Annals of Internal Medicine | Clinical Guidelines

Strategies To Reduce Postoperative Pulmonary Complications after Noncardiothoracic Surgery: Systematic Review for the American College of Physicians

Valerie A. Lawrence, MD; John E. Cornell, PhD; and Gerald W. Smetana, MD

Background: Postoperative pulmonary complications are as frequent and clinically important as cardiac complications in terms of morbidity, mortality, and length of stay. However, there has been much less research and no previous systematic reviews of the evidence of interventions to prevent pulmonary complications.

Purpose: To systematically review the literature on interventions to prevent postoperative pulmonary complications after noncardiothoracic surgery.

Data Sources: MEDLINE English-language literature search, 1 January 1980 through 30 June 2005, plus bibliographies of retrieved publications.

Study Selection: Randomized, controlled trials (RCTs); systematic reviews; or meta-analyses that met predefined inclusion criteria.

Data Extraction: Using standardized forms, the authors abstracted data on study methods, quality, intervention and control groups, patient characteristics, surgery, postoperative pulmonary complications, and adverse events.

Data Synthesis: The authors qualitatively synthesized, without meta-analysis, evidence from eligible studies. Good evidence (2 systematic reviews, 5 additional RCTs) indicates that lung expansion interventions (for example, incentive spirometry, deep breathing exercises, and continuous positive airway pressure) reduce pulmonary risk. Fair evidence suggests that selective, rather than routine, use of nasogastric tubes after abdominal surgery (2 meta-analyses) and short-acting rather than long-acting intraoperative neuromuscular blocking agents (1 RCT) reduce risk. The evidence is conflicting or insufficient for preoperative smoking cessation (1 RCT), epidural anesthesia (2 meta-analyses), epidural analgesia (6 RCTs, 1 meta-analysis), and laparoscopic (vs. open) operations (1 systematic review, 1 meta-analysis, 2 additional RCTs), although laparoscopic operations reduce pain and pulmonary compromise as measured by spirometry. While malnutrition is associated with increased pulmonary risk, routine total enteral or parenteral nutrition does not reduce risk (1 meta-analysis, 3 additional RCTs). Enteral formulations designed to improve immune status (immunonutrition) may prevent postoperative pneumonia (1 meta-analysis, 1 additional RCT).

Limitations: The overall quality of the literature was fair: Ten of 20 RCTs and 6 of 11 systematic reviews were good quality.

Conclusions: Few interventions have been shown to clearly or possibly reduce postoperative pulmonary complications.

Ann Intern Med. 2006;144:596-608. www.annals.org
For author affiliations, see end of text.

Postoperative pulmonary complications are as common as cardiac complications for patients undergoing noncardiothoracic surgery (1–6). Further, these complications have similar mortality rates and length of stay after elective abdominal surgery or hip fracture repair (1, 2). In an accompanying systematic review (7), we identify patient, procedure, and laboratory risk factors for postoperative pulmonary complications. Our current systematic review synthesizes the evidence on preventive strategies and focuses on atelectasis, pneumonia, and respiratory failure. While we have written the review primarily for internists, this field crosses specialty disciplines.

Methods

Literature Search and Selection Criteria

We performed a systematic MEDLINE English-language literature search from 1 January 1980 to 30 June 2005. The search strategy and inclusion and exclusion criteria are described in the accompanying review of risk factors and in further detail in its Appendix, available at www.annals.org (7). The search strategy used 1) the Medical Subject Heading (MeSH) terms *preoperative care*, *intraoperative care*, *postoperative care*, *intraoperative complications*, and *postoperative complications* as a focus of the article; 2) the MeSH text term *perioperative complications* as a text term in the title or abstract; and 3) additional MeSH and text terms for pulmonary, respiratory, or cardiopulmonary conditions, complications, or care. In addition, we performed additional focused searches for preoperative chest radiography and spirometry, laparoscopic versus open major abdominal operations, general versus spinal or epidural anesthesia, intraoperative neuromuscular blockade, postoperative pain management, and postoperative lung expansion techniques. Eligible studies were randomized, controlled trials; systematic reviews; or meta-analyses. We

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excluded studies with less than 25 participants per group; studies from developing countries (because of potential differences in respiratory and intensive care technology); studies that used physiologic (for example, lung volumes and flow, oximetry) rather than clinical outcome measures; studies of gastric pH manipulation; studies of complications that are unique to the surgery (for example, upper airway obstruction after uvulectomy); studies of cardiopulmonary, pediatric, or organ transplantation surgery (because of profoundly immunosuppressive drugs); and studies that used only administrative data to identify postoperative complications (for example, International Classification of Diseases, Ninth Revision, Clinical Modification [ICD-9-CM], codes) because of recent evidence that administrative data have poor validity for postoperative complications (8, 9).

Assessment of Study Quality

We used the Quality of Reporting of Meta-analyses (QUOROM) statement for reporting meta-analyses and the U.S. Preventive Services Task Force criteria for hierarchy of research design to assess internal validity and study quality (good, fair, or poor) and to make conclusions about strength of the evidence (10, 11).

Statistical Analysis

We used simple means and chi-square tests to calculate CIs and *P* values when they were not provided in publications. We did not perform quantitative pooling because multiple meta-analyses were beyond the scope of a broad review of multiple potential interventions. We report pooled results from previous meta-analyses when applicable.

Role of the Funding Source

The Veterans Evidence-based Research, Dissemination, and Implementation Center (VERDICT) (Veterans Affairs Health Services Research and Development, HFP 98-002) provided the research librarian and administrative support for the study. The funding source had no role in the design, conduct, or reporting of the study or in the decision to submit the manuscript for publication.

RESULTS

The search and inclusion criteria identified 20 randomized clinical trials and 11 systematic reviews or meta-analyses (12–42). Figure 1 in the accompanying review (7) of risk factors for postoperative pulmonary complications details the search results. **Appendix Tables 1** through 7 (available at www.annals.org) provide detailed characteristics of the eligible randomized trials and systematic reviews.

Preoperative Smoking Cessation

In the only trial of preoperative smoking cessation (12), 108 older, relatively healthy men undergoing hip or knee replacement were randomly assigned to usual care or weekly meetings with a nurse for advice about smoking cessation and nicotine withdrawal plus individualized nicotine replacement for 6 to 8 weeks before surgery until 10 days after surgery. The mean age of the men was 65 years, and 95% were American Society of Anesthesiologists (ASA) physical status class I or II. Of 56 patients in the intervention group, 36 stopped smoking and 14 reduced smoking before surgery. Overall complications rates were lower in the intervention group (18% vs. 52%; $P < 0.001$), primarily due to fewer wound complications and urinary tract infections. The only pulmonary outcome, postoperative ventilator support, occurred in 1 patient in each group. Non–statistically significant trends favored shorter mean hospital stay (11 days vs. 13 days; $P = 0.41$) and fewer cardiac complications (0% vs. 10%; $P = 0.08$) in the intervention group.

Although the trial was of good quality, several factors limit its ability to demonstrate decreased risk for postoperative pulmonary complications. Pulmonary risk is inherently low with hip and knee replacement. Furthermore, the timing of smoking cessation seems important. A previous cohort study showed paradoxically higher postoperative pulmonary complication rates for smokers who stopped or reduced smoking within 2 months before noncardiothoracic surgery (43). Smoking cessation may increase short-term risk because of transiently increased mucus production due to improved mucociliary activity and reduced coughing due to less bronchial irritation.

Anesthetic and Analgesic Techniques

Anesthetics disrupt central regulation of breathing and result in uncoordinated neural messaging. Due to resulting hypoventilation plus positional dependence, regional atelectasis occurs shortly after induction. It persists postoperatively and is compounded by ongoing disruption of respiratory muscles, limited respiratory excursion due to pain, and disruption of neurally mediated diaphragmatic functions after manipulation of abdominal viscera (43).

Neuromuscular Blockade

One good-quality trial found no difference in rates of postoperative pulmonary complications between intermediate-acting (atracurium, vecuronium) and long-acting (pancuronium) neuromuscular blocking agents among 691 patients undergoing elective abdominal, gynecologic, or orthopedic surgery (13). However, the incidence of residual neuromuscular block was higher among patients receiving pancuronium (26% vs. 5%; $P < 0.001$). Patients with residual blockade after pancuronium were 3 times more likely to develop postoperative pulmonary complications than those without residual block (17% vs. 5%; $P < 0.02$). In contrast, among patients receiving intermediate-acting agents, postoperative pulmonary complication rates did not differ between those with (4%) and without (5%) prolonged blockade. Therefore, pancuronium may directly lead to higher rates of prolonged neuromuscular blockade and indirectly to increased pulmonary risk compared with shorter-acting agents.

Table 1. **Randomized, Controlled Trials of Combined Intraoperative Anesthesia and Postoperative Analgesia***

Author, Year (Reference)	Type of Surgery	Intervention Group	Patients		
			Total, *n*	Men, *n*	Age, *y*
Norris et al., 2001 (14)	Elective abdominal aortic surgery	Four groups: 1) intraoperative GETA + postoperative IV PCA; 2) intraoperative GETA + postoperative epidural PCEA; 3) intraoperative GETA + supplemental epidural + postoperative IV PCA; 4) intraoperative GETA + supplemental epidural + postoperative PCEA	168	115	Mean, 68 (SD, 9.5)
Rigg et al., 2002 (15)	Elective abdominal or esophageal surgery	Two groups: 1) intraoperative GETA + postoperative IV opioid; 2) intraoperative GETA + epidural local anesthetic + postoperative epidural local anesthetic and additional opioid as needed	915	NR‡	NR‡
Park et al., 2001 (16)	Elective abdominal surgery (Veterans Hospitals)	Two groups: 1) intraoperative GETA + postoperative IV or IM opioid; 2) intraoperative GETA + epidural anesthesia + postoperative epidural opioid	1021	1021	Mean, 67 (SD, 8.8)
Fléron et al., 2003 (17)	Elective abdominal aortic surgery	Two groups: 1) intraoperative GETA + IV opioid + postoperative IV opioid; 2) intraoperative GETA + epidural opioid + postoperative IV opioid	217	192	Mean, 66.5 (SD, 10.5)
Mann et al., 2000 (18)	Elective major abdominal surgery for cancer	Two groups: 1) intraoperative GETA + postoperative IV PCA with morphine; 2) intraoperative GETA + epidural + postoperative PCEA with combined local anesthetic and sufentanil	70	38	Mean, 76.5 (SD, 5.2)
Cuschieri et al., 1985 (19)	Elective cholecystectomy	Three groups: 1) intraoperative GETA + postoperative IM morphine; 2) intraoperative GETA + postoperative IV morphine; 3) intraoperative GETA + epidural local anesthetic + postoperative epidural local anesthetic for 12 h then morphine as needed	75	16	52 (range, 18–75)

* GETA = general endotracheal anesthesia; IM = intramuscular; IV = intravenous; NR = not reported; NS = not significant; PCA = patient-controlled analgesia; PCEA = patient-controlled epidural analgesia; PPC = postoperative pulmonary complication.
† Level of evidence for all studies is I = randomized clinical trial.
‡ Sex and age not given in primary publication or previous methods publication.

Anesthesia and Analgesia

Neuraxial blockade (either spinal or epidural anesthesia) blocks a constellation of stress responses to surgery (neuroendocrine, cytokine, and pain threshold) and may improve recovery and prevent complications (44). Postoperative epidural analgesia may reduce respiratory muscle dysfunction and pain-related hypoventilation. The epidural approach involves either a single injection or an infusion and can be used for both intraoperative anesthesia and postoperative analgesia. Spinal anesthesia has a faster onset (5 to 10 minutes vs. 15 to 20 minutes), produces denser sensory and motor block, and is technically easier than epidural anesthesia. However, spinal anesthesia is administered only as a single injection because of practical constraints of indwelling intrathecal catheters. The possible benefit of neuraxial blockade has generated studies of general versus neuraxial blockade anesthesia, followed by trials comparing epidural analgesia to other modes of analgesic delivery (for example, oral, intramuscular, intravenous, patient-controlled analgesia) and, more recently, trials of combined epidural intraoperative anesthesia and epidural postoperative analgesia.

Intraoperative General Anesthesia versus Neuraxial Blockade

A recent good-quality meta-analysis combined 141 trials ($n = 9559$) comparing general anesthesia and neuraxial blockade in patients undergoing a variety of operations (32). The authors compared patients receiving neuraxial blockade (with or without concomitant general anesthesia) with those receiving only general anesthesia. Neuraxial blockade reduced overall mortality (2% vs. 3%; odds ratio, 0.70 [95% CI, 0.54 to 0.90]), pneumonia (3% vs. 5%; odds ratio, 0.61 [CI, 0.48 to 0.76]), and respiratory failure (0.5% vs. 0.8%; odds ratio, 0.41 [CI, 0.23 to 0.73]). In a subgroup analysis of trials of neuraxial blockade alone versus general anesthesia alone, results were similar (odds ratio, 0.63 [CI, 0.46 to 0.87] for pneumonia; odds ratio, 0.37 [CI, 0.11 to 1.21] for respiratory failure).

Potential sources of bias in the meta-analysis include 1) clinically heterogeneous studies; 2) unusually high mortality rates in several trials; 3) older literature (82% of included studies were published before 1990); 4) small studies (81% of included studies had ≤ 50 patients); and 5) statistically significant benefit only for orthopedic surgery in subgroup analyses (45–47).

A smaller good-quality systematic review identified 15 randomized or quasi-randomized trials of 2162 patients undergoing hip fracture repair (33). Postoperative pneumonia rates were almost identical: 5.1% of 529 patients having neuraxial blockade and 5.5% of 567 patients having general anesthesia (odds ratio, 0.92 [CI, 0.53 to 1.59]). Twelve of the 15 trials were also included in the larger

Table 1—**Continued**

Random Allocation Concealed	Blinded Outcome Assessment	PPCs	Level of Evidence†; Study Quality	Results
Yes	Yes	Reintubation, prolonged intubation, pneumonia (primary outcome was length of stay; PPCs were secondary outcomes)	I; good	Overall PPCs: 20% vs. 17% vs. 25% vs. 9%; P = NS Reintubation: 0%–2.9%; P = 0.9 Prolonged intubation: 7%–22%; P = 0.3 Pneumonia: 0%–2.8%; P = 0.6
No	No	Respiratory failure, overall infection	I; fair	Infection: 47% in IV group, 43% in epidural group; P = 0.26 Respiratory failure: 30% in IV group, 23% in epidural group; P = 0.02
Yes	No	Primary outcomes: death, respiratory failure; secondary outcome: pneumonia	I; fair	Mortality: 4% vs. 3% Respiratory failure: 10% with epidural vs. 14%; P = 0.06 Pneumonia: 5% with epidural vs. 8%; P = 0.15
Yes	No	Pneumonia, lobar atelectasis, respiratory failure	I; fair	Overall PPCs: 16% with epidural, 23% with IV opioid; P = 0.32
Yes	No	Segmental or lobar atelectasis, pneumonia, major PPCs defined by clinical score based on physical examination	I; poor	Atelectasis: 23% with epidural vs. 18%; P = 0.77 Major PPCs: 3% vs. 3%
Unclear	No	Atelectasis, pneumonia	I; poor	Atelectasis: 20% with epidural vs. 28% with IV and 40% with IM morphine; P = NS Pneumonia: 4% with epidural vs. 20% with IV morphine (P = 0.20) and 24% with IM morphine (P = 0.11)

meta-analysis (32), which included 44 trials of orthopedic surgery (n = 3617). Why the results for pneumonia differ between the 2 meta-analyses is not clear, but important variables may include type or duration of procedure (hip fracture repair is inherently low risk for postoperative pulmonary complications), intraoperative fluids, and postoperative pain and rehabilitative management.

Combined Intraoperative and Postoperative Anesthesia and Analgesia

Table 1 summarizes 6 eligible trials that compared various regimens of intraoperative anesthesia and postoperative analgesia. In a double-blind, good-quality efficacy trial of patients undergoing abdominal aortic surgery (14), investigators randomly assigned patients to 1 of 4 combined anesthetic and analgesic protocols. The trial standardized the entire episode of anesthesia and pain management to optimize efficacy in all 4 groups. The primary outcome measure was length of stay; secondary outcomes included postoperative pulmonary complications. Sample sizes were small (37, 38, 39, and 46 participants, respectively), and median length of stay (7 to 8 days for all groups) or postoperative pulmonary complication rates did not differ among the groups.

Strengths of the trial include the double-blind design and equally highly standardized protocols for both anesthesia and analgesia (48, 49). Unequally optimized regimens can introduce bias that systematically favors one type of intervention. Potential weaknesses, regarding prevention of postoperative pulmonary complication, include length of stay as the primary outcome measure and small sample size (50–52).

In a subsequent fair-quality effectiveness trial (15), 915 patients undergoing major abdominal surgery were randomly assigned to general anesthesia and 1) postoperative intravenous opioid or 2) intraoperative epidural local anesthetic plus postoperative epidural analgesia. Overall infections did not differ, and the authors did not report results for pneumonia. Statistically significantly less pain and respiratory failure occurred with epidural anesthesia, but only 225 of 447 patients in the epidural group completed the protocol.

In a subgroup analysis of high-risk patients (respiratory insufficiency by arterial blood gas analysis, severe obstructive or restrictive lung disease, acute respiratory failure within the past 2 years, or morbid obesity), rates of pneumonia (11% vs. 12%; P = 0.71) or mechanical ventilation for more than 24 hours (8% for both groups) did not differ. Respiratory failure (ventilation > 24 hours, reintubation, $Pa_{O_2} \geq 50$ mm Hg, or $Pa_{CO_2} \geq 50$ mm Hg on room air) occurred significantly less often with epidural (45% vs. 29%; odds ratio, 0.5 [CI, 0.29 to 0.88]) (53).

In a large fair-quality trial (16), 1021 patients undergoing abdominal surgery were randomly assigned to general anesthesia and 1) postoperative systemic opioid or 2) intraoperative epidural anesthesia plus postoperative epidural morphine. Mortality rates did not differ, and non–statistically significant trends favored the epidural approach for pneumonia and respiratory failure.

In 1 fair-quality trial (17), 217 patients undergoing elective abdominal aortic surgery were randomly assigned to general anesthesia alone or general anesthesia plus intraoperative epidural opioid. Both groups received the same postoperative pain management. A non–statistically significant trend favored intraoperative epidural for overall postoperative pulmonary complications. Rates of individual types of postoperative pulmonary complications did not differ, but statistical power was low.

In a smaller poor-quality trial (18), 70 elderly patients undergoing major abdominal surgery were randomly assigned to general anesthesia and 1) postoperative patient-controlled morphine or 2) intraoperative neuraxial blockade plus postoperative patient-controlled epidural analgesia. Rates of atelectasis or major pulmonary complications did not differ. In an additional, small poor-quality trial (19), 75 patients undergoing elective cholecystectomy were randomly assigned to general anesthesia and 1) postoperative intramuscular morphine, 2) continuous intravenous morphine, or 3) intraoperative epidural local anesthesia plus postoperative epidural local anesthetic for 12 hours. Postoperative pneumonia occurred less often with epidural (4%) than with either intramuscular morphine (24%; $P = 0.05$) or intravenous morphine (20%; $P = 0.11$).

Postoperative Analgesic Technique

A fair-quality meta-analysis examined the evidence for 3 epidural techniques: intercostal nerve block, systemic opioids, and wound infiltration with local anesthetic (34). The number of trials that compared any 2 strategies varied from 2 to 11. Compared with systemic opioids, epidural opioids reduced atelectasis (relative risk, 0.53 [CI, 0.33 to 0.85]; 11 studies) but not pneumonia (relative risk, 0.53 [CI, 0.18 to 1.53]; 5 studies). Compared with systemic opioids, epidural local anesthetic reduced "pulmonary infection" (relative risk, 0.36 [CI, 0.21 to 0.65]; 5 studies) but not atelectasis (relative risk, 0.74 [CI, 0.50 to 1.11]; 4 studies). However, the authors pooled studies of both on-demand (that is, as requested) and patient-controlled intravenous analgesia, which could bias the results of the meta-analysis in favor of epidural analgesia.

In contrast, a good-quality meta-analysis identified 32 trials ($n = 1029$) of patient-controlled opioid analgesia versus the same drug given intravenously, intramuscularly, or subcutaneously (35). Opioid consumption, pain scores, length of stay, or adverse effects did not differ. In the 2 trials reporting postoperative pulmonary complications, fewer complications occurred in the patient-controlled analgesia group (odds ratio, 0.93 [CI, 0.86 to 0.99]; number needed to treat, 15 [CI, 8 to 98]).

Summary

Evidence from 1 good-quality trial suggests that shorter-acting neuromuscular blocking drugs may prevent postoperative pulmonary complications. Intraoperative neuraxial blockade, either alone or in combination with general anesthesia, may prevent postoperative pulmonary complications, but the evidence is conflicting. Several meta-analyses (which included small unblinded studies) suggest that epidural anesthesia may reduce pulmonary risk, but recent large randomized trials do not confirm benefit. Randomized trials of combined intraoperative and postoperative anesthetic or analgesic regimens do not clearly indicate that a combined epidural approach prevents postoperative pulmonary complications. Two meta-analyses of postoperative analgesic regimens suggest that part of the variability may be due to on-demand analgesia (intravenous, intramuscular, or subcutaneous) versus patient-controlled analgesia (intravenous or epidural). Postoperative epidural and patient-controlled intravenous analgesia both seem superior to on-demand delivery of opioids in preventing postoperative pulmonary complications. Epidural analgesia may further reduce postoperative pulmonary complications. More good-quality efficacy trials with standardized optimal regimens for all groups and sufficient size to examine pulmonary complication rates are needed (14). The risk for epidural bleeding due to postoperative epidural catheters in patients receiving heparin (especially low-molecular-weight heparin) makes timing of catheter placement important and may influence decisions about modalities for pain control and thromboembolism prophylaxis (54–56).

Laparoscopic versus Open Procedures

Our search identified many trials comparing laparoscopic and open procedures, but few reported postoperative pulmonary complication rates. Those that did focused on cholecystectomy and colorectal surgery. Downs and colleagues (36) performed a good-quality systematic review through March 1995 of open and laparoscopic cholecystectomy. They identified 18 trials ($n = 1645$) that were published with sufficient detail to judge methodologic quality. Twelve trials had at least 40 patients per study group, and the largest study had 150 participants per group. Since the authors did not quantitatively pool data because of clinical heterogeneity and methodologic problems, we examined the studies individually. None met the criteria for inclusion in our review (<25 participants per group [8 studies] or no clinical postoperative pulmonary complications reported [10 studies]).

Among the 4 highest-quality trials reporting spirometric outcomes, unblinded outcome assessment found statistically significantly greater compromise in FVC and FEV_1 at 24 hours and 48 hours postoperatively with open cholecystectomy. In 1 study that followed patients until pul-

monary function recovered to within 10% to 15% of preoperative levels, pulmonary function recovered 4 to 10 days earlier with laparoscopic cholecystectomy. Only 1 very small ($n = 40$) blinded trial assessed whether reduced pulmonary dysfunction translated into clinically important differences in postoperative pulmonary complication rates. On postoperative chest radiography, atelectasis occurred significantly less often with laparoscopic operations (40% vs. 90%; $P = 0.001$).

We identified 1 subsequent, poor-quality trial of laparoscopic versus open cholecystectomy (20). Among 82 patients, the frequency and severity of atelectasis, assessed by radiologists who were blinded to type of procedure, were significantly less among patients randomly assigned to laparoscopic cholecystectomy (frequency, 29% vs. 63% [$P < 0.05$]; severity, chi-square for trend $P < 0.05$). However, the analysis was not intention-to-treat: Patients who converted from laparoscopic to open operations were excluded from analysis.

Table 2 summarizes the results of a good-quality meta-analysis of laparoscopic versus open resection of colorectal cancer (37). Overall mortality did not differ. Risk was consistently less with laparoscopic operations for several complications but was not statistically significantly less with the more conservative statistical approach of random-effects modeling. The reduced risk for overall complications was primarily due to fewer wound complications, especially wound infection. Regarding pulmonary complications, a non–statistically significant trend favored laparoscopic resection. Three studies that evaluated postoperative pulmonary complications reported that respiratory recovery (defined by spirometry) was statistically significantly faster. Nine studies reporting data confirmed shorter length of hospital stay (mean, 21% shorter [range, 14% to 38%]) after laparoscopic operations (37).

We identified 1 additional good-quality trial of laparoscopic versus open colorectal resection in 384 patients; 269 were in an earlier publication that was included in the previous meta-analysis discussed (21). Again, a nonsignificant trend favored lower rates of pneumonia after laparoscopic operations (3 of 190 [1.8%] patients and 6 of 194 [3.5%] patients; $P = 0.52$) (21).

Two large retrospective cohort studies highlight the problems with using designs other than a randomized trial and ICD-9-CM codes to identify postoperative pulmonary complications to compare open and laparoscopic operations (57, 58). Atelectasis (the only postoperative pulmonary complication studied) occurred significantly less often with laparoscopic ($n = 19\,662$) compared with open ($n = 23\,771$) cholecystectomy (4% vs. 2%; $P < 0.001$) (57). Overall postoperative pulmonary complications were significantly less frequent after laparoscopic ($n = 709$) compared with open ($n = 17\,735$) sigmoid resection (2.5% vs. 6%; $P < 0.001$) (58). The results of these 2 studies may be unreliable because of lack of systematic prospective surveillance. Clinicians may have been biased to order more postoperative chest radiographs (and therefore identify more atelectasis) after open procedures. Furthermore, in a recent study comparing discharge ICD-9-CM codes and systematic chart review for complications (8), specificity of ICD-9 codes was high but sensitivity was low: 35% (CI, 30% to 41%) for all complications and 32% (CI, 19% to 45%) for all infectious complications.

Table 2. **Summary of Results of Meta-Analysis of 12 Randomized, Controlled Trials for Laparoscopic Operations Relative to Open Operations for Colorectal Cancer***

Result	Odds Ratio (95% CI)	
	Fixed-Effects Model	Random-Effects Model
Mortality	Data not given	0.85 (0.33–2.21)
Overall morbidity	0.62 (0.45–0.85)	0.68 (0.38–1.24)
Overall complications	0.60 (0.45–0.79)	0.62 (0.38–1.03)
Wound complications	0.47 (0.28–0.78)	0.47 (0.28–0.78)
Wound infection	0.47 (0.28–0.80)	0.47 (0.28–0.80)
Respiratory complications	0.65 (0.28–1.49)	0.65 (0.28–1.49)

* Data from Abraham et al. (37).

In summary, while supported by spirometric, postoperative pain, and length of stay data, whether laparoscopic procedures reduce the risk for *clinically important* pulmonary complications is not clear. The literature did not systematically assess or report pulmonary complications, and most studies did not have sufficient statistical power to detect differences in postoperative pulmonary complication rates.

Nasogastric Decompression after Abdominal Surgery

Selective use of nasogastric decompression, or tubes, refers to use only for postoperative nausea or vomiting, inability to tolerate oral intake, or symptomatic abdominal distension. Routine decompression (that is, standard use until bowel function returns) has been thought to speed bowel recovery and decrease risk for aspiration. We identified 2 meta-analyses of studies of routine versus selective nasogastric decompression (38, 39, 59). One or both meta-analyses included all the trials that we identified.

The first meta-analysis was of good methodologic quality up to quantitative analyses, which pooled data from randomized trials, nonrandomized trials, "uncontrolled" trials, and case–control studies (38). For the overall group of 26 studies (which comprised 15 RCTs, 3 nonrandomized trials, and 8 case–control studies [$n = 3964$]), patients receiving selective decompression had significantly lower rates of pneumonia (odds ratio, 0.49; $P < 0.001$) and atelectasis (odds ratio, 0.46; $P = 0.001$) and shorter time to oral intake (3.5 days vs. 4.6 days; $P = 0.04$). Aspiration rates (odds ratio, 0.61; $P = 0.88$) did not differ. Selective decompression did not statistically significantly increase nausea, vomiting, or abdominal distension. For 20 higher-quality studies (15 trials and 5 case–control studies), patients receiving selective decompression also had

Table 3. **Meta-Analyses and Randomized, Controlled Trials of Lung Expansion Interventions To Prevent Postoperative Pulmonary Complications***

Author, Year (Reference)	Type of Surgery	Intervention	Studies Identified/ Eligible RCTs, *n/n*	Random Allocation Concealed	Blinded Outcome Assessment
Systematic reviews or meta-analyses					
Thomas and McIntosh, 1994 (40)	Any upper abdominal surgery	IS, IPPB, DBEs	116/14	NA	NA
Overend et al., 2001 (41)	Upper and lower abdominal surgery	IS, IPPB, DBEs, CPAP, PEP, or CPAP with PT	85/4	NA	NA
Subsequent RCTs					
Chumillas et al., 1998 (22)	Elective upper abdominal surgery	DBEs vs. no prophylaxis		Unclear	Unclear
Fagevik Olsén et al., 1997 (23)	Elective open abdominal surgery	Low risk: DBEs vs. no prophylaxis; high risk: DBEs plus PEP vs. no prophylaxis‡		Unclear	Unclear
Hall et al., 1991 (24)	Abdominal surgery	IS, chest PT (control)		Yes	Yes
Hall et al., 1996 (25)	Abdominal surgery	Low risk: IS vs. DBEs; high risk: IS vs. IS plus chest PT§		Yes	Yes
Böhner et al., 2002 (26)	Elective intra-abdominal vascular surgery	Nasal CPAP for 12 h after surgery vs. O_2 by nasal cannula to keep saturation > 95%		Yes	Unclear

* CDC = Centers for Disease Control and Prevention; CPAP = continuous positive airway pressure; DBE = deep breathing exercise; Fio_2 = fraction of inspired oxygen; IPPB = intermittent positive-pressure breathing; IQR = interquartile range; IS = incentive spirometry; NA = data not available; OR = odds ratio; PEP = positive respiratory pressure throughout expiration; PPC = postoperative pulmonary complication; PT = physical therapy; RCT = randomized, controlled trial.
† Level of evidence for all studies is I = randomized controlled trial.
‡ High risk = age > 50 y and current smoker or body mass index > 30 kg/m^2 or lung disease requiring daily medication.
§ High risk = American Society of Anesthesiologists class > I or age ≥ 60 y.

lower rates of pneumonia (odds ratio, 0.59; $P = 0.01$) and atelectasis (odds ratio, 0.52; $P = 0.002$), a trend toward shorter time to oral intake (3.5 days vs. 4.5 days; $P = 0.07$), no difference in aspiration rates, and significantly higher rates of vomiting (odds ratio, 1.45; $P = 0.005$) and abdominal distension (odds ratio, 1.34; $P = 0.02$)

The recent meta-analysis was of good quality, and it identified 28 eligible trials ($n = 4194$) of routine versus selective nasogastric decompression after open laparotomy (39, 59). It included 15 of the 17 RCTs in the previous meta-analysis. Of 19 trials ($n = 2892$) reporting postoperative pulmonary complication, 18 included only elective operations (39, 59). Patients who were randomly assigned to selective decompression had fewer postoperative pulmonary complications, and the benefit approached statistical significance (relative benefit increase, 1.35 [CI, 0.98 to 1.86]; $P = 0.07$; calculated relative risk reduction, 0.74 [CI, 0.54 to 1.02]). Selective decompression also resulted in earlier bowel recovery (8 studies; $n = 862$; 0.46 day [CI, 0.28 day to 0.64 day]; $P < 0.001$).

In summary, the evidence suggests that selective nasogastric decompression (that is, for specific indications rather than routine decompression) improves return of bowel function and may reduce the incidence of postoperative pulmonary complications after elective abdominal operations.

Lung Expansion Modalities

Decreased lung volumes and atelectasis due to surgery-related shallow breathing, bed rest, diaphragmatic dysfunction, pain, and impaired mucociliary clearance may be the

Table 3—**Continued**

Participants			PPCs/Outcomes	Level of Evidence†; Study Quality	Results
Total, *n*	Men, *n*	Age, *y*			
1337	NA	NA	Atelectasis or infiltrate on chest radiograph	I; poor	IS vs. no treatment: 2 studies (n = unclear) (OR, 0.44 [95% CI, 0.18–0.99]) IS vs. IPPB: 3 studies (n = unclear) (OR, 0.73 [CI, 0.39–1.36]) IS vs. DBE: 4 studies (n = unclear) (OR, 0.91 [CI, 0.57–1.4]) IPPB vs. DBE: 2 studies (n = unclear) (OR, 0.94 [CI, 0.28–3.17])
NA	NA	NA	No data except wide variability noted	I; poor	No quantitative pooling due to clinical heterogeneity; no quantitative results for individual studies reported. In 3 studies (all with < 25 participants per group), IS was no better than DBEs or no treatment and was inferior to CPAP or PEP. In a fourth study (41–44 participants per group), IS, DBEs, and IPPB (PPC rates of 21%, 22%, and 22%, respectively) were equally superior to no prophylaxis (PPC rate 48%; $P < 0.05$ for all comparisons).
81	35	Mean, 64.1 (range, 18–84)	Bronchitis, atelectasis, pneumonia	I; poor	DBEs: fewer abnormalities on chest radiograph (15% vs. 39%; $P = 0.02$) and trend toward fewer PPCs (8% vs. 20%; $P = 0.11$)
368; 79 (20%) were high-risk‡	158	Mean, 53.4 (range, 19–92)	Pneumonia	I; poor	DBEs: lower rate of overall pneumonia (0.6% vs. 7%; $P < 0.05$)
876	430	Median, 55 (IQR, 32–72)	Clinical examination of collapse or consolidation plus abnormal chest radiograph or positive sputum "microbiology"	I; poor	No difference between IS and chest PT in rates of PPCs (16% vs. 15%) and abnormal chest radiograph (22% both groups)
456	209	Low-risk: median, 36 (IQR, 29–44); high risk: median, 68 (IQR, 58–76)	Clinical examination of collapse or consolidation plus abnormal chest radiograph or positive sputum "microbiology"	I; poor	No difference in rate of PPCs: low risk: 8% vs. 11% ($P = 0.50$); high risk: 19% vs. 13% ($P = 0.18$)
204	166	Mean, 64 (SD 11.8)	Pneumonia per CDC criteria, severe hypoxemia ($Pao_2 < 70$ mm Hg at $Fio_2 \geq 0.70$)	I; good	Nasal CPAP: lower rate of severe hypoxemia (5% vs. 16%; $P = 0.01$); trends toward lower rate of pneumonia (2% vs. 5%; $P = 0.45$) and reintubation (1% vs. 5%; $P = 0.21$)

first events in a cascade leading to postoperative pulmonary complication. However, the evidence on prophylactic lung expansion is limited by variable techniques, inconsistent definitions of postoperative pulmonary complications, and poor-quality trials. Techniques include incentive spirometry, deep breathing exercises, chest physical therapy (which may include variable combinations of deep breathing, cough, postural drainage, percussion and vibration, suctioning, and ambulation), intermittent positive-pressure breathing, and continuous positive airway pressure. **Table 3** summarizes the evidence.

The first of 2 poor-quality systematic reviews focused on upper abdominal surgery and identified 14 randomized trials (sample size, 17 to 200 participants) (40). Across all lung expansion modalities, a trend favored fewer postoperative pulmonary complications compared with controls (odds ratio, 0.85 [CI, 0.59 to 1.2)], but heterogeneity was statistically significant. In 2 studies, postoperative pulmonary complications occurred less often in patients receiving incentive spirometry compared with control (odds ratio, 0.44 [CI, 0.18 to 0.99]). In 4 studies, postoperative pulmonary complications occurred less often in patients who were randomly assigned to deep breathing exercises (odds ratio, 0.43 [CI, 0.27 to 0.63]), but heterogeneity was again statistically significant. Across other studies, no single modality was clearly superior. The second systematic review identified 4 randomized trials of patients undergoing abdominal surgery (41). The authors did not report raw or pooled postoperative pulmonary complication rates. In the only trial in our systematic review that met our sample size

criteria, incentive spirometry, deep breathing exercises, and intermittent positive-pressure breathing equally prevented postoperative pulmonary complications compared with no intervention.

We identified 5 other trials in patients undergoing major abdominal surgery. The first 4 trials were of poor quality. Two trials compared chest physiotherapy with no prophylaxis (22, 23). In the first study, patients who were randomly assigned to chest expansion, maximum inspiration exercises, cough, and early ambulation had fewer abnormalities on postoperative chest radiography and a non–statistically significant trend toward fewer postoperative pulmonary complications (22). In the second trial, patients who were randomly assigned to cough and deep breathing exercises had significantly lower rates of pneumonia (0.6% vs. 7%; $P < 0.05$) (23).

The third trial compared "conventional chest physiotherapy" with incentive spirometry in 876 patients undergoing abdominal surgery and found no difference in rates of overall postoperative pulmonary complication, abnormal postoperative chest radiography, or Pa_{O_2} less than 60 mm Hg (24). The fourth poor-quality study compared 1) incentive spirometry and deep breathing exercises in 155 low-risk patients and 2) incentive spirometry versus incentive spirometry plus chest physiotherapy in 301 high-risk patients (ASA class > I or age ≥ 60 years) undergoing abdominal surgery (25). Among high- or low-risk patients, postoperative pulmonary complication rates did not differ with any intervention.

In the fifth and only good-quality trial (26), 204 patients undergoing intra-abdominal vascular surgery were randomly assigned to supplemental oxygen to maintain arterial oxygen saturation greater than 95% or to nasal continuous positive airway pressure for 12 hours after surgery. Severe hypoxemia ($Pa_{O_2} < 70$ mm Hg at fraction of inspired oxygen ≥ 0.70%) occurred statistically significantly less often (5% vs. 16%; $P = 0.01$), and non–statistically significant trends favored less pneumonia and reintubation with continuous positive airway pressure.

For patients having abdominal surgery, the evidence suggests that any type of lung expansion intervention is better than no prophylaxis. No modality seems superior, and combined modalities do not seem to provide additional risk reduction. Incentive spirometry may be the least labor-intensive, while continuous positive airway pressure may be particularly beneficial for patients who cannot participate in incentive spirometry or deep breathing exercises.

Nutritional Support

Total Parenteral or Total Enteral Hyperalimentation

A fair-quality meta-analysis of 14 randomized or quasi-randomized trials of total parenteral nutrition (TPN) versus no TPN through August 1986 concluded that routine TPN in major surgery was not beneficial, except perhaps for severe malnutrition or for extended periods (10 days to 14 days) of inadequate enteral nutrition (60). The meta-analysis did not report results specific to pulmonary complications and was therefore ineligible for our review.

Subsequently, a good-quality multisite trial randomly assigned 395 patients undergoing laparotomy or noncardiac thoracotomy to perioperative TPN or no TPN (27). Overall rates of major complications (26% vs. 25%) and 90-day mortality (13% vs. 11%) were similar between the groups. Total parenteral nutrition was associated with non–statistically significant trends toward *higher* rates of pneumonia and empyema but significantly lower rates of noninfectious complications (5.3% vs. 42.9%; $P = 0.03$).

We identified 1 poor-quality meta-analysis (230 patients) and 2 additional, good-quality trials of TPN versus total enteral nutrition (TEN) (28, 29, 42). In the meta-analysis, infections were twice as common among patients receiving TPN (35% vs. 16%; $P = 0.01$) even after excluding patients with catheter sepsis from analysis (29% vs. 16%; $P = 0.03$) (42). There was a nonstatistically significant trend toward more frequent pneumonia in patients receiving TPN. In a trial of 241 patients, there was a non–statistically significant trend toward more postoperative pulmonary complications with TEN (7% vs. 13%; $P = 0.12$) (28). In a second, larger trial, 317 malnourished patients (>10% weight loss in previous 6 months) were randomly assigned to TPN or TEN (29). Rates of overall complications and infectious complications were statistically significantly lower with TEN, but rates of pneumonia (9 of 159 patients vs. 14 of 158 patients; $P = 0.39$) or the combined outcome of pneumonia and respiratory failure (13 of 159 patients vs. 20 of 158 patients; $P = 0.27$) did not differ.

Immunonutrition

Immunonutrition refers to enteral feedings with additional ingredients (variable combinations of arginine, Ω-3 fatty acids, or ribonucleic acids) to enhance the immune system and to possibly prevent infection. A good-quality meta-analysis of trials found that for patients undergoing elective surgery, enteral immunonutrition had no mortality benefit but resulted in significantly fewer overall infectious complications (relative risk, 0.53 [CI, 0.42 to 0.68]) (61). The authors did not report results for respiratory infections; therefore, the study was not eligible for our review.

In a subsequent good-quality trial of enteral immunonutrition (30), 305 patients undergoing elective resection of gastrointestinal cancer were randomly assigned to an enteral solution enriched with arginine, Ω-3 fatty acids, and ribonucleic acids preoperatively (5 days before surgery; $n = 102$) or perioperatively (5 days before surgery plus jejunal tube feeding begun within 12 hours of surgery and continued until oral intake was resumed; $n = 101$) or to a control group ($n = 102$) of postoperative intravenous glucose and electrolytes. Overall infection rates were significantly lower with immunonutrition (14% and 16% vs. 30%; $P = 0.006$ and 0.02, respectively), but rates of pneu-

Table 4. **Strength of the Evidence for Specific Interventions To Reduce the Risk for Postoperative Pulmonary Complications**

Risk Reduction Strategy	Strength of Evidence*	Type of Complication Studied
Postoperative lung expansion modalities	A	Atelectasis, pneumonia, bronchitis, severe hypoxemia
Selective postoperative nasogastric decompression	B	Atelectasis, pneumonia, aspiration
Short-acting neuromuscular blockade	B	Atelectasis, pneumonia
Laparoscopic (vs. open) operation	C	Spirometry, atelectasis, pneumonia, overall respiratory complications
Smoking cessation	I	Postoperative ventilator support
Intraoperative neuraxial blockade	I	Pneumonia, postoperative hypoxia, respiratory failure
Postoperative epidural analgesia	I	Atelectasis, pneumonia, respiratory failure
Immunonutrition	I	Overall infectious complications, pneumonia, respiratory failure
Routine total parenteral or enteral nutrition†	D	Atelectasis, pneumonia, empyema, respiratory failure
Right-heart catheterization	D	Pneumonia

* Definitions for categories of strength of evidence, modified from the U.S. Preventive Services Task Force categories (11). A = good evidence that the strategy reduces postoperative pulmonary complications and benefit outweighs harm; B = at least fair evidence that the strategy reduces postoperative pulmonary complications and benefit outweighs harm; C = at least fair evidence that the strategy may reduce postoperative pulmonary complications, but the balance between benefit and harm is too close to justify a general recommendation; D = at least fair evidence that the strategy does not reduce postoperative pulmonary complications or harm outweighs benefit; I = evidence of effectiveness of the strategy to reduce postoperative pulmonary complications is conflicting, of poor quality, lacking, or insufficient or the balance between benefit and harm cannot be determined.

† Evidence remains uncertain (strength of evidence I) on total parenteral or enteral nutrition for severely malnourished patients or when a protracted time of inadequate nutritional intake is anticipated.

monia (3 of 102 patients and 6 of 101 patients vs. 8 of 102 patients) did not differ (30).

In summary, while hypoalbuminemia and malnutrition increase postoperative complications, including pneumonia, routine TPN has no benefit over either TEN or no hyperalimentation, except perhaps for patients with severe malnutrition or for long periods of inadequate oral nutrition. More research is needed on enteral formulations that may enhance immune status. Prompt resumption of oral intake after surgery is important because atrophy of intestinal villi occurs quickly with inadequate intake and increases the risk for bacterial translocation across gut mucosa and subsequent sepsis (62).

Intervention of No Benefit: Pulmonary Artery Catheterization

After observational data suggested higher rates of respiratory failure and pneumonia in patients receiving right-heart catheterization for noncardiac surgery (63), Sandham and colleagues (31) performed a good-quality RCT. High-risk patients ($n = 1994$; age ≥ 60 years; ASA class III or IV) undergoing urgent or elective major noncardiac operations were randomly assigned to usual care or treatment guided by perioperative pulmonary artery catheter. Pulmonary artery catheterization did not reduce the primary outcome of in-hospital all-cause mortality (7.8% vs. 7.7%) or the rate of postoperative pneumonia, a secondary outcome (6.7% vs. 7.3%; $P = 0.70$).

DISCUSSION

Recent evidence has shown that postoperative pulmonary and cardiac complications are equally prevalent and clinically important in morbidity, mortality, and length of stay. However, compared with postoperative cardiac complications, much less research on prevention of pulmonary complications has been published. **Table 4** summarizes the strength of available evidence, based on our systematic review, on interventions to reduce the risk for postoperative pulmonary complications.

Strategies of Proven Benefit

Good evidence suggests that lung expansion therapy (for example, incentive spirometry, deep breathing exercises, and continuous positive airway pressure) reduces postoperative pulmonary risk after abdominal surgery. Well-designed trials are needed to clarify the magnitude of benefit and the comparative effectiveness of different modalities.

Strategies of Probable Benefit

Fair evidence suggests that selective nasogastric tube decompression after abdominal surgery reduces risk. Fair evidence also suggests that short-acting neuromuscular blocking agents result in lower rates of residual neuromuscular blockade and may reduce risk for pulmonary complications.

Strategies of Possible Benefit

Laparoscopic, compared with open, abdominal operations reduce pain and pulmonary compromise as measured by spirometry and oxygenation. However, the evidence is insufficient to determine whether laparoscopic operations prevent clinically important pulmonary complications. Given the benefits of laparoscopic procedures in pain control and length of stay, future trials to adequately assess clinical pulmonary outcomes are unlikely.

Strategies of Unclear Benefit

Evidence is insufficient to judge the potential benefit of preoperative smoking cessation in reducing risk. Risk may actually increase transiently after stopping or reducing smoking within 2 months of surgery due to increased secretions. We need trials of preoperative smoking cessation

before higher-risk surgeries that adequately address optimal duration of cessation.

Evidence on intraoperative epidural anesthesia and postoperative epidural analgesia is insufficient. More good-quality efficacy trials of sufficient size (in which all groups receive equally standardized and optimized regimens) are needed to accurately examine complication rates.

Strategies of No Benefit

Although malnutrition is associated with increased risk for postoperative pulmonary complications, good evidence indicates that routine total parenteral or enteral hyperalimentation nutrition does not reduce risk, except perhaps for patients with severe malnutrition or for those undergoing long periods with inadequate oral intake. Enteral formulations that are tailored to enhance immune status and reduce postoperative infections may be promising.

Evidence from 1 well-done randomized trial indicates that invasive perioperative monitoring with pulmonary artery catheterization does not reduce risk of pulmonary complications.

Limitations

A limitation of our review is the overall quality of the literature. Only 10 of 20 RCTs and 6 of 11 systematic reviews or meta-analyses were of good quality.

Future Research

Future studies of interventions to reduce postoperative pulmonary complications should be randomized trials that are designed to overcome methodologic problems in earlier literature. Cohort studies using secondary analyses of administrative databases should use measures for pulmonary complications that are proven valid and reliable by direct clinical assessment or medical chart audit. Studies should be large enough to adjust for known potential risk factors and confounding variables (as synthesized in the accompanying systematic review of preoperative risk stratification [7]) and should go beyond surrogate or intermediate physiologic or spirometric outcomes to detect clinically meaningful differences in clinical pulmonary complications. This is important for 2 reasons: to base patient care on clinically meaningful evidence and to determine when it is appropriate to substitute intermediate outcomes to shorten study timelines and reduce study cost. Researchers should define postoperative pulmonary complications a priori according to explicit criteria and, whenever possible, use outcome assessment that is masked, or blinded, to intervention assignment.

From the South Texas Veterans Health Care System and The University of Texas Health Science Center at San Antonio, San Antonio, Texas, and Beth Israel Deaconess Medical Center, Harvard Medical School, Boston, Massachusetts.

Disclosure: Members of the American Society of Anesthesiologists also reviewed the manuscript. Their review implies neither agreement with nor endorsement of this document.

Acknowledgments: The authors gratefully acknowledge the tremendous contribution of medical librarian Martha R. Harris, MA, for her time and expertise in searching the medical literature and managing the resulting project database. They also thank the Department of Anesthesiology, especially Christopher Jankowski, MD, of the Mayo Clinic, Rochester, Minnesota, for assistance in interpreting the anesthesiology literature.

Grant Support: By the Veterans Evidence-based Research, Dissemination, and Implementation Center (VERDICT) (Veterans Affairs Health Services Research and Development, HFP 98-002).

Potential Financial Conflicts of Interest: *Stock ownership or options (other than mutual funds):* G.W. Smetana (SafeMed Harvard Imaging); *Other:* G.W. Smetana (Novartis Pharma Schweiz).

Requests for Single Reprints: Valerie A. Lawrence, MD, Medicine/General Medicine, University of Texas Health Science Center at San Antonio, 7703 Floyd Curl Drive, Mail Code 7879, San Antonio, TX 78229-3900; e-mail, vlawrence@uthscsa.edu.

Current author addresses are available at www.annals.org.

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Current Author Addresses: Drs. Lawrence and Cornell: Medicine/General Medicine, University of Texas Health Science Center at San Antonio, 7703 Floyd Curl Drive, Mail Code 7879, San Antonio, TX 78229-3900.

Dr. Smetana: Division of General Medicine and Primary Care, Beth Israel Deaconess Medical Center, 330 Brookline Avenue, Boston, MA 02215.

Appendix Table 1. Abstracted Data for Eligible Randomized Trials*

Author, Year (Reference)	Intervention	Intervention Description	Control Description	Type of Surgery	Inclusion Criteria	Exclusion Criteria	Patients Blinded	Outcome Assessment Blinded	Multicenter	Randomization Allocation Concealment	ITT Analysis
Møller et al., 2002 (12)	Preoperative smoking cessation	Weekly meeting with project nurse; estimate of nicotine dependence; free, tailored nicotine replacement; smoking status measured by carbon monoxide in expired air; advice about cessation or reduction, benefits, side effects, or management of withdrawal symptoms and weight	Standard care: "little or no information about risk of smoking or cessation counselling"	Elective knee or hip replacement	Daily smokers	Weekly alcohol intake > 35 units	No	Yes	Yes: 3 university-affiliated hospitals, Copenhagen, Denmark	Adequate	Yes
Berg et al., 1997 (13)	Long-acting vs. intermediate-acting neuromuscular blockade	Pancuronium	Atracurium or vecuronium	Elective major lower extremity, gynecologic, breast, or abdominal surgery	"Adults," general anesthesia, ASA class I–III	Expected duration of anesthesia < 60 min, >30% ideal body weight, neuromuscular disease, preoperative drugs affecting neuromuscular transmission, renal or liver "insufficiency," increased preoperative creatinine level	No data	Yes	Yes: 2 university-affiliated hospitals, Copenhagen, Denmark	Adequate	Yes
Norris et al., 2001 (14)	General anesthesia vs. general + regional anesthesia and IV PCA vs. epidural PCA	1) General + regional with IV PCA; 2) general + regional with epidural PCA	3) General with IV PCA; 4) general with epidural PCA	Elective abdominal aortic surgery	Elective abdominal aortic surgery	Cross-clamping of thoracic aorta, contraindication to epidural, major operation in the previous 14 d, opioid dependence	Yes	Yes	No	Yes	Yes
Rigg et al., 2002 (15)	Intraoperative + postoperative epidural analgesia	Intraoperative general anesthesia and epidural local anesthetic, then postoperative epidural local anesthetic for 72 h with as-needed opioid (fentanyl or pethidine)	Intraoperative general anesthesia, then postoperative IV opioid and as-needed NSAID, opioid, and paracetamol	Elective major nonlaparoscopic abdominal operations or esophagectomy	Age > 18 y	Surgery < 12 h after admission, contraindication to epidural block	No	No	Yes: Hospitals in Australia, East Asia, and Middle East	Yes	Yes
Park et al., 2001 (16)	Intraoperative epidural anesthesia + postoperative epidural analgesia	Intraoperative "light" general anesthesia + epidural bupivacaine, then postoperative epidural morphine and as-needed IV opioid	Intraoperative general anesthesia, then postoperative IV or IM opioid	Elective aortic, gastric, biliary, or colon operations	Veterans, age ≥ 21 y	Age < 21 y; women; confusion; ASA class I, II, or V; surgery ≤ 12 h after admission; myocardial infarction ≤ 6 mo; previous abdominal surgery ≤ 3 mo; previous aortic procedure; tracheostomy or endotracheal tube; chemo- or immunosuppression therapy other than corticosteroids; study drug hypersensitivity; contraindication to epidural; physician refusal; enrolled in other Veterans Affairs study	No	Yes	Yes: 15 Veterans Affairs hospitals	Yes	Yes
Fleron et al., 2003 (17)	Intraoperative epidural opioid	Intraoperative general anesthesia and epidural sufentanil and morphine	Intraoperative general anesthesia and IV sufentanil	Elective abdominal aortic surgery	Consecutive patients for elective abdominal aortic surgery	Contraindication to epidural	No	No	No	Yes	No
Mann et al., 2000 (18)	General anesthesia + epidural anesthesia then PCEA	Intraoperative general anesthesia and epidural local anesthetic or opioid, then postoperative PCEA + opioid	Intraoperative general anesthesia, then postoperative patient-controlled IV opioid	Elective major abdominal surgery for malignant condition	Age >70 y, ASA class I or II, normal preoperative mental status, no severe malnutrition or cerebrovascular insufficiency, no contraindication to epidural	No additional data	No	Yes for chest radiography, unclear for other outcomes	No	Yes	No

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Appendix Table 1—**Continued**

Author, Year (Reference)	Intervention	Intervention Description	Control Description	Type of Surgery	Inclusion Criteria	Exclusion Criteria	Patients Blinded	Outcome Assessment Blinded	Multicenter	Randomization Allocation Concealment	ITT Analysis
Cuschieri et al., 1985 (19)	General anesthesia + intraoperative and postoperative local anesthetic	Intraoperative general anesthesia and local anesthetic, then postoperative epidural local anesthetic for 12 h, then as-needed IM morphine	Intraoperative general anesthesia, then as-needed IV continuous morphine or intermittent IM morphine	Elective cholecystectomy	Age < 75 y	No additional information	No	Unclear	No	Unclear	Yes
Karayiannakis et al., 1996 (20)	LC	LC with 4-trocar technique	OC with transverse right subcostal incision	Elective cholecystectomy	All patients with symptomatic cholelithiasis	Acute cholecystitis, choledocholithiasis, age > 65 y, body mass index > 29 kg/m^2, history of pulmonary disease, >10 cigarettes/d	No	Yes for chest radiography	No	Yes	No
Vignali et al., 2004 (21)	LCR	LCR	OCR	Elective colorectal resection	Age > 18 y and candidate for laparoscopic resection	Cancer infiltrating adjacent organs by imaging, NYHA class > 3, arterial Po_2 < 70 mm Hg, liver dysfunction (Child–Pugh class C), "ongoing infection," neutrophil count < 2 × 10^9 cells/L	No	Yes	No	Yes	Yes
Chumillas et al., 1998 (22)	"Respiratory rehabilitation" with breathing exercises	Instruction about forced expiration technique and cough, chest expansion exercises and diaphragm mobilization, maximum inspiration for 3–5 s, and early ambulation after surgery; exercises were done for 10–15 min QID before surgery and for 10 min every 2 h on postoperative days 1 and 2	No description	Elective supraumbilical laparotomy	Age > 15 y	Not stated a priori	No	Unclear	No	Unclear	No
Fagevik Olsén et al., 1997 (23)	Chest physiotherapy	Preoperative training in DBEs with pursed lips, huffing, coughing every tenth breath hourly after surgery; importance of position change in bed and early mobilization; high-risk patients were also given PEP; postoperative therapy was adjusted per physiotherapist or physician "according to pulmonary status"; duration of treatment was 10–15 min before and 15–20 min after surgery	No training before surgery, no therapy after surgery unless pulmonary complications occurred, then patients given physiotherapy with PEP	Elective open abdominal surgery	No data	No data	No	No data	No	No: "[T]o avoid patient interference, cluster randomization was performed in alternate months"	Unclear
Hall et al., 1991 (24)	IS vs. chest physiotherapy	IS device on bedside table, patient instructed in use; attending physicians' responsibility to promote its use perioperatively, preferably for 5 min in each waking hour	Treatment according to the clinical judgment of attending physicians and physiotherapists	Laparotomy "with manipulation of viscera"	Laparotomy "with manipulation of viscera"	Age < 14 y, preoperative pulmonary complication per outcome definitions	No	Yes	No	Yes	Yes
Hall et al., 1996 (25)	Low-risk patients: 1) IS vs. 2) DBEs; high-risk patients: 3) IS vs. 4) IS + chest physiotherapy	1) and 3) IS: information sheet and encouragement to use IS at least 10 times hourly	2) DBEs: seen once and encouraged to take 10 deep breaths hourly; 4) IS + chest physiotherapy had physiotherapy aimed at producing maximum inspiratory effort at least once daily for postoperative days 1–3, then at further rate per physiotherapist	Laparotomy "with manipulation of viscera"	Laparotomy "with manipulation of viscera"; high-risk patients defined as ASA class > I or age ≥ 60 y	Language, pulmonary complication before surgery, lack of consent due to declined participation or insufficient time before surgery	No	Yes	No	Yes	Yes

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Appendix Table 1—**Continued**

Author, Year (Reference)	Intervention	Intervention Description	Control Description	Type of Surgery	Inclusion Criteria	Exclusion Criteria	Patients Blinded	Outcome Assessment Blinded	Multicenter	Randomization Allocation Concealment	ITT Analysis
Böhner et al., 2002 (26)	Nasal CPAP for 12 h after surgery	Intermediate care for at least 24 h after surgery with nasal CPAP at 10 cm H_2O for at least 12 h after surgery to keep o_2 saturation > 95%	Intermediate care for at least 24 h after surgery with oxygen by face mask or nasal cannula to keep oxygen saturation > 95%	Elective midline abdominal vascular surgery	Elective midline abdominal vascular surgery scheduled to be extubated in the operating room	Emergency surgery, repair of thoracoabdominal aneurysm, exclusively retroperitoneal approach	No	No data	No	Yes	Yes
VA TPN Cooperative Study Group, 1991 (27)	Preoperative TPN	TPN to caloric goal of 1000 kcal > resting metabolic expenditure; optimal was 7–15 d before surgery; suboptimal was < 7 d; TPN continued 72 h after surgery; oral intake as clinically allowed or tolerated	No TPN or forced enteral intake before surgery or after surgery for 72 h, then TPN or enteral if indicated	Elective laparotomy or thoracotomy	Age ≥ 21 y, elective laparotomy or thoracotomy	Death expected within 90 d, TPN in previous 15 d, other surgery within previous 30 d, contraindication to delay in surgery for TPN, TPN contraindicated, major concurrent illness, TPN essential, well-nourished	No	No	Yes	Yes	Yes
Pacelli et al., 2001 (28)	TEN vs. TPN	Postoperative TEN (during induction of TEN, TPN was added to achieve the same caloric intake as in the TPN group)	Postoperative TPN	Major elective abdominal operations	Age 18–80 y, malnourished, nutritional risk index < 90%	Emergency surgery, elective appendectomy, cholecystectomy or viscerolysis	No	Unclear	Yes	Yes	Yes
Bozzetti et al., 2001 (29)	TEN vs. TPN	Postoperative TEN: jejunostomy feeding tube or nasojejunal feeding tube placed during surgery	Postoperative TPN	Elective major resection for gastrointestinal cancer	Weight loss ≥ 10% usual body weight in previous 6 mo, histologically proven cancer	Age < 18 y, liver dysfunction (Child–Pugh class > 2), serum creatinine level > 265.2 μmol/L (>3 mg/dL) or hemodialysis, NYHA functional class > III, history of stroke, pregnancy, ongoing infection, previous intestinal anastomosis of the large bowel without a diverting stoma	No	No	Yes	Yes	Yes
Gianotti et al., 2002 (30)	Enteral immunonutrition	1) Oral immunonutrition for 5 d before surgery, no supplementation after surgery; 2) oral immunonutrition for 5 d before surgery and by jejunal feeding after surgery until oral intake resumed	3) Usual care, no enteral supplement, IV 5% glucose and electrolytes	Elective major resection for gastrointestinal cancer	Histologically proven cancer	Weight loss ≥ 10% of usual body weight in past 6 mo, age < 18 y, liver dysfunction (Child–Pugh class > B), Pao_2 < 70 mm Hg, creatinine level > 265.2 μmol/L (>3 mg/dL) or hemodialysis, NYHA class > 3, Karnofsky < 60, pregnancy, ongoing infection, neoadjuvant radiochemotherapy or neutrophil count < 2×10^9 cells/L	No	Unclear	No	Yes	Yes
Sandham et al., 2003 (31)	Pulmonary artery catheter in high-risk surgical patients	Pulmonary artery catheter placed before surgery; treatment directed to a priori established physiologic goals and priorities	No pulmonary artery catheter, central venous catheter allowed	Urgent and elective major abdominal, thoracic, vascular, or hip fracture surgery	Age ≥ 60 y, ASA class III or IV	No additional inclusion criteria	No	Yes	Yes	Yes	Yes

* ASA = American Society of Anesthesiologists; CPAP = continuous positive airway pressure; DBE = deep breathing exercise; IM = intramuscular; IS = incentive spirometry; ITT = intention-to-treat; IV = intravenous; LC = laparoscopic cholecystectomy; LCR = laparoscopic colorectal resection; NSAID = nonsteroidal anti-inflammatory drug; NYHA = New York Heart Association; OC = open cholecystectomy; OCR = open colorectal resection; PCA = patient-controlled analgesia; PCEA = patient-controlled epidural analgesia; PEP = positive expiratory pressure; QID = four times daily; TEN = total enteral nutrition; TPN = total parenteral nutrition; VA TPN = Veterans Affairs Total Parenteral Nutrition.

Appendix Table 2. **Abstracted Data for Eligible Randomized Trials, Continued***

Author, Year (Reference)	Sampling Strategy	Comorbid Conditions	Important Baseline Differences?	Important Intraoperative Differences?	Anesthesia	Follow-up	Important Differences in Co-Interventions Relevant for Pulmonary Complications?	Crossovers	Participant Accrual	Participant Attrition
Møller et al., 2002 (12)	Consecutive	Chronic heart disease, chronic obstructive lung disease, diabetes	No	None regarding percentage of patients receiving general anesthesia, duration of surgery, or number of hip or knee operations	General or regional	Hospital stay	No	No	166 eligible, 46 declined, 120 randomly assigned	4 (intervention) and 8 (control): operation delayed or canceled
Berg et al., 1997 (13)	No data	Smoking status, pulmonary disease	No; trends toward more smokers, droperidol, and inhaled anesthetic in the pancuronium group	Significantly more anesthetic minutes, residual neuromuscular block and minutes to extubation with pancuronium compared with vecuronium or atracurium	General	Postoperative day 6	No	No	No data other than 693 patients eligible and enrolled	2 protocol violations
Norris et al., 2001 (14)	Consecutive?	Diabetes, hypertension, renal insufficiency, cardiovascular and peripheral vascular disease, smoking	No	General anesthesia associated with significantly less operation and cross-clamping time compared with general + regional anesthesia		Postoperative day 7 and 1, 3, 6, and 12 mo for mortality	No	No	309 evaluated, 62 ineligible, 48 declined, 24 "administrative exclusions," 176 consented, 7 not randomly assigned due to failed epidural, 8 randomly assigned to pilot study, 160 randomly assigned to reported study	None
Rigg et al., 2002 (15)	Consecutive?	Morbid obesity, diabetes, chronic renal failure, cardiac failure, respiratory insufficiency, acute myocardial infarction, exertional angina, myocardial ischemia, severe liver disease	No	No data		30 d for mortality, complications; hospital stay?	No data	Unclear how analgesia was handled for 222 patients assigned to epidural but not fully adherent to protocol	920 randomly assigned, 32 excluded after randomization	32 excluded after randomization: 5 entered in study for second operation and 27 ineligible or canceled surgery
Park et al., 2001 (16)	Consecutive?	ASA class II or III, Goldman cardiac risk index, previous angina, myocardial infarction, congestive heart failure, hypertension, chronic obstructive lung disease, diabetes, renal failure, cerebrovascular accident, current smoking, history of alcoholism, alcoholic liver disease	No	No differences in operation severity or duration		30 d	Groups received similar antibiotic prophylaxis, bowel preparation, and intraoperative monitoring	Control to intervention: 48 patients; intervention to control: 32 patients	2731 screened, 1360 excluded, 350 declined, 1021 randomly assigned	26 surgeries canceled, 11 withdrawals
Fleron et al., 2003 (17)	Consecutive	Coronary artery disease, hypertension, congestive heart failure, chronic obstructive lung disease, diabetes	No	No		30 d	No	Lumbar puncture could not be done in 3 patients in epidural group: They were switched to the control group for analysis	"217 patients who met all inclusion criteria were randomized"	
Mann et al., 2000 (18)	Consecutive?	Coronary artery disease, diabetes, hypertension, chronic obstructive lung disease, depression	No	Patients randomly assigned to epidural had significantly less sufentanil and isoflurane, significantly more ephedrine, and significantly longer time to extubation		Clinical: daily through postoperative day 7; chest radiography: postoperative days 1, 3, 5	No	No data	108 evaluated, 4 declined, 34 ineligible, 70 randomly assigned	4 patients: no surgical resection; 2 patients: declined to use patient-controlled anesthesia

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Appendix Table 2—**Continued**

Author, Year (Reference)	Sampling Strategy	Comorbid Conditions	Important Baseline Differences?	Important Intraoperative Differences?	Anesthesia	Follow-up	Important Differences in Co-Interventions Relevant for Pulmonary Complications?	Crossovers	Participant Accrual	Participant Attrition
Cuschieri et al., 1985 (19)	Consecutive?	Weight, smoking, respiratory disease	No	No for duration of anesthesia, trend toward more intraoperative opioids and longer time to first dose of postoperative analgesia in IM morphine group		Postoperative day 3	No data	4 failed epidural catheter placement and received IM morphine	"75 patients were included in the study, 25 in each group"	None
Karayiannakis et al., 1996 (20)	Consecutive	None reported	No for age, sex, weight, height, or other baseline data reported	No for operation and anesthesia time but trend toward shorter operation time (97 min ± 19 min vs. 108 min ± 23 min) and anesthesia time (116 min ± 15 min vs. 139 min ± 18 min) with LC	General	Hospital stay	No	3 randomly assigned to LC required conversion to open operation and were excluded from analysis	147 eligible, 49 declined, 98 randomly assigned	7 (2 LCs, 5 OCs) declined after randomization; 2 LCs excluded due to incomplete pulmonary tests; 3 LCs excluded due to conversion to OC; 4 OCs excluded due to common bile duct exploration
Vignali et al., 2004 (21)	Consecutive	ASA class, weight loss > 10%, cancer	Patients having OCR were older than those having LCR (62 y ± 13.4 y vs. 66 y ± 12.2 y; $P = 0.02$); no differences for other reported comorbid conditions	No for intraoperative transfusion amount, tumor stage, or reason for operation; LCR was associated with longer operation time (221 min ± 69 min vs. 178 min ± 68 min; $P = 0.0001$), less intraoperative blood loss (177 mL ± 200 mL vs. 264 mL ± 292 mL; $P = 0.01$), less frequent transfusion (17% vs. 42%; $P = 0.0001$).	General + thoracic epidural	30 d after discharge with weekly office visits	No	10 randomly assigned to LCR required conversion to OCR	384 randomly assigned	None
Chumillas et al., 1998 (22)	Consecutive	No data	No data except "no significant differences in sample characteristics or risk factors of both groups, including preoperative chest x-ray, with the exception of sex distribution"	No data except "no significant differences in average operation duration or types of incision"	General	Postoperative day 6	No	No data	115 randomly assigned, 34 excluded (emergency operation, extrapulmonary complications, infraumbilical extension of incision, patient cooperation with intervention), 81 "evaluable patients"	
Fagevik Olsén et al., 1997 (23)	Consecutive	Overweight smokers with high-risk ASA class	"No significant differences in background variables"	No significant difference in distribution of operation types but trend toward more upper abdominal operations in control group (30% vs. 39%)	General	Hospital stay	No data	No data	368 randomly assigned	4 noncompletions: 2 control, 2 treatment
Hall et al., 1991 (24)	Consecutive	Preoperative hospital stay > 3 d, current smoker, chronic bronchitis, abnormal chest radiograph, Po_2 < 80 mm Hg, ASA class	No	No for anesthesia time, distribution among 12 surgeons, intraperitoneal infection, type of incision, postoperative nasogastric decompression	Unclear, presumably all general	Hospital stay	No data	No data	1032 screened; 156 excluded (5 <14 y of age, 3 retardation, 8 language, 14 declined, 25 preoperative pulmonary complication, 101 insufficient time to consent); 876 randomly assigned	35 randomly assigned patients did not have surgery: 21 IS, 14 chest physiotherapy
Hall et al., 1996 (25)	Consecutive	ASA class, cancer, current smoker, chronic bronchitis	No	No for operation time, procedure type, intraperitoneal infection, incision type or length, reoperation, nasogastric decompression, epidural analgesia	No data, presumably all general, some with additional epidural anesthesia	Hospital stay	No data	No data	619 screened; 143 excluded (13 language, 14 declined, 15 preoperative pulmonary complication, 115 lack of consent); 476 randomly assigned	20 randomly assigned patients did not have surgery

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Appendix Table 2—**Continued**

Author, Year (Reference)	Sampling Strategy	Comorbid Conditions	Important Baseline Differences?	Important Intraoperative Differences?	Anesthesia	Follow-up	Important Differences in Co-Interventions Relevant for Pulmonary Complications?	Crossovers	Participant Accrual	Participant Attrition
Böhner et al., 2002 (26)	Consecutive	Smoking, coronary heart disease, pulmonary disease, ASA class	No	No for duration of surgery, blood loss, crystalloid, transfusion, autotransfusion, hypotension, hypertension, oxygenation	No data, presumably general	Hospital stay	No	9 patients did not tolerate nasal CPAP	237 randomly assigned	33 excluded after randomization for ineligible surgery or patient could not be extubated in operating room: 17 nasal CPAP, 16 control
VA TPN Cooperative Study Group, 1991 (27)	Consecutive	Surgical diagnosis, nutritional status, percentage of usual body weight, serum albumin level, serum prealbumin level, triceps skinfold, nutrition risk index score, subjective global assessment	No differences except lower serum albumin level (3.65 ± 3.6 mg/dL vs. 3.71 ± 3.7 mg/dL; P = 0.06†) and nutritional risk index score (92.3 ± 6.4 vs. 93.8 ± 6.0; P = 0.01), more severe malnutrition (15% vs. 9%; P = 0.03) in TPN group	No data	No data, presumably general	30 d after surgery	No data	Of 192 randomly assigned to TPN: 130 received optimal TPN, 49 received suboptimal TPN, and 13 received no TPN; of 203 randomly assigned to control, 3 received TPN	3259 screened, 811 excluded, 1497 did not meet nutrition criteria, 169 no surgery, 323 declined, 459 randomly assigned	Of 459 randomly assigned, 64 did not have surgery (n = 395 study patients)
Pacelli et al., 2001 (28)	Consecutive	Weight, percentage of usual weight, serum albumin level, type of cancer, benign gastrointestinal disease	"Similar" for demographic characteristics, nutritional status, and surgical diagnosis	No for type of surgery, blood loss, intraoperative contamination	No data, presumably general	Hospital stay	All received heparin subcutaneously for prophylaxis and antibiotic prophylaxis	14 patients receiving TEN converted to TPN	241 randomly assigned	None
Bozzetti et al., 2001 (29)	Consecutive	Hypertension; heart valve disease; diabetes; arrhythmia; atherosclerotic disease (cardiac or peripheral); respiratory, liver, and central nervous system disease; neoadjuvant therapy	No	No for site of primary tumor, type of surgery, intraoperative contamination, duration of surgery, blood loss, transfusion	No data, presumably general	Hospital stay	No data	14 patients receiving TEN converted to TPN: 5 tube problems, 3 diarrhea, 5 anastomotic leak or bleeding, 1 intestinal obstruction	411 screened, 317 randomly assigned	None
Gianotti et al., 2002 (30)	Consecutive	Hypertension; heart valve disease; diabetes; arrhythmia, atherosclerotic disease (cardiac or peripheral); respiratory, liver, and central nervous system disease; neoadjuvant therapy	No	No for type of surgery, blood loss, or transfusion	No data, presumably general	30 d after discharge	No data except similar bowel preparation in all groups	No data	517 screened, 212 ineligible, 305 randomly assigned	None
Sandham et al., 2003 (31)	Consecutive	History of angina, myocardial infarction, congestive heart failure, NYHA class, ASA risk class	No	No for type of surgery or percentage of urgent cases	No data	Hospital stay, 12 mo for mortality	No	Intervention: 58 did not receive planned therapy, 5 withdrew consent, 5 pulmonary artery catheter failed; control: 52 did not receive planned therapy, 24 crossed over to use of pulmonary artery catheter	3803 screened, 1074 declined, 370 no ICU bed, 365 physicians did not refer to study, 1994 randomly assigned	Hospital stay, none

* ASA = American Society of Anesthesiologists; CPAP = continuous positive airway pressure; ICU = intensive care unit; IM = intramuscular; IS = incentive spirometry; LC = laparoscopic cholecystectomy; LCR = laparoscopic colorectal resection; NYHA = New York Heart Association; OC = open cholecystectomy; OCR = open colorectal resection; TEN = total enteral nutrition; TPN = total parenteral nutrition; VA TPN = Veterans Affairs Total Parenteral Nutrition.

† To convert serum albumin values to g/L, multiply by 10.

Appendix Table 3. Abstracted Data for Eligible Randomized Trials, Continued*

Author, Year (Reference)	Lost to Follow-up or Incomplete Follow-up	Patients in Intervention Group, *n*	Patients in Control Group, *n*	Age Range, *y*	Mean (SD) Age, *y*	Men, *n (%)*
Møller et al., 2002 (12)	None	56	52	30–85	66 (64)	24 (22)
Berg et al., 1997 (13)	2 patients with clinical signs of pneumonia declined chest radiography	230 pancuronium	230 vecuronium; 231 atracurium	24–81	53 pancuronium; 54 vecuronium; 50 atracurium (no data given for SDs)	No data
Norris et al., 2001 (14)	None	1) 39 general + regional + IV PCA; 2) 46 general + regional + epidural PCA	3) 37 general + IV PCA; 4) 38 general + epidural PCA		1) 70 (9.5); 2) 67 (10); 3) 68 (9.9); 4) 68 (8.4)	1) 29 (78); 2) 26 (69); 3) 25 (63); 4) 35 (77)
Rigg et al., 2002 (15)	None	441	447	Intervention: 22–93; control: 26–92	Intervention: 69 (11); control: 69 (11)	503 (57)
Park et al., 2001 (16)	Follow-up at 30 d not completed for 11 patients	514 enrolled; 489 completed follow-up at 30 d	507 enrolled; 495 completed follow-up at 30 d		Intervention: 66.5 (8.9); control: 67 (8.8)	1021 (100); women excluded
Fleron et al., 2003 (17)	None	102 (105 randomly assigned, epidural could not be done in 3 patients so they were assigned to the control group for analysis)	115 (3 patients were from the intervention group)		Intervention: 67 (11); control: 66 (10)	Intervention: 93 (89); control: 99 (88)
Mann et al., 2000 (18)	None	35	35		Epidural: 76 (5.6); control: 76.8 (4.7)	Epidural: 20 (57); control: 18 (51)
Cuschieri et al., 1985 (19)	None	25	25 and 25	18–75	Epidural: 51; IV morphine: 52; IM morphine: 52 (no data given for SDs)	Epidural: 5 (20); IV morphine: 4 (28); IM morphine: 7 (28)
Karayiannakis et al., 1996 (20)	None	42	40	LC: 32–79; OC: 34–76	LC: 57 (range, 32–79); OC: 56 (range, 34–76)	LC: 18 (43); OC: 18 (45)
Vignali et al., 2004 (21)	None	190	194		LCR: 62 (13.4); OCR: 66 (12.2)	LCR: 92 (48); OCR: 108 (56)
Chumillas et al., 1998 (22)	None	40	41	18–85	64 (range, 18–84)	35 (43)
Fagevik Olsén et al., 1997 (23)	None	172	192	19–92	Intervention: 53.5 (17.4); control: 52.9 (17.5)	Intervention: 72 (41); control: 86 (44)
Hall et al., 1991 (24)	None	431 IS	445 chest physiotherapy	IS: IQR, 32–70; chest physiotherapy: IQR, 32–72	IS: 54; chest physiotherapy: 56	IS: 221 (51); chest physiotherapy: 216 (49)
Hall et al., 1996 (25)	None	1) 79 low-risk IS; 3) 152 high-risk IS	2) 76 low-risk DBE; 4) 149 high-risk IS + chest physiotherapy	1) IQR, 29–44; 2) IQR, 62–76; 3) IQR, 29–43; 4) IQR, 58–76	1) 38 (IQR, 29–44); 2) 34 (IQR, 29–43); 3) 68 (IQR, 62–76); 4) 67 (IQR, 58–76)	1) Low-risk IS: 34 (43); 2) high-risk IS: 70 (46); 3) low-risk DBE: 34 (45); 4) high-risk IS + chest physiotherapy: 71 (48)
Böhner et al., 2002 (26)	None	99	105		Nasal CPAP: 64.1 (12); control: 64.5 (11)	Nasal CPAP: 84 (85); control: 82 (78)
VA TPN Cooperative Study Group, 1991 (27)	None	192	203		62.9 (9.9)	455 (99)
Pacelli et al., 2001 (28)	None	119 TEN	122 TPN		TEN: 61.5 (10.8); TPN: 61.6 (11.8)	TEN: 73 (61); TPN: 72 (59)
Bozzetti et al., 2001 (29)	None	159 TEN	158 TPN		TEN: 64.8 (11); TPN: 64.1 (10)	TEN: 93 (58); TPN: 92 (58)
Gianotti et al., 2002 (30)	None	1) 102; 2) 101	3) 102		1) 62.3 (12.3); 2) 65.6 (11.5); 3) 63.4 (11.9)	1) 50 (49); 2) 60 (59); 3) 56 (55)
Sandham et al., 2003 (31)	101 patients, 5% for 6-mo mortality; 143 patients, 7% for 12-mo mortality	997	997		Intervention: 72.3 (7); control: 72.6 (7)	Intervention: 716 (72); control: 702 (70)

* CPAP = continuous positive airway pressure; DBE = deep breathing exercise; IM = intramuscular; IQR = interquartile range; IS = incentive spirometry; IV = intravenous; LC = laparoscopic cholecystectomy; LCR = laparoscopic colorectal resection; OC = open cholecystectomy; OCR = open colorectal resection; PCA = patient-controlled analgesia; TEN = total enteral nutrition; TPN = total parenteral nutrition; VA TPN = Veterans Affairs Total Parenteral Nutrition.

Appendix Table 4. **Abstracted Data for Eligible Randomized Trials, Continued***

Author, Year (Reference)	Outcomes			
	Outcome Measure	Intervention	Control	*P* Value
Møller et al., 2002 (12)	Overall complications	10 (18%)	27 (52%)	0.0003
	Wound complications	3 (5%)	16 (31%)	0.001
	Second operation	2 (4%)	8 (15%)	0.07
	Cardiovascular insufficiency	0	5 (10%)	0.08
	Respiratory insufficiency	1 (2%)	1 (2%)	0.97
	Nonorthopedic hospital days	2/752 (0.3%)	49/816 (6%)	0.0001
Berg et al., 1997 (13)	Postoperative $O_2 > 3$ L/min	23 (10%)	4.8 (6%)	Pancuronium vs. atracurium, 0.047; pancuronium vs. vecuronium, 0.16
	PPC: pneumonia or atelectasis	19 (8%)	14 (6.1%)	Difference NS; *P* not given
	Patients with PPC and train-of-four ratio < 0.70	10/59 (17%)	1/24 (4.2%) atracurium or vecuronium	<0.002, but this *P* value is for comparison of pancuronium with and without train-of-four < 0.70, not a comparison of pancuronium vs. vecuronium or atracurium
	Median end of surgery to extubation (5th–95th percentile)	15 min (0–40 min)	11 min (2–27 min); 10 min (0–25 min)	<0.05
	Median duration of anesthesia (5th–95th percentile)	160 min (75–290 min)	150 min (70–265 min); 152 min (70–280 min)	<0.05
	Postoperative train-of-four ratio < 0.70	59 (26%)	13 (6%); 11 (5%)	<0.001
Norris et al., 2001 (14)	Length of stay	1) 7 d; 2) 7 d	3) 8 d; 4) 7 d	0.83
	Hours to extubation	1) 19 h; 2) 16 h	3) 19 h; 4) 13 h	0.01
	Hospital mortality	1) 2 (5%); 2) 2 (5%)	3) 3 (7%); 4) 2 (4%)	0.96
	Cardiac mortality	1) 0; 2) 1 (2.8%)	3) 0; 4) 0	0.47
	12-mo mortality	1) 4 (10%); 2) 2 (5%)	3) 4 (10%); 4) 2 (4.4%)	0.64
	Reintubation	1) 1/35 (3%); 2) 0/36	3) 1/30 (3%); 4) 1/44 (2%)	0.9
	Prolonged intubation	1) 6/35 (17%); 2) 6/36 (17%)	3) 8/36 (22%); 4) 3/44 (7%)	0.27
	Pneumonia	1) 0/35; 2) 1/36 (3%)	3) 1/36 (3%); 4) 0/44	0.58
Rigg et al., 2002 (15)	30-d mortality	5.2%	4.3%	0.67
	Respiratory failure	23.3%	30.2%	0.02
	Cardiovascular event	25.7%	24.0%	0.61
Park et al., 2001 (16)	Mortality	20 (4%)	17 (3%)	0.74
	Respiratory failure	51 (10%)	71 (14%)	0.06
	Pneumonia	28 (5%)	40 (8%)	0.15
	Major cardiovascular complication	44 (9%)	57 (11%)	0.12
	Subgroup analysis, abdominal aortic surgery			
	Mortality	4/184 (2%)	5/190 (3%)	0.96
	Respiratory failure	26/184 (14%)	53/190 (28%)	<0.01
	Pneumonia	8/184 (4%)	19/190 (10%)	0.06
	Major cardiovascular complication	18/184 (10%)	34/190 (18%)	0.03
Fleron et al., 2003 (17)	Mortality	2 (2%)	7 (6%)	NS; *P* not given
	Lobar atelectasis	3 (3%)	9 (8%)	NS; *P* not given
	Pneumonia	5 (5%)	6 (5%)	NS; *P* not given
	Respiratory failure	7 (7%)	9 (8%)	NS; *P* not given
	Any pulmonary complication	17 (16%)	26 (23%)	*P* calculate = 0.32
Mann et al., 2000 (18)	Segmental or lobar atelectasis	7/31 (23%)	6/33 (18%)	0.77
	Moderate pulmonary complication	3/31 (10%)	2/33 (6%)	NS
	Major pulmonary complication	1/31 (3%)	1/33 (3%)	NS
Cuschieri et al., 1985 (19)	Atelectasis	5 (20%)	IM: 10 (40%); IV: 7 (28%)	IM or IV vs. epidural = NS; IM vs. epidural = 0.05 reported; 0.11 calculated from raw data; IV vs. epidural = 0.20; IM vs. epidural = 0.01; IV vs. epidural = NS
	Chest infection	1 (4%)	IM: 6 (24%); IV: 5 (20%)	
	All pulmonary complications	6 (24%)	IM: 16 (64%); IV: 12 (48%)	

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Appendix Table 4—**Continued**

Author, Year (Reference)	Outcomes			
	Outcome Measure	**Intervention**	**Control**	***P* Value**
Karayiannakis et al., 1996 (20)	Hospital stay	2.04 ± 0.62	5.65 ± 1.16	<0.05
	Atelectasis incidence	12/42 (27%)	24/40 (63%)	<0.05
	Atelectasis severity	7 micro, 3 focal, 2 segmental, 0 lobar	14 micro, 7 focal, 3 segmental, 0 lobar	<0.05
	Pneumonia	No pneumonia	No pneumonia	Not applicable
Vignali et al., 2004 (21)	Respiratory tract infection	3/190 (1.8%)	6/194 (3.5%)	0.52
Chumillas et al., 1998 (22)	Clinical pulmonary complications (atelectasis, bronchitis, pneumonia)	3 (7.5%)	8 (20%)	0.11
	Atelectasis on chest radiography	6 (15%)	16 (39%)	0.017
Fagevik Olsén et al., 1997 (23)	Pulmonary complications (Sao_2 < 92% or 2 of temperature > 38.2 °C, pathologic auscultation, atelectasis, or pneumonia on chest radiography)	10/172 (6%)	52/192 (27%)	<0.001
	Pneumonia	1/172 (0.6%)	13/192 (7%)	<0.05
	Overall pulmonary complications			
	High-risk patients	6/40 (15%)	20/39 (51%)	<0.001
	Low-risk patients	4/132 (3%)	32/153 (21%)	<0.001
	Obese patients	3/36 (8%)	27/48 (56%)	<0.001
Hall et al., 1991 (24)	Clinical features of consolidation or collapse plus temperature > 38 °C and abnormal chest radiograph or sputum culture	IS: 68/471 (16%)	Chest physiotherapy: 68/445 (15%)	0.84
	Abnormal chest radiograph	IS: 96 (22%)	Chest physiotherapy: 96 (22%	NS
Hall et al., 1996 (25)	Clinical features of consolidation or collapse plus temperature > 38 °C and abnormal chest radiograph or sputum culture	1) Low-risk IS: 6/79 (8%); 3) high-risk IS: 29/152 (19%)	2) Low-risk DBE: 8/76 (11%); 4) high-risk IS + chest physiotherapy: 20/149 (13%)	Low risk: 1 vs. 3 (P = 0.53); high risk: 2 vs. 4 (P = 0.18)
Böhner et al., 2002 (26)	Pao_2 < 70 mm Hg with Fio_2 ≥ 0.7	5 (5.1%)	17 (16.2%)	0.012
		2 (2%)	5 (4.8%)	0.45
	Reintubation	1 (1%)	5 (4.8%)	0.21
VA TPN Cooperative Study Group, 1991 (27)	Pneumonia or empyema	16 (8%)	9 (4%)	0.15
	Respiratory failure > 4 d	13 (7%)	11 (5%)	0.67
	Atelectasis	6 (3%)	8 (4%)	0.79
	Transient respiratory failure	6 (3%)	6 (3%)	1.0
Pacelli et al., 2001 (28)	Major postoperative complication	45 (38%)	48 (39%)	0.89
	Death	7 (6%)	3 (2.5%)	0.21
	Major infectious complication	17 (14%)	14 (11%)	0.57
	Major noninfectious complication	28 (24%)	27 (9%)	0.88
	Pneumonia	10 (8%)	5 (4%)	0.19
	Respiratory failure	6 (5%)	4 (3%)	0.54
	Pneumonia + respiratory failure	16 (13%)	9 (7%)	0.14
	Minor infection	23 (19%)	23 (19%)	1.0
Bozzetti et al., 2001 (29)	Overall complications	54 (34%)	78 (49%)	0.005
	Minor complications	40 (25%)	57 (36%)	0.035
	Major complications	14 (9%)	21 (13%)	0.207
	Infectious complications	25 (16%)	42 (27%)	0.018
	Noninfectious complications	42 (26%)	57 (36%)	0.064
	Respiratory tract infection	9 (6%)	14 (9%)	0.39
	Respiratory failure	4 (3%)	6 (4%)	0.75
	Respiratory infection + failure	13 (8%)	20 (13%)	0.27

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Appendix Table 4—**Continued**

Author, Year (Reference)	Outcomes			
	Outcome Measure	Intervention	Control	*P* Value
Gianotti et al., 2002 (30)	Death	1) 1 (1%); 2) 2 (2%)	3) 1 (1%)	NS
	Infectious complications	1) 14 (14%); 2) 16 (16%)	3) 31 (30%)	1 vs. 3 = 0.006; 2 vs. 3 = 0.02
	Noninfectious complications	1) 30 (29%); 2) 28 (28%)	3) 36 (35%)	NS
	Any complication	1) 36 (35%); 2) 34 (34%)	3) 49 (48%)	NS
	Respiratory tract infection	1) 3 (3%); 2) 6 (6%)	3) 8 (8%)	1 vs. 3 = 0.21; 2 vs. 3 = 0.78
	Respiratory failure	1) 6 (6%); 2) 9 (9%)	3) 6 (6%)	1 vs. 3 = 1.0; 2 vs. 3 = 0.59
	Respiratory infection or failure	1) 9 (9%); 2) 15 (15%)	3) 14 (14%)	1 vs. 3 = 0.38; 2 vs. 3 = 1.0
Sandham et al., 2003 (31)	In-hospital mortality	78 (7.8%)	77 (7.7%)	0.93
	Pneumonia	63 (6.6%)	70 (7.3%)	0.70

* DBE = deep breathing exercise; Fi_{O_2} = fraction of inspired oxygen; IM = intramuscular; IV = intravenous; NS = not significant; PPC = postoperative pulmonary complication; Sa_{O_2} = arterial oxygen saturation; VA TPN = Veterans Affairs Total Parenteral Nutrition.

Appendix Table 5. Abstracted Data for Eligible Randomized Trials, Continued*

Author, Year (Reference)	Adverse Effect: Intervention	Adverse Effect: Control	*P* Value	Conclusion	Study Quality	Comment
Møller et al., 2002 (12)	No data	No data		The smoking cessation program reduced overall postoperative complications, primarily due to a significant reduction in wound complications, and nonorthopedic hospital days in total hip and knee replacement. The rate of PPC was too low to show an effect.	Good	
Berg et al., 1997 (13)	No data	No data		Incidence and duration of residual block occurs significantly more often with pancuronium. Residual block with long-acting pancuronium is associated with more PPCs; residual block with intermediate-acting vecuronium or atracurium is not associated with higher risk for PPCs.	Good	
Norris et al., 2001 (14)	No data	No data		No advantage to epidural analgesia or combined general + regional anesthesia; very few PPCs overall occurred.	Good	
Rigg et al., 2002 (15)	No data	No data		Combined intraoperative general anesthesia and epidural local anesthetic + postoperative epidural local anesthetic was associated with a significantly lower rate of respiratory failure but no difference in 30-d mortality, cardiac complications, or other postoperative morbidity.	Fair	Only 225 of 447 patients assigned to epidural were fully adherent to the epidural protocol (222 protocol violations: no epidural catheter, 29; catheter removed < 72 h after surgery, 190; catheter removed > 72 h after surgery, 3).
Park et al., 2001 (16)	No data	No data		Overall, epidural anesthesia and analgesia was associated with a trend toward less respiratory failure ($P = 0.06$), pneumonia ($P = 0.15$), and major cardiovascular complications ($P = 0.18$). In the subgroup having abdominal aortic surgery, epidural was associated with significantly less respiratory failure ($P < 0.01$) and major cardiovascular complications ($P = 0.03$) and a trend toward less pneumonia ($P = 0.06$). There was no difference in mortality.	Fair	
Fleron et al., 2003 (17)	No data	No data		Intraoperative epidural opioids, compared with intraoperative IV opioids, were not associated with reduced PPCs.	Fair	
Mann et al., 2000 (18)	Postoperative hypotension: 5 patients Severe hypotension, systolic BP < 78 mm Hg: no patients Motor blockade: no patients Abscess or neurologic complication due to epidural: no patients	Postoperative hypotension: no patients Severe hypotension, systolic BP < 78 mm Hg: no patients Motor blockade: no patients	0.01 NS NS	Combined intraoperative general and epidural anesthesia and analgesia with postoperative PCEA was not associated with fewer PPCs compared with general anesthesia alone and postoperative IV PCA.	Poor	Low statistical power
Cuschieri et al., 1985 (19)	Hypotension: 9 patients; urinary tract infection: 4 patients	No data		Intraoperative and postoperative epidural anesthetic may reduce PPCs compared with analgesia with IM morphine.	Poor	Small sample size, not helpful that epidural seemed better than IM morphine because IM morphine is rarely used now. *P* values were not reported for IV vs. epidural comparisons; we calculated them from the raw data.
Karayiannakis et al., 1996 (20)	3 LC patients converted to OC but were excluded from analysis			LC was associated with a significantly lower incidence and severity of atelectasis compared with OC.	Poor	Analysis was not intention-to-treat; no pneumonia occurred in either group.
Vignali et al., 2004 (21)	10 LCR patients converted to OCR but were included in intention-to-treat analyses			LCR was associated with a nonsignificant trend toward fewer respiratory tract infections.	Good	
Chumillas et al., 1998 (22)				A program of perioperative breathing exercises that included forced expiration, cough, chest expansion exercises and diaphragm mobilization, maximum inspiration for 3–5 s, and early ambulation after surgery was associated with fewer PPCs.	Poor	Low statistical power
Fagevik Olsén et al., 1997 (23)				Intensive chest physiotherapy, compared with none, was associated with fewer PPCs.	Poor	Very weak definition of pulmonary complications; apparently no uniform surveillance protocol.
Hall et al., 1991 (24)				No difference between IS and chest physiotherapy in rate of postoperative pneumonia.	Poor	No routine surveillance protocol for all patients; chest radiography done only on patients suspected of a pulmonary complication (IS, 44%; chest physiotherapy, 43%). No information about amount and intensity of therapy actually received.

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Appendix Table 5—Continued

Author, Year (Reference)	Adverse Effect: Intervention	Adverse Effect: Control	*P* Value	Conclusion	Study Quality	Comment
Hall et al., 1996 (25)				In low-risk patients, there was no difference in rate of PPCs between IS and DBEs. In high-risk patients, there was no difference between IS and IS combined with chest physiotherapy.	Poor	Both studies by Hall and colleagues seem to have identical methods; some of the methods language is identical, some not. "Presence of clinical signs was determined each day by the attending physician." Chest radiography was done only for suspected complications. Sputum was sent for testing "when the patient produced discoloured sputum." Some surveillance for PPCs was routine (clinical signs), some not (chest radiography, sputum testing). There is no way to tell how many patients from the previous publication were included in the report.
Böhner et al., 2002 (26)	Superficial nose ulcer: 4 (4%)	None (0%)		Nasal CPAP for 12 h after high-risk abdominal vascular surgery was associated with fewer episodes of severe hypoxemia (Fio_2 < 70 mm Hg with Fio_2 ± 0.7) and trends toward fewer episodes of pneumonia and respiratory failure.	Good	
VA TPN Cooperative Study Group, 1991 (27)	Major infectious complications: 27/192 (14%)	Major infectious complications: 13/203 (6%)	0.01	Overall, there was no benefit of TPN for preventing pulmonary complications. Overall, TPN was associated with more major infectious complications and more catheter-related complications.	Good	Subgroup analyses suggested mild malnutrition, no benefit; TPN associated with more infections, especially pneumonia and wound infection; severe malnutrition, no increased infection, but significantly fewer noninfectious complications.
	Major noninfectious complications: 32/192 (17%)	Major noninfectious complications: 45/203 (22%)	0.20			
	Noninfectious catheter-related complications: 11/192 (6%)	Noninfectious catheter-related complications: 2/203 (1%)	0.01			
Pacelli et al., 2001 (28)	3 bloating; 4 diarrhea; 4 tube problems; 2 chylous fistula; 1 bleed from jejunostomy	5 transient hypoglycemia; 2 catheter sepsis	0.11	There was no difference between postoperative TEN and TPN in rates of overall complications, pneumonia, respiratory failure, combined pulmonary complications, or adverse events of the 2 interventions.	Good	
Bozzetti et al., 2001 (29)	Distension: 23 (14%)	10 (6%)	0.018	TEN, compared with TPN, was associated with fewer overall, minor, and infectious complications and marginally significantly fewer noninfectious complications but no benefit regarding pulmonary complications. TEN, compared with TPN, was associated with significantly more abdominal distension and cramps but not more diarrhea and vomiting.	Good	
	Cramps: 21 (13%)	8 (5%)	0.012			
	Diarrhea: 13 (8%)	9 (6%)	0.385			
	Vomiting: 4 (3%)	3 (2%)	0.709			
	Total: 56 (35%)	22 (14%)	<0.0001			
Gianotti et al., 2002 (30)	Cramping or bloating: 1) 16, 2) 42; diarrhea: 1) 3, 2) 7; vomiting: 1) 1, 2) 2	Cramping or bloating: 14; diarrhea: 3) 3; vomiting: 3) 2	All NS, except *P* < 0.001 for 2 (perioperative) vs. 1 (preoperative) and 3 (control)	Preoperative and perioperative enteral immunonutrition, compared with no enteral nutrition was associated with fewer infectious complications but no benefit in noninfectious complications, respiratory tract infection, or respiratory failure.	Good	
Sandham et al., 2003 (31)	Overall: 17	Overall: 5	0.016	Perioperative pulmonary artery catheters in high-risk surgical patients did not improve inpatient mortality or reduce the rate of the secondary outcome of pneumonia and was associated with a statistically significantly higher rate of adverse catheter-related events. For unclear reasons, the rate of the secondary outcome of pulmonary embolism was also significantly higher in patients receiving pulmonary artery catheter (8 vs. 0; *P* = 0.004).	Good	

* BP = blood pressure; CPAP = continuous positive airway pressure; DBE = deep breathing exercise; Fio_2 = fraction of inspired oxygen; IM = intramuscular; IS = incentive spirometry; IV = intravenous; LC = laparoscopic cholecystectomy; LCR = laparoscopic colorectal resection; NS = not significant; OC = open cholecystectomy; OCR = open colorectal resection; PCA = patient-controlled analgesia; PCEA = patient-controlled epidural analgesia; PPC = postoperative pulmonary complication; TEN = total enteral nutrition; TPN = total parenteral nutrition; VA TPN = Veterans Affairs Total Parenteral Nutrition.

Appendix Table 6. **Abstracted Data for Eligible Systematic Reviews and Meta-Analyses***

Author, Year (Reference)	Type of Surgery	Intervention	Literature Search						
			Dates	Electronic Databases	Gray Literature	Unpublished Studies	English-Language Literature Only	Trials Identified, *n*	Eligible Trials, *n*
Rodgers et al., 2000 (32)	No restriction	Regional anesthesia (epidural or spinal)	1966–1998	Current Contents, EMBASE, MEDLINE, Cochrane Library	No data	Yes	No	158	141
Urwin et al., 2000 (33)	Hip fracture repair	Regional anesthesia (epidural or spinal)	Not stated	Current Contents, EMBASE, MEDLINE, Cochrane Library Clinical Trials Registry, CINAHL	No data	No	No	Not stated	15
Ballantyne et al., 1998 (34)	No restriction	Postoperative analgesic therapy	1966–1995	MEDLINE	No data	No	No data	195	48
Walder et al., 2001 (35)	No restriction	IV PCA	1966–2000	EMBASE, MEDLINE, Cochrane Library Clinical Trials Registry	No data	No	No	95	32
Downs et al., 1996 (36)	Cholecystectomy	LC	1987–1996	EMBASE, MEDLINE	Yes	Yes	No	Unclear	15 total; only 1 assessed a clinically relevant pulmonary complication (atelectasis)
Abraham et al., 2004 (37)	Resection of colorectal cancer	Laparoscopic resection	1966–2002	EMBASE, MEDLINE, Cochrane Library Clinical Trials Registry	No data	No	Yes	62	12; unclear number assessing pulmonary complications
Cheatham et al., 1995 (38)	Elective laparotomy	Selective postoperative nasogastric decompression	No data, published 1995	Current Contents, MEDLINE	No data	No	Yes	17	15
Nelson et al., 2005 (39)	Laparotomy	Selective postoperative nasogastric decompression	No data, published 2005	EMBASE, MEDLINE, Cochrane Library Clinical Trials Registry	No data	No	Unclear	33	28 total; 19 report pulmonary complications
Thomas and McIntosh, 1994 (40)	Upper abdominal surgery	Postoperative lung expansion therapies	1966–1992	MEDLINE, CINAHL	No data	No	Yes	Unclear	14
Overend et al., 2001 (41)	Abdominal surgery	Postoperative lung expansion therapies	1966–2000	Current Contents, MEDLINE, CINAHL, HealthSTAR	No data	No	Yes	Unclear	26
Moore et al., 1992 (42)	High-risk surgery, no restrictions	Early enteral vs. TPN	No data	No data	Yes	Yes	No data	Unclear	8 total; all appear to be industry-sponsored by 1 company

* IV = intravenous; LC = laparoscopic cholecystectomy; PCA = patient-controlled analgesia; TPN = total parenteral nutrition.

Appendix Table 7. **Abstracted Data for Eligible Systematic Reviews and Meta-Analyses, Continued***

Author, Year (Reference)	Analysis						Results
	Fixed- or Random-Effects Models	Heterogeneity Assessed	Sensitivity Analysis	Subgroup Analysis	Publication Bias Assessed	Study Quality	
Rodgers et al., 2000 (32)	Fixed	Yes	Yes	Yes	Yes	Good	Regional anesthesia, with or without general anesthesia, was associated with lower mortality overall (OR, 0.70 [95% CI, 0.51–0.97]) and orthopedic surgery (results depicted in Forest plot; OR and CI not stated) but not for other surgical subgroups. Regional anesthesia vs. general anesthesia alone was also associated with reduced mortality (OR, 0.64 [CI, 0.47–0.87]; n = 5202). Regional anesthesia was associated with less pneumonia (OR, 0.61 [CI, 0.48–0.76]), respiratory depression (OR, 0.41 [CI, 0.23–0.73]), deep venous thrombosis (OR, 0.56 [CI, 0.43–0.72]), and less need for transfusion (OR, 0.50 [CI, 0.39–0.66]).
Urwin et al., 2000 (33)	Fixed or random per heterogeneity ($P < 0.1$)	Yes	No	Yes	No data	Good	Regional, compared with general, anesthesia was associated with lower 30-d mortality (OR, 0.66 [CI, 0.47–0.96]) and deep venous thrombosis (OR, 0.41 [CI, 0.23–0.72]) but not lower 3-, 6-, or 12-mo mortality, risk for pneumonia (OR, 0.92 [CI, 0.53–1.59]), or several other medical complications, including all pulmonary embolisms. Regional anesthesia was associated with significantly fewer fatal pulmonary embolisms (OR and CI not stated).
Ballantyne et al., 1998 (34)	Random	Yes	Yes	Yes	No data	Fair	Epidural opioid, compared with systemic opioid, was associated with less atelectasis (OR, 0.53 [CI, 0.33–0.85]) but not "pulmonary infection" (OR, 0.53 [CI, 0.18–1.53]) or overall PPCs (OR, 0.51 [CI, 0.20–1.33]). Epidural local anesthetic, compared with systemic opioid, was associated with less "pulmonary infection" (OR, 0.36 [CI, 0.21–0.65]) and overall PPCs (OR, 0.58 [CI, 0.42–0.80]) but not atelectasis (OR, 0.74 [CI, 0.50–1.11]). There were nonsignificant trends toward fewer PPCs with epidural opioid + anesthetic compared with systemic opioid and with intercostal nerve block compared with systemic opioid.
Walder et al., 2001 (35)	Fixed or random per heterogeneity ($P < 0.1$)	Yes	No	Yes	No data	Good	In a subgroup analysis of 2 morphine trials reporting PPCs (n = 147), IV PCA was associated with lower risk (OR, 0.93 [CI, 0.86–0.99]). In a separate trial of 60 patients, there was no benefit regarding "chest infection" (no data given). Among 689 patients, respiratory depression was not more frequent with PCA (OR, 1.08 [CI, 0.44–2.68]).
Downs et al., 1996 (36)	Quantitative pooling not done				No data	Good	LC, compared with OC, was associated with less compromise and faster recovery of postoperative pulmonary function. In 1 trial of 40 patients with blinded assessment of postoperative chest radiography, LC was associated with less atelectasis (frequency, 29% vs. 63%; $P < 0.05$; severity, chi-square for trend, $P < 0.05$).
Abraham et al., 2004 (37)	Fixed or random per heterogeneity assessment	Yes	No	No	No data	Good	LCR, compared with OCR, for cancer was associated with no mortality benefit, a trend toward fewer respiratory complications (OR, 0.65 [CI, 0.28–1.49]), fewer overall complications (OR, 0.62 [CI, 0.38–1.03])—primarily due to fewer wound complications, primarily wound infection (OR, 0.47 [CI, 0.28–0.80])—faster recovery of respiratory function (PEF, 44% faster [CI, 32%–67%]; FEV_1, 36% faster [CI, –33% to 50%]; FVC, 40% faster [CI, 0%–50%]) and shorter hospital stay (21% shorter [CI, 14%–38%]).

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Appendix Table 7—**Continued**

Author, Year (Reference)	Analysis						Results
	Fixed- or Random-Effects Models	Heterogeneity Assessed	Sensitivity Analysis	Subgroup Analysis	Publication Bias Assessed	Study Quality	
Cheatham et al., 1995 (38)	Quantitative pooling not done				No	Poor	The meta-analysis was good quality up to quantitative pooling, which pooled RCTs, uncontrolled studies, and case–control studies, thus rendering the results unusable. For the overall group of 26 studies (which appears to comprise 15 RCTs, 3 nonrandomized trials, and 8 case–control studies [$n = 3964$]), selective decompression was associated with less pneumonia (RR, 0.49; $P < 0.0001$) and atelectasis (RR, 0.46; $P = 0.001$) and shorter time to oral intake (3.5 d vs. 4.6 d; $P = 0.04$). There was no difference in aspiration rates (RR, 0.61; $P = 0.88$), nausea (RR, 0.98; $P = 0.31$), vomiting (RR, 1.19; $P = 0.11$), or abdominal distension (RR, 0.98; $P = 0.36$). For 20 higher-quality studies (15 RCTs plus 5 case–control studies [$n = 2915$]), selective nasogastric decompression was also associated with less pneumonia (RR, 0.59; $P = 0.01$) and atelectasis (RR, 0.52; $P = 0.002$), a trend toward shorter time to oral intake (3.5 d vs. 4.5 d; $P = 0.07$), no difference in aspiration (RR, 0.94; $P = 0.91$) but more vomiting (RR, 1.45; $P = 0.005$) and abdominal distension (RR, 1.34; $P = 0.02$). Insufficient data were reported for calculating pooled effects for RCTs only and CIs.
Nelson et al., 2005 (39)	Fixed or random per heterogeneity assessment	Yes	Yes	Yes	No	Good	Selective, compared with routine, nasogastric decompression was associated with a trend toward fewer PPCs (reported as relative benefit increase of 1.35 [CI, 0.98–1.86] converted to RR reduction of 0.74 [CI, 0.54–1.02]; $P = 0.07$). Data were insufficient or too heterogeneous to pool for nausea, vomiting, aspiration, or abdominal distension, and 15 of the 28 included trials were also included in the Cheatham et al. review (38).
Thomas and McIntosh, 1994 (40)	No data	Yes	No	Yes	No	Poor	Across all lung expansion modalities, there was a trend toward fewer PPCs compared with controls (OR, 0.85 [CI, 0.59–1.2]), but there was unexplained significant heterogeneity. IS, compared with control (2 studies [$n = 212$]) was associated with fewer PPCs (OR, 0.44 [CI, 0.18–0.99]) with no significant heterogeneity. DBEs, compared with control (4 studies [$n = 564$]), were also associated with fewer PPCs (OR, 0.43 [CI, 0.27–0.63]), but the heterogeneity test was significant. Among studies comparing different modalities, none (IS, DBEs, IPPB) was clearly superior.
Overend et al., 2001 (41)	Quantitative pooling not done				No	Poor	The authors reported no raw data on rates of PPCs. In the only trial in the review that met our sample size inclusion criteria, DBEs and IPPB reportedly equally prevented PPCs compared with no lung expansion intervention.
Moore et al., 1992 (42)	Fixed	Yes	No	Yes	No	Poor	Infections were twice as frequent among patients receiving TPN compared with those receiving early enteral nutrition (35% vs. 16%; $P = 0.01$), even after excluding patients with catheter sepsis from analysis (29% vs. 16%; $P = 0.03$). Overall infections and pneumonia were significantly reduced in trauma patients, but power was very low for "nontrauma" (? elective surgery) patients for overall infections (4/28 vs. 3/32; $P = 0.70$) and pneumonia (3/28 vs. 1/32; $P = 0.33$).

* DBE = deep breathing exercise; IPPB = intermittent positive-pressure breathing; IS = incentive spirometry; IV = intravenous; LC = laparoscopic cholecystectomy; LCR = laparoscopic colorectal resection; OC = open cholecystectomy; OCR = open colorectal resection; OR = odds ratio; PCA = patient-controlled analgesia; PEF = peak expiratory flow; PPC = postoperative pulmonary complication; RCT = randomized, controlled trial; RR = relative risk; TPN = total parenteral nutrition.