CONGRESS OF NEUROLOGICAL SURGEONS SYSTEMATIC REVIEW AND EVIDENCE-BASED GUIDELINES FOR PERIOPERATIVE SPINE: PREOPERATIVE SURGICAL RISK ASSESSMENT

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:
BMI: body mass index
HbA_{1c}: hemoglobin A_{1c}
SSI: surgical site infection

ABSTRACT

Background: Patient factors (increased body mass index [BMI], smoking, and diabetes) may impact outcomes after spine surgery. There is a lack of consensus regarding which factors should be screened for and potentially modified preoperatively to optimize outcome.
Objective: The purpose of this evidence-based clinical practice guideline is to determine if preoperative patient factors of diabetes, smoking, and increased BMI impact surgical outcomes.
Methods: A systematic review of the literature for studies relevant to spine surgery was performed using the National Library of Medicine PubMed database and the Cochrane Library. Clinical studies evaluating the impact of diabetes or increased BMI with reoperation and/or surgical site infection (SSI) were selected for review. In addition, the impact of preoperative smoking on patients undergoing spinal fusion was reviewed.
Results: Six hundred ninety-nine articles met inclusion criteria and 64 were included in the systematic review. In patients with diabetes, a preoperative hemoglobin A_{1c} (HbA_{1c}) >7.5 mg/dL is associated with an increased risk of reoperation or infection after spine surgery. The review noted conflicting studies regarding the relationship between increased BMI and SSI or reoperation. Preoperative smoking is associated with increased risk of reoperation (Grade B). There is insufficient evidence that cessation of smoking before spine surgery decreases the risk of reoperation.
Conclusion: This evidence-based guideline provides a Grade B recommendation that diabetic individuals undergoing spine surgery should have a preoperative HbA_{1c} test before surgery and should be counseled regarding the increased risk of reoperation or infection if the level is >7.5 mg/dL. There is conflicting evidence that BMI correlates with greater SSI rate or reoperation rate (Grade I). Smoking is associated with increased risk of reoperation (Grade B) in patients undergoing spinal fusion.

RECOMMENDATIONS

Question:
1. In patients with diabetes undergoing spine surgery, what preoperative diagnostic studies predict increased risk for reoperation or postoperative infection?

Recommendations:
Diabetic individuals undergoing spine surgery should have a preoperative hemoglobin A_{1C} (HbA_{1c}) test before surgery and be counseled regarding the increased risk of reoperation or infection if the level is >7.5 mg/dL.
Strength of Recommendation: Grade B

There was insufficient evidence to support other preoperative diagnostic studies for predicting the risk for reoperation or postoperative infection in patients with diabetes undergoing spine surgery (e.g., preoperative blood glucose levels).
Strength of Recommendation: Grade Insufficient

Question:

2. Is increased body mass index (BMI) associated with increased risk for reoperation or postoperative infection in patients undergoing spine surgery?

Recommendations:

There is conflicting evidence that increased BMI is associated with a greater risk of SSI in patients undergoing spinal surgery. Given the number of studies demonstrating a correlation between a BMI >30 kg/m^2 and SSI, particularly with lumbar surgery, the task force recommends that clinicians counsel patients with elevated BMI regarding this possible risk.
Strength of Recommendation: Grade Insufficient

There is conflicting evidence that increased BMI is correlated with an increased risk of reoperation after spinal surgery.
Strength of Recommendation: Grade Insufficient

Question:

3. Is preoperative smoking associated with increased risk of reoperation in patients undergoing spinal fusion surgery? Does preoperative smoking cessation decrease risk of reoperation?

Recommendations:

Individuals undergoing spinal fusion surgery who are active smokers should be counseled regarding the increased risk of reoperation.
Strength of Recommendation: Grade B

There is insufficient evidence that cessation of smoking before spine surgery decreases risk of reoperation, but it is suggested that patients be counseled to abstain from smoking before and after spinal fusion surgery.
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.

Objectives

Most spine surgeries are performed electively. This affords the surgeon and the preoperative team the opportunity to evaluate an individual patient for risk factors and to potentially optimize these factors before surgery. Diabetes, obesity, and smoking are 3 prevalent comorbidities that negatively impact health status, increase health care costs,[1] and have been implicated in worse

outcomes after spine surgery. There is a lack of consensus regarding appropriate screening for these factors and if preoperative modification improves outcome.

One objective of this review is to determine preoperative diagnostic studies that predict increased risk of reoperation or SSI in patients with diabetes. In addition, the published literature was assessed to determine if an increased BMI correlates with an increased risk of reoperation or SSI. Finally, the impact of preoperative smoking and risk of reoperation after spinal fusion was evaluated and if smoking cessation decreases risk.[1-4]

METHODS

The guidelines task force initiated a systematic review of the literature and evidence-based guideline relevant to the preoperative treatment of patients with spinal disorders. 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/parameter 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 “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. For 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 5 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.”[5] 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 initial 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, the literature search yielded 699 abstracts for this question. Task force members reviewed all abstracts yielded by the initial literature search. They identified the literature for full text review and extraction that addressed 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 192 full-text articles for full text review. Of these, 128 were rejected for not meeting inclusion criteria or for being off-topic. Sixty-four were included in the systematic review (Supplemental Digital Content 6). There were 5 articles selected for question 1 concerning diabetic preoperative diagnostic tests, and all of these were graded Level II. Question 2 had 54 articles selected where 41 focused on increased BMI and SSI. Thirty were graded Level II and 11 Level III. Sixteen were selected on reoperation with 14 graded Level II and 2 graded

Level III). Lastly, 8 articles were chosen for question 3 concerning reoperation risk factors with 6 graded Level II and 2 graded Level III.

DISCUSSION

Question

In patients with diabetes undergoing spine surgery, what preoperative diagnostic studies predict increased risk for reoperation or postoperative infection?

Recommendation

Diabetic individuals undergoing spine surgery should have a preoperative HbA_{1c} test before surgery and be counseled regarding an increased risk of reoperation or infection if the level is >7.5 mg/dL.

Strength of Recommendation: Grade B

There was insufficient evidence to support other preoperative diagnostic studies for predicting the risk for reoperation or postoperative infection in patients with diabetes undergoing spine surgery (e.g., preoperative blood glucose levels).

Strength of Recommendation: Grade Insufficient

There were 5 articles (Level II studies) demonstrating the relationship between increased HbA_{1c} and risk of reoperation or infection after spinal surgery. Cancienne et al[6] used preoperative HbA_{1c} levels in patients with diabetes in 3341 anterior cervical diskectomy and fusion patients requiring reoperation. In the series, a significant relationship was observed between increased HbA_{1c} level and reoperation rate ($P = .005$), where a subanalysis determined the inflection point in the area under the curve of 7.5 mg/dL with a sensitivity of 46% and specificity of 68%. Hikata et al[7] performed a retrospective review of 36 patients with diabetes (19 males and 17 females; median age 64.3 years) who underwent thoracic and lumbar spinal fusion over a 6-year period (2005–2011). Diabetics had an overall higher rate of infection (6/36 vs 10/309). There was no difference in infection based on preoperative serum glucose level, but preoperative HbA_{1c} values were significantly higher in patients who developed SSI (7.6 mg/dL) than in those who did not (6.9 mg/dL). The authors defined controlled diabetes as a HbA_{1c} <7.0 mg/dL, and there were no infections in that population compared with 35.3% in patients with HbA_{1c} >7.0 mg/dL.

In a separate analysis, Cancienne et al[8] reviewed the effect of HbA_{1c} on 5194 single-level lumbar decompressions and patients with diabetes. The inflection point for infection by HbA_{1c} level was >7.5 mg/dL ($P = .01$; specificity 70%, sensitivity 53%). In a subanalysis controlled for patient demographics and medical comorbidities, the authors reported that HbA_{1c} >7.5 mg/dL correlated with a higher risk for deep SSI (odds ratio [OR] 2.9 [95% confidence interval {CI} 1.8–4.9, $P < .0001$). Caputo et al[9] analyzed 3138 patients (2005–2010) and found that patients with diabetes had an increased risk for SSI (6.4% vs 3.2%). Perioperative blood glucose levels >140 mg/dL doubled the risk of an SSI ($P = .0091$). These authors did not identify a correlation with HbA_{1c} measurements preoperatively; however, they used a higher threshold for HbA_{1c} than the other studies (8.0%). Koutsoumbelis et al[10] analyzed 3218 patients with posterior lumbar instrumented fusion over 6 years (2000–2006) and reported a postoperative infection rate of 2.6%. Multiple regression analysis noted that diabetes mellitus was a predictor for SSI. Preoperative serum glucose levels did not correlate with SSIs, but there was a significant relationship with higher postoperative glucose levels and the infected group ($P < .001$).

Question:
Is increased body mass index associated with an increased risk for reoperation or postoperative infection in patients undergoing spine surgery?
Recommendations:
There is conflicting evidence that increased BMI is associated with greater risk of SSI in patients undergoing spinal surgery. Given the number of studies demonstrating a correlation between BMI >30 kg/m^2 and SSI, particularly with lumbar surgery, the task force recommends that clinicians counsel patients with elevated BMI regarding this possible risk.
Strength of Recommendation: Grade Insufficient

There is conflicting evidence that increased BMI is correlated with an increased risk of reoperation after spinal surgery
Strength of Recommendation: Grade Insufficient

Lumbar
There were 42 lumbar surgery articles identified assessing increased BMI and SSI. Thity-one of the articles (25 Level II and 6 Level III articles) noted a direct correlation between increased BMI and SSI, while 10 articles (6 Level II and 5 Level III articles) showed no significant difference.

Lumbar Surgery: Studies Showing a Correlation Between Increased BMI and SSI
Most of the lumbar surgery studies were Level II and noted a positive correlation with increased BMI and a higher risk of SSI. Mehta et al[11] reported 298 lumbar patients treated at a single institution (2006-2008) where 24 (8%) had postoperative infections. They reported that increased BMI (≥30 kg/m^2) correlated with SSI (P = .025). Jain et al[12] reviewed 36,440 patients (28,813 patients [79.07%] undergoing lumbar spine surgery) using the American College Surgeons (ACS) NSQIP database. The overall rate of SSI was 0.72% (n = 264). They reported a significant correlation with increased BMI and infection (P < .001) that persisted in multivariate analysis. Wang et al[13] reported a posterior lumbar SSI rate of 3.0% (267/8879 cases) and a significant correlation between increased BMI and SSI (P < .0001). De la Garza-Ramos et al[14] retrospectively reviewed 732 lumbar fusion patients, 662 (90.44%) nonobese and 70 (9.56%) obese, and showed that increased BMI was associated with increased risk of postoperative SSI (relative risk 3.11 [CI 1.48-6.52]). Li et al[15] further reviewed 448 patients undergoing transforaminal interbody fusion (TLIF) and compared SSI risk factors. In univariate analysis, there was a significant correlation with increased BMI (P < .001). Kurtz et al[16] reviewed Medicare data with 15,069 primary fusion procedures and 605 revision procedures and noted an SSI rate of 8.5% in primary and 12.2% in revision procedures. Increased BMI was a significant predictor of 10-year infection risk (P < .001). Puvanesarajah et al[17] reviewed 48,210 patients ≥65 years of age using Medicare data and noted that increased BMI had a significantly higher OR of wound infection (3.71, P < .0001 and 2.22, P < .0001). Buerba et al[18] reviewed 10,387 patients in the ACS NSQIP database and reported that increased BMI correlated with a significantly increased risk of wound complications. Lieber et al[19] also reviewed the NSQIP database for 61,079 subjects with 1110 (1.84%) postoperative wound infections and reported a correlation with increased BMI >30 kg/m^2. Glassman et al[20] pooled 3 large spine surgery databases: the National Neurosurgery Quality and Outcomes Database (N = 2653), DaneSpine 1993, and the

Japan Multicenter Spine Database (N = 3798). They reported that increased BMI correlated with an increased risk of SSI (OR 1.07, $P < .001$).[20] Ilyas et al[21] reviewed 1592 lumbar surgeries (decompression and fusion) at a single institution and noted a significant correlation between SSI and morbid obesity (OR 6.99 [95% CI 2.65-22.03], $P < .001$). Ranson et al[22] studied the ACS NSQIP database and identified 22,909 patients undergoing posterior lumbar fusion from 2011 to 2014. One thousand eight hundred eighty-one patients (8.2%) had BMI >40 kg/m^2 and a direct correlation between increased BMI and wound complication was observed ($P < .001$). In another single-institution series, Koutsoumbelis et al[10] analyzed 3218 patients undergoing posterior lumbar fusion and noted that obesity was the strongest risk factor for postoperative spinal infection in a multivariate regression analysis (OR 6.76 [95% CI 2.91-15.71], $P < .001$). Klemencsics et al[23] examined 817 posterior lumbar surgery patients and 37 patients (4.5%) developed SSI. Their analysis noted a correlation between an increased risk of infection and obesity (relative risk 6.216 [95% CI 1.832-9.338], $P = .005$).

Two Level III studies also supported a correlation between increased BMI and SSI after lumbar spine surgery. Ee et al[24] reported 27 lumbar SSIs that were matched against 162 control subjects without SSI (Class III). The BMI of the noninfected patients was 24.9 ± 3.8 kg/m^2 compared with 28.2 ± 6.3 kg/m^2 in the infected population ($P = .016$). Maragakis et al[25] performed a case-control study of 104 spinal surgery patients with SSI compared with 104 control subjects without SSI. Multivariate analysis identified obesity (OR 4.0 [95% CI 1.6-10], $P < .01$) as a risk for SSI.

Lumbar Surgery: Studies Showing No Correlation Between Increased BMI and SSI

Two Level II studies reported no correlation between increased BMI and SSI. Both studies had smaller subject populations and involved anterior surgery, which is associated with an overall lower rate of SSIs than posterior surgery. Adogwa et al[26] reported 63 patients (29 obese and 34 nonobese patients) undergoing lateral lumbar interbody fusion for degenerative spine disease (2010-2012). There was no correlation between increased BMI and SSI.[26] Rodgers et al[27] performed a retrospective review of lateral lumbar interbody fusion for lumbar degenerative disease in 313 patients (156 obese and 157 nonobese patients) and noted no association between increased BMI and SSI.

Three Level III studies did not show an association between SSI and increased BMI. Pereira et al[28] reviewed 118 lumbar surgeries performed in 100 patients and noted no correlation between increased BMI and SSI. The 2 additional studies involved minimally invasive surgery approaches, which overall have a low incidence of infections. Goldin and Alander[29] reviewed 82 patients who underwent lumbar surgery via various minimally invasive techniques with no significant difference in SSI rate (3 infections in the obese group and none in the control population). Fakouri et al[30] reported a smaller series of patients undergoing minimally invasive surgery lumbar discectomy (34 obese and 30 nonobese patients) performed over 3 years and noted that obese patients had 2 superficial infections, but this was not significant.

Multilevel Lumbar or Thoracolumbar Surgery: Studies Showing A Correlation Between Increased BMI and SSI

There were 8 studies with multilevel lumbar or thoracolumbar surgery demonstrating a correlation between increased BMI and SSI (4 Level II studies and 4 Level III studies). Soroceanu et al[31] reviewed 175 nonobese and 66 obese patients with adult spinal deformity

(ASD). Their regression model noted that obese patients had a higher overall incidence of wound infection (OR 4.88, $P = .02$). In a retrospective study by Zhang et al,[32] 153 patients with adult degenerative scoliosis with multilevel spinal fusion and 2 years of follow-up reported an association between an increased risk of infection and elevated BMI (OR 1.11, $P = .008$). Sing et al[33] identified 2536 patients in the ACS-NSQIP database undergoing revision spine surgery and evaluated early (30-day) complications. They found that revision spine surgery and obesity correlated with increased wound complications on multivariate analysis ($P = .028$).[33] Elsamadicy et al[34] reviewed 500 patients (281 nonobese and 219 obese patients) undergoing elective spine surgery and reported an association between increased BMI and an increased risk for deep SSI ($P = .04$).

A study using the NIS database evaluated 244,170 thoracolumbar or lumbar spine fusion patients treated for degenerative disease (1988-2004). The authors reported that patients with morbid obesity (BMI >40 kg/m^2) were 70% more likely to have an SSI ($P < .01$).[35] Chin et al[36] further reported on 1010 patients, 642 in a hospital setting and 368 in an outpatient setting, where increased BMI >30 kg/m^2 was associated with a significant increase in SSI (RR 9.3, $P = .005$). Pull ter Gunne et al[37] performed a retrospective review of 830 adult patients undergoing spinal deformity surgery for kyphosis or scoliosis. SSI occurred in 29 patients (3.5%) and increased BMI was found to be an independent risk factor ($P = .014$).[37] In a case-control study of 55 patients with SSI after spinal surgery and 179 control spine surgery patients, increased BMI was noted as a risk factor for SSI in 32 of 47 (68%) versus 72 of 167 (43%) (OR 2.81 [95% CI 1.41-5.59], $P < .003$).[38]

Four studies did not note a correlation between SSI and increased BMI performed in multilevel lumbar or thoracolumbar spine surgery. Two Level II articles both featured cohorts of patients with deformities; 1 included 532 patients where 20 (4%) experienced SSIs.[39] The second case-control study by Boston et al[38] also reported no correlation in 55 patients who developed SSIs after spinal surgery and 179 control subjects with high BMI. An additional Level III article by Savetti et al[40] reported no association between obesity and SSI in 387 spine surgery patients. The fourth article, a Level III article by Elsamadicy et al,[41] reviewed 112 ASD patients (BMI >30 kg/m^2) undergoing elective complex spinal fusion (>7 levels) for deformity correction and found no correlation with increased BMI and SSI.

Cervical

Three studies demonstrated a correlation (all Level II) between BMI and SSI and 2 did not (both Level II). Jalai et al[42] reviewed 3057 patients undergoing surgery for cervical spondylotic myelopathy with an overall infection rate of 1.15 % (35/3057). Logistic regression analysis revealed that SSI correlated with increased BMI (OR 1.162 [95% CI 1.269-1.064], $P = .001$).[42] In a review of patients undergoing posterior cervical spine surgery, 9 of 483 (1.86%) patients had an acute postoperative deep SSI. A significantly higher rate of infection was noted in patients with BMI >30 kg/m^2 (OR 4.1 [95% CI 1.5-7.7], $P = .005$).[43] In a study of 5441 posterior cervical surgery patients, 160 patients with SSI (2.94%), a multivariate analysis noted that a BMI >35 kg/m^2 (OR 1.78, $P = .003$) independently correlated with SSI.[44]

Buerba et al[45] used the ACS-NSQIP database from 2005 to 2010 to examine cervical anterior or posterior fusion and did not identify an association with increased BMI and SSI. In addition,

Srinivasan et al[46] evaluated a smaller series of 69 anterior cervical fusion patients and noted no significant correlation between BMI and SSI, but it should be noted this study was underpowered to detect a difference because of the rare occurrence of anterior cervical infections.

Increased BMI and Risk of Reoperation

There is conflicting evidence regarding the association between increased BMI and reoperation rate, with most studies failing to demonstrate a correlation. There were 12 studies (11 Level II and 1 Level III) that showed no correlation. Specifically, cervical surgery studies (4 Grade II) and thoracolumbar (2 Level II) reported no association of increased BMI and reoperation. Four studies (3 Level II and 1 Level III) did report a correlation between increased BMI and reoperation, with all studies restricted to lumbar surgery.

Lumbar: Increased BMI Does Not Correlate With Increased Risk of Reoperation

Narain et al[47] examined 274 patients who had undergone lumbar minimally invasive transforaminal interbody fusion (TLIF) with multivariate Cox proportional hazards survival analysis to evaluate the risk of increased BMI and reoperation. Increased BMI was not associated with undergoing reoperation within 2 years after minimally invasive TLIF ($P = .599$).[47] Gerling et al[48] performed a multivariate regression analysis of the 8-year postoperative follow-up from the SPORT trial for spondylolisthesis (406 patients, 72% instrumented, 21% noninstrumented fusion, and 7% decompression alone) and reported no correlation between increased BMI and reoperation. In addition, Leven et al[49] analyzed the 8-year postoperative follow-up from a multicenter randomized controlled lumbar discectomy trial and noted a reoperation rate of 15% (691 no reoperation, 119 reoperation) with no correlation between increased BMI and reoperation. Kahn et al[50] evaluated 569 patients who had undergone open posterior lumbar spine fusion with 290 (50.97%) BMI <30 kg/m^2 (nonobese) and 279 (49.03%) BMI ≥30 kg/m^2 (obese). There was no difference in reoperation rates between the 2 groups.[50] Owens et al[51] reviewed 164 patients in a case-control study (Level III) with 5-year reoperation rate by BMI. There was no correlation between reoperation rate and BMI, stratified into 3 tiers: BMI 20-25 kg/m^2 (normal), BMI 25-30 kg/m^2 (overweight), and BMI 30-40 kg/m^2 (obese).[51] Wadhwa et al[52] reviewed the National Neurosurgery Quality and Outcomes Database lumbar spine registry and identified 9853 lumbar degenerative surgery patients. They reported a 2% 30-day reoperation rate that did not correlate with increased BMI.[52] Kara et al[53] retrospectively reviewed 80 lumbar discectomy patients. The authors noted no association between increased BMI and reoperation rates in the 46 patients that had a single operation and the 34 that required a reoperation.[53]

Lumbar Article: BMI Correlates to Increased Reoperation

Rihn et al[54] analyzed the 4-year postoperative follow-up from the SPORT degenerative spondylolisthesis trial and observed twice the reoperation rate at 4 years for patients with BMI ≥30 kg/m^2 compared with those with BMI <30 kg/m^2 (20% vs 11%, $P = .01$). Obesity, however, did not negatively impact the overall clinical outcome.[54] Bohl et al[55] reviewed 226 single-level minimally invasive lumbar discectomy patients and 23 (10.2%) underwent reoperation. The 2-year risk of reoperation was 1.8% for nonobese patients, 12.5% for overweight patients, 9.1% for obese patients, and 25.0% for morbidly obese patients. In the multivariate-adjusted analysis model, increased BMI was independently associated with undergoing reoperation ($P = .038$).[55] Beack et al[56] examined 160 patients undergoing primary lumbar discectomy with 24 reoperations (15%) for recurrent disc herniation and noted that a BMI >30 kg/m^2 was significantly associated

with reoperation ($P < .05$). A final Level III article by Gaudelli et al[57] reported patients with BMI >35 kg/m^2 who underwent elective lumbar spine surgery had an increased risk of postsurgical complications, as evidenced by reoperation within 3 months postoperatively (RR 1.73 [95% CI 1.03-2.90]).

Multilevel Lumbar or Thoracolumbar Surgery: Increased BMI Does Not Correlate With Increased Reoperation

Puvanesarajah et al[58] appraised 2293 patients with ASD with ≥8 fusion levels. At the 5-year follow-up, 424 (18.5%) patients required reoperation. Multivariate analysis did not identify an association between increased BMI and reoperation.[58] Hofler et al[59] assessed 148,081 thoracic or lumbar fusion patients. Two thousand six hundred sixty-five (1.8%) patients developed pseudarthrosis and there was no correlation between reoperation and increased BMI.[59] There were no thoracic or >2 region articles that noted a positive correlation between increased BMI and reoperation.

Cervical: Increased BMI Does Not Correlate With an Increased Risk of Reoperation
Bovonratwet et al[60] evaluated 37,261 patients who had undergone anterior cervical decompression and fusion, reporting an incidence of 0.40% for hematoma requiring reoperation. In this group, there was no correlation between reoperation and increased BMI.[60] Narain et al[61] retrospectively reviewed primary 1- to 2-level anterior cervical decompression and fusion for degenerative cervical disease. Patients were stratified by BMI: normal weight (<25.0 kg/m^2), overweight (25.0-29.9 kg/m^2), obese I (30.0-34.9 kg/m^2), or obese II-III (≥35.0 kg/m^2). No association with reoperation was identified.[61] Hofler et al[59] further assessed 107,420 cervical fusion patients with 1295 (1.2%) patients undergoing reoperation for pseudarthrosis. There was no correlation between reoperation and increased BMI.[59] Overall, there were no cervical articles that noted a positive correlation between increased BMI and reoperation.

Question:
Is preoperative smoking associated with increased risk of reoperation in patients undergoing spinal fusion surgery? Does preoperative smoking cessation decrease risk of reoperation?
Recommendations:
Individuals undergoing spinal fusion surgery who are active smokers should be counseled regarding the increased risk of reoperation.
Strength of Recommendation: Grade B

There is insufficient evidence that cessation of smoking before spine surgery decreases the risk of reoperation, but it is suggested that patients be counseled to abstain from smoking before and after spinal fusion surgery
Strength of Recommendation: Grade Insufficient

In total, there are 8 studies included in the analysis of the effect of smoking on reoperation for patients undergoing spinal fusion surgery. Six studies showed a positive correlation between smoking and reoperation with all 6 being Class II evidence. The literature for cervical spinal fusion demonstrated a consistent association between smoking and reoperation (4 Class II articles).[43,59,62,63]

Hofler et al[59] reviewed the Healthcare Cost and Utilization Project State Inpatient Databases in New York, California, Florida, and Washington for adult patients who had undergone new spinal fusion from 2009 to 2011 to define factors that correlated with pseudarthrosis. Of 107,420 cervical surgery patients, 1295 (1.2%) developed pseudarthrosis. In cervical spine surgery patients, smoking had a significant relationship with the development of a pseudarthrosis (P = .01).[59] Lee et al[63] performed a retrospective analysis of 1358 cervical spine patients and 94 had a reoperation for adjacent segment pathology. Smoking was associated with an increased risk of reoperation by a factor of 1.75 times (95% CI 1.15-2.67).[63] An addition cervical analysis of 1038 primary surgeries noted higher rates of adjacent level pathology in tobacco users.[62] Lee et al[62] reviewed 1038 anterior cervical diskectomy infusion patients that developed adjacent level disease and noted that smoking was in independent risk factors for reoperation.

Gerling et al[48] performed a subanalysis of patients undergoing lumbar fusion from a multicenter randomized controlled trial for lumbar spondylolisthesis. Multivariate analysis identified no correlation between smoking and reoperation at 8 years of follow-up. Hofler et al[59] analyzed 148,081 thoracic and lumbar surgeries of which 2665 (1.8%) developed pseudarthrosis. In the thoracolumbar group (P < .001), smoking history demonstrated a significant relationship with pseudarthrosis.[59] Macki et al[64] reviewed 110 instrumented lumbar fusions and bone morphogenetic protein usage and noted that the tobacco users had a 32% risk of reoperation for pseudoarthrosis, which was significantly greater than nonsmokers (P = .027). However, this effect on reoperation also extended to the nonfusion population. Bydon et al[65] reported 500 patients who had undergone primary laminectomy and noted on a multiple logistic regression analysis that tobacco was an independent predictor for reoperation in single level (OR 11.3, P = .02) and multilevel laminectomy (OR 1.98, P = .05).

There were 2 studies that assessed the relationship between smoking and reoperation in patients with adult spinal deformity. Puvanesarajah et al[58] reported in a multivariate analysis of 2293 patients an association between history of smoking and increased risk of reoperation (OR 1.37). De la Garza Ramos et al,[66] in a series of 1368 patients with adult spinal deformity, also noted a higher reoperation rate among smokers, but this was not statistically significant as well as Grade III.

One study analyzed patients requiring reoperation for SSI after spine surgery. Macki et al[67] reviewed 209 instrumented lumbar fusions and tobacco use was the highest predictor of reoperation for SSI (OR 5.75, P = .007).

The literature search did not identify any studies that specifically addressed the question of preoperative smoking cessation and risk of reoperation and that met inclusion and exclusion criteria.

Future Research

This review shows that there are numerous gaps in our knowledge about perioperative spine care. Future research should be focused on how to optimize patients for pending spinal surgical treatments. Specifically, optimal preoperative goals to maximize postoperative outcomes in terms of preoperative weight loss, smoking cessation, and diabetic blood sugar control are

needed. In addition, an analysis of timing to initiate these strategies and duration of optimization would enhance patient care.

Conclusions

There remains significant work for preoperative optimization of spine patients. Particularly, defining target goals that patients should meet to reduce perioperative risk and timing of these interventions are needed. There is evidence, however, that patients with preoperative HbA_{1c} level >7.5 mg/dL have an increased risk of postoperative infection and reoperation after spine surgery. Therefore, individuals with diabetes who are undergoing elective degenerative spine surgery should undergo preoperative HbA_{1c} testing before surgery and be counseled regarding the increased risk of reoperation or infection if the level is >7.5 mg/dL (Grade B). There is conflicting evidence regarding increased BMI and SSI rate. Given the preponderance of studies demonstrating a correlation between BMI >30 kg/m^2 and increased SSI, it is suggested that patients with elevated BMI should be appropriately preoperatively risk assessed. Finally, preoperative smoking correlates with an increased risk of reoperation in patients undergoing spinal fusion surgery. Preoperative counseling will benefit patients to understand these associated risk factors and care should be directed toward reducing these variables.

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.

Author	Disclosure
Marjorie Wang, MD	Zimmer Biomet, Medtronic Abbott ABNS, AANS JNS Spine Editorial Board
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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 do 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.[1]

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.

[1]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 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

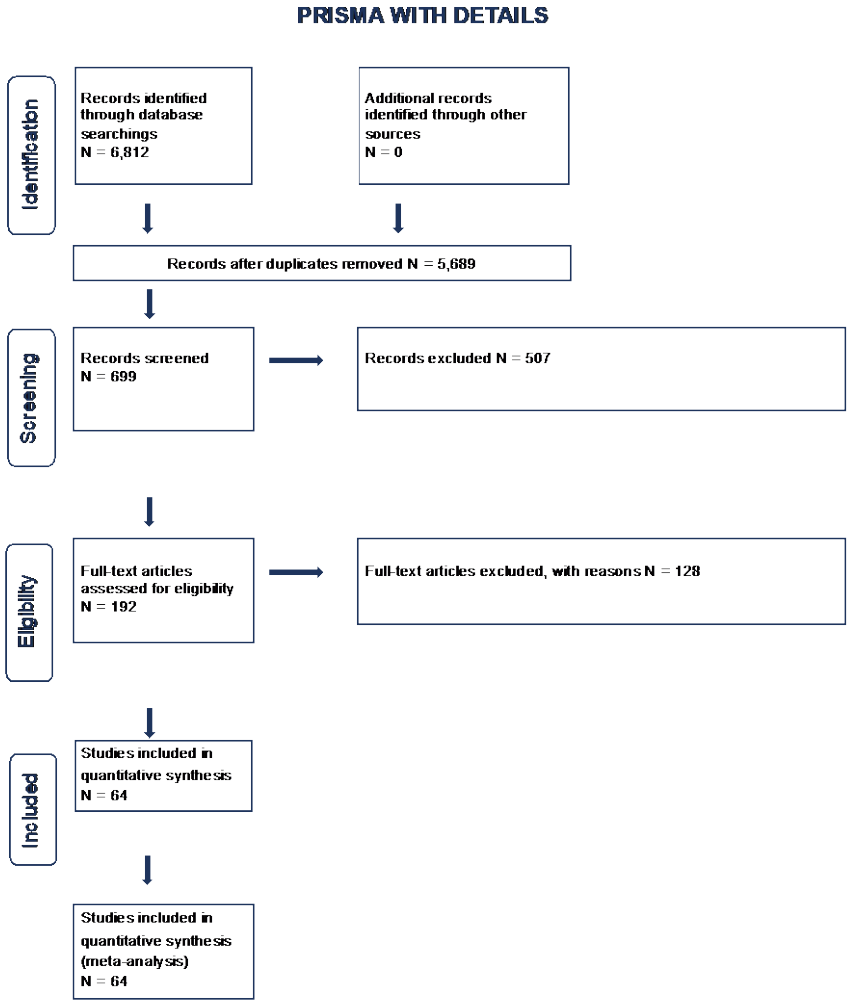
RCT, randomized controlled trial.
[a]A complete assessment of quality of individual studies requires critical appraisal of all aspects of the study design.
[b]A combination of results from ≥2 previous studies.
[c]Studies provided consistent results.
[d]Study was started before the first patient enrolled.
[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



This flow chart will, where appropriate, also document articles not identified by literature searches but, rather, were supplied by Guideline Committee members.

Supplemental Digital Content 6. Evidence table

PICO Question	Author, Year	Type of Evidence	Study Type	Level of Evidence	Reviewer's Conclusions
1	Cancienne et al., 2017[8]	Prognostic	Retrospective case series	III	The study used preoperative HbA_{1c} levels in patients with diabetes in 3341 anterior cervical diskectomy and fusion patients requiring reoperation. In the series, a significant relationship was observed between increased HbA_{1c} level and reoperation rate (*P* = .005), where a subanalysis determined the inflection point in the area under the curve of 7.5 mg/dL with a sensitivity of 46% and specificity of 68%
1	Cancienne et al., 2017[6]	Diagnostic	Retrospective case series	II	The study looked at HbA_{1c} on 5194 single-level lumbar decompressions and patients with diabetes. The inflection point for infection by HbA_{1c} level was >7.5 mg/dL (*P* = .01, specificity 70%, sensitivity 53%). In a subanalysis controlled for patient demographics and medical comorbidities, the authors reported that HbA_{1c} level >7.5 mg/dL correlated with a higher risk for deep SSI (OR 2.9 [95% CI 1.8-4.9], *P* < .0001)
1	Caputo et al., 2013[9]	Prognostic	Retrospective case series	II	The study analyzed 3138 patients (2005-2010) and illustrated

					that patients with diabetes had an increased risk for SSI (6.4% vs 3.2%)
1	Hikata et al., 2014[7]	Prognostic	Retrospective case series	II	Study supports HbA_{1c} as a preoperative laboratory test to define risks of SSI. Patients with diabetes whose blood glucose levels were poorly controlled before surgery were at high risk for SSI. To prevent SSI in patients with diabetes, we recommend lowering the HbA_{1c} to <7.0% before performing surgery
1	Koutsoumbelis et al., 2011[10]	Prognostic	Retrospective case control	II	Negates PICO questions 1. Review of 3218 patients who underwent posterior lumbar instrumented arthrodesis noted no correlation of preoperative blood glucose levels to SSI
2	Adogwa et al., 2016[26]	Prognostic	Retrospective case series	II	Study finds no difference between obese and nonobese in terms of wound infection
2	Beack et al., 2019[56]	Prognostic	Retrospective case series	II	BMI >30 kg/m^2 was considered obese and was significantly related with herniated lumbar disc revision ($P < .05$). Obese patients were at 1.2-times higher risk for revision than were nonobese patients (OR 1.20 [95% CI 1.06-1.37]). Patients with high BMI or severe disc degeneration should be

					informed of herniated lumbar disc revision
2	Bohl et al., 2016[55]	Prognostic	Retrospective Case Series	II	Study found high BMI is an independent risk factor for revision procedure after lumbar decompression
2	Boston et al., 2009[38]	Prognostic	Retrospective case series	III	The presence of comorbidities and increased surgical duration are risks for postoperative infection. However, increased infection did not correlate with increased revision or reoperation rate
2	Bovonratwet et al., 2019[60]	Prognostic	Retrospective case series	II	Study shows low BMI correlated with reoperation
2	Buerba et al., 2014[45]	Prognostic	Retrospective case series	II	The study negates high BMI, regardless of obesity class, does not appear to be associated with increased complications after cervical fusion in the 30-day postoperative period. No difference in the incidence of wound complications or rate of return to the OR in obese patients compared with nonobese
2	Buerba et al., 2014[18]	Prognostic	Retrospective case series	II	The study affirms high BMI correlates with SSI. Reviewed 10,387 patients in the ACS NSQIP database and reported increased BMI correlated with a significantly increased

					risk of wound complications
2	Chin et al., 2017[36]	Prognostic	Retrospective case series	III	Reported on 1010 patients, 642 in a hospital setting and 368 in an outpatient setting, where increased BMI >30 kg/m^2 was associated with a significant increase in SSI (P = .005; RR 9.3). Modifiable risk factors for SSI are smoking and BMI, in addition to the number of levels necessary for operation. BMI >30 kg/m^2 had a RR of 9.3 (95% CI 2.65-32.41), P = .005 for SSI. High degree of variance/heterogeneity of treatment and patient population. Variables not defined (e.g., failure to use validated outcomes)
2	De la Garza-Ramos et al., 2016[66]	Prognostic	Retrospective case series	II	The study retrospectively reviewed 732 lumbar fusion patients 662 (90.44%) nonobese and 70 (9.56%) obese and showed that increased BMI was associated with increased risk of postoperative SSI (RR 3.11 [95% CI 1.48-6.52]). BMI is a risk factor for SSI for lumbar surgery
2	De la Garza-Ramos et al., 2015[14]	Prognostic	Retrospective case control	II	This study affirms for SSI but negates for wound dehiscence

2	Ee et al., 2014[24]	Prognostic	Retrospective case series	III	The study finds BMI (OR 1.2 [95% CI 1.0-1.3]; *P* = .010) were predictive of an increased risk in SSI
2	Elsamadicy et al., 2016[34]	Prognostic	Retrospective case series	II	The study looked at 500 patients (281 nonobese and 219 obese) undergoing elective spine surgery and reported an association between increased BMI and increased risk for deep SSI (*P* = .04)
2	Elsamadicy et al., 2019[41]	Prognostic	Retrospective case series	II	Study negates PICO 2. A review of 112 ASD patients (BMI >30 kg/m^2) undergoing elective complex spinal fusion (>7 levels) for deformity correction and found no correlation with increased BMI and SSI
2	Fakouri et al., 2015[30]	Prognostic	Retrospective case series	II	Study reported a smaller series of patients undergoing MIS lumbar discectomy (34 obese and 30 nonobese) performed over 3 years. Obese patients had 2 superficial infections, but this was not significant in this small series
2	Fanous et al., 2019[39]	Prognostic	Retrospective case series	II	This study negates PICO 2. There was no association of BMI with SSI. 532 thoracolumbar scoliotic deformity patients with 20 (4%) experiencing SSI. Diabetes mellitus is the only demographic risk factor associated with

					risk of SSI. No association with BMI
2	Gaudelli et al., 2012[57]	Prognostic	Retrospective case series	III	This study affirms that obese (BMI >35 kg/m^2) had higher risk for reoperation. Downgraded because of limited methodology details and heterogeneity. 101 subjects (3%) required reoperation in the 3 months after elective lumbar spine surgery. The obese group had a statistically significant higher reoperation rate compared with the non-obese group (4.8% vs 2.8%). This corresponds to RR of 1.73 (95% CI 1.03-2.90)
2	Gerling et al., 2017[48]	Prognostic	Retrospective case series	II	This study negates PICO 2 in that there was no association with reoperation and BMI for degenerative spondylolisthesis patients. The incidence of reoperation for degenerative spondylolisthesis patients was 22% at 8 years after surgery. Patients with a history of no neurogenic claudication and patients taking antidepressants were more likely to undergo reoperation. Patients who were smokers, diabetics, obese, or on worker's compensation

					were not at greater risk for reoperation
2	Glassman et al., 2017[20]	Prognostic	Retrospective case control	III	This study affirms PICO 2 that there is an association between BMI and SSI. Control matched study of 94 diabetics (51 NIDDM, 43 IDDM) and 43 controls matched for age, sex, and lumbar fusion procedure. There was a correlation of increased BMI and SSI
2	Goldin et al., 2015[29]	Prognostic	Retrospective case series	III	This study negates PICO 2 and was downgraded because of heterogeneity, inclusion population is not well defined, and the procedures are not identified. The study has no statistically significant difference in SSIs
2	Hofler et al., 2018[59]	Prognostic	Retrospective case series	II	The study negates PICO 3. 107,420 cervical fusion patients where 1295 (1.2%) developed pseudoarthrosis requiring reoperation. On multivariable analysis, no association with obesity. For thoracic or lumbar fusion, 2665 (1.8%) developed pseudoarthrosis and no association with BMI
2	Ilyas et al., 2019[21]	Prognostic	Retrospective case series	II	This study affirms PICO 2. BMI morbid obesity (OR 6.99 [95% CI 2.65-

					22.03], $P < .001$) was associated with SSI
2	Jain et al., 2018[12]	Prognostic	Retrospective case control	III	The study affirms evaluating and intervention not a risk factor and was downgraded because of heterogeneous population
2	Jalai et al., 2016[42]	Prognostic	Retrospective case control	II	The study affirms PICO 2 that obesity is associated with higher rates of SSI. SSI rate was 1.15%, and high BMI was a predictor of infection in the surgical cervical spondylitis myelopathy
2	Kara et al., 2005[53]	Prognostic	Prospective case series	II	Study negates PICO, it found that high BMI was not a risk factors for reoperation after lumbar disc surgery. The logistic regression analysis demonstrated that the lack of regular physical exercise was the only a significant predictor (OR 4.595 [95% CI 1.38-15.28]), whereas gender, age, BMI, occupation, or smoking did not
2	Khan et al., 2019[50]	Prognostic	Retrospective case series	II	Study negates PICO 2 since found no difference among the groups in terms of BMI and SSI. Retrospective review of 569 obese and nonobese patients following open PLSF found no correlation with obesity and infection or reoperation
2	Klemencsics et al., 2016[23]	Prognostic	Retrospective case control	II	Affirms PICO 2, 1030 lumbar spine

					degenerative patients where a higher BMI predisposed patients to increased risk for SSI
2	Koutsoumbelis et al., 2011[10]	Prognostic	Retrospective case series	II	Affirms PICO 2. Review of 3218 patients who underwent posterior lumbar instrumented arthrodesis noted obesity and a history of chronic obstructive pulmonary disease were the strongest risk factors for postoperative spinal infection after adjusting for all other variables
2	Kurtz et al., 2012[16]	Prognostic	Retrospective case series	II	The study affirms PICO question 2. The study reviewed 15,069 patients with primary fusion procedures and 605 with revision of instrumented lumbar fusion. Noted a predictor of 10-year infection risk included diagnosis of obesity ($P < .001$)
2	Leven et al., 2015[49]	Prognostic	Retrospective case series	II	This study negates PICO 2 and notes no association of obesity with reoperation for lumbar discectomy
2	Li et al., 2019[15]	Prognostic	Retrospective case series	II	Study affirms PICO 2, 448 lumbar degenerative disease treated with open transforaminal lumbar interbody fusion. SSI group vs non-SSI group univariate and multiple logistic regression analyses noted BMI ($P < .001$) as an independent risk factor

2	Lieber et al., 2016[19]	Prognostic	Retrospective case control case series	III	This study was downgraded because of heterogeneity of population and Affirms PICO 2. 1110 of the 60,179 patients (1.84%) had SSIs. BMI >30 kg/m^2 was an independent predictor of infection
2	Maragakis et al., 2009[25]	Prognostic	Retrospective case control	III	This study affirms PICO question 2. 104 patients with SSI after spinal surgery were compared with 104 randomly selected control patients. Obesity (OR 4.0 [95% CI 1.6-10]; $P < .01$) was an independent risk factor for SSI
2	Mehta et al., 2012[11]	Prognostic	Retrospective case series	II	This study affirms PICO Question 2. Obesity (BMI ≥30) ($P = .025$) were found to be significant risk factors for SSI
2	Narain et al., 2018[47]	Prognostic	Retrospective case series	II	Study negates PICO 2. 274 single-level MIS TLIF for degenerative pathology. BMI category was not associated with undergoing a revision procedure
2	Narain et al., 2018[61]	Prognostic	Retrospective case series	II	Study negates PICO 2 and notes no association between higher BMI and incidence of reoperation in 1- to 2-level ACDF for degenerative spinal pathology. Higher BMI demonstrated surgical outcomes, narcotics consumption, and hospital costs

					comparable to those of patients with a lower BMI with no association with SSI
2	Owens et al., 2016[51]	Prognostic	Retrospective case control	III	The study negates PICO 2. Three comparison groups, 1 with BM) ≥20-25 kg/m^2 (normal), another with ≥25-<30 kg/m^2 (overweight), and another with ≥30-40 kg/m^2 (obese) were created using propensity matching. Revision rates were not different in groups (14 vs 15 vs 13, *P* = .917)
2	Pahys et al., 2013[43]	Prognostic	Retrospective case control case series	II	Affirms PICO questions 2, authors reviewed 1001 posterior cervical spine procedures and correlated body mass index of ≥30 kg/m^2 (*P* = .005; OR 4.1 [95% CI 1.5-7.7]) to SSI
2	Pereira et al., 2014[28]	Prognostic	Retrospective case series	III	Negates PICO 2, and was downgraded because of failure to define dependent and independent variables. BMI was not a complicating factor for the outcome of patients undergoing surgery for degenerative lumbar spine disorders in terms of SSI, surgical complications, and reoperation rates
2	Pull ter Gunne et al., 2010[37]	Prognostic	Retrospective case series	III	Study affirms PICO 2. Large cohort of deformity patients retrospective review noted increased BMI was an independent risk factor for all SSI (*P* =

					.014 and $P = .013$). The study was downgraded because of heterogeneity and high degree of variance
2	Puvanesarajah et al., 2016[58]	Prognostic	Retrospective case control	III	This study affirms regarding SSI and increased BMI. Wound infection (OR 3.71; $P < .0001$ and OR 2.22; $P < .0001$) and dehiscence (OR 3.80; $P < .0001$ and OR 2.59; $P < .0001$) rates were increased in morbidly obese and obese patients, respectively
2	Puvanesarajah et al., 2017[17]	Prognostic	Retrospective case series	II	This study affirms regarding reoperation and its association to increased BMI. Obesity had an independent risk odds ratio 1.32 (95% CI 1.01-1.72), $P = .038$ for reoperation and wound infection (OR 3.7)
2	Ranson et al., 2018[22]	Prognostic	Retrospective case series	II	This study affirms and showed BMI >1 standard deviation above the mean in the morbidly obese group was associated with a 2 times increased risk of reoperation and over a 1.5 times increased risk of unplanned readmission following PLF compared with morbid obesity
2	Rihn et al., 2012[54]	Prognostic	Retrospective case series	II	This study affirms that obese patients had higher rates of infection and reoperation an obesity subgroup analysis

2	Rodgers et al., 2010[27]	Prognostic	Retrospective case series	II	Study negates and finds no difference among groups in terms of BMI and infection or reoperation rate
2	Salvetti et al., 2018[40]	Prognostic	Retrospective case control	III	The study negates PICO question 2. In review of 387 thoracic deformity patients there was no association between SSI and obesity
2	Sebastian et al., 2016[44]	Prognostic	Retrospective case series	II	The study affirms PICO questions 2. In review of 5441 posterior cervical patients it was noted that obese patients should be counseled on elevated SSI risk. The review noted that BMI >35 kg/m^2 was independent risk for SSI
2	Shamji et al., 2009[35]	Prognostic	Retrospective case series	II	This study did not show statistically significant results
2	Sing et al., 2016[33]	Prognostic	Retrospective case series	II	This study affirms PICO 2. Obesity is an independent risk factor for early complications after revision spine surgery
2	Soroceanu et al., 2015[31]	Prognostic	Retrospective case series	II	This study affirms PICO 2. Review of 175 nonobese and 66 obese patients. Regression models showed that obese patients had a higher overall incidence of major complications (IRR 1.54, P = .02) and wound infections (OR 4.88, P = .02)
2	Srinivasan et al., 2014[46]	Prognostic	Retrospective case series	II	This study negates PICO 2. Study analyzed 69 patients BMI >30 kg/m^2 who underwent anterior cervical fusion

					surgery. There was no association with increased BMI in SSI or reoperations
2	Wadhwa et al., 2017[52]	Prognostic	Retrospective case series	II	This study negates, BMI was not associated with reoperations within 30 days in lumbar spine surgery
2	Wang et al., 2017[13]	Prognostic	Retrospective case series	II	The study negates and finds there is no association between BMI and risk of infection
2	Zhang et al., 2018[32]	Prognostic	Retrospective case series	II	The study affirms 153 adult deformity surgeries that underwent long level spinal fusion with 2-year follow-up noted. Wound infections (OR 4.88, $P = .02$) were caused by the obesity
3	Boston et al., 2009[38]	Prognostic	Retrospective case series	III	Study finds the presence of comorbidities and increased surgical duration are risks for postoperative infection. However, increased infection did not correlate with increased revision or reoperation rate
3	Bydon et al., 2015[65]	Prognostic	Retrospective case control	II	500 primary laminectomy patients were noted on a multiple logistic regression analysis that tobacco was an independent predictor for reoperation in single level (OR 11.3, $P = .02$) and multilevel laminectomy (OR 1.98, $P = .05$)
3	Chin et al., 2017[36]	Prognostic	Retrospective case control	III	This study reviewed 2205 spine patients that

					developed SSIs and noted smoking to have the highest relative risk (10.9) for reoperation. The level of evidence was downgraded because of the high degree of variance or heterogeneity in the patient population
3	De La Garza Ramos et al., 2017[66]	Prognostic	Retrospective case series	III	1368 patients with adult spinal deformity were included in this study that noted a higher reoperation rate among smokers, but this was not statistically significant. The level of evidence was downgraded because of the high degree of variance or heterogeneity in the patient population
3	Gerling et al., 2017[48]	Prognostic	Retrospective case series	II	This study negates PICO 3 in that there was no association with reoperation and BMI for patients with degenerative spondylolisthesis. The incidence of reoperation for patients with degenerative spondylolisthesis was 22% at 8 years after surgery. Patients with a history of no neurogenic claudication and patients taking antidepressants were more likely to undergo reoperation. Patients who were smokers, diabetics, obese, or on worker's compensation

					were not at greater risk for reoperation
3	Hofler et al., 2018[59]	Prognostic	Retrospective case series	II	The study affirms PICO 3. 107,420 cervical fusion patients where 1295 (1.2%) developed pseudoarthrosis requiring reoperation. On multivariable analysis, smoking was a risk factor (OR 1.19 [95% CI 1.05-1.34]). For thoracic or lumbar fusion, 2665 (1.8%) developed pseudoarthrosis and again smoking was a risk factor (OR 1.22 [95% CI 1.12-1.33])
3	Lee et al., 2015[62]	Prognostic	Retrospective case series	II	This study affirms and evaluates reoperation rate and its association with RF of smoking. The Kaplan-Meier analysis predicted that 22.2% of patients would need reoperation at adjacent segments by 10 years postoperatively and smoking was associated with increased risk
3	Lee et al., 2014[63]	Prognostic	Retrospective case series	II	This study affirms PICO 3. 1038 consecutive patients who underwent primary anterior cervical spine arthrodesis for radiculopathy and/or myelopathy Smokers had a higher chance of clinical adjacent-

					segment pathology after cervical spine surgery
3	Macki et al., 2017[67]	Prognostic	Retrospective case series	II	Affirms PICO 3 that smoking is an independent risk factor for reoperation. In review of 209 instrumented PLF patients a logistical regression model that predicted reoperation for SSI among all patients after instrumented posterolateral fusion had a OR 5.41 and highest factor of those analyzed
3	Macki et al., 2017[64]	Prognostic	Retrospective case series	II	Logistic regression analysis of 110 patients showed that smoking is a risk factor for SSI
3	Maragakis et al., 2009[25]	Prognostic	Retrospective case control	III	This study negates PICO question 3. Smoking did not correlate with SSI
3	Puvanesarajah et al., 2017[17]	Prognostic	Retrospective case series	II	This study affirms regarding reoperation and its association smoking. Positive smoking usage had an independent risk OR 1.37 (95% CI 1.10-1.70), $P = .005$
3	Salvetti et al., 2018[40]	Prognostic	Retrospective case control	III	In review of 387 thoracic deformity patients, this study negates PICO question 3, there was no association between SSI and obesity
3	Sebastian et al., 2016[44]	Prognostic	Retrospective case series	II	The study affirms, in a review of 5441 posterior cervical patients there was no noted association between tobacco and reoperation

ACDF, anterior cervical decompression and fusion; ACS NSQIP, American College of Surgeons National Surgical Quality Improvement Program; BMI, body mass index; CI, confidence interval; HbA_{1c}, hemoglobin A1C; MIS, minimally invasive surgery; OR, odds ratio; PICO, patient/population, intervention, comparison, and outcomes; PLF, posterior lumbar fusion; PLSF, posterior lumbar spine fusion; SSI, surgical site infection.