CONGRESS OF NEUROLOGICAL SURGEONS SYSTEMATIC REVIEW AND EVIDENCE-BASED GUIDELINES FOR PERIOPERATIVE SPINE: PREOPERATIVE PULMONARY EVALUATION AND OPTIMIZATION

Sponsored by: Congress of Neurological Surgeons (CNS) and the Section on Disorders of the Spine and Peripheral Nerves
Endorsement: Reviewed for evidence-based integrity and endorsed by the American Association of Neurological Surgeons (AANS) and Congress of Neurological Surgeons (CNS)

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Abbreviations:
ACDF: anterior cervical discectomy and fusion
ACS NSQIP: American College of Surgeons National Surgical Quality Improvement Program
BMI: body mass index
CHF: congestive heart failure

COPD: chronic obstructive pulmonary disease
DVT: deep vein thrombosis
NIS: National Inpatient Sample
OSA: obstructive sleep apnea
PE: pulmonary embolism
VTE: venous thromboembolism

ABSTRACT

Background: There are no current recommendations for preoperative pulmonary evaluation and management of patients undergoing elective spine surgery.

Objective: The aim of this guideline is to determine preoperative risk factors for perioperative and postoperative pulmonary adverse events and to determine the optimal preoperative evaluation and management of at-risk patients.

Methods: A systematic review of the literature was performed using the National Library of Medicine PubMed database and the Cochrane Library for studies relevant to postoperative pulmonary adverse events in patients undergoing spine surgery. Clinical studies evaluating preoperative patient risk factors and preoperative diagnostic and treatment interventions were selected for review.

Results: The literature search yielded 152 abstracts relevant to the PICO (patient/population, intervention, comparison, and outcomes) questions included in this chapter. The task force selected 65 articles for full-text review, and 24 were selected for inclusion in this systematic review. Twenty-three articles addressed preoperative patient risk factors. One article addressed preoperative diagnostic studies of pulmonary function. There were no studies meeting the inclusion criteria for preoperative pulmonary treatment.

Conclusion: There is substantial evidence for multiple preoperative patient factors that predict an increased risk of a postoperative pulmonary adverse event. Individuals with these risk factors (functional dependence, advanced age [≥65 years], chronic obstructive pulmonary disease [COPD], congestive heart failure [CHF], weight loss, and obstructive sleep apnea [OSA]) who are undergoing spine surgery should be counseled regarding the potential increased risk of a perioperative and postoperative pulmonary adverse events. There is insufficient evidence to support any specific preoperative diagnostic test for predicting the risk of postoperative pulmonary adverse events or any treatment intervention that reduces risk. It is suggested, however, to consider appropriate preoperative pulmonary diagnostic testing and treatment to address active pulmonary symptoms of existing or suspected disease.

RECOMMENDATIONS

Question:

1. What preoperative patient factors are associated with increased risk of postoperative pulmonary adverse events in patients undergoing spine surgery?

Recommendation:

Clinicians should consider risk factors associated with an increased risk of postoperative pulmonary adverse events (functional dependence, advanced age, chronic obstructive pulmonary disease, congestive heart failure, weight loss, and obstructive sleep apnea) when determining patient suitability for spine surgery and counsel at-risk patients about the potential for postoperative pulmonary adverse events.

Strength of Recommendation: Grade B

Question:
2. What preoperative diagnostic studies of pulmonary function predict risk of postoperative pulmonary adverse events in patients undergoing spine surgery?
Recommendation:
There is insufficient evidence to support the efficacy of any preoperative pulmonary test on predicting the risk of postoperative pulmonary adverse events in patients undergoing elective spine surgery. However, the task force recommends that clinicians perform the appropriate preoperative pulmonary tests based on the clinical presentation of active pulmonary symptoms or to confirm a suspected pulmonary disease.
Strength of Recommendation: Grade Insufficient

Question:
3. Do preoperative pulmonary interventions reduce the risk of postoperative pulmonary adverse events in patients undergoing spine surgery?
Recommendation:
There is insufficient evidence regarding preoperative pulmonary interventions to reduce the risk of postoperative pulmonary adverse events in patients undergoing spine surgery. However, the task force recommends that clinicians proceed with the appropriate preoperative pulmonary interventions to treat active pulmonary symptoms or suspected pulmonary disease.
Strength of Recommendation: Grade Insufficient

INTRODUCTION

Goals and Rationale

This clinical guideline was created to improve patient care by outlining the appropriate information gathering and decision-making processes involved in the treatment of patients with perioperative spinal disease. Spinal surgical care is provided in many different settings by many different providers. This guideline has been created as an educational tool to guide qualified physicians through a series of diagnostic and treatment decisions in an effort to improve the quality and efficiency of care.

This guideline should not be construed as including all proper methods of care or excluding methods of care reasonably directed to obtaining the same results. The ultimate judgment regarding any specific procedure or treatment must be made in light of all circumstances presented by the patient and the needs and resources particular to the locality or institution. Postoperative pulmonary adverse events are serious complications that can lead to increased morbidity and mortality. Recent studies demonstrated up to a 10-fold increase in mortality in the first 30 days after surgery in patients who experience a postoperative pulmonary adverse event. Pulmonary complications are 1 of 4 patient safety indicators leading to 68% of all reported patient safety postoperative events.[1] Recent literature has identified several patient risk factors for postoperative pulmonary complications (e.g., pneumonia, reintubation, prolonged ventilation, and venous thromboembolism), with many commonly occurring because of advanced age and associated comorbid medical conditions in patients who are undergoing elective spine surgery.

METHODS

The guidelines task force initiated a systematic review of the literature and evidence-based guideline relevant to the preoperative evaluation and management of patients who are at risk for postoperative pulmonary adverse events. Through objective evaluation of the evidence and transparency in the process of making recommendations, this evidence-based clinical practice guideline was developed for the diagnosis and treatment of adult patients with various spinal conditions. These guidelines are developed for educational purposes to assist practitioners in their clinical decision-making processes. Additional information about the methods used in this systematic review is provided below.

Literature Search

The task force members identified search terms/parameters and a medical librarian implemented the literature search, consistent with the literature search protocol (see Supplemental Digital Content 1), using the National Library of Medicine/PubMed database and Embase for the period from 1946 to September 20, 2019 using the search strategies provided in Supplemental Digital Content 1.

Inclusion/Exclusion Criteria

Articles were retrieved and included only if they met specific inclusion/exclusion criteria (Supplemental Digital Content 2). These criteria were also applied to articles provided by guideline task force members who supplemented the electronic database searches with articles from their own files. To reduce bias, these criteria were specified before conducting the literature searches.

Rating Quality of Diagnostic Evidence

The guideline task force used a modified version of the North American Spine Society's (NASS) evidence-based guideline development methodology. The NASS methodology uses standardized levels of evidence (Supplemental Digital Content 3) and grades of recommendation (Supplemental Digital Content 4) to assist practitioners in easily understanding the strength of the evidence and recommendations within the guidelines. The levels of evidence range from Level I (high quality randomized controlled trial) to Level IV (case series). Grades of recommendation indicate the strength of the recommendations made in the guideline based on the quality of the literature. Levels of evidence have specific criteria and are assigned to studies before developing recommendations. Recommendations are then graded based upon the level of evidence. To better understand how levels of evidence inform the grades of recommendation and the standard nomenclature used within the recommendations, see Supplemental Digital Content 4.

Guideline recommendations were written using a standard language that indicates the strength of the recommendation. "A" recommendations indicate a test or intervention is 2 "recommended"; "B" recommendations "suggest" a test or intervention and "C" recommendations indicate a test or intervention or "is an option." "I" or "Insufficient Evidence" statements clearly indicate that "there is insufficient evidence to make a recommendation for or against" a test or intervention. Task force consensus statements clearly state that "in the absence of reliable evidence, it is the task force's opinion that" a test or intervention may be appropriate.

In evaluating studies as to levels of evidence for this guideline, the study design was interpreted as establishing only a potential level of evidence. As an example, a therapeutic study designed as a randomized controlled trial would be considered a potential Level I study. The study would then be further analyzed as to how well the study design was implemented and significant shortcomings in the execution of the study would be used to downgrade the levels of evidence for the study's conclusions (see Supplemental Digital Content 2 for additional information and criteria).

Revision Plans

In accordance with the Institute of Medicine's standards for developing clinical practice guidelines, the task force will monitor related publications after the release of this document and will revise the entire document and/or specific sections "if new evidence shows that a recommended intervention causes previously unknown substantial harm; that a new intervention is significantly superior to a previously recommended intervention from an efficacy or harms perspective; or that a recommendation can be applied to new populations."[2] In addition, the task force will confirm within 5 years from the date of publication that the content reflects current clinical practice and the available technologies for the evaluation and treatment for patients with perioperative spinal disease.

RESULTS

The literature search encompassed terms relevant to all chapters in this guideline series and yielded 6812 abstracts (5689 after duplicates were deleted). After a double-blind review, 152 abstracts were identified as relevant to this PICO question (Supplemental Digital Content 5). Task force members reviewed all abstracts yielded from the literature search and identified the literature for full text review and extraction, addressing the clinical questions, in accordance with the literature search protocol (Supplemental Digital Content 1). Task force members identified the best research evidence available to answer the targeted clinical questions. When Level I, II, and/or III literature was available to answer specific questions, the task force did not review Level IV studies.

The task force selected 65 full-text articles for full text review. Of these, 41 were rejected for not meeting the inclusion criteria or for being off-topic. Twenty-four articles were selected for systematic review (Supplemental Digital Content 6).

Per the criteria for grading the evidence, baseline study design was determined to assign the initial level of evidence. All prognostic studies, which evaluated the impact of a patient characteristic on the outcome, and designed as a retrospective cohort study, were determined to be a Level II study (Supplemental Digital Content 3). A study may be downgraded based on criteria detailed in Supplemental Digital Content 6. For example, a study may be downgraded because of a high degree of variance or heterogeneity in patient population with respect to diagnosis, demographics, or treatment, or failure to appropriately define and assess independent and dependent variables.

DISCUSSION

Question:

1. What preoperative patient factors are associated with increased risk of postoperative pulmonary adverse events in patients undergoing spine surgery?

Recommendation:

Clinicians should consider risk factors associated with an increased risk of postoperative pulmonary adverse events (functional dependence, advanced age, chronic obstructive pulmonary disease, congestive heart failure, weight loss, and obstructive sleep apnea) when determining patient suitability for spine surgery and counsel at-risk patients about the potential for postoperative pulmonary adverse events.

Strength of Recommendation: Grade B

Functional Dependence

One Level II and 1 Level III study demonstrated the relationship between preoperative functional dependence and the risk of developing postoperative pulmonary adverse events. Burton et al[1] studied the impact of preoperative functional dependence (defined as the inability to independently perform activities of daily living-ADLs) on postoperative pulmonary adverse events. They defined postoperative pulmonary complication as pneumonia, reintubation, and prolonged mechanical ventilation (i.e., the need for mechanical ventilation for >48 hours). In this study, the investigators evaluated the association between preoperative functional dependence in 26,263 patients scheduled for elective cervical spine surgery and postoperative pulmonary adverse events. Five hundred fifty patients (2.1%) of this cohort were found to be functionally dependent. Functionally dependent patients were twice as likely to experience unplanned 30-day reintubation, with a hazard ratio of 2.05. Among all reintubated patients, the adjusted odds of 30-day mortality was significantly higher in functionally dependent patients compared with independent patients (odds ratio [OR] 5.82 [95% confidence interval {CI} 1.59-23.4], $P < .001$). This study provides Level II evidence in support of the association between functional dependence and postoperative pulmonary adverse events.

Bohl et al[3] found that functional dependence was an independent risk factor for postoperative pneumonia in patients undergoing elective anterior cervical discectomy and fusion (ACDF). Patients who were functionally dependent had >5 times the risk of developing postoperative pneumonia compared with patients who were functionally independent. They evaluated 11,353 patients who met inclusion criteria and found that functional dependence was the second strongest predictor of postoperative pneumonia, after advanced age (≥70 years). This study provides Level III evidence supporting the association between functional dependence and postoperative pneumonia.

Advanced Age

A total of 7 Level II and 3 Level III studies evaluated the association of advanced age. Most studies used a cutoff of ≥65 years of age as the definition of advanced age with the incidence of postoperative pulmonary adverse events (cutoff age varied among studies). In a retrospective review of the American College of Surgeons National Surgical Quality Improvement Program (ACS NSQIP) database, Di Capua et al[4] evaluated a total of 20,563 patients undergoing elective ACDF. The authors divided the cohort based on age and found that patients who were >60 years of age were 3 times more likely to experience a postoperative pulmonary adverse event in the form of pneumonia, unplanned reintubation, prolonged ventilation, or venous thromboembolism (VTE) compared with younger patients (OR 3.25). This study provides Level II evidence to

support the relationship between advanced age and the risk of a postoperative pulmonary adverse event.

Similarly, Buerba et al[5] used the ACS NSQIP database to evaluate the incidence of postoperative pulmonary complications in advanced-age patients undergoing elective ACDF. The authors analyzed 6253 patients, divided into 4 cohorts based on age, and found that patients who were ≥75 years of age were 6 times more likely to experience postoperative pulmonary complications compared with the reference group (younger groups, ages 18-39 and 40-64 years, respectively). They also found that patients who were 65 to 74 years of age were 4 times more likely to experience postoperative VTE compared with the younger age group. This study is Level II supporting the association between advanced age and postoperative pulmonary adverse events.

In a retrospective review (Level II evidence), Fineberg et al[6] investigated the incidence and risk factors for aspiration pneumonia in patients undergoing cervical spine surgery. The authors found that the incidence of aspiration pneumonia was 5.3 per 1000 cases, and that patients ≥65 years of age are twice as likely to have aspiration pneumonia. Marquez-Lara et al[7] evaluated the risk factors for reintubation in patients undergoing anterior cervical spine surgery. Multivariate logistic regression analysis demonstrated that the advanced age patient population had 1.5 times the risk of reintubation. This is a Level II evidence study.

De la Garza Ramos et al[8,9] evaluated the incidence and risk factors of postoperative pulmonary adverse events including reintubation and pneumonia in 2 Level II studies of adult spinal deformity surgery. In 1 retrospective review,[9] using the National Inpatient Sample (NIS), the authors evaluated 9734 patients undergoing adult spinal deformity surgery and found that advanced age is an independent risk factor for postoperative respiratory failure caused by pneumonia. Reintubation increased the rate of mortality 10-fold. In another retrospective cohort study using the ACS NSQIP database,[8] the authors investigated risk factors associated with postoperative reintubation and prolonged ventilation in patients undergoing adult spinal deformity surgery and found that advanced-age patients have a slightly increased risk of reintubation. Advanced-age patients were at a 1.06-times higher chance of developing postoperative pulmonary adverse events after multivariate analysis compared with younger patients.

Two Level III studies evaluated the association of advanced age with postoperative pneumonia and reintubation because of airway obstruction. Bohl et al[3] performed a retrospective cohort study aimed to determine the incidence and risk factors for pneumonia after elective ACDF using the NSQIP Database. After multivariate analysis, patients who were 60 to 69 years of age had 4.3 times the risk of developing pneumonia, and patients who were ≥70 years of age had a 9.5 times higher risk of developing pneumonia after ACDF. Li et al[10] found that advanced-age patients are twice as likely to require reintubation after anterior cervical spine surgery.

VTEs, including deep vein thrombosis (DVT) and pulmonary embolism (PE), are considered serious and potentially fatal complications after spine surgery. Using a national database, Gephart et al[11] (Level II) observed with multivariate regression analysis that advanced age was a significant predictor of VTE after thoracic and thoracolumbar spine surgery. Similarly, Buchanan et al[12] (Level III) evaluated the incidence and risk factors for readmission for VTE

after degenerative spine surgery and found that patients ≥75 years of age had nearly twice the odds of being readmitted because of VTE complication.

COPD

Four studies evaluated COPD as a risk factor for postoperative pulmonary complications. In a Level II study, Bohl et al[13] used the ACS NSQIP database to perform a retrospective cohort study evaluating the incidence and risk factors for pneumonia after posterior lumbar fusion surgery. They found that COPD increased the risk of postoperative pneumonia 2.7-fold. In another Level III study, Bohl et al[3] used the same database to analyze the incidence of pneumonia after cervical spine surgery (ACDF). They found COPD to be an independent risk factor for postoperative pneumonia with a 4-times increased risk. Patients who developed pneumonia were at higher risk of mortality (risk ratio 27).[13]

In a Level II study by De La Garza Ramos et al[9] using the NIS, the incidence of reintubation was reported to be 1.8% after adult spinal deformity surgery. After multivariate analysis, chronic lung disease in the form of COPD was an independent risk factor for postoperative acute respiratory failure, which was the strongest indication for reintubation in this cohort. Elsamadicy et al[14] performed a retrospective cohort study at a single institution focusing on COPD as a risk factor for pneumonia and found that the COPD cohort experienced a higher rate of pneumonia compared to the non-COPD cohort (5% vs 0.4%). This is a Level III study demonstrating the relationship between COPD and risk of postoperative pneumonia.

CHF

CHF was evaluated as a risk factor for postoperative reintubation, aspiration pneumonia, and VTE in 4 Level II studies. De La Garza Ramos et al[9] evaluated the incidence and associated risk factors for reintubation after adult spinal deformity surgery. Patients with a preoperative diagnosis of CHF were more than twice as likely to experience postoperative respiratory failure, which was the strongest indication for reintubation (OR 2.6). Similarly, Marques-Lara et al[7] evaluated the incidence and risk factors for reintubation after anterior cervical spine surgery using the NIS database. They found with multivariate analysis that patients with CHF were more than twice as likely to require postoperative reintubation (OR 2.6).

Fineberg et al[6] using the NIS database, found multiple comorbidities associated with postoperative aspiration pneumonia in a retrospective cohort study of patients who had undergone cervical spine surgery. After multivariate logistic regression analysis, patients with CHF were 3 times more likely to be at risk of postoperative aspiration pneumonia. As a result, aspiration pneumonia was an independent predictor for hospital mortality (OR 19.5). CHF was also found to be an independent risk factor for postoperative VTE in patients who had undergone thoracolumbar spinal fusion surgery. Gephart et al[11] investigated a cohort in the NIS database that showed patients who underwent thoracic or thoracolumbar fusion were at highest risk for postoperative VTE. After multivariate analysis, they found that patients with CHF and other comorbidities like anemia and weight loss were twice as likely to develop postoperative VTE (DVT or PE).

Weight Loss

Two Level II studies evaluated weight loss as an independent risk factor for postoperative pulmonary adverse events. In a retrospective analysis of thoracic and thoracolumbar spine fusion surgery,[11] patients with a preoperative diagnosis of weight loss were found to be 3 times more likely to experience a postoperative VTE. In another study of cervical spine surgery patients, Fineberg et al[6] performed a multivariate logistic regression analysis of different preoperative comorbidities and their association with postoperative aspiration pneumonia. They found that patients with preoperative weight loss were 8 times more likely to suffer aspiration pneumonia after cervical spine surgery. Both studies that evaluated the impact of weight loss on postoperative pulmonary adverse events used the NIS database. The database incorporated data from patients records that included *International Classification of Diseases, 9th* and *10th revision* diagnostic codes for weight loss. The exact definition of weight loss was not specifically defined in either study.

Coagulopathy

Preoperative coagulopathy is an unlikely risk factor for postoperative pulmonary adverse events. However, in a retrospective review of the NIS database, De La Garza Ramos et al[8,9] found that patients with adult spinal deformity with coagulopathy were nearly 4 times more likely to experience postoperative respiratory failure requiring reintubation and mechanical ventilation. In a study of patients with adult spinal deformity using the ACS NSQIP database, patients with preoperative coagulopathy/a preexisting bleeding disorder were almost 6 times more likely to require reintubation and prolonged ventilation in the postoperative period. In a study using the NIS database, Fineberg et al[6] found that coagulopathy was an independent risk factor for postoperative aspiration pneumonia after cervical spine surgery (OR 2.5). All 3 studies were Level II evidence supporting the association between coagulopathy and postoperative pulmonary adverse events.

Anemia

Preoperative anemia as an independent risk factor for postoperative pulmonary adverse events was investigated by Marquez-Lara et al[7] and De La Garza Ramos et al[9] in 2 different surgical cohorts using the NIS database. Marquez-Lara et al[7] found that anemia was an independent risk factor for postoperative reintubation in patients who underwent anterior cervical fusion surgery. Patients with preoperative anemia had twice the risk of needing reintubation. Similarly, for patients undergoing adult spinal deformity surgery, preoperative deficiency anemia was an independent risk factor for postoperative respiratory failure (OR 1.5). Patients in both cohorts experienced higher mortality rates because of postoperative pulmonary complications. Both studies were Level II evidence studies.

Corticosteroids

In a retrospective cohort study (Level II) using the ACS NSQIP database, Bohl et al[13] evaluated the incidence and risk factors for postoperative pneumonia after posterior lumbar fusion surgery. They found that the use of preoperative oral steroids was an independent risk factor for development of pneumonia. Buchanan et al[12] evaluated the incidence and risk factors of VTE after degenerative spine surgery using the Nationwide Readmission Database (Level III evidence). In a multivariate adjusted logistic regression analysis, patients using corticosteroids had nearly twice the odds of developing VTE at 30 days (OR 1.58) and 90 days (OR 1.97).

Obesity

Obesity as a risk factor for postoperative pulmonary adverse events was evaluated in a Level II study through retrospective review of the NIS database for adult spinal deformity surgery. In a study using the NIS database,[9] the authors found that obese patients were almost twice as likely to develop postoperative respiratory failure and require reintubation. Yoshida et al[15] (Level II) performed a retrospective study to develop a sliding scale for predicting postoperative complications after adult spinal deformity surgery. They used a prospective database at a single institution to perform the study. They found that high body mass index (BMI) was an independent risk factor for multiple postoperative complications, including pneumonia and VTE.

Sing et al[16] evaluated obesity as a risk factor for pneumonia, reintubation, and prolonged ventilation after revision spine surgery in a retrospective review of the ACS NSQIP database. The authors used the World Health Organization classification of obesity: nonobese (BMI 18.5-29.9 kg/m^2), obese class I (BMI 30-34.9 kg/m^2), and obese class II/III (BMI $\geq$35 kg/m^2). The investigators found that obese class II/III patients were nearly twice as likely to experience postoperative pneumonia, reintubation, and prolonged ventilation after revision surgery compared with the nonobese group. This study was downgraded to level III evidence because of the heterogeneity of the types of revision surgeries.

Similarly, Buerba et al[17] performed a retrospective cohort study of patients undergoing lumbar spine surgery. They analyzed patients from the ACS NSQIP database and found that obese class III patients were twice as likely to develop postoperative pneumonia, reintubation, and prolonged ventilation compared with their reference group. In a single-institution retrospective study, Li et al[10] identified that obese patients are twice as likely to experience postoperative reintubation and upper airway obstruction after anterior cervical spine surgery. Both studies provide level III evidence supporting the relationship between obesity and postoperative pulmonary adverse events.

OSA

OSA is associated with cardiac and pulmonary comorbidities. Lin et al[18] performed a study using the NIS database and found that OSA was an independent risk factor for respiratory complications. However, it was paradoxically associated with a lower risk of postoperative PE. This study was downgraded to Level III evidence because of a heterogeneous, poorly defined surgical population. Chung et al[19] evaluated a heterogeneous cohort of cervical, thoracic, and lumbar fusion and decompression surgery using the NIS database and found after multivariate logistic regression analysis that patients with OSA are nearly 3 times more likely to experience postoperative pulmonary complications in the form of respiratory failure, pneumonia, and the need for reintubation or mechanical ventilation. Patients with OSA experienced twice the incidence of DVT. This study was downgraded to level III evidence because of the heterogeneity of surgical procedures.

Smoking

Durand et al[20] performed a multivariate analysis using the NIS and ACS NSQIP databases and found that smokers were at increased risk of postoperative pneumonia and reintubation. This study was downgraded to Level III evidence because of heterogeneity of the population and surgery. Similarly, De La Garza Ramos et al[9] found, in a Level II evidence NIS retrospective

cohort study of patients undergoing adult spinal deformity surgery, that smoking was associated with an increased risk of postoperative pneumonia and was a leading cause of postoperative intubation. In contrast, another Level III study using the ACS NSQIP database by the same investigators[21] compared 30-day morbidity and mortality between current smokers and nonsmokers using multivariate logistic regression analysis. Interestingly, active smoking was not associated with an increased odds of developing pulmonary complications. There were significant baseline differences between the smoking versus nonsmoking cohorts, including younger age and fewer fusion levels in the smoking group. Finally, Li et al[10] evaluated the risk factors for postoperative reintubation and airway obstruction after anterior cervical spine surgery in a level III study and found that smoking increased the odds of postoperative reintubation (OR 1.5)

Other patient factors had insufficient evidence to support a recommendation regarding their association with risk of postoperative pulmonary adverse event. These factors include preoperative neurologic status and opioid use disorders.

Preoperative Neurologic Status, i.e., Myelopathy
A retrospective cohort study of the NIS database evaluated the impact of preoperative myelopathy on the incidence of postoperative pneumonia and PE.[22] After logistic regression analysis, patients with myelopathy were almost 4 times more likely to develop postoperative pneumonia after cervical anterior cervical fusion surgery and were 3 times more likely to experience pneumonia after posterior cervical fusion. Likewise, patients with myelopathy were found to be twice as likely to develop PE when compared with patients without myelopathy. The authors hypothesized that myelopathy-induced respiratory muscle dysfunction and impaired mobility increases the incidence of pneumonia and thromboembolism, respectively. Because this is a single Level II study without additional supporting studies, it was graded insufficient to consider preoperative myelopathy as a risk factor for postoperative pulmonary complications.

Opioid Use Disorders
Martini et al[23] evaluated the risk of patients with opioid use disorder on postoperative outcomes after lumbar fusion surgery. The authors used the NIS database to perform a retrospective cohort study and found that patients with opioid use disorder had significantly higher rates of pneumonia (OR 3.059), DVT (OR 4.165), and PE (OR 4.97). This is the only study addressing this risk factor that met inclusion criteria. Because this is a single Level III study without additional supporting studies, it was graded insufficient to consider opioid use disorder as a risk factor for postoperative pulmonary complications.

Question:
2. What preoperative diagnostic studies of pulmonary function predict risk of postoperative pulmonary adverse events in patients undergoing spine surgery?
Recommendation:
There is insufficient evidence to support the efficacy of any preoperative pulmonary test on predicting the risk of postoperative pulmonary adverse events in patients undergoing elective spine surgery. However, the task force recommends that clinicians perform the appropriate preoperative pulmonary tests based on the clinical presentation of active pulmonary symptoms or to confirm a suspected pulmonary disease.

Strength of Recommendation: Grade Insufficient

There was only 1 Level IV evidence study that met inclusion criteria.[24] Inoue et al[24] evaluated the use of D-dimer and other biomarkers in the preoperative setting to predict the incidence of postoperative DVT and PE. As a result, investigators found that an elevated level of plasminogen activator inhibitor-1 before surgery was higher in the VTE group compared with the non-VTE group, concluding that preoperative elevation of plasminogen activator inhibitor-1 is an effective marker for both DVT and PE. This study was downgraded to Level IV because of failure to report sensitivity and specificity.

Question:
3. Do preoperative pulmonary interventions reduce risk of postoperative pulmonary adverse events in patients undergoing spine surgery?
Recommendation:
There is insufficient evidence regarding preoperative pulmonary interventions to reduce the risk of postoperative pulmonary adverse events in patients undergoing spine surgery. However, the task force recommends that clinicians proceed with the appropriate preoperative pulmonary interventions to treat active pulmonary symptoms or suspected pulmonary disease.
Strength of Recommendation: Grade Insufficient

No relevant studies meeting inclusion criteria were identified for this question.

Future Research
There is a need for further research related to preoperative pulmonary diagnostic studies and intervention in patients who are undergoing spine surgery. There are several studies that evaluate risk factors associated with postoperative pulmonary adverse events; however, there is a paucity of research related to diagnostic tests that predict the likelihood of postoperative pulmonary complications. Future studies may focus particularly on susceptible subpopulations (e.g., higher frailty index) and patients undergoing spine surgery with higher overall pulmonary morbidity (e.g., adult spinal deformity surgery).

There were no studies evaluating preoperative pulmonary interventions and impact on incidence of postoperative pulmonary complications. The potential benefit of preoperative treatment in patients with significant pulmonary risk factors, such as active smoking status or poor functional dependence, should be studied. Investigation of different pulmonary interventions and multi-modal strategies including inspiratory muscle training, deep breathing exercise, and preoperative incentive spirometry in high-risk patient populations should be performed.

CONCLUSIONS
Postoperative pulmonary adverse events can be a significant source of morbidity in patients who are undergoing spine surgery. Identifying risk factors may guide clinicians in preoperative patient counseling. Functional dependence, advanced age, and multiple comorbidities, including COPD and CHF, are significant risk factors for postoperative pulmonary complications. Appropriate preoperative assessment of these factors may facilitate determining patient suitability for elective surgery and inform risk versus benefit discussion.

There is a lack of evidence regarding preoperative diagnostic tests for predicting the risk of pulmonary complications or therapeutic interventions to reduce occurrence. High-quality studies are required regarding pulmonary diagnostic and therapeutic interventions with a focus on high-risk patients and procedures. Despite insufficient evidence, clinicians should consider appropriate preoperative evaluation and intervention in individuals with active pulmonary symptoms of existing or suspected disease.

Conflicts of Interest

All Guideline Task Force members were required to disclose all potential COIs before beginning work on the guideline, using the COI disclosure form of the AANS/CNS Joint Guidelines Review Committee. The CNS Guidelines Committee and Guideline Task Force Chair reviewed the disclosures and either approved or disapproved the nomination and participation on the task force. The CNS Guidelines Committee and Guideline Task Force Chair may approve nominations of task force members with possible conflicts and restrict the writing, reviewing, and/or voting privileges of that person to topics that are unrelated to the possible COIs. See below for a complete list of disclosures.

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Disclaimer of Liability
This clinical, systematic, evidence-based clinical practice guideline was developed by a multi-disciplinary physician volunteer taskforce and is provided as an educational tool based on an assessment of the current scientific and clinical information regarding this guideline topic. These guidelines are disseminated with the understanding that the recommendations by the authors and consultants who have collaborated in their development are not meant to replace the individualized care and treatment advice from a patient's physician(s). If medical advice or assistance is required, the services of a physician should be sought. The proposals contained in these guidelines may not be suitable for use in all circumstances. The choice to implement any particular recommendation contained in these guidelines must be made by a managing physician in light of the situation in each particular patient and on the basis of existing resources.

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Supplemental Digital Content 1. Literature searches

See Chapter 1: Congress of Neurological Surgeons Systematic Review and Evidence-Based Practice Guidelines for Perioperative Spine: Preoperative Opioid Evaluation for details on full PubMed and EMBASE search terms.

Supplemental Digital Content 2. Inclusion Criteria

Articles that did not meet the following criteria, for the purposes of this evidence-based clinical practice guideline, were excluded. To be included as evidence in the guideline, an article had to be a report of a study that:

- Investigated patients with cervical spine surgery, thoracic spine surgery, and lumbar spine surgery;
- Excluded patients with tumor, trauma, or infections;
- Included patients ≥18 years of age;
- Were studies that enrolled ≥80% of cervical spine surgery, thoracic spine surgery, and lumbar spine surgery (we include studies with mixed patient populations if they report results separately for each group/patient population);
- Was a full article report of a clinical study;
- Was not a medical records review, meeting abstract, historical article, editorial, letter, or commentary;
- Appeared in a peer-reviewed publication or a registry report;
- Enrolled a minimum of 20 patients;
- Was of humans;
- Was published in or after 1946;
- Quantitatively presented results;
- Was not an in vitro study;
- Was not a biomechanical study;
- Was not performed on cadavers;
- Was published in English;
- Was not a systematic review, meta-analysis, or guideline developed by others.*

Systematic reviews or meta-analyses conducted by others, or guidelines developed by others were not included as evidence to support this review due to the differences in article inclusion/exclusion criteria specified compared with the criteria specified by the Guidelines Task Force. Although these articles were not included as evidence to support the review, these articles were recalled for full-text review for the Guidelines Task Force to conduct manual searches of the bibliographies.

*The guideline task force did not include systematic reviews, guidelines or meta-analyses conducted by others. These documents are developed using different inclusion criteria than those specified in this guideline; therefore, they may include studies that do not meet the inclusion criteria specific in this guideline. In cases where these types of documents' abstract suggested relevance to the guideline's recommendations, the task force searched their bibliographies for additional studies.

Supplemental Digital Content 3.
Criteria for grading the evidence

The task force used the criteria provided below to identify the strengths and weaknesses of the studies included in this guideline. Studies containing deficiencies were downgraded 1 level (no further downgrading allowed, unless so severe that study had to be excluded). Studies with no deficiencies based on study design and contained clinical information that dramatically altered current medical perceptions of topic were upgraded.

1. Baseline study design (i.e., therapeutic, diagnostic, prognostic) determined to assign initial level of evidence.

2. Therapeutic studies reviewed for following deficiencies:
    - Failure to provide a power calculation for a randomized controlled trial (RCT);
    - High degree of variance or heterogeneity in patient populations with respect to presenting diagnosis/demographics or treatments applied;
    - Less than 80% of patient follow-up;
    - Failure to utilize validated outcomes instrument;
    - No statistical analysis of results;
    - Crossover rate between treatment groups of greater than 20%;
    - Inadequate reporting of baseline demographic data;
    - Small patient cohorts (relative to observed effects);
    - Failure to describe method of randomization;
    - Failure to provide flowchart following patients through course of study (RCT);
    - Failure to account for patients lost to follow-up;
    - Lack of independent post-treatment assessment (e.g., clinical, fusion status, etc.);
    - Utilization of inferior control group:
        - Historical controls
        - Simultaneous application of intervention and control within same patient
    - Failure to standardize surgical/intervention technique;
    - Inadequate radiographic technique to determine fusion status (e.g., static radiographs for instrumented fusion).

3. Methodology of diagnostic studies reviewed for following deficiencies:
    - Failure to determine specificity and sensitivity;
    - Failure to determine inter- and intraobserver reliability;
    - Failure to provide correlation coefficient in the form of kappa values.

4. Methodology of prognostic studies reviewed for following deficiencies:
    - High degree of variance or heterogeneity in patient populations with respect to presenting diagnosis/demographics or treatments applied;
    - Failure to appropriately define and assess independent and dependent variables (e.g., failure to use validated outcome measures when available).

Rating evidence quality. Levels of evidence for primary research question[a]

Types of Studies				
	Therapeutic studies: Investigating the results of treatment	Prognostic studies: Investigating the effect of a patient characteristic on the outcome of disease	Diagnostic studies: Investigating a diagnostic test	Economic and decision analyses: Developing an economic or decision model
Level I	High-quality randomized trial with statistically significant difference or no statistically significant difference but narrow confidence intervals Systematic review[b] of Level I RCTs (and study results were homogeneous[c])	High-quality prospective study[d] (all patients were enrolled at the same point in their disease with ≥80% follow-up of enrolled patients) Systematic review[b] of Level I studies	Testing of previously developed diagnostic criteria on consecutive patients (with universally applied reference gold standard) Systematic review[b] of Level I studies	Sensible costs and alternatives; values obtained from many studies with multiway sensitivity analyses Systematic review[b] of Level I studies
Level II	Lesser quality RCT (e.g., <80% follow-up, no blinding, or improper randomization) Prospective[d] comparative study[e] Systematic review[b] of Level II studies or Level I studies with inconsistent results	Retrospective[f] study Untreated control subjects from an RCT Lesser quality prospective study (e.g., patients enrolled at different points in their disease or <80% follow-up) Systematic review[b] of Level II studies	Development of diagnostic criteria on consecutive patients (with universally applied reference criterion standard) Systematic review[b] of Level II studies	Sensible costs and alternatives; values obtained from limited studies with multiway sensitivity analyses Systematic review[b] of Level II studies

Level III	Case control study[g] Retrospective[f] comparative study[e] Systematic review[b] of Level III studies	Case control study[g]	Study of nonconsecutive patients without consistently applied reference criterion standard Systematic review[b] of Level III studies	Analyses based on limited alternatives and costs and poor estimates Systematic review[b] of Level III studies
Level IV	Case series[h]	Case series	Case-control study Poor reference standard	Analyses with no sensitivity analyses

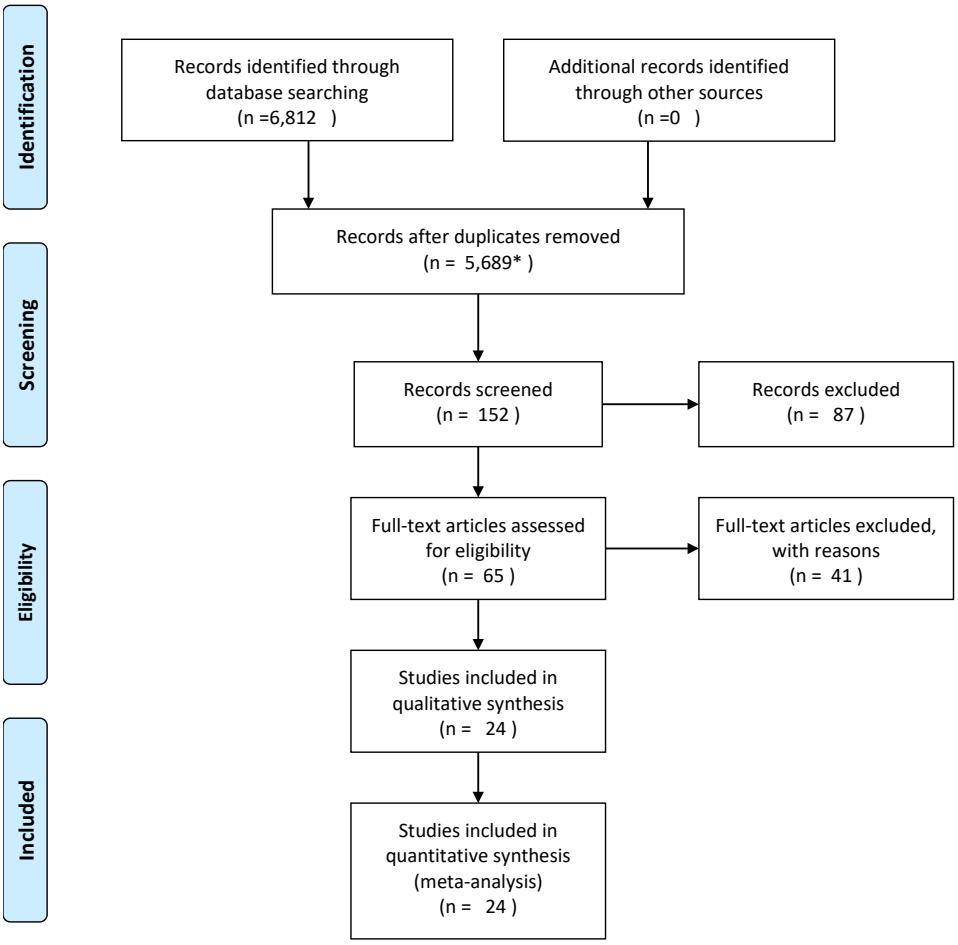
RCT, randomized controlled trial.
[a]A complete assessment of quality of individual studies requires critical appraisal of all aspects of the study design.
[b]A combination of results from ≥2 previous studies.
[c]Studies provided consistent results.
[d]Study was started before the first patient enrolled.
[e]Patients treated one way (e.g., instrumented arthrodesis) compared with a group of patients treated in another way (e.g., uninstrumented arthrodesis) at the same institution.
[f]Study was started after the first patient enrolled.
[g]Patients identified for the study based on their outcome, called "cases" (e.g., pseudoarthrosis) are compared with those who did not have outcome, called "controls" (e.g., successful fusion).
[h]Patients treated one way with no comparison group of patients treated in another way.

Supplemental Digital Content 4. Linking levels of evidence to grades of recommendation

Grade of Recommendation	Standard Language	Levels of Evidence	
A	Recommended	≥2 consistent Level I studies	
B	Suggested	One Level I study with additional supporting Level II or III studies	≥2 consistent Level II or III studies
C	Is an option	One Level I, II, or III study with supporting Level IV studies	≥2 consistent Level IV studies
I (insufficient or conflicting evidence)	Insufficient evidence to make recommendation for or against	A single Level I, II, III, or IV study without other supporting evidence	≥1 study with inconsistent findings*

*Note that in the presence of multiple consistent studies, and a single outlying, inconsistent study, the grade of recommendation will be based on the level of the consistent studies.

Supplemental Digital Content 5. PRISMA Flowchart



*In addition to duplicate removal, the librarian also removed strictly animal or children/adolescent studies not identified by search strategy and case reports dealing with 1 to 2 persons as encountered.

Supplemental Digital Content 6. Evidence table

PICO Question	Author, Year	Type of Evidence	Study Type	Level of Evidence	Reviewer's Conclusions
1	Bohl et al, 2016[3]	Prognostic	Retrospective cohort study	III	This was a prognostic study. The study affirms that patients who are older, are functionally dependent, or who have COPD are at greater risk for postoperative pulmonary adverse events after ACDF surgery. Study downgraded to Level III because of failure to appropriately define independent and dependent variables
1	Bohl et al, 2016[13]	Prognostic	Retrospective cohort study	II	This study affirms that patients with COPD, steroid use, diabetes mellitus, and a greater number of operative levels are at greater risk of postoperative pulmonary adverse events after posterior lumbar fusion surgery
1	Buchanan et al, 2019[12]	Prognostic	Retrospective cohort study	III	This study affirms that old age and the use of corticosteroids are independently associated with the higher likelihood of readmission with VTE within 30 days. Study was downgraded because of heterogeneity of the patient population
1	Buerba et al, 2014[17]	Prognostic	Retrospective cohort study	III	This study was downgraded because of heterogeneity of the patient population regarding the treatment approach to lumbar spine surgery in obese patients. The study affirms that obesity class III patients (BMI $\geq$40 kg/m^2) are at a higher risk of postoperative pulmonary complications

1	Buerba et al, 2014[5]	Prognostic	Retrospective cohort study	II	This study affirms that only patients 65-74 years of age were more likely to have a PE/DVT, whereas only patients ≥75 years of age were more likely to experience respiratory complications, central nervous system complications, or death
1	Burton et al, 2018[1]	Prognostic	Retrospective cohort study	II	This prognostic study affirms functional dependence in activities of daily living is associated with postoperative pulmonary disease adverse events—the study showed that patients with preoperative functional dependence are twice as likely to develop severe postoperative pulmonary events
1	Chung et al, 2018[19]	Prognostic	Retrospective cohort study	III	This study affirms that OSA was an independent predictor of pulmonary complications. This study was downgraded because of the heterogeneity of the surgical procedure
1	De La Garza Ramos et al, 2017[21]	Prognostic	Retrospective cohort study	III	This study negates smoking. Smoking was not associated with increased rates of postoperative complications, including pulmonary complications such as pneumonia, reintubation, or PE. This study was downgraded because of heterogeneity of the patient population
1	De la Garza Ramos et al, 2017[8]	Prognostic	Retrospective cohort study	II	This prognostic study affirms the association of age and bleeding disorder with prolonged ventilation and reintubation in adult spinal deformity surgery

1	De la Garza Ramos et al, 2017[9]	Prognostic	Retrospective cohort study	II	This study affirms that the following risk factors were independent predictors of reintubation and respiratory failure after adult spine deformity surgery: CHF, coagulopathy, fusion of ≥8 levels, deficiency anemia, and chronic lung disease
1	Di Capua et al, 2017[4]	Prognostic	Retrospective case control	II	This prognostic study affirms that age (>61 years) is associated with pulmonary complications, including pneumonia, unplanned reintubation, or duration of ventilator-assisted respiration >48 hours, and VTE (PE and DVT)
1	Durand et al, 2019[20]	Prognostic	Retrospective cohort study	III	This study affirms that smokers were at increased risk of postoperative pulmonary complications (including pneumonia and reintubation). The study was downgraded because of heterogeneity of the patient population and surgical approach
1	Elsamadicy et al, 2018[14]	Prognostic	Retrospective cohort study	III	This study was downgraded because of heterogeneity of the patient population. The study affirms COPD is associated with pneumonia (PICO question 1)
1	Fineberg et al, 2013[6]	Prognostic	Retrospective cohort study	II	This study affirms that advanced age (≥65 years), male sex, CHF, coagulopathy, neuropsychiatric disorders, and weight loss are independent predictors of aspiration in cervical spine surgery

1	Gephart et al, 2012[11]	Prognostic	Retrospective cohort study	II	This study shows that spinal fusion at the thoracic/thoracolumbar level, increasing age, Medicare insurance coverage (vs private insurance), urban teaching hospital (vs urban nonteaching hospital), combined anterior/posterior surgical approach (vs posterior-only approach), and the presence of congestive heart failure or weight loss (Elixhauser comorbidity groups) were each independently associated with an increased OR of VTE complications
1	Li et al, 2017[10]	Prognostic	Retrospective cohort study	III	The study was downgraded because it failed to define patient variables. This is a prognostic study that affirms that age, smoking, and BMI are associated with airway obstruction and reintubation after anterior cervical spine surgery
1	Lin et al, 2019[18]	Prognostic	Retrospective cohort study	III	This study affirms that OSA is an independent risk factor for postoperative pulmonary complications; however, it was an independent predictor of decreased patient mortality. Study was downgraded because of the heterogeneous poorly defined surgical population
1	Marquez-Lara et al, 2014[7]	Prognostic	Retrospective cohort study	II	This study affirms there are significant predictors for reintubation included ≥3-level fusions, CHF, anemia, postoperative aspiration pneumonia, hematoma, thromboembolic events, and dysphagia

1	Martini et al, 2019[22]	Prognostic	Retrospective cohort study	III	Retrospective analysis of patients who had undergone lumbar spine surgery to evaluate outcome in patients with OUD vs those without OUD. Patients with OUD are at higher risk of postoperative pulmonary complications (pneumonia, PE, and DVT). Study was downgraded because of heterogeneity of the patient population and the surgical approach
1	Shamji et al, 2008[22]	Prognostic	Retrospective cohort study	II	This study affirms that myelopathy is associated with pneumonia
1	Sing et al, 2016[16]	Prognostic	Retrospective cohort study	III	This study was downgraded because of heterogeneity of the types of revision surgeries. This study affirms that patients with obesity class II/III (BMI ≥35 kg/m^2) are twice as likely to experience postoperative pulmonary complications after revision spine surgery
1	Yoshida et al, 2018[15]	Prognostic	Retrospective cohort study	II	This study affirms that the only independent predictor of DVT/PE after adult spine deformity surgery was high BMI (OR 1.160 [95% CI 1.024-1.315], P = .020)
2	Inoue et al, 2018[23]	Diagnostic	Prospective diagnostic study	IV	Study showed negative association for CT and D-dimer preoperatively but affirms PAI. The study was downgraded because it failed to report sensitivity and specificity of a diagnostic study

ACDF, anterior cervical decompression and fusion; CHF, congestive heart failure; CI, confidence interval; COPD, chronic obstructive pulmonary disease; CT, computed tomography; DVT, deep vein thrombosis; OR, odds ratio; OSA, obstructive sleep apnea; OUD, opioid use disorder; PAI, plasminogen activator inhibitor-1; PE, pulmonary embolism; VTE, venous thromboembolism.