td>Naproxen, 400 ppm in diet</td>
<td>226</td>
<td>148 ± 15 (54% ↓)§</td>
<td>1/30 (94% ↓)§</td>
</tr>
<tr>
<td>None</td>
<td>224</td>
<td>323 ± 33</td>
<td>15/30</td>
</tr>
</tbody>
</table>

*Rats received OH-BBBN beginning at 56 d of age. Treatment with naproxen and NO-naproxen initiated either 2 wk or 3 mo after the final OH-BBN treatment; studies terminated 8 and 7 mo after final OH-BBN, respectively.

†Urinary bladder plus lesion weights were those observed at sacrifice of the rats. Values are means ± SEM (number in parenthesis is percent decrease from control).

‡Values represent the number of rats with urinary bladder weights of ≥200 mg divided by the number of rats in the group. Number in parenthesis is percent decrease from control.

§Significantly different (P < 0.01) from the respective control group.

| Table 2. Effects of NO-naproxen and naproxen against MNU-induced mammary cancer |

<table>
<thead>
<tr>
<th>Treatment*</th>
<th>Mean final body weights (g)</th>
<th>Mammary cancers†</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>% incidence</td>
<td>Number/rat</td>
</tr>
<tr>
<td>NO-naproxen, 550 ppm in diet</td>
<td>240</td>
<td>87</td>
</tr>
<tr>
<td>Naproxen, 400 ppm in diet</td>
<td>251</td>
<td>73</td>
</tr>
<tr>
<td>None</td>
<td>251</td>
<td>100</td>
</tr>
</tbody>
</table>

*MNU administered to rats (15/group) at 50 d of age. Chemopreventive agents initiated at 55 d of age.

†Incidence, number, and weight of mammary tumors at end of study (148 d after MNU). Number in parenthesis is percent decrease from control.
our rationale for evaluating the efficacy of naproxen. Interestingly, this agent has infrequently been used in preclinical chemoprevention studies. The second major toxicity associated with the use of NSAIDs is the development of gastric lesions in susceptible individuals. To address this problem, we examined NO-naproxen because there is both preclinical and clinical data showing that the NO-NSAIDs have lower gastric toxicity than the parent NSAIDs (9, 10).

One of the major concerns regarding doses used in animal studies is their comparability to human doses. Although one might attempt to compare serum levels in animals and humans, this is extremely difficult when the agent is administered by diet. A reasonable approach is to use general scaling factors. The doses of naproxen used in the rat studies were between 128 and 400 ppm in the diet, which is equivalent to 12 and 36 mg/kg body weight. Using a 6-fold scaling factor to extrapolate rat doses to human doses, this would be equivalent to human doses of 2 and 6 mg/kg. Such doses would translate to human doses of 160 and 480 mg in a human weighing 80 kg. These doses are comparable with a single naproxen dosing in humans of approximately 225 and 500 mg, which would correspond to one or two standard doses of 225 mg/day. It is important to note that in the studies described here, we found that doses less than the standard human equivalent dose were still highly effective in preventing both colon and urinary bladder cancers. These doses can be compared with the classic doses of celecoxib used in animal studies (1,000-1,500 ppm), which are approximately five to eight times higher than the recommended human dose using similar scalings. The possibility that naproxen is effective at significantly less than the standard human dose (although interesting), would require detailed dose reduction studies to confirm.

The reduction in ACF per colon by naproxen and NO-naproxen are comparable with that normally seen with a variety of NSAIDs. In our studies, the parent compound naproxen inhibited total ACFs slightly more than NO-naproxen, but both were moderately (40-60% inhibition) effective. When measuring only larger multicrypt foci, the effect is more pronounced (50-70% inhibition); again, the naproxen was slightly more effective than the NO-naproxen. These two NSAID compounds were effective in the colon because the inflammatory process is proposed to drive the cancer process in this organ. The ACF has been recognized as an early preneoplastic lesion of colon cancer (28, 29). It is generally observed that agents that inhibit colonic ACF formation will similarly exhibit chemopreventive activity against colon cancer (30). Previous studies have shown that reduction of colon crypt multiplicity of four or more ACFs/focus has been a consistent predictor of colon tumor inhibition (31, 32).

In the OH-BBN urinary bladder model, both naproxen and NO-naproxen were highly active in blocking the development of urinary bladder cancers. Again in bladder cancer the inflammatory process is known to promote cancer development. Clinical trials with NSAIDs are ongoing. Most importantly, these agents were still highly effective even when the administration was initiated after microscopic cancers already existed. This implies that most of the preventive activity seen in early intervention studies may be actually due to efficacy late in the study. Furthermore, these results show the promise that these agents may be preventive in a late or adjuvant clinical setting. This is particularly important in view of the high recurrence rate for human bladder cancer.

The mammary findings are not surprising, and replicate what is typically seen for NSAIDs in the MNU-induced rat mammary cancer model, i.e., limited to moderate activity for most NSAIDs and COX-2 inhibitors (33). The data show modest nonsignificant reductions in mammary cancer incidence and multiplicity. Because the cancer process in the mammary gland is not driven to a large extent by the inflammatory process, such agents would likely have little effect in human breast cancer prevention. This study also shows that one does not see a striking effect due to any potential release of NO in the animals.

Overall, these data provide strong evidence for the continued development of naproxen and NO-naproxen, especially...
as chemopreventive agents for colon (where a variety of NSAIDs have proven clinically effective) and urinary bladder cancer. The lack of effects of these agents on mammary cancers is consistent with previous data from our laboratories regarding NSAIDs. Identifying NSAIDs that have minimal CV or GI toxicity will allow these compounds to be used clinically in the prevention of colon, urinary bladder, and skin cancer.

References


Disclosure of Potential Conflicts of Interest

No potential conflicts of interest were disclosed.

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