NONSTEROIDAL antiinflammatory drugs (NSAIDs) have been shown to reduce pain and opioid consumption and often accelerate recovery after surgery. However, perioperative inhibition of prostaglandin synthesis by NSAIDs may cause complications, including renal injury, gastric ulceration, and bleeding. Recent molecular studies distinguishing between constitutive cyclooxygenase-1 (COX-1) and inflammation-inducible cyclooxygenase-2 (COX-2) enzymes have led to the exciting hypothesis that the therapeutic and adverse effects of NSAIDs could be uncoupled. The purpose of this article is to review the mechanistic differences between nonselective NSAIDs and selective COX-2 inhibitors (COX-2Is) and to examine currently available COX-2 clinical trials to consider the role of these drugs in postoperative pain management.

Safety and Analgesic Efficacy of NSAIDs

The administration of NSAIDs is one of the most common nonopioid analgesic techniques currently used for postoperative pain management. The efficacy of NSAIDs for postoperative pain has been repeatedly demonstrated in many analgesic clinical trials. The efficacy of traditional NSAIDs can be summarized by results from recent meta-analyses of postoperative single-dose trials showing numbers needed to treat (to obtain one patient showing numbers needed to treat (to obtain one patient
preferentially reduce spontaneous postoperative pain, NSAIDs have comparable efficacy for both spontaneous and movement-evoked pain, the latter of which may be more important in causing postoperative physiologic impairment. Furthermore, NSAIDs have been shown to reduce postoperative opioid consumption and accelerate postoperative recovery after certain types of surgery and are thus thought to be an important component of balanced postoperative analgesic regimens.

The majority of data about adverse effects of NSAIDs come from the setting of chronic use for arthritis. However, perioperative inhibition of cyclooxygenase (also called prostaglandin H synthase) by NSAIDs may also cause serious complications, including renal injury, gastric ulceration, and excessive bleeding. Brief perioperative NSAID use in healthy adults does not seem to cause important renal dysfunction, but clinicians continue to be cautioned by occasional but recurring reports of perioperative NSAID-related renal failure. Similarly, cases of gastrointestinal ulceration or bleeding have been reported after brief NSAID use, making this an important risk to consider when using NSAIDs for postoperative pain. Finally, the potential for excessive, and infrequently catastrophic, perioperative blood loss due to NSAID use has been well documented as yet another hazard of these drugs. Careful patient screening for renal dysfunction, gastritis, gastric ulcers, or bleeding diathesis and judicious administration of NSAIDs may largely prevent these major complications. Rare NSAID-related problems, which are also thought to be due to cyclooxygenase inhibition, include hepatocellular injury, asthma exacerbation, anaphylactoid reactions, tinnitus, and urticaria.

Mechanisms of Analgesia and NSAID-related Adverse Effects

Traditional NSAIDs comprise a chemically diverse group of compounds (e.g., salicylates, benzothiazines, and indoleacetic, pyrrolacetic, and propionic acids)
which, among other actions, inhibit prostaglandin synthesis by competing with arachidonic acid for binding to the cyclooxygenase active site. Until recently, NSAIDs have been thought mainly to suppress the peripheral nociceptive manifestations of postinjury inflammation. After the conversion of membrane phospholipids to arachidonic acid by phospholipase A2 in the periphery, cyclooxygenase converts arachidonic acid to the cyclic endoperoxide prostaglandin G2 (fig. 1) and then acts as a peroxidase to reduce prostaglandin G2 to the cyclic endoperoxide prostaglandin H2. Several synthases then convert prostaglandin H2 to other prostaglandins (e.g. prostaglandin D2, prostaglandin E2, prostaglandin F2-alpha, prostaglandin I2) and to thromboxane A2. It has been observed that cyclooxygenase inhibition results in shunting of arachidonic acid to lipoxygenase pathways, resulting in increased leukotriene synthesis, a putative mechanism of NSAID-induced bronchospasm. NSAIDs are thought to reduce postoperative pain by suppressing cyclooxygenase-mediated production of prostaglandin E2, which is thought to be the primary inflammatory prostaglandin that directly activates and also up-regulates the sensitivity of peripheral nociceptors to cause pain. Prostaglandins have also been shown to play a role in spinal nociception, thus contributing to a growing body of evidence supporting a spinal analgesic mechanism of NSAIDs. NSAID-mediated suppression of prostaglandins and thromboxanes, which play a homeostatic role in the stomach (prostaglandin E2 and prostaglandin I2), kidney (prostaglandin E2), and platelets (prostaglandin I2 and thromboxane A2), is also thought to be the primary mechanism by which NSAIDs cause some of the adverse effects described above. In addition to these three major complications, inhibition of prostaglandin synthesis by NSAIDs is also thought to be the primary mechanism underlying NSAID-induced asthma and the suppression of heterotopic bone formation.

COX-1 and COX-2 Isoforms of Cyclooxygenase

Subsequent to cloning the gene that encodes for cyclooxygenase in 1988, several studies yielded the discovery of a second form of cyclooxygenase and distinguished between the constitutive COX-1 and the inducible COX-2 isoforms of cyclooxygenase. The advent of new selective COX-2Is has allowed the investigation of differential inhibition of COX-1 versus COX-2 such that NSAIDs, new and old, can be evaluated with respect to their COX-1/COX-2 inhibitory profile (table 1). The data shown in table 1 indicate that all NSAIDs have at least some effect on both COX-1 and COX-2 isoenzymes and that there are, as yet, no specific values that define a drug as a purely selective COX-2 inhibitor. COX-1 is active and present at a constant concentration in most tissues, particularly in the kidney, stomach, and platelets, where it plays a homeostatic and protective role through the production of prostaglandin E2 and prostaglandin I2. However, is normally present in only very low concentrations but is induced peripherally under conditions of inflammation. This functional distinction has led to the exciting hypothesis that selective COX-2Is could uncouple the therapeutic and adverse effects of traditional NSAIDs. However, it is important to note that some exceptions do exist, i.e., COX-2 plays a homeostatic role in the renal medulla, and COX-1 may produce some prostaglandins that contribute to inflammation. Also of great interest in pain management, recent work has shown that COX-2 is constitutively expressed in
brain and spinal cord and is further up-regulated after persistent noxious inputs such that spinal COX-2 inhibition may be an important mechanism for reducing postinjury hyperalgesia. Finally, COX-2 inhibition results in selective suppression of prostaglandin I<sub>2</sub> without affecting thromboxane A<sub>2</sub>. This imbalance may explain the potential for cardiovascular toxicity discussed in the section entitled “Safety of Selective COX-2 Inhibitors in the Treatment of Chronic Arthritis.”

Evidence Suggesting Potential Advantages of COX-2 Inhibitors

Administration of aspirin to arthritis patients resulted in decreased platelet aggregation, whereas the COX-2 selective celecoxib failed to inhibit platelet aggregation. Consistent with animal studies showing that COX-1 inhibition but not COX-2 inhibition leads to gastric ulceration, multicenter arthritis trials have reported decreased incidences of gastrointestinal ulceration with COX-2Is in comparison with nonselective NSAIDs. Although these data do not come from the postoperative setting, they do provide further support for the theoretical advantages of COX-2Is.

Safety of Selective COX-2 Inhibitors in the Treatment of Chronic Arthritis

The majority of postmarketing data about COX-2Is comes from experience with celecoxib and rofecoxib, which were approved in the United States in 1998 and 1999, respectively. Other COX-2Is available in Europe include meloxicam and nimesulide. The COX-2Is nimesulide and meloxicam were marketed in Europe long before the discovery of COX-2 and have since been used as molecular precursors for the development of newer COX-2Is. Currently, the major indication of chronic COX-2Is is for the treatment of arthritic pain, although early studies may suggest promise for the prevention of colorectal cancer and Alzheimer disease. Evidence gathered to date suggests that COX-2Is are safer than traditional NSAIDs with respect to gastrointestinal ulceration and bleeding but not renal dysfunction, and furthermore, COX-2Is may confer increased risk for cardiovascular events (e.g., cerebrovascular accident, angina, or myocardial infarction). Preclinical studies demonstrating the role of COX-2 in the kidney have been echoed by human data indicating that COX-2Is can cause sodium retention and decreased glomerular filtration rate and thus warrant similar precautions that are followed for traditional NSAIDs. Gastrointestinal safety data comes largely from two studies, the Vioxx Gastrointestinal Outcomes Research trial (VIGOR) and the Celecoxib Long-term Arthritis Safety Study (CLASS). In the VIGOR trial, rofecoxib was shown to cause a significantly lower incidence of upper gastrointestinal perforation, ulceration and bleeding as compared to naproxen. In the CLASS study, there was no difference in gastrointestinal toxicity between celecoxib and traditional NSAIDs across patients who were also taking low-dose aspirin; however, in patients not taking aspirin, celecoxib did demonstrate a lower incidence of symptomatic ulcers and ulcer complications compared to traditional NSAIDs. It was suggested that aspirin’s gastrointestinal risks eliminated celecoxib’s benefits. Important recent reports have suggested that COX-2Is cause an increased risk of thrombotic cardiovascular events. It has been postulated that COX-2Is may unfavorably alter the thromboxane-prostacyclin balance by inhibiting the vasoprotective prostacyclin (prostaglandin I<sub>2</sub>) but not the procoagulant thromboxane (thromboxane A<sub>2</sub>). In the VIGOR trial, rofecoxib caused a fourfold increase in the incidence of myocardial infarction compared to naproxen, whereas no increase in risk was observed for celecoxib in the CLASS trial. However, in the CLASS study, 22% of patients were taking low-dose aspirin for cardioprotection, and this trial did not include patients with rheumatoid arthritis.

### Table 1. COX-1 versus COX-2 Selectivity of Various NSAIDs

<table>
<thead>
<tr>
<th>Drug</th>
<th>COX-1 IC&lt;sub&gt;50&lt;/sub&gt; μM</th>
<th>COX-2 IC&lt;sub&gt;50&lt;/sub&gt; μM</th>
<th>COX-2/COX-1 IC&lt;sub&gt;50&lt;/sub&gt; Ratio</th>
<th>Assay Model</th>
</tr>
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<tbody>
<tr>
<td>Nonselective NSAIDs</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Piroxicam&lt;sup&gt;59&lt;/sup&gt;</td>
<td>0.0065</td>
<td>0.3</td>
<td>600</td>
<td>Cultured animal cells</td>
</tr>
<tr>
<td>Aspirin&lt;sup&gt;59&lt;/sup&gt;</td>
<td>1.67</td>
<td>278</td>
<td>166</td>
<td>Cultured animal cells</td>
</tr>
<tr>
<td>Indomethacin&lt;sup&gt;59&lt;/sup&gt;</td>
<td>0.028</td>
<td>1.68</td>
<td>60</td>
<td>Cultured animal cells</td>
</tr>
<tr>
<td>Ketorolac&lt;sup&gt;124&lt;/sup&gt;</td>
<td>0.00001</td>
<td>0.00007</td>
<td>7</td>
<td>Purified COX in vitro</td>
</tr>
<tr>
<td>Ibuprofen&lt;sup&gt;125&lt;/sup&gt;</td>
<td>12</td>
<td>80</td>
<td>6.7</td>
<td>Human monocytes</td>
</tr>
<tr>
<td>Diclofenac&lt;sup&gt;59&lt;/sup&gt;</td>
<td>1.57</td>
<td>1.1</td>
<td>0.7</td>
<td>Cultured animal cells</td>
</tr>
<tr>
<td>COX-2 inhibitors</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Meloxicam&lt;sup&gt;60&lt;/sup&gt;</td>
<td>4.8</td>
<td>0.43</td>
<td>0.09</td>
<td>Human whole blood</td>
</tr>
<tr>
<td>Nimesulide&lt;sup&gt;60&lt;/sup&gt;</td>
<td>9.2</td>
<td>0.52</td>
<td>0.06</td>
<td>Human whole blood</td>
</tr>
<tr>
<td>Celecoxib&lt;sup&gt;61&lt;/sup&gt;</td>
<td>6.3</td>
<td>0.96</td>
<td>0.15</td>
<td>Human whole blood</td>
</tr>
<tr>
<td>Rofecoxib&lt;sup&gt;61&lt;/sup&gt;</td>
<td>18.8</td>
<td>0.53</td>
<td>0.028</td>
<td>Human whole blood</td>
</tr>
</tbody>
</table>

COX = cyclooxygenase; IC<sub>50</sub> = drug concentrations that inhibit COX-1 or COX-2 activity by 50%; NSAID = nonsteroidal antiinflammatory drug.

Modified from Vane et al.<sup>63</sup>
who have an increased risk of cardiovascular complications.\textsuperscript{68} This remains a critical issue that requires further investigation, and until resolved, the potential for cardiovascular toxicity should be considered when using COX-2Is in patients at risk for coronary artery disease. Using the example that even brief perioperative $\beta$ blockade may significantly reduce mortality,\textsuperscript{73} the potential for postoperative COX-2I administration, however brief, to cause cardiovascular complications must be addressed. Further concerns regarding potential cardiovascular effects of COX-2Is are raised by a recent study in hypertensive osteoarthritis patients demonstrating that the COX-2I rofecoxib but not the NSAID namebutone increased nocturnal blood pressure.\textsuperscript{74}

**Selective COX-2 Inhibitors and Postoperative Pain**

In contrast to chronic treatment of arthritis, routine perioperative pain management generally occurs over a period of less than 4 weeks. However, surgery is associated with a set of special situations and problems, including blood loss, fluid shifts, risks of infection and thrombosis, and concomitant administration of anesthetic, analgesic, anticoagulant, and antibiotic drugs. For these reasons, the study and implementation of COX-2Is in the setting of perioperative pain require a unique perspective.

**Perioperative Clinical Trials of COX-2Is**

Literature searches of perioperative analgesic clinical trials of COX-2Is were conducted using the Cochrane Controlled Trials Register (third quarter 2002) and MEDLINE Database (1966 to February 2003). The database search strategy involved a Boolean search of [celecoxib OR etoricoxib OR flosulide OR meloxicam OR nimesulide OR parecoxib OR rofecoxib OR valdecoxib] AND [postoperative pain OR surgery OR surgical] AND [randomized controlled trials]. Trials reported in abstract form at recent scientific congresses were not included, given their preliminary nature and sometimes limited peer review. It has been well recognized that the use of a placebo control in analgesic trials serves to minimize the risk of false-positive and false-negative results.\textsuperscript{75,76} Only double-blind, randomized, placebo-controlled trials were evaluated in this review for these reasons. For differing measures of analgesic efficacy and side effects across these trials, statistically significant differences ($P < 0.05$) between treatments (e.g., COX-2I, NSAID comparator, placebo) were reported in this review. Most studies use multiple analgesic efficacy measures (e.g., analgesic use, pain intensity, pain relief). Only the outcome measure that demonstrated a difference was reported on in studies showing significant differences between treatment groups.

The above database search yielded a total of 27 publications of COX-2I trials, one of which described 6 trials, for a total of 32 controlled trials reported (table 2). These included 25 single-dose and 7 multidose trials (number of trials/drug) of rofecoxib (19), celecoxib (6), parecoxib (5), valdecoxib (3), nimesulide (1), and meloxicam (1). Some trials included more than one COX-2I among their treatment arms. Surgical procedures studied in these trials included minor oral surgery, gynecologic surgery, prostatectomy, lumbar discectomy, spinal fusion, and major joint arthroplasty. Reported efficacy measures also varied across studies and included pain intensity, pain relief, and consumption of other analgesics (table 3).

**Analgesic Efficacy**

Of the 19 rofecoxib trials, 17 demonstrated superior efficacy of rofecoxib to placebo,\textsuperscript{77–88} whereas two trials showed no difference.\textsuperscript{89,90} Five of the six celecoxib trials showed superiority to placebo,\textsuperscript{81,85,91–93} and one showed no difference.\textsuperscript{94} Parecoxib (the parenteral prodrug of valdecoxib),\textsuperscript{95–99} valdecoxib,\textsuperscript{80,100,101} nimesulide,\textsuperscript{102} and meloxicam\textsuperscript{103} were found to be superior to placebo in all reported trials. A recent meta-analysis of five rofecoxib trials that investigated 1,118 patients (of whom 211 received placebo and 464 received 50 mg rofecoxib) reported a number needed to treat of 2.3.\textsuperscript{104} Of 23 trial comparisons with nonselective NSAIDs (17), acetaminophen (3), or opioids (3), 13 NSAID\textsuperscript{81–85,92,97,99,102} and 1 opioid\textsuperscript{91} comparator were no different than the studied COX-2I (table 4). The studied COX-2I was observed to be more efficacious than the comparator NSAID\textsuperscript{79} or opioid\textsuperscript{78,91,97} in four comparative trials and less efficacious in two trials.\textsuperscript{81,93} It should be noted that the reported comparative studies are mostly single-dose trials that do not necessarily address relative potency of the drugs being compared. Thus, although one drug may be more potent than another, that drug can only be said to be more efficacious if optimal doses of each drug are being compared. Three trials compared COX-2Is to each other, two of which showed that rofecoxib is more efficacious than celecoxib,\textsuperscript{81,85} and the third of which demonstrated that valdecoxib is more efficacious than rofecoxib.\textsuperscript{80} One orthopedic trial by Reuben et al.\textsuperscript{96} showed that 50 mg rofecoxib given 1 h preoperatively was more effective at reducing postoperative pain than the same dose given 15 min postoperatively, suggesting that, as with traditional NSAIDs, COX-2Is may have preemptive analgesic effects.

**Postoperative Analgesic Dose–Response Studies**

The analgesic dose–response relation of COX-2Is has been studied in trials of rofecoxib,\textsuperscript{85,84} parecoxib,\textsuperscript{95–99} valdecoxib,\textsuperscript{100,101} and nimesulide\textsuperscript{102} (table 5). Rofecoxib was studied at 7.5, 12.5, 25, 50, 100, and 200 mg orally.
Table 2. Double-blind, Randomized, Placebo-controlled Postoperative COX-2 Inhibitor Trials

<table>
<thead>
<tr>
<th>Drug/Reference</th>
<th>Study Drug, Dose, No. of Patients</th>
<th>Comparators, Dose, No. of Patients</th>
<th>Surgery</th>
<th>Duration/Timing of Dose</th>
<th>Analgesic Efficacy Results</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Rofecoxib (oral)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>77</td>
<td>R, 50 mg, 31</td>
<td>PLC, 30</td>
<td>Lumbar disc</td>
<td>Hours before surgery + 30 min before surgery (2 doses)</td>
<td>R &gt; PLC</td>
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<tr>
<td>78</td>
<td>R, 50 mg, 182</td>
<td>PLC, 31, COD, 60 mg + A, 600 mg, 180</td>
<td>Oral surgery</td>
<td>Postoperatively as soon as moderate to severe pain (1 dose)</td>
<td>R &gt; COD + A &gt; PLC</td>
</tr>
<tr>
<td>79</td>
<td>R, 50 mg, 121</td>
<td>PLC, 63, D, 50 mg TID, 121</td>
<td>Oral surgery</td>
<td>R: immediately after surgery (1 dose)</td>
<td>R &gt; D; R &gt; PLC</td>
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<tr>
<td>80</td>
<td>R, 50 mg, 82</td>
<td>PLC, 41</td>
<td>Oral surgery</td>
<td>Within first 4 h after surgery (1 dose)</td>
<td>V &gt; R &gt; PLC</td>
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<tr>
<td>81</td>
<td>R, 50 mg, 90</td>
<td>CEL, 200 mg, 46</td>
<td>Oral surgery</td>
<td>Postoperatively as soon as moderate to severe pain (1 dose)</td>
<td>R = I &gt; CEL &gt; PLC but R has longer duration than I</td>
</tr>
<tr>
<td>82</td>
<td>R, 50 mg, 50</td>
<td>PLC, 50</td>
<td>Oral surgery</td>
<td>Postoperatively as soon as moderate to severe pain (1 dose)</td>
<td>R = I &gt; PLC but R has longer duration than I</td>
</tr>
<tr>
<td>83 (6 trials)</td>
<td>1, R, 50 mg, 32; R 250, 8; R 500, 20</td>
<td>1, PLC, 32; I, 400 mg, 20</td>
<td>Oral surgery</td>
<td>Postoperatively as soon as moderate to severe pain (1 dose)</td>
<td>R 25, 50, 100, and 200 mg = UN &gt; PLC</td>
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<tr>
<td>84</td>
<td>2, R, 7.5 mg, 39; R 25, 37; R 50, 38; R 100, 39</td>
<td>2, PLC, 39; NAP, 550 mg, 39</td>
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<tr>
<td>85</td>
<td>R, 50 mg, 20</td>
<td>CEL, 200 mg, 20</td>
<td>Spinal fusion</td>
<td>1 h before surgery (1 dose)</td>
<td>R &gt; CEL &gt; PLC</td>
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<tr>
<td>86</td>
<td>R, 50 mg, 20 preincision</td>
<td>PLC, 20</td>
<td>Arthroscopic meniscectomy</td>
<td>Preincision: 1 h before surgery (1 dose)</td>
<td>R preincision &gt; R postincision &gt; PLC</td>
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<tr>
<td>87</td>
<td>R, 25 mg, 50</td>
<td>PLC, 50</td>
<td>TKA</td>
<td>Daily starting 3 d before surgery (5 doses)</td>
<td>R &gt; PLC</td>
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<td>88</td>
<td>R, 50 mg, 30</td>
<td>PLC, 30</td>
<td>ENT surgery</td>
<td>1 h before surgery (1 dose)</td>
<td>R = PLC</td>
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<td>89</td>
<td>R, 50 mg, 15</td>
<td>PLC, 15</td>
<td>Prostatectomy</td>
<td>1 hour before surgery (1 dose)</td>
<td>R = PLC</td>
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<td>90</td>
<td>R, 0.625 mg/kg + A, 20 mg/kg, 40</td>
<td>PLC + A, 20 mg/kg, 18</td>
<td>Tonsillectomy</td>
<td>1 h before surgery (1 dose)</td>
<td>I + A &gt; PLC + A, R + A = PLC + A</td>
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<td>I, 5 mg/kg + A, 20 mg/kg, 40</td>
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<td><strong>Celecoxib (oral)</strong></td>
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<tr>
<td>81</td>
<td>CEL, 200 mg, 91</td>
<td>PLC, 45, I, 400 mg, 46</td>
<td>Oral surgery</td>
<td>Postoperatively as soon as moderate to severe pain (1 dose)</td>
<td>R = I &gt; CEL &gt; PLC but R has longer duration than I</td>
</tr>
<tr>
<td>85</td>
<td>CEL, 200 mg, 20</td>
<td>PLC, 20</td>
<td>Spinal fusion</td>
<td>1 h before surgery (1 dose)</td>
<td>R &gt; CEL &gt; PLC</td>
</tr>
<tr>
<td>91</td>
<td>CEL, 200 mg, 141 (single dose)</td>
<td>PLC, 141 (single dose), H, 10 mg + A, 1 g, 136 (single dose)</td>
<td>Ambulatory orthopedic surgery</td>
<td>Single-dose: within 24 h after surgery Multidose: TID from 8 h after 1st dose for up to 5 days</td>
<td>Single dose: CEL = H + A &gt; PLC Multidose: CEL &gt; H + A</td>
</tr>
<tr>
<td></td>
<td>CEL, 200 mg, 185 (multidose)</td>
<td>H, 10 mg + A, 1 g, 181 (multidose)</td>
<td>Oral surgery</td>
<td>Postoperatively as soon as moderate to severe pain (1 dose)</td>
<td>CEL = I &gt; PLC</td>
</tr>
<tr>
<td>92</td>
<td>CEL, 200 mg, 37</td>
<td>PLC, 36, I, 600 mg, 30</td>
<td>Oral surgery</td>
<td>8 h before surgery and 1 h before surgery (2 doses)</td>
<td>CEL = I &gt; PLC</td>
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<tr>
<td>93</td>
<td>CEL, 200 mg, 74</td>
<td>PLC, 26, I, 400 mg, 74</td>
<td>Oral surgery</td>
<td>Postoperatively as soon as moderate to severe pain (1 dose)</td>
<td>I &gt; CEL &gt; PLC</td>
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<td>94</td>
<td>CEL, 200 mg, 28</td>
<td>PLC, 28</td>
<td>ENT surgery</td>
<td>30–60 min before surgery (1 dose)</td>
<td>CEL + A &gt; CEL, CEL + A &gt; PLC, CEL = PLC</td>
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</table>

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Table 2. Continued

<table>
<thead>
<tr>
<th>Drug/Reference</th>
<th>Study Drug, Dose, No. of Patients</th>
<th>Comparators, Dose, No. of Patients</th>
<th>Surgery</th>
<th>Duration/Timing of Dose</th>
<th>Analgesic Efficacy Results</th>
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<td>Parecoxib (intramuscular/parenteral)</td>
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<td>95</td>
<td>PAR, 20 mg IM, 51</td>
<td>PLC, IM/IV (double dummy), 51</td>
<td>Oral surgery</td>
<td>Postoperatively as soon as moderate to severe pain (1 dose)</td>
<td>PAR 40 IV and PAR 40 IM = K &gt; PLC but PAR has longer duration</td>
</tr>
<tr>
<td>96</td>
<td>PAR, 20 mg IV, 56</td>
<td>PLC, IV, 56</td>
<td>Oral surgery</td>
<td>30–45 min before surgery (1 dose)</td>
<td>PAR &gt; PLC (analgesic ceiling at 40 mg)</td>
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<tr>
<td>97</td>
<td>PAR, 20 mg IV, 43</td>
<td>PLC, IV, 39 K, 30 mg IV, 42 Morphine, 4 mg IV, 42</td>
<td>TKA</td>
<td>Postoperative day 1, within 6 h of stopping PCA opioid (1 dose)</td>
<td>PAR 40 = K 30; PAR 40 &gt; PLC PAR 40 &gt; morphine 4</td>
</tr>
<tr>
<td>98</td>
<td>PAR, 20 mg IV, 19</td>
<td>PLC, IV, 18</td>
<td>Gynecologic surgery</td>
<td>Postoperatively at time of 1st analgesic request, 12 h and 24 h after surgery (3 doses)</td>
<td>PAR 20 = PAR 40 &gt; PLC</td>
</tr>
<tr>
<td>99</td>
<td>PAR, 20 mg IV, 39</td>
<td>PLC, IV, 42 K, 30 mg IV, 41 Morphine, 4 mg IV, 42</td>
<td>Gynecologic surgery</td>
<td>Postoperatively as soon as moderate to severe pain after discontinuing PCA morphine</td>
<td>PAR 20 = PAR 40 &gt; K 30 &gt; morphine &gt; PLC</td>
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<td>Valdecoxib (oral)</td>
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<tr>
<td>80</td>
<td>V, 40 mg, 80 R, 50 mg, 82</td>
<td>PLC, 41</td>
<td>Oral surgery</td>
<td>Within first 4 h after surgery (1 dose)</td>
<td>V &gt; R &gt; PLC</td>
</tr>
<tr>
<td>100</td>
<td>V, 20 mg, 73</td>
<td>PLC, 71</td>
<td>THA</td>
<td>BID starting 1–3 h before surgery (4 doses)</td>
<td>V 20 mg/kg and V 40 mg/kg &gt; PLC</td>
</tr>
<tr>
<td>101</td>
<td>V, 10 mg, 56</td>
<td>PLC, 112</td>
<td>Oral surgery or bunionectomy</td>
<td>60–75 min before surgery</td>
<td>V 80 = V 40 &gt; V 20 &gt; V 10 &gt; PLC</td>
</tr>
<tr>
<td>Nimesulide (oral)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>102</td>
<td>NIM, 100 mg, 35</td>
<td>PLC, 33</td>
<td>Oral surgery</td>
<td>Postoperatively as soon as moderate to severe pain (1 dose)</td>
<td>Niflumic acid = NIM 100 = NIM 200 &gt; PLC</td>
</tr>
<tr>
<td>103</td>
<td>NIM, 200 mg, 34</td>
<td>Niflumic acid, 250 mg, 32</td>
<td>Abdominal hysterectomy</td>
<td>Preoperatively after induction of anesthesia (1 dose)</td>
<td>M &gt; PLC</td>
</tr>
<tr>
<td>Meloxicam (oral)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>103</td>
<td>M, 15 mg rectally, 18</td>
<td>PLC, rectally, 18</td>
<td>Abdominal hysterectomy</td>
<td>Preoperatively after induction of anesthesia (1 dose)</td>
<td>M &gt; PLC</td>
</tr>
</tbody>
</table>

A = acetaminophen; BID = twice daily; CEL = celecoxib; COD = codeine; D = diclofenac; ENT = ears, nose, and throat; H = hydrocodone; I = ibuprofen; IM = intramuscular; IV = intravenous; K = ketorolac; M = meloxicam; NAP = naproxen; NIM = nimesulide; PAR = parecoxib; PCA = patient-controlled analgesia; PLC = placebo; R = rofecoxib; THA = total hip arthroplasty; TID = three times daily; TKA = total knee arthroplasty; V = valdecoxib; >, <, denote statistically no different, lesser, or greater.

in the six controlled trials reported by Morrison et al. and, whereas 50 mg was significantly more efficacious than 7.5, 12.5, and 25 mg, no differences were noted between 50 mg and 100 or 200 mg, suggesting an analgesic ceiling at approximately 50 mg. During the mid-dose segment (postoperative days 2–5) of the orthopedic rofecoxib trial by Reicin et al. daily doses of 50 mg rofecoxib but not 25 mg resulted in significantly less consumption of supplemental analgesic medication (hydrocodone-ace-taminophen). In the parecoxib trial by Desjardins et al., 40 mg intravenously was more efficacious than 20 mg but indistinguishable from 80 mg. Rasmussen et al. also observed that 40 mg parecoxib was more effective than 20 mg after knee surgery, but higher doses were not studied. Postoperative differences between 20 and 40 mg intravenous parecoxib were not as pronounced in the oral surgery study by Daniels et al. Camu et al. and Tang et al. showed no difference in pain scores or analgesic consumption between 20 and 40 mg oral valdecoxib or between 20 and 40 mg intravenous parecoxib in two other postoperative trials. A recent study of valdecoxib by Desjardins et al. demonstrated dose-dependent analgesia between 10 and 40 mg but no difference between 40 and 80 mg, suggesting an analgesic ceiling also for valdecoxib. Finally, the oral surgery study by Ragot et al. showed no difference between 100 and 200 mg nimesulide. In summary, these data suggest that COX-2Is, at least in the case of rofecoxib, parecoxib, and valdecoxib, have a postoperative analgesic dosage ceiling similar to that of traditional NSAIDs (table 5).

Safety of COX-2Is in the Postoperative Setting

Evaluation and reporting of adverse effects varied considerably across studies from no measures at all to spontaneous patient reporting to specific measures of nausea, vomiting, or blood loss (table 3). All but six trials reported no difference between the studied COX-2I and...
placebo or active comparator in the overall incidence of adverse effects. However, it should be noted that all COX-2I trials included here were designed and statistically powered with analgesia, not adverse effects, as the primary outcome. One trial did not report adverse effects,86 and in two trials, a significantly greater incidence of postdental extraction alveolitis ("dry socket") was observed with 50 mg oral rofecoxib as compared to placebo.80,83 Four trials reported significantly fewer adverse effects with the studied COX-2I in comparison with placebo or the active comparator.78,81,91,94 Only three perioperative studies incorporated specific measures of blood loss in the trial design (table 3), and none of these three reported any difference in blood loss between the studied COX-2I and placebo.85,87,90 In addition to adverse effects reported in the postoperative trials cited in this review, single isolated cases of celecoxib-induced oliguria105 and rofecoxib-induced aseptic meningitis106 after brief postoperative use have been recently reported.

**Side Effect Profiles from Postoperative COX-2I Trials**

Common (5–28%) treatment-emergent signs and symptoms associated with COX-2Is (rofecoxib, parecoxib, and valdecoxib) from postoperative clinical trials that tabulated adverse effects79,80,84,95–97,100 include headache, nausea, vomiting, dizziness, and postdental extraction alveolitis. However, only one of these, postdental extraction alveolitis, occurred more frequently with rofecoxib than with placebo,85 which was also observed in one of the trials reported by Morrison et al.85

**Summary**

Postoperative pain management has gone through revolutionary innovations over the past century with the
widespread clinical introduction of systemic and neuraxial opioids, regional local anesthetic techniques, patient-controlled analgesia, and coanalgesic therapies such as NSAIDs. Current needs for improvement in postoperative pain management include (1) more effective relief of pain and suffering for all postoperative patients; (2) preventing and/or treating other postoperative symptoms (which may or may not be related to analgesic therapies) such as nausea, pruritus, sedation, and cognitive dysfunction; and (3) promoting recovery from surgery by preventing and/or treating postoperative physiologic dysfunction such as atelectasis and ileus. Thus, therapeutic improvements in postoperative pain management should advance at least one of these goals without impeding the others. In the interest of relieving postoperative pain for all patients, further attention needs to be given to special populations such as patients undergoing tonsillectomy, ocular procedures, spinal fusion, and other surgeries for which nonselective NSAIDs have a relative contraindication.

Current evidence published to date does not suggest that COX-2Is provide a major advantage over traditional NSAIDs. However, it is possible that their development will lead to specific drugs with a superior therapeutic profile. For example, after oral surgery, valdecoxib was recently shown to be significantly more effective than rofecoxib, which in turn was shown to be more effective than codeine–acetaminophen or diclofenac. It remains to be determined whether these differences in analgesic efficacy can be replicated using multidose trials with equipotent dose comparisons and after other, more painful procedures. However, such observations lead to

Table 4. Placebo-controlled Trials Comparing COX-2s to Nonselective NSAIDs

<table>
<thead>
<tr>
<th>Drug/Reference</th>
<th>NSAID Comparator</th>
<th>Primary Outcome Measure of Trial</th>
<th>Analgesic Efficacy Results</th>
<th>Adverse Effect Results*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rofecoxib (oral)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>79</td>
<td>Diclofenac</td>
<td>Pain relief</td>
<td>R &gt; D</td>
<td>R = D</td>
</tr>
<tr>
<td>81</td>
<td>Ibuprofen</td>
<td>Pain relief</td>
<td>R = I &gt; CEL</td>
<td>R = I = CEL</td>
</tr>
<tr>
<td>82</td>
<td>Ibuprofen</td>
<td>Pain intensity and relief</td>
<td>R = I</td>
<td>R = I</td>
</tr>
<tr>
<td>83 (6 trials)</td>
<td>1. Ibuprofen</td>
<td>Pain relief</td>
<td>R = I; R = N</td>
<td>R = I; R = N</td>
</tr>
<tr>
<td>2. Naproxen</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Naproxen</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Ibuprofen</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Naproxen</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. Ibuprofen</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>84</td>
<td>Naproxen</td>
<td>Pain intensity and relief</td>
<td>R = N</td>
<td>R = N</td>
</tr>
<tr>
<td>90</td>
<td>Ibuprofen</td>
<td>Analgesic use</td>
<td>I + A = R + A</td>
<td>I + A = R + A</td>
</tr>
<tr>
<td>Celecoxib (oral)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>81</td>
<td>Ibuprofen</td>
<td>Pain relief</td>
<td>R = I &gt; CEL</td>
<td>R = I = CEL</td>
</tr>
<tr>
<td>92</td>
<td>Ibuprofen</td>
<td>Pain intensity</td>
<td>CEL = I</td>
<td>Not reported</td>
</tr>
<tr>
<td>93</td>
<td>Ibuprofen</td>
<td>Pain intensity and relief</td>
<td>I &gt; CEL</td>
<td>I = CEL</td>
</tr>
<tr>
<td>Parecoxib (intravenous)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>86</td>
<td>Ketorolac</td>
<td>Pain intensity and relief</td>
<td>PAR = K</td>
<td>PAR = K</td>
</tr>
<tr>
<td>88</td>
<td>Ketorolac</td>
<td>Pain intensity</td>
<td>PAR = K</td>
<td>PAR = K</td>
</tr>
<tr>
<td>99</td>
<td>Ketorolac</td>
<td>Pain intensity</td>
<td>PAR = K</td>
<td>PAR = K</td>
</tr>
</tbody>
</table>

* Reported trials are designed and statistically powered to detect differences in the primary outcome of pain intensity or relief, not adverse effects.

CEL = celecoxib; COX = cyclooxygenase; D = diclofenac; I = ibuprofen; K = ketorolac; N = naproxen; NSAID = nonsteroidal antiinflammatory drug; PAR = parecoxib; R = rofecoxib; –, <, > denote statistically no different, lesser, or greater.

Table 5. Postoperative Analgesic Dose–Response Studies

<table>
<thead>
<tr>
<th>Drug/Reference</th>
<th>Doses Studied</th>
<th>Study Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rofecoxib (oral)</td>
<td>7.5, 12.5, 25, 50, 100, and 200 mg</td>
<td>Analgesic ceiling at 50 mg; 50 mg more efficacious than 25 mg</td>
</tr>
<tr>
<td>83</td>
<td>25 and 50 mg</td>
<td>50 mg more efficacious than 25 mg</td>
</tr>
<tr>
<td>84</td>
<td>20 and 40 mg</td>
<td>NS</td>
</tr>
<tr>
<td>Parecoxib (intravenous)</td>
<td>20 and 40 mg</td>
<td>Analgesic ceiling at 40 mg; 40 mg more efficacious than 20 mg</td>
</tr>
<tr>
<td>96</td>
<td>20, 40, and 80 mg</td>
<td>40 mg more efficacious than 20 mg</td>
</tr>
<tr>
<td>97</td>
<td>20 and 40 mg</td>
<td>NS</td>
</tr>
<tr>
<td>98</td>
<td>20 and 40 mg</td>
<td>NS</td>
</tr>
<tr>
<td>99</td>
<td>20 and 40 mg</td>
<td>NS</td>
</tr>
<tr>
<td>Valdecoxib (oral)</td>
<td>20 and 40 mg</td>
<td>Analgesic ceiling at 40 mg</td>
</tr>
<tr>
<td>100</td>
<td>20 and 40 mg</td>
<td>NS</td>
</tr>
<tr>
<td>101</td>
<td>10, 20, 40, and 80 mg</td>
<td>Dose-dependent up to 40 mg; analgesic ceiling at 40 mg</td>
</tr>
<tr>
<td>Nimesulide (oral)</td>
<td>100 and 200 mg</td>
<td>NS</td>
</tr>
</tbody>
</table>
the anticipation that future advances in drug development may result in COX-2Is with clinically important advantages over traditional NSAIDs.

Several COX-2I trials have demonstrated an opioid-sparing effect after surgery,\(^\text{78,91}\) and comparisons with opioids have reported fewer postoperative side effects.\(^\text{78,91}\) Thus, COX-2Is are at least as effective as nonselective NSAIDs in reducing opioid requirements and/or opioid-related adverse effects after surgery. Provided that recent evidence of fewer gastrointestinal complications with COX-2Is from arthritis studies\(^\text{67,68}\) holds true in the postoperative setting, it is hoped that patients with gastrointestinal risk factors (e.g., previous gastritis, ulcers), in whom NSAIDs are contraindicated, may safely benefit from the addition of a COX-2I to their postoperative analgesic regimen. Both experimental and clinical evidence suggest that NSAIDs impair bone healing.\(^\text{113,114}\) Thus, spinal fusion surgery patients present another group who may be denied the benefits of NSAIDs because of fear of postoperative deleterious effects on bone graft healing. Early evidence from a rabbit model\(^\text{115}\) and a small spinal fusion clinical trial\(^\text{85}\) suggesting that COX-2Is do not interfere with bone healing has led to the optimistic proposal that COX-2Is may be a useful alternative for these patients.\(^\text{116}\) More recent data does in fact support a role for COX-2 in bone healing,\(^\text{117}\) and further clinical investigation is needed to address this problem.\(^\text{118}\)

Issoui et al.\(^\text{94}\) were unable to demonstrate any difference in postoperative recovery times across postoperative patients receiving acetaminophen, celecoxib, their combination, or placebo. No study has been reported to date that compares COX-2Is to nonselective NSAIDs with respect to postoperative recovery or postoperative physiologic impairment. Such investigations as have been previously conducted with nonselective NSAIDs\(^\text{119}\) are needed to identify whether COX-2Is have any advantage.

Cardiovascular risks of COX-2Is discussed above remain controversial, and more recent evidence suggests that COX-2Is may not confer greater cardiovascular danger than nonselective NSAIDs.\(^\text{120,121,122}\) However, comparative postoperative studies that carefully track cardiovascular outcomes are needed to resolve this controversy.

Discovery of the COX-2 enzyme and subsequent development of selective COX-2Is has contributed to a resurgence of therapeutic research in postoperative pain. However, whether these developments have resulted in any tangible improvements in patient care requires further study. Comparative COX-2I trials published to date generally suggest similar analgesic efficacy to nonselective NSAIDs in postoperative pain. Also, these mostly single-dose studies suggest similar safety and tolerability as compared to currently used NSAIDs. Additional data from larger, multicenter, multidose comparative trials could determine whether individual COX-2Is are more efficacious, cost-effective, and/or safe versus nonselective NSAIDs with respect to gastric, renal, and coagulation problems and whether COX-2Is confer greater cardiovascular risk in the postoperative setting. Multiple unresolved questions (table 6) remain to be answered. Until then, cost–benefit considerations\(^\text{123}\) will likely guide therapeutic choices in the absence of strong evidence supporting any major advantage of COX-2Is.

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### References


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**Table 6. Unresolved Questions Regarding the Utility of COX-2s for Postoperative Pain**

- Do COX-2Is demonstrate preemptive analgesic efficacy?
- Do COX-2Is cause clinically significantly less perioperative blood loss than non-selective NSAIDs?
- Do COX-2Is impair postoperative bone healing in humans?
- Do COX-2Is cause gastrointestinal toxicity in patients at risk (e.g., previous gastric ulceration)?
- Does perioperative use of COX-2Is result in cardiovascular toxicity (e.g., hypertension, CVA, MI)?
- Do COX-2Is provide more favorable cost-benefit or cost-effectiveness than non-selective NSAIDs?

COX = cyclooxygenase; CVA = cerebrovascular accident; MI = myocardial infarction; NSAID = nonsteroidal antiinflammatory drug.


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