A systematic review of clinical and surgical predictors of complications following surgery for degenerative cervical myelopathy

Lindsay Tetreault, BSc,¹ Ahmed Ibrahim, MD, FRCS, PhD,¹ Pierre Côté DC, PhD,²
Anoushka Singh, PhD,¹ and Michael G. Fehlings, MD, PhD, FRCSC¹

¹Toronto Western Hospital, University Health Network; and ²University of Ontario Institute of Technology (UOIT), UOIT-CMCC Centre for the Study of Disability Prevention and Rehabilitation, Toronto, Ontario, Canada

OBJECTIVE Although generally safe and effective, surgery for the treatment of cervical spondylotic myelopathy (CSM) is associated with complications in 11%–38% of patients. Several predictors of postoperative complications have been proposed but few are used to detect high-risk patients. A standard approach to identifying “at-risk” patients would improve surgeons’ ability to prevent and manage these complications. The authors aimed to compare the complication rates between various surgical procedures used to treat CSM and to identify patient-specific, clinical, imaging, and surgical predictors of complications.

METHODS The authors conducted a systematic review of the literature and searched MEDLINE, MEDLINE in Process, EMBASE, and Cochrane Central Register of Controlled Trials from 1948 to September 2013. Cohort studies designed to evaluate predictors of complications and intervention studies conducted to compare different surgical approaches were included. Each article was critically appraised independently by 2 reviewers, and the evidence was synthesized according to the principles outlined by the Grading of Recommendation Assessment, Development and Evaluation (GRADE) Working Group.

RESULTS A total of 5472 citations were retrieved. Of those, 60 studies met the inclusion criteria and were included in the review. These studies included 36 prognostic cohort studies and 28 comparative intervention studies. High evidence suggests that older patients are at a greater risk of perioperative complications. Based on low evidence, other clinical factors such as body mass index, smoking status, duration of symptoms, and baseline severity score, are not predictive of complications. With respect to surgical factors, low to moderate evidence suggests that estimated blood loss, surgical approach, and number of levels do not affect rates of complications. A longer operative duration (moderate evidence), however, is predictive of perioperative complications and a 2-stage surgery is related to an increased risk of major complications (high evidence). In terms of surgical techniques, higher rates of neck pain were found in patients undergoing laminoplasty compared with anterior spinal fusion (moderate evidence). In addition, with respect to laminoplasty techniques, there was a lower incidence of C-5 palsy in laminoplasty with concurrent foraminotomy compared with non-foraminotomy (low evidence).

CONCLUSIONS The current review suggests that older patients are at a higher risk of perioperative complications. A longer operative duration and a 2-stage surgery both reflect increased case complexity and can indirectly predict perioperative complications.

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KEY WORDS cervical spondylotic myelopathy; systematic review; surgery; complications; degenerative

CERVICAL spondylotic myelopathy (CSM) is a progressive degenerative spine disease and the most common cause of spinal cord dysfunction in adults worldwide.^{33,65} Although generally safe and effective, surgery for the treatment of CSM is associated with compli-

cations in 11%–38% of patients.^{6,15} These include dysphagia, C-5 radiculopathy, wound infection, axial pain, and postoperative kyphosis.

Guidelines for the surgical management of CSM are rapidly evolving, and surgeons must consider several vari-

ABBREVIATIONS ACDF = anterior cervical discectomy and fusion; ADF = anterior decompression and fusion; BMI = body mass index; CDH = cervical disc herniation; CSM = cervical spondylotic myelopathy; EOLP = expansive open-door laminoplasty; GRADE = Grades of Recommendation Assessment, Development and Evaluation; ICD = International Classification of Disease; JOA = Japanese Orthopaedic Association; KQ = key question; OPLL = ossification of the posterior longitudinal ligament; PCB = plate cage Benezech.

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ables when selecting a surgical approach.⁶⁹ These include comorbidities, pathology, clinical presentation, level of stenosis, cervical sagittal alignment, presence of axial neck pain, and familiarity with the technique.⁴⁶ In addition, the safety of the procedure and risks of complications also inform the surgical decision-making process. Historically, posterior laminectomy was considered to be the gold standard and treatment choice for CSM; however, the risk of surgery-related complications including postoperative kyphosis, segmental instability, and progression of myelopathy has promoted the addition of fusion to simple laminectomy. Unfortunately, fusion does affect the biomechanics of the cervical spine and can lead to decreased mobility, neck stiffness, and adjacent segment degeneration. Laminoplasty was later developed to enlarge the spinal canal while preserving neck motion and spinal curvature. However, this technique is contraindicated in patients with neutral or kyphotic alignment and can lead to worsening or persistence of preexisting neck pain. The anterior approach, on the other hand, has recently grown in popularity and is becoming the preferred method of decompression for the majority of CSM cases.

Although the rate of complications associated with surgery are well documented, we lack comparative measures of complication rates between surgical approaches and techniques. This knowledge gap is important as this information can help surgeons balance the risks and benefits of each procedure. Furthermore, several variables may be predictive of postoperative complications, including specific patient characteristics, imaging parameters, and other surgical factors. By identifying these key predictors, clinicians will be better equipped to detect their high-risk patients and take appropriate preoperative and intraoperative preventative measures to optimize patient outcome.

This systematic review addresses 2 key questions (KQs). KQ1: Are there clinical, imaging, or surgical factors associated with complications during or following surgery? KQ2: Do the rates of complications differ across surgical interventions?

Methods

Eligibility Criteria

Population

Our review targeted studies of adult patients (> 18 years) with cervical myelopathy secondary to spondylosis, disc herniation, ossification of the posterior longitudinal ligament (OPLL), congenital stenosis, or subluxation. All patients were treated surgically and were followed up postoperatively. Studies were excluded if they included patients with traumatic spinal cord injury, thoracic or lumbar myelopathy, radiculopathy, tumor, or infection. Furthermore, studies were excluded if patients were undergoing revision surgery (Table 1).

Prognostic Factors

For KQ1, we sought studies that evaluated various predictors of complications including clinical, imaging, and surgical factors. Studies were excluded if their focus was on the predictive value of neuromonitoring or surgical materials. For KQ2, we focused on studies that compared

complication rates between different surgical approaches or techniques (Table 1).

Outcomes

Our primary outcome measure was overall postoperative complication rates or rates of specific complications such as C-5 nerve root palsy, dysphagia, infection, or instability. Studies that focused on predictors of heterotopic ossification, progression of myelopathy, or adjacent segment degeneration were excluded. Studies that defined axial pain and postoperative kyphosis as complications were included. However, those that discussed axial pain and sagittal alignment as measures of pain and radiographic outcomes, respectively, were excluded (Table 1).

Study Characteristics

For KQ1, we sought cohort studies designed to evaluate the association between complications and clinical, imaging, and surgical factors using a multivariate analysis. For the sake of thoroughness, studies that did not conduct a multivariate analysis were still summarized but were not included when rating the overall body of evidence. For KQ2, we focused on cohort or case-control studies that measured the association between surgical approach or technique and complications, while controlling for important confounders. For both KQ1 and KQ2, studies had to report p values to be included.

Information Sources

Studies were identified using 4 electronic databases: MEDLINE, MEDLINE in Process, EMBASE, and Cochrane Central Register of Controlled Trials. The last search was performed on September 23, 2013.

Search

We developed a search strategy with a librarian who specializes in neuroscience research. The strategy was first developed in MEDLINE and then appropriately modified for the other 3 databases. We used the following terms to search all databases: CSM or OPLL AND Prediction or Risk of Complications arising from Surgery or Neurosurgery. Only studies involving humans and written in English were considered for inclusion, with no other limits applied.

Study Selection

All abstracts and titles were reviewed independently in an unblinded, standardized manner by 2 of the authors (L.T., A.S.). The abstracts were sorted by our predefined inclusion criteria and were classified as relevant, possibly relevant, or irrelevant. Full text investigation of the possibly relevant studies was done for further clarification. Disagreement between reviewers was resolved through discussion.

Data Extraction and Synthesis

The following data were extracted from each included article: study design; patient sample and characteristics, including diagnosis and treatment administered; clinical,

TABLE 1. Inclusion and exclusion criteria for studies reviewed

Characteristic	Inclusion	Exclusion
Patients	Patients w/ cervical myelopathy secondary to spondylosis, disk herniation, OPLL, congenital stenosis, & subluxation (DCM); treated surgically; age >18 yrs	Patients w/ traumatic spinal cord injury, thoracic or lumbar myelopathy, tumor, infection radiculopathy or other nondegenerative myelopathy; patients undergoing revision surgery
Prognostic factors	Clinical factors: age, duration of symptoms, baseline severity score, signs, symptoms, comorbidities, smoking status, sex, BMI, diagnosis Imaging factors: signal changes on T1- or T2-WI, transverse area, AP diameter, no. of compressed segments, level of max compression, compression ratio, shape of OPLL lesion, cervical alignment, range of motion Surgical factors: surgical approach, technique, no. of operated segments, no. of stages, fusion, operative time, EBL	Different types of surgical materials (e.g., drills, grafting material), neuromonitoring
Outcome	Postop complications: nerve root palsy, axial pain, surgical, dysphagia, infection, instability, systemic	Heterotopic ossification, progression of myelopathy, ASD
Study design	KQ1: cohort studies designed to evaluate prognostic factors using multivariate analyses KQ2: cohort or case-controlled studies designed to compare complication rates between 2 surgical groups, while controlling for important confounders Must report p values or ORs	Review articles, opinions, studies w/ <15 patients, animal or biomechanical studies

AP = anteroposterior; ASD = adjacent-segment degeneration; DCM = degenerative cervical myelopathy; EBL = estimated blood loss; OR = odds ratio; T1-WI = T1-weighted MRI; T2-WI = T2-weighted MRI.

imaging, and surgical prognostic factors evaluated; primary complication outcome; and results of association, including reported odds ratios, regression coefficients, or p values.

Risk of Bias in Individual Studies

The class of evidence for each article was rated (Class I, II, III, IV) independently by 2 reviewers using criteria outlined by the Journal of Bone and Joint Surgery for prognostic (KQ1) and therapeutic (KQ2) studies and modified to encompass both methodological quality and risk of bias. Prognostic studies included in this review were all cohort studies and were assessed based on whether patients were at a similar time point in their disease/treatment, the rate of follow-up, and whether the analysis controlled for important confounders. Therapeutic studies were rated based on study design, patient selection, if the analysis included intention to treat, blinded assessment, whether cointerventions were equally applied, rates of follow-up, statistical power, and control for confounding. The level of evidence for therapeutic studies in this review was judged based on how the study was designed to compare and analyze rates of complications across surgical cohorts.

Risk of Bias Across Studies

The overall body of evidence was then assessed using a scoring system developed by the Grading of Recommendation Assessment, Development and Evaluation (GRADE) working group with recommendations from the Agency for Healthcare Research and Quality (AHRQ).¹ For KQ1, we only considered results from studies conducting a multivariate analysis.

The initial strength of the overall body of evidence was graded and classified as “high” if the majority of studies

were Class I or II and “low” if the majority of the studies were Class III or IV. The body of evidence was downgraded 1 or 2 levels if the results were inconsistent, the evidence was indirect, the effect estimates were imprecise, or if there was a non a priori statement of subgroup analyses. In contrast, the body of evidence was upgraded 1 or 2 levels if there was a large magnitude of effect or a dose-response gradient. The final rating of the body of evidence expresses our confidence in the estimate of effect and the impact of further research on this topic. An overall strength of high means we have high confidence that the evidence reflects the true effect. Further research is very unlikely to change our confidence in the estimate of effect. The overall strength of “moderate” means we have moderate confidence that the evidence reflects the true effect. Further research may change our confidence in the estimate of effect and may change the estimate. A grade of low means we have low confidence that the evidence reflects the true effect. Further research is likely to change the confidence in the estimate of effect and likely to change the estimate. Finally, a grade of “insufficient” means that evidence either is unavailable or does not permit a conclusion.

Results

Study Selection

The search yielded a total of 5472 citations. After initial review of abstracts and titles, 5259 studies did not meet our inclusion criteria. Following full text investigation, an additional 153 studies were excluded because 1) not all patients were diagnosed with degenerative cervical myelopathy, 2) p values were not provided for analyses, and/or 3) a statistical test was not used to compare complication rates or demographic differences between 2 groups.

A total of 60 studies were deemed relevant following this rigorous review process.

Study Characteristics

For KQ1, we identified 36 prognostic cohort studies discussing key clinical, imaging, or surgical predictors of complications. Of these studies, only 9 (3 prospective, 6 retrospective) conducted a multivariate analysis and controlled for potential confounding variables.^{3,13,19,21,26,34,36,37,41} Sample sizes ranged from 81 to 58,118 surgical patients, with mean ages between 57 and 64.1 years. All patients were diagnosed with some form of degenerative cervical myelopathy, with the majority presenting with either CSM or OPLL. The main outcome was postoperative complications in 4 studies,^{3,13,19,21} C-5 or upper extremity palsy in 3,^{26,34,41} major intraoperative blood loss in 1,³⁷ and axial pain in 1.³⁶ As indicated by Table 2, several clinical, imaging, and surgical predictors were evaluated in these studies. Twenty-seven additional papers reported on predictors of complications but did not use an adequate multivariate statistical analysis. The following is a summary of the primary outcomes of these studies: postoperative complications (n = 4);^{20,27,50,52} nerve root palsy (n = 8);^{7-9,12,31,42,49,53} radiculopathy (n = 3);^{24,40,67} shoulder stiffness and neck pain (n = 1);⁷⁶ instability (n = 1);²⁵ postoperative kyphosis (n = 2);^{34,64} axial pain (n = 3);^{54,55,61} pseudarthrosis (n = 1);¹⁶ graft dislodgement (n = 2);^{16,45} closure of lamina (n = 2);^{51,68} and reconstruction failure (n = 1).⁵⁶

For KQ2, a total of 28 therapeutic cohort studies (2 randomized control trials, 11 prospective, 15 retrospective) met our inclusion criteria. These studies were designed to compare the efficacy and complication rates between 2 different surgical interventions or varying techniques. Studies reported on differences between anterior and posterior approaches (n = 9);^{15,18,19,22,30,42,44,48,59} laminoplasty and laminectomy and fusion (n = 4);^{10,19,70,72} anterior decompression and Bryan disc (n = 1);¹¹ and anterior cervical discectomy and fusion (ACDF) and corpectomy (n = 2).^{47,63} In addition, 11 studies compared laminoplasty techniques or considered technical differences such as laminoplasty with and without foraminotomy or muscle preservation.^{28,29,34,38,39,43,57,58,60,66,71}

Risk of Bias

For the prognostic studies, we critically appraised 9 studies in which a multivariate analysis was conducted. Of these, 3 were considered Class II and 6 were rated Class III. The 3 Class II studies were prospective in nature, had adequate follow-up rates, and accounted for key confounding variables in their analyses. The Class III studies had moderately high risk of bias as most were retrospective cohort studies that violated ≥ 1 criteria required for a good-quality (Class II) cohort study.

For the therapeutic studies, the majority were graded Class III as they were moderate or poor-quality cohort studies. These studies were downgraded from Class II to Class III because cointerventions were not applied equally; assessment was not blinded in prospective studies; data were unreliable in retrospective studies; follow-up rates were $< 80\%$; and/or analyses did not control for

important confounders. Three studies were Class II evidence.

Results of Individual Studies

KQ1: Are There Clinical or Imaging Factors That Can Predict Perioperative Complications?

Complications

Three studies considered age and comorbidities as important clinical predictors of perioperative complications.^{3,19,21} Boakye et al. reported that patients aged 65 years or older were 2.28 (OR 2.28, 95% CI 1.74–2.98) times more likely to experience complications following spinal fusion than those aged 18 to 44 years. Furthermore, patients 85 years or older were at an even higher risk of postoperative complications (OR 5.1, 95% CI 3.08–8.35). In a study by Fehlings et al., age was considered to be an important predictor of minor and major perioperative complications (OR 1.029, 95% CI 1.002–1.057, $p = 0.035$). Similarly, Furlan et al. concluded that age was significantly associated with postoperative complications (OR 1.09, 95% CI 1.015–1.172, $p = 0.018$).

According to Boakye et al., patients with 3 or more comorbidities were twice (OR 1.98, 95% CI 1.59–2.48) as likely to experience complications following spinal fusion than healthy individuals. In an analysis by Fehlings et al., a comorbidity score was developed to encompass both number of comorbidities and severity of disease. Patients who experienced major or minor perioperative complications did not have a significantly different comorbidity score than those who did not ($p = 0.84$). In a univariate analysis by Furlan et al., there was a greater number of comorbidities, as defined by the number of International Classification of Disease (ICD)-9 codes, in the complication group compared with the noncomplication group ($p = 0.033$). In addition, the mean Charlson Comorbidity Index was higher in patients with postoperative complications, although this difference did not reach statistical significance ($p = 0.092$). In multivariate analysis, however, neither the number nor the severity of comorbidities were found to be predictive.

Cook et al. focused on the impact of diabetes on various complication categories, including dysphagia, postoperative infection, and procedural.¹³ In univariate analysis, patients with diabetes experienced a higher rate of dysphagia ($p < 0.01$), transfusion ($p = 0.01$) and cardiac ($p < 0.01$), peripheral vascular ($p = 0.01$), respiratory ($p < 0.01$), and hematoma complications ($p = 0.01$) than patients without diabetes. In addition, cardiac ($p = 0.01$) and hematoma ($p = 0.01$) complications were more prevalent in patients with uncontrolled diabetes as compared to those with controlled disease. There were no significant differences in complication rates between patients with Type I and Type II diabetes. Following adjustment for confounders, patients with diabetes were at a higher risk of cardiac complications than those without diabetes (OR 1.57, 95% CI 1.14–2.16, $p = 0.01$). In addition, patients with uncontrolled diabetes were more likely to experience cardiac complications (OR 2.82, 95% CI 1.14–7.01, $p = 0.03$), complications of hematomas (OR 5.13, 95% CI 2.16–12.17, $p < 0.01$), and postoperative infection (OR

TABLE 2. Demographics and characteristics of complication prognostic studies with multivariate analysis

Authors & Year; Design (class)	Sex, %	Mean Age (range)*	Characteristic, n	Surgery	Clinical or Imaging Factors Assessed	Surgical Factors Assessed	Complications
Boakye et al., 2008; RC (III)	M, 58.1%	NA	CSM (n = 58,115)	Spinal fusion	Age, sex, race, comorbidities	None	Neurological; pulmonary; thromboembolic, cardiac, renal, & hematoma complications; infection; hoarseness; dysphagia
Cook et al., 2008; RC (III)	M, 56.0%	NA	CSM (n = 37,732), diabetes (n = 3,432)	Spinal fusion	Diabetes (presence vs absence, Type I vs Type II, controlled vs uncontrolled)	None	CNS, respiratory, cardiac, peripheral vascular, procedural, wound & hematoma complications, CSF leak or persistent fistula, carotid or vertebral artery injury, transfusion, postop infection, hoarseness, dysphagia
Fehlings et al., 2012; PC (II)	M, 58.9%	57 (29–86)	CSM (n = 302)	Anterior (n = 176), posterior (n = 107), combined (n = 19)	Age, sex, comorbidity score, BMI, baseline severity, smoking status	Approach, no. of stages, no. of levels, spinal fusion, fusion approach, laminectomy, corpectomy, operative duration, blood loss	Minor & major periop complications, major periop complications
Furlan et al., 2011; PC (II)	M, 70.4%	57 (32–88)	CSM (n = 81)	Anterior (n = 56), posterior (n = 23), combined (n = 2)	Age, sex, duration of symptoms, comorbidities (no. & CCI)	Approach, no. of levels	Postop complications
Hasegawa et al., 2007; RC (III)	NA	NA	CSM (n = 587), OPLL (n = 143), CDH (n = 117) OLF (n = 10)	ADF (n = 424), laminoplasty (n = 345), laminectomy (n = 88)	Age, sex, baseline severity, diagnosis	Procedure, no. of levels	Postop UE palsy
Kaneyama et al., 2010; PC (II)	M, 74.0%	64.1 (NA)	CSM (n = 108), OPLL (n = 31), CDH (n = 7)	Open-door laminoplasty (n = 73), double-door laminoplasty (n = 73)	Age, sex, baseline severity, diagnosis, physical signs†, radiologic exams‡, CMAP amplitude	Surgical technique, no. of levels	C-5 palsy§
Kato et al., 2012; RC (III)	M, 78.7%	62.7 (NA)	OPLL (n = 545)	Open-door laminoplasty (n = 234), double-door laminoplasty (n = 286), other types of laminoplasty (n = 25)	Age, sex, comorbidities, size of OPLL, OPLL type, occupying ratio, C2–7 angle, high SI on T2-WI	Surgical technique, no. of levels	Major intraop blood loss (>500 g)

(continued)

TABLE 2. Demographics and characteristics of complication prognostic studies with multivariate analysis (continued)

Authors & Year; Design (class)	Sex, %	Mean Age (range)*	Characteristic, n	Surgery	Clinical or Imaging Factors Assessed	Surgical Factors Assessed	Complications
Kato et al., 2008; RC (III)	M, 69.6%	61 (38–82)	CSM (n = 135), OPLL (n = 10)	Open-door lami- noplasty	Age, sex, diag- nosis, duration of symptoms, baseline sever- ity, preop align- ment, preop ROM	Operative dura- tion, blood loss, preservation of paraspinal muscles	Axial pain††
Kimura et al., 2012; RC (III)	M, 75.3%	60 (31–84)	OPLL (n = 150)	ADF	Occupying ratio, C2–7 angle	Operative dura- tion, blood loss, no. of fused segments	Postop UE paresis**

CCI = Charlson Comorbidity Index; CDH = cervical disc herniation; CMAP = compound muscle action potential; NA = not available; OLF = ossification of the ligamen-
tum flavum; PC = prospective cohort; RC = retrospective cohort; ROM = range of motion; SI = signal intensity; UE = upper-extremity.

* Age in years.

† Included muscle strength of deltoid and biceps, muscle stretch reflex of deltoid and biceps tendon, and neurologic impediment level of myelopathy.

‡ Included cervical alignment, number of compressed segments, position of the superior articular process, cord inclination, and high-intensity area on T2-weighted image.

§ Deterioration of bicep and deltoid muscle strength by at least 1 level in a standard muscle manual test without any deterioration of other neurological symptoms.

†† New development or progression of axial pain at 6 months to 2 years after surgery.

** Deterioration of upper-extremity function.

7.46, 95% CI 1.33–41.79, $p = 0.02$) as compared to patients with controlled diabetes.

Other clinical predictors such as sex, duration of symptoms, baseline severity score, smoking status, or body mass index (BMI) were not found to be significantly associated with postoperative complications in either univariate or multivariate analysis (Table 3).^{3,19,21}

Upper Extremity or C-5 Palsy

Hasegawa et al., Kaneyama et al., and Kimura et al. explored various clinical and imaging risk factors of upper extremity palsy following surgical decompression.^{26,34,41} The sample used in the studies by Hasegawa et al. and Kaneyama et al. consisted of surgical patients with various forms of degenerative cervical myelopathy, including CSM, OPLL, and cervical disc herniation (CDH). Both studies found that patients with OPLL as the primary diagnosis were at a markedly higher risk of experiencing upper extremity palsy than those with other forms of degenerative myelopathy (Hasegawa et al., OR 19.0, $p < 0.0001$; Kaneyama et al., OR 43.8, $p < 0.05$). In the study by Hasegawa et al., although older age was found to be a significant predictor of upper extremity palsy in univariate analysis (OR 0.1, $p < 0.05$), it was not significant in multivariate analysis (OR 2.59, $p = 0.108$). Age was also found to be an insignificant predictor of C-5 palsy in the study by Kaneyama et al.

Kimura et al. conducted a study on 150 OPLL patients to determine the risk factors for neurological complications occurring within 2 weeks of anterior decompression and fusion (ADF). High occupying ratio was the only significant clinical or imaging predictor of postoperative upper extremity paresis (OR 1.047, $p = 0.040$). Age was not considered in this analysis.

Sex, baseline severity score, and various clinical signs were not significant clinical predictors of upper extremity palsy.^{26,34} Several imaging factors were also not related to

postoperative palsy development, including cervical alignment, number of compressed segments, position of superior articular process, cord inclination, signal change on T2-weighted MRI, and mid-C-2 to mid-C-7 angle.^{34,41}

Major Blood Loss

A single study by Kato et al. examined important clinical and imaging predictors of major intraoperative blood loss during laminoplasty in patients with OPLL.³⁷ When comparing a group of patients with > 500 mL blood loss to a group with ≤ 500 mL, there were no significant differences with respect to age, sex, size, or type of OPLL (continuous, segmental, mixed, or local), C2–7 alignment, or high signal intensity on T2-weighted MRI. The occupying ratio, however, was significantly higher ($48.3\% \pm 13.4\%$) in the major blood loss group as compared to the control group ($42.7\% \pm 13.2\%$, $p = 0.02$). Furthermore, an occupying ratio of 60% or greater was the only significant risk factor following stepwise multivariate, logistic regression (OR 2.94, 95% CI 1.1–5.3, $p = 0.03$).

Axial Pain

Kato et al. defined postoperative axial pain as pain from the nuchal to scapular region developing or progressing between 6 months and 2 years postoperatively.³⁶ Following multivariate analysis, older age was the only significant predictor of axial pain (> 63 , OR 0.17, 95% CI 0.04–0.72, $p > 0.05$). Sex, diagnosis, duration of symptoms, baseline severity score, preoperative alignment, and range of motion were not significant risk factors.

KQ1: Are There Surgical Factors That Can Predict Complication Development?

Complications

Two studies assessed the value of various surgical factors as predictors of complications.^{19,21} Based on univari-

TABLE 3. Important clinical, imaging, and surgical predictors of perioperative complications, including nerve root palsy, axial pain, and major intraoperative blood loss*

Authors & Year	Level of Evidence†	Parameters for Univariate Analysis	Multivariate Analysis (clinical/imaging factors)	Multivariate Analysis (surgical factors)
Boakye et al., 2008	Pres/ab of complications	Age: $p < 0.0001$; comorbidities: $p < 0.0001$; sex: $p = 0.60$; race: $p = 0.48$	Age (ref = 18–44)—45–64: OR 1.41 (1.10–1.83); 65–84: OR 2.28 (1.74–2.98); ≥ 85 : OR 5.07 (3.08–8.35) Comorbidities (ref = 0)—1: OR 1.27 (1.04–1.54); 2: OR 1.47 (1.18–1.83); ≥ 3 : OR 1.98 (1.59–2.48)	None
Fehlings et al., 2012	Pres/ab of minor &/or major complications	Any periop complication—age: $p = 0.006$; no. of stages: $p = 0.016$; operative duration: $p = 0.009$; operative blood loss: $p = 0.005$; comorbidity score§: $p = 0.84$; sex: $p = 0.75$; BMI: $p = 0.48$, baseline mJOA: $p = 0.28$; smoking status: $p = 0.47$; surgical approach: $p = 0.11$; no. of levels: $p = 0.067$; spinal fusion: $p = 0.82$; fusion approach: $p = 0.064$; laminoplasty performed: $p = 0.48$; corpectomy performed: $p = 0.84$	Any periop complication—age, OR 1.029 (1.002–1.057), $p = 0.035$ Major complication—age: OR: 1.054 (1.015–1.094), $p = 0.006$. Not significant in either model—sex: $p > 0.05$; comorbidity score§: $p > 0.05$; BMI: $p > 0.05$; smoking status: $p > 0.05$; baseline severity: $p > 0.05$	Any periop complication—operative duration: OR 1.005 (1.002–1.008), $p = 0.001$; no. of stages: $p > 0.05$ Major complication—combined anterior-posterior procedure: OR: 5.297 (1.626–17.256), $p = 0.006$; operative duration: $p > 0.05$ Not significant in either model—operative blood loss: $p > 0.05$; approach: $p > 0.05$; no. of levels: $p > 0.05$; laminoplasty: $p > 0.05$; corpectomy: $p > 0.05$
Furlan et al., 2011	Pres/ab of complications	Age: $p = 0.006$; no. of ICD-9 codes: $p = 0.033$; approach: $p = 0.018$; sex: $p = 0.534$; duration of symptoms: $p = 0.106$; CCI: $p = 0.09$; no. of levels: $p = 0.233$	Age: OR 1.09 (1.015–1.172), $p = 0.018$; sex: $p = 0.188$; no. of ICD-9 codes: $p = 0.113$; duration of symptoms: $p = 0.309$	Surgical approach: $p = 0.248$; no. of levels: $p = 0.454$
Cook et al., 2008	Pres/ab of complication subgroups‡	Diabetes (vs no diabetes)—respiratory complications: $p < 0.01$; cardiac complications: $p < 0.01$; peripheral vascular complications: $p = 0.01$; complications of hematomas: $p = 0.01$; transfusion: $p = 0.01$; dysphagia: $p < 0.01$; other complications: $p = 0.001$ Controlled diabetes (vs uncontrolled)—cardiac complications: $p = 0.01$; complications of hematomas: $p = 0.01$	Diabetes (ref = no diabetes)—cardiac complications: OR 1.57 (1.14–2.16), $p = 0.01$; other complications: OR 1.54 (1.17–2.01), $p = 0.01$ Uncontrolled diabetes (ref = controlled diabetes)—cardiac complications: OR 2.82 (1.14–7.01), $p = 0.03$; complications of hematomas: OR 5.13 (2.16–12.17), $p < 0.01$; postop infection: OR 7.46 (1.33–41.79), $p = 0.02$	
Hasegawa et al., 2007	Pres/ab of UE palsy	All patients, anterior procedure—age: $p < 0.05$, < 0.01 ; diagnosis: < 0.0001 , < 0.001 ; no. of levels: $p = 0.0591$, < 0.001 ; procedure: NS, NA; sex: NS, NS; baseline severity score: NS, NS	All patients—diagnosis (OPLL): OR 19.0, $p < 0.0001$; age: OR 2.59, $p = 0.108$ Anterior procedure—age OR: 3.13, $p = 0.076$	Anterior procedure—no. of levels: OR 11.5, $p < 0.001$
Kaneyama et al., 2010	Pres/ab of C-5 palsy	Approach: $p < 0.05$	Diagnosis (OPLL): OR 43.8 (1.03–999.99), $p = 0.048$; age: $p = 0.964$; sex: $p = 0.252$; baseline severity: $p = 0.219$; physical signs¶: $p = 0.117$ –0.998; radiologic exams**: $p = 0.101$ –0.314; CMAP amplitude: $p = 0.112$ –0.291	Open-door laminoplasty (vs double-door): OR 69.6 (1.14–999.99), $p = 0.043$; no. of opened laminae: $p = 0.493$
Kimura et al., 2012	Pres/ab of UE paresis	Occupying ratio: $p = 0.005$; blood loss: $p = 0.021$; operative duration: $p = 0.002$; long fusion (≥ 3 segments): $p = 0.017$; C2–7 angle: $p = 0.758$	Occupying ratio: 1.047 (1.002–1.093), $p = 0.040$	Blood loss: 1.002 (1.000–1.003), $p = 0.047$; operative duration: $p = 0.74$; long fusion (≥ 3 segments): $p = 0.77$

(continued)

TABLE 3. Important clinical, imaging, and surgical predictors of perioperative complications, including nerve root palsy, axial pain, and major intraoperative blood loss* (continued)

Authors & Year	Level of Evidence†	Parameters for Univariate Analysis	Multivariate Analysis (clinical/imaging factors)	Multivariate Analysis (surgical factors)
Kato et al., 2012	Pres/ab of major intraoperative blood loss	Occupying ratio: $p = 0.02$; operative duration: $p < 0.001$; diabetes: $p = 0.30$; hypertension: $p = 0.1$; no. of levels: $p = 0.68$; sex: $p = 0.17$; age: $p = 0.10$; size of OPLL: $p = 0.23$; OPLL type: $p = 0.14$; C2–7 angle: $p = 0.93$; high SI on T2-WI: $p = 0.51$	Occupying ratio ($\geq 60\%$): OR 2.4 (1.1–5.3), $p = 0.03$; age: $p > 0.05$; sex: $p > 0.05$; size of OPLL: $p > 0.05$; OPLL type: $p > 0.05$	
Kato et al., 2008	Pres/ab of postop axial pain	No factors were significant in univariate analysis (all factors analyzed are shown in adjacent columns)	Age (> 63 yrs): OR 0.17 (0.04–0.72), $p < 0.05$; sex: $p > 0.05$; diagnosis: $p > 0.05$; duration of symptoms: $p > 0.05$; baseline severity: $p > 0.05$; preop alignment: $p > 0.05$; preop ROM: $p > 0.05$	Preserving of paraspinal muscles attached at C-2 (vs nonpreserving): OR 0.13 (0.02–0.98), $p < 0.05$; operative time: $p > 0.05$; blood loss: $p > 0.05$; preserving of paraspinal muscles attached at C-7 (vs nonpreserving): $p > 0.05$

exams = examinations; mJOA = modified JOA; NA = not applicable; NS = not significant; Pres/ab = presence or absence.

* Results of univariate and multivariate analyses.

† All study designs were multiple logistic regression analysis.

‡ Multiple logistic regression analysis controlling for age, discharge year, race, sex, household income, hospital size, hospital type, primary insurance payer, and number of levels fused.

§ Includes both severity and number of comorbidities (1 for mild, 2 for moderate, 3 for severe) summed over several types of comorbidities.

¶ Included muscle strength of deltoid and biceps, muscles stretch reflex of deltoid and biceps tendon, and neurologic impediment level of myelopathy.

** Included cervical alignment, number of compressed segments, position of the superior articular process, cord inclination, and high-intensity area on T2-weighted image.

ate analysis, a 2-stage anteroposterior surgery ($p = 0.016$), a longer operative duration ($p = 0.009$), and greater blood loss ($p = 0.005$) were significantly associated with perioperative complications. Following multivariate analysis, however, operative time was the only significant surgical predictor of overall (major and minor) perioperative complications (OR 1.005, 95% CI 1.002–1.008, $p = 0.001$).¹⁹ Fehlings et al. also explored risk factors for only major complications, defined as an event resulting in permanent or prolonged morbidity, prolongation of hospital stay, or invasive intervention.¹⁹ Patients who were treated surgically with a 2-stage procedure were 5.30 times more (OR 5.30, 95% CI 1.626–17.256) likely to experience a major complication as compared to those undergoing either a single-stage anterior or posterior surgery ($p = 0.006$). Furlan et al. reported that the anterior approach was associated with fewer postoperative complications than either a posterior or circumferential procedure ($p = 0.018$).²¹ This surgical factor, however, was not a significant predictor following multivariate analysis ($p = 0.248$).

Fehlings et al. identified no differences in surgical approach ($p = 0.11$) or number of vertebrae operated on ($p = 0.067$) between patients who experienced perioperative complications and those who did not. Furthermore, whether the procedure included spinal fusion ($p = 0.82$) (anterior or posterior, $p = 0.064$), a laminoplasty ($p = 0.48$), or a corpectomy ($p = 0.84$) did not influence postoperative complication rates.

Upper Extremity or C-5 Palsy

Hasegawa et al. reported that surgical approach (anterior vs posterior or ADF vs laminoplasty vs laminectomy) did not influence the occurrence of C-5 palsy.²⁶ The num-

ber of decompressed levels tended to be higher in patient with C-5 palsy, although this relationship did not reach statistical significance. Following stepwise logistic regression, a greater number of levels was predictive of postoperative C-5 palsy in patients undergoing ADF (OR 11.5, $p < 0.001$).

In a study by Kimura et al., patients with fusion of 3 or more levels ($p = 0.017$) and a longer operative duration ($p = 0.002$) were at an increased risk of developing upper-extremity palsy.⁴¹ These 2 relationships, however, were not significant in multivariate analysis ($p = 0.77$, $p = 0.74$, respectively). Increased intraoperative blood loss was the only identified surgical predictor of upper-extremity palsy (OR 1.002, 95% CI 1.000–1.003, $p = 0.047$).

Finally, Kaneyama et al. reported that patients undergoing open-door laminoplasty were at a significantly higher risk of developing C-5 nerve palsy than those treated with double-door laminoplasty (OR 69.6, 95% CI 1.14–999.99, $p = 0.043$).³⁴ This estimate, however, is unstable. Number of open laminae was the only other surgical factor considered in this study and was not predictive of C-5 palsy ($p = 0.483$).

Major Blood Loss

There was no difference in the number of operated levels between patients who experienced excessive blood loss (5.1 ± 1.0) and those who did not (5.0 ± 0.8 , $p = 0.68$).³⁷ Operative duration, however, was longer in the major blood loss group (240 ± 112 minutes vs 149 ± 59 minutes, $p < 0.001$).

Axial Pain

Based on multivariate analysis, preservation of paraspinal

nal muscles attached at C-2 decreased the risk of postoperative axial pain (OR 0.13, 95% CI 0.02–0.98, $p < 0.05$).³⁶ Operative duration, blood loss, and preservation of paraspinal muscles attachment at C-7 were not significantly associated with postoperative axial pain.

Results of Studies Without Multivariate Analyses

Table 4 summarizes the results of studies that identified important predictors of complications but did not conduct a multivariate analysis.

Based on the results of 2 studies, preoperative severity was not related to overall complication rates.^{20,27} In a study by Holly et al., complication rates were compared between patients older than 75 years and patients under 65 years. In the elderly group, the complication rate (38%) was significantly higher than in the younger group (6%, $p = 0.002$). In a study by Lu et al., the incidence of complications was also much higher (35%) in the aged group (≥ 70 years) compared with the control group (9.7%) (< 70 years), although this relationship did not reach statistical significance.⁵⁰

There was consensus in the literature that age ($n = 4$),^{7,31,43,53} sex ($n = 2$),^{7,31} preoperative severity ($n = 5$),^{7,12,31,43,53} muscle manual test results ($n = 2$),^{7,43} duration of symptoms ($n = 2$),^{31,43} diagnosis ($n = 2$),^{31,53} preoperative cervical lordosis ($n = 2$),^{31,53} and cervical curvature ($n = 2$)^{43,49} are not significant predictors of nerve root palsy. In a study by Imagama et al., patients experiencing C-5 palsy had a smaller C-5 intervertebral foramen width and a higher degree of anterior protrusion of the superior articular process of C-5. Komagata et al., however, noted no significant difference in the extent of anterior protrusion between patients with (4.3 ± 4) and without (3.73 ± 3) palsy ($p = 0.51$).^{31,42} Hyperintensity on a MRI was also not an important imaging predictor of nerve root palsy.^{7,31}

Three studies examined important predictive factors of radiculopathy following surgery.^{24,40,65} In a study by Greiner-Perth et al., patients who had symptoms of C-5 and/or C-6 radiculopathy were on average older (62.4 vs 58.6 years, $p < 0.01$) and had a greater number of operated levels (2.2 vs 1.7 levels, $p < 0.001$) than those who did not. The incidence of postoperative radiculopathy, however, was not different between an elderly patient group (≥ 70 years) and a younger patient group (< 70 years) in a study by Kawaguchi et al. ($p = 0.18$). There was consensus in the literature that preoperative severity ($n = 2$) was not significantly associated with postoperative radiculopathy.^{24,65}

Risk factors for stability complications such as instability ($n = 1$)²⁵ and postoperative kyphosis ($n = 2$)^{35,64} were assessed by 3 studies. Guigui et al. reported that patients who were younger ($p = 0.03$), had a hypermobile spine ($p < 0.0001$), had greater preoperative range of motion ($p < 0.0001$), and received a C-2 laminectomy ($p = 0.0164$) were more susceptible to spinal destabilization. With respect to postoperative kyphosis, a single study reported that a diagnosis of CSM, smaller preoperative Cobb angle in neutral ($p = 0.000$), larger degree of preoperative flexion ($p = 0.023$), and small degree of preoperative extension ($p = 0.025$) were all important predictors.⁶²

As demonstrated by 2 studies, an increase in the number of operative lamina is significantly associated with an

increase incidence of axial pain ($p < 0.001$, $p = 0.03$).^{54,61} A diagnosis of OPLL (compared with CSM) is also an important clinical predictor of axial pain ($p = 0.027$).⁵⁴

As indicated by single studies, risk factors for various surgical complications include 1) younger age ($p < 0.05$) and multilevel surgery ($p < 0.002$) for pseudarthrosis,¹⁶ 2) previous surgery for graft complications ($p < 0.001$),¹⁶ 3) preoperative kyphosis for closure of lamina ($p = 0.014$),⁵¹ and 4) a larger number of fused segments for reconstruction failure (4.2 vs 3.5, $p < 0.05$).⁵⁶ Age ($n = 3$)^{51,56,68} and sex ($n = 3$)^{51,56,68} were not significant predictors of surgical complications.

QK2: Are Rates of Complications Different Between Surgical Interventions or Varying Techniques?

Anterior Versus Posterior

Fehlings et al. compared rates of complications between anterior and posterior surgical groups.^{18,19} The patient demographics were significantly different in the 2 cohorts: patients treated anteriorly were on average younger, their condition was less severe, they had fewer operated levels, and experienced a smaller volume of blood loss than those treated posteriorly. There were, however, no significant differences in rates of major and/or minor complications ($p = 0.11^{19}$ and $p = 0.197^{18}$), major complications ($p = 0.61$), new neurological deficits ($p = 1.00$), C-5 radiculopathy ($p = 1.00$), or dysphagia ($p = 0.65$). Based on results from Fehlings et al., there was a higher incidence of postoperative infection in the posterior group (4.7%) compared with the anterior group (0.6%, $p = 0.030$). Ghogawala et al. also reported similar overall complication rates ($p = 1.00$) between patients who underwent anterior cervical decompression and fusion and those treated posteriorly by laminectomy with fixation.²² In addition, there were no significant differences in rates of overall ($p = 0.654$), surgical ($p = 0.507$), medical ($p = 1.00$), or irreversible complications ($p = 0.74$) between corpectomy and laminectomy and fusion surgeries.⁴⁴ The frequency of dysphagia and transient hoarseness, however, was greater in the corpectomy group (7.1%) compared with the laminectomy and fusion group (0%).

Five studies analyzed differences in complication rates between anterior decompression surgery and laminoplasty.^{15,30,42,48,59} The surgical approach was at the discretion of the attending surgeon in 2 studies.^{15,48} In the other 3 studies, the design was quasi-randomized: patients were treated anteriorly within a specific time frame and posteriorly in subsequent years.^{30,42,59} Based on results from Edwards et al. and Liu et al., there was a higher incidence of complications in the anterior group (ACDF with plate cage Benezech [PCB; $p < 0.05$] or corpectomy [$p < 0.05$]) compared with laminoplasty group. The rates of axial pain were found to be significantly higher in the laminoplasty group as compared to the ADF group.³⁰ These conclusions, however, were based on single studies. According to Sakaura et al., there were no significant differences in rates of C-5 palsy, bone graft complications, donor site morbidities, axial pain, or postoperative kyphosis between the groups.⁵⁹

Anterior Techniques

Three studies compared the efficacy and safety of various anterior approaches: ACDF versus Bryan disc pros-

TABLE 4. Clinical, imaging, and surgical predictors or complication development, including stability and surgical complications*

Authors & Year	Patient Population	Surgical Treatment	Related To	Not Related To
Postop complication rates				
Fehlings et al., 2013	CSM (n = 278)	Anterior (n = 169), posterior (n = 95), combined (n = 14)		Preop severity
Holly et al., 2008	CSM (n = 70)	Anterior (n = 10), posterior (n = 24), combined (n = 2)	Older age	Preop severity
Lu et al., 2008	CSM (n = 51)	Corpectomy		Age
Meyer et al., 2011	CSM (n = 12)	OPLL (n = 28), laminoplasty		Diagnosis
Neurological complications: nerve root palsy				
Chen et al., 2007	OPLL (n = 49)	Laminectomy & posterior fixation		Age, sex, preop severity, MMT, no. of operated levels, preop lordosis, occupying ratio SI on T2-WI
Chen et al., 2009	OPLL (n = 83)	Laminectomy & instrumented fusion		Preop lordosis, occupying ratio presence of snake-eye sign on MRI
Chen et al., 2013	OPLL (n = 30)	Posterior hybrid technique (n = 15), laminoplasty (n = 15)		Segmental instability
Chiba et al., 2002	OPLL, CSM, CDH (n = 208)	Laminoplasty		Preop severity
Imagama et al., 2010	CSM (n = 1570), OPLL (n = 288)	Laminoplasty	Smaller width of C-5 intervertebral foramen, higher degree of anterior protrusion of the superior articular process of C-5	Age, sex, duration of symptoms, preop severity, diagnosis, preop lordosis, no. of compressed levels, SI on T2-WI, operative duration, EBLP, position of bony gutter, surgical procedure
Komagata et al., 2004	CSM (n = 197), OPLL (n = 108)	Laminoplasty		Age, duration of symptoms, preop severity, deltoid MMT, CSCI, degree of anterior protrusion of superior articular process
Liu et al., 2010	CSM (n = 101)	Laminectomy & posterior internal fixation		Mean cervical curvature, CSCI
Minoda et al., 2003	CSM (n = 27), OPLL (n = 14)	Laminoplasty		Age, preop severity, diagnosis, preop lordosis, foramen diameter, preop lamina angle, gutter position, spinal cord flatness, preop anterior cord distance
Neurological complications: radiculopathy				
Greiner-Perth et al., 2005	CSM (n = 121)	Corpectomy	Older age, greater no. of levels	Preop severity
Kawaguchi et al., 2003 ³⁹	CSM (n = 106)	Laminoplasty		Age
Uematsu et al., 1998	CSM, OPLL, developmental canal stenosis (n = 365)	Laminoplasty		Diagnosis, narrowest level, preop severity, degree of flatness, cervical curvature, extent of anterior protrusion of the superior articular process, the laterality of the osteophytes or OPLL, angle of lamina before expansion.
Neurological complications: shoulder stiffness & neck pain				
Yoshida et al., 2002	CSM (n = 90), OPLL (n = 66), CDH (n = 14), CLF (n = 3)	Laminoplasty		Age, AP canal diameter, preop JOA, diagnosis, cervical alignment

(continued)

TABLE 4. Clinical, imaging, and surgical predictors or complication development, including stability and surgical complications* (*continued*)

Authors & Year	Patient Population	Surgical Treatment	Related To	Not Related To
Stability complications: instability				
Guigui et al., 1998	CSM (n = 58)	Laminectomy w/o fusion	Greater preop ROM, younger age, C-2 laminectomy, & hypermobility	Sex, no. of removed lamina, preop olisthesis, preop type of curvature
Stability complications: postop kyphosis				
Kaptain et al., 2000	CSM (n = 46)	Laminectomy		Sex, age, history of smoking, C-2 laminectomy, foraminotomy, no. of levels, preop type of curvature (lordosis vs straight)
Suk et al., 2007	CSM (n = 52), OPLL (n = 29), CDH (n = 4)	Laminoplasty	Diagnosis of CSM, smaller preop Cobb angle in neutral, preop lordosis angle <10° in neutral, preop kyphotic angle during flexion > lordotic angle during extension	
Axial pain				
Motosuneya et al., 2011	CSM (n = 42), OPLL (n = 33)	Laminoplasty	Diagnosis of OPLL, no. of open lamina	
Ohnari et al., 2006	CSM (n = 33), OPLL (n = 14), CYL (n = 2), CDH (n = 1), OYL (n = 1)	Laminoplasty		Age, blood loss, operative duration, sex, duration of cervical orthosis use, reconstruction of semispinalis cervicis muscle & preop axial symptoms
Sasai et al., 2005	CDH (n = 32)	Microsurgical posterior hemi-laminotomy w/ EBLP	No. of EBLPs	
Surgical complications: pseudarthrosis (Emery et al., 1998); graft (Emery et al., 1998; Kumar et al., 2009); closure of lamina (Matsumoto et al., 2008; Wang et al., 2011); reconstruction failure (Okawa et al., 2011)				
Emery et al., 1998	CSM (n = 108)	Anterior decompression & arthrodesis	Pseudarthrosis: younger age, multi-level surgery	Smoking
Emery et al., 1998	CSM (n = 108)	Anterior decompression & arthrodesis	Graft: previous surgery	
Kumar et al., 2009	OPLL, CSM (n = 410)	Corpectomy		No. of levels, the location of the lower mortise in the C-7 body (compared to other vertebral bodies)
Matsumoto et al., 2008	CSM (n = 67), OPLL (n = 15)	Laminoplasty	Preop kyphosis	Sex, age, cause of myelopathy, use of anchor screws.
Wang et al., 2011	CSM (n = 24), OPLL (n = 6)	Laminoplasty		Age, sex
Okawa et al., 2011	CSM (n = 7), OPLL (n = 24)	Corpectomy & reconstruction	Larger no. of fused segments	Age, sex, preservation of vertebral endplates, preop C2-7 lordotic angle, fused lordotic angle, C-7 horizontal angle, screw type & the use of intermediate screws for fibular grafting.

CLF = calcification of the ligamentum flavum; CSCI = cervical spine curvature index; CYL = calcification of the yellow ligament; EBLP = en bloc laminoplasty; JOA = Japanese Orthopaedic Association; MMT = muscle manual test; OYL = ossification of the yellow ligament.

* Data are results of prognostic studies without a multivariate analysis.

thesis ($n = 1$)¹¹ and ACDF versus corpectomy ($n = 2$).^{47,63} Cheng et al. conducted a randomized control trial to compare operative and postoperative characteristics between a Bryan disc and an ACDF group.¹¹ Complication rates were higher in the ACDF group since dysphagia was seen in 7 patients as compared to only 1 in the Bryan group ($p < 0.001$).

When comparing ACDF to anterior corpectomy, there were no significant differences in rates of surgical complications ($p = 0.694$), CSF ($p = 0.604$), hoarseness (Song et al., $p = 0.742$ ⁶³; Lin et al., $p = 1.00$ ⁴⁷), epidural hematoma ($p = 1.00$), C-5 radiculopathy ($p = 1.00$), dysphagia (Song et al., $p = 0.436$; Lin et al., $p = 1.00$), graft dislodgement ($p = 0.246$), subsidence ($p = 0.121$), and dural tear ($p = 0.688$). Although graft-related complications were not significantly different between surgical groups in the study by Song et al., Lin et al. reported a higher incidence of total instrumented and graft-related complications in the corpectomy group ($p = 0.032$).

Posterior Techniques

Four studies compared complication rates between laminoplasty and laminectomy and fusion.^{10,19,70,72} According to studies by Fehlings et al. and Woods et al., there is no difference in overall complication rates between posterior surgeries (Fehlings et al., $p = 0.14$; Woods et al., $p = 0.087$). In addition, rates of wound infections (Yang et al., $p = 0.285$; Fehlings et al., $p = 0.43$), dysphagia ($p = 0.32$), neck pain ($p = 0.066$), CSF leakage ($p = 0.252$), kyphosis ($p = 0.756$), and restenosis ($p = 0.448$) were not significantly different between the 2 groups. In studies by Chen et al. and Yang et al., there was a higher incidence of C-5 palsy in the laminectomy and fusion group compared with the laminoplasty group ($p < 0.05$). Fehlings et al., however, noted no differences in C-5 radiculopathy rates between the 2 posterior techniques. Although Chen et al. reported no significant differences between laminoplasty and laminectomy and fusion with respect to axial pain, Yang et al. found a higher incidence of axial pain in patients treated with laminectomy and fusion.

Laminoplasty Techniques

Various laminoplasty techniques have been designed and modified to improve surgical outcome and decrease postoperative morbidity. In this review, 11 studies compared complication rates between different forms of laminoplasty procedures. In a quasi-randomized study, Park et al. observed no significant differences in aggravated neck pain ($p = 0.34$), C-5 palsy ($p = 0.34$), or other complications ($p = 1.00$) between midline-splitting and unilateral single-door laminoplasty.⁵⁷ Similarly, hinge position (wide group: hinge located at the inner margin of the lateral mass; narrow group: hinge at the lamina margin) was not associated with the development of C-5 palsy ($p = 0.17$).⁷¹ In a comparative study between open-door and double-door laminoplasty, C-5 palsy rates tended to be higher following open-door laminoplasty ($p < 0.05$).³⁴

Selective expansive open-door laminoplasty (EOLP) was designed to reduce damage to cervical posterior elements and prevent common long-term problems of laminoplasty, such as axial symptoms, malalignment, and

decreased range of motion.⁶⁶ This procedure consists of an open-door laminoplasty at the levels of stenosis and a partial laminectomy combined with laminoplasty at the most inferior stenosis level. As indicated by Tsuji et al., the incidence of C-5 palsy was significantly lower in the selective EOLP group than in a C3–7 EOLP group ($p = 0.037$).

Another modification of laminoplasty was designed to reduce the amount of bone graft during operation (3 levels only in the open side), shorten the period of orthosis application, and encourage patients to exercise their posterior neck muscles postoperatively.³⁹ Complication rates in this modified group were compared with rates following traditional open-door en bloc laminoplasty.³² There was a lower incidence of axial pain and neck stiffness in the modified group ($p = 0.0019$).³⁹

Two studies examined the effectiveness of foraminotomy in combination with laminoplasty in preventing postoperative C-5 palsy.^{38,43} Both Komagata et al. and Katsumi et al. reported a significant lower incidence of C-5 palsy in the concurrent foraminotomy group ($p < 0.05$).

Four studies have explored muscle-preserving techniques and have compared rates of axial pain, postoperative kyphosis, and C-5 nerve root palsy.^{28,29,58,60} Sakaura et al. examined whether preservation of 1) subaxial deep extensor muscles or 2) the funicular section of the nuchal ligament attached to the C-6 and C-7 spinous process could prevent poor radiological outcomes and axial pain. Based on results from these 2 studies, there was no significant difference in rates of axial pain between muscle-preserving and muscle-disrupting groups. Incidence of postoperative kyphosis was not different between the subaxial deep extensor preserving group and the control group.

The cohort study conducted by Hosono et al. compared C3–7 to C3–6 laminoplasty. The only difference between the procedures was that the C-7 lamina was opened in the C3–7 group because these patients exhibited cord compression at C-6/C-7 or lower levels. Early and late axial pain rates were higher in the C3–7 group, likely due to disruption of the trapezius and rhomboideus minor muscles that typically attach to the C-7 vertebra (early: $p = 0.006$; late: $p = 0.015$). These results were confirmed by a second study by Hosono et al.: there was a higher incidence of early and late axial pain in the left-opened C3–7 group compared with either the left or right opened C3–6 groups (early: $p = 0.0008$; late: $p = 0.0036$). These studies are summarized in Table 5.

Summary of Evidence

Table 6 describes how the overall quality of evidence was derived. High evidence suggests that old age is predictive of perioperative complications. Low evidence reports old age decreases the risk of postoperative axial pain. Age, however, is not associated with upper extremity/C-5 palsy (low evidence).

Based on low evidence, there is no association between comorbidities, baseline severity score, BMI, duration of symptoms and smoking status, and perioperative complications. Sex is also not a significant predictor (moderate evidence).

Low evidence suggests that patients with a diagnosis of

TABLE 5. Comparative surgical studies reporting differences in complication rates

Authors & Year (class)	Allocation, Diagnosis, & Surgical Procedure	Similarities & Differences Btwn Groups	Complications	Results
Anterior vs posterior				
Fehlings et al., 2013 (III)	Discretion of surgeon; CSM (n = 264); anterior (n = 169), posterior (n = 95)	No difference in sex, smoking status, or duration of symptoms; age (52.33 yrs in anterior vs 62.83 yrs in posterior, p < 0.0001); preop mJOA (13.47 in anterior vs 11.84 in posterior, p < 0.0001); preop Nurick (3.96 in anterior vs 4.40 in posterior, p < 0.0001); no. of operated levels (3.13 in anterior vs 5.12 in posterior, p < 0.0001)	Complication rate, new neurological deficits, superficial infection	No significant differences in rates of complication (p = 0.197), new neurological deficits (p = 1.00), or superficial wound infections (p = 0.058)
Fehlings et al., 2012 (III)	Discretion of surgeon; CSM (n = 283); anterior (n = 176), posterior (n = 107)	No difference in operative duration; age (52.3 yrs in anterior vs 62.9 yrs in posterior, p < 0.001); preop mJOA (13.6 in anterior vs 11.8 in posterior, p < 0.001); EBL (170 ml in anterior vs 381 ml in posterior, p < 0.001)	Minor &/or major complications, major complications, wound infection, C-5 radiculopathy, & dysphagia	No significant differences in rates of minor &/or major complications (p = 0.11), major complications (p = 0.61), C-5 radiculopathy (p = 1.00), or dysphagia (p = 0.65); higher incidence of wound infection in posterior group (p = 0.030)
Anterior discectomy vs laminectomy				
Ghogawala et al., 2011 (III)	Discretion of surgeon; CSM (n = 50); ACDF (n = 28), LMF (n = 22)	No difference in age, sex & preop NDI, QoL5 or SF-36; baseline mJOA (13.4 in anterior vs 11.6 in posterior, p < 0.01); no. of operated levels (2.1 in anterior vs 3.1 in posterior, p < 0.001)	Complications	No significant difference in complications (p = 1.00)
Anterior corpectomy vs laminectomy				
Kristof et al., 2009 (III)	Quasi-randomized; CSM (n = 103); corpectomy (n = 42), LMF (n = 61)	No difference in sex, comorbidities, ASA, BMI, duration of symptoms, preop Nurick, preop neck pain, Cobb angle C3-7, or blood loss; age (62.5 yrs in corpectomy vs 66.0 yrs in LMF, p = 0.012); operative duration (229 min in corpectomy vs 184 in LMF, p < 0.001)	Surgical, medical or irreversible complications, radiculopathy, dysphagia, wound infection, hardware failure, pneumonia, renal failure, sepsis	No significant difference in overall complications (p = 0.654), surgical complications (p = 0.507), radiculopathy (p = 0.232), wound infection (p = 0.331), hardware failure (p = 0.108), medical complications (p = 1.00), pneumonia (p = 0.797), or irreversible complications (p = 0.74); higher incidence of dysphagia/transient hoarseness in corpectomy group (p = NR)
Anterior decompression vs laminoplasty				
Edwards et al., 2002 (III)	Discretion of surgeon; CSM (n = 25), OPLL (n = 1); corpectomy (n = 13), LMP (n = 13)	No difference in age, duration of symptoms, myelopathy severity, mean lordosis, C2-7 sagittal motion, or operative duration	Complications, axial pain	Higher incidence of complications in corpectomy group (p < 0.05); no significant differences in axial pain
Hosono et al., 1996 (III)	Quasi-randomized; CSM (n = 98); corpectomy (n = 26), LMP (n = 72)	No difference in age, sex, preop JOA, or AP spinal canal diameter	Axial pain	Higher incidence of axial symptoms in LMP group (p < 0.05)

(continued)

TABLE 5. Comparative surgical studies reporting differences in complication rates (*continued*)

Authors & Year (class)	Allocation, Diagnosis, & Surgical Procedure	Similarities & Differences Btwn Groups	Complications	Results
<i>Anterior decompression vs laminoplasty (continued)</i>				
Koakutsu et al., 2010 (II)	Quasi-randomized; soft disc herniation (n = 50); ACDF (n = 25), LMP (n = 25)	No difference in age, sex, level of disc herniation, AP canal diameter, or operative duration; blood loss (128 ml in ACDF vs 63 ml in LMP, p = 0.0084); occupying ratio (47.4% in ACDF vs 55.5% in LMP, p = 0.0043)	Neck pain	Higher incidence of neck pain at 1 yr in LMP group (p = 0.037)
Liu et al., 2011 (III)	Discretion of surgeon; CSM (n = 52); ACDF w/ PCB (n = 25), LMP (n = 27)	No difference in age, duration of symptoms, no. of blocks, canal diameter, preop JOA score, sagittal alignment, Cobb angle, sagittal diameter, or ROM; operative duration (116 in ACDF vs 188 min in LMP, p < 0.001); EBL (118 ml in ACDF vs 361 ml in LMP, p < 0.001)	Complications	Higher incidence of complications in ACDF group (p < 0.05)
Sakaura et al., 2005 (III)	Quasi-randomized; CDH (n = 43); ASF (n = 21), LMP (n = 22)	No difference in age, preop JOA, duration of symptoms, no. of levels of disc herniation, AP diameter, or transverse area	C-5 palsy, bone graft, donor-site morbidities, axial pain, kyphotic deformities	No significant difference in C-5 palsy, bone graft complications, donor-site morbidities, axial pain, or kyphotic deformities
<i>ACDF vs Bryan disc</i>				
Cheng et al., 2011 (II)	Randomized; CDH or stenosis (n = 83); ACDF (n = 42), Bryan (n = 41)	No difference in age, sex, smoking status, preop NDI, SF-36, or JOA; blood loss (100 ml in Bryan vs 150 ml in ACDF, p < 0.0001); operative duration (132.4 min in Bryan vs 115.1 min in ACDF, p < 0.0001)	Dysphagia	Higher incidence of dysphagia in ACDF (p < 0.001)
<i>Anterior discectomy vs corpectomy</i>				
Lin et al., 2012 (III)	Allocation undefined; CSM (n = 120); ACDF (n = 57), ACCF (n = 63)	No difference in age, sex, or operative segments; blood loss (103 ml in ACDF vs 149 ml in ACCF, p = 0.000); operative duration (138 min in ACDF vs 125 min in ACCF, p = 0.021)	CSF, hoarseness, epidural hematoma, C-5 radiculopathy, dysphagia, graft dislodgement, subsidence	No significant difference in surgery-related complications (p = 0.694), including CSF leak (p = 0.604), hoarseness (p = 1.00), epidural hematoma (p = 1.00), C-5 radiculopathy (p = 1.00), & dysphagia (p = 1.00); no significant difference in graft dislodgement (p = 0.246) or subsidence (p = 0.121); higher incidence of total instrumentation & graft-related complications in ACCF group (p = 0.032).
Song et al., 2012 (III)	Allocation undefined; CSM (n = 40); ACDF (n = 25), ACCF (n = 15)	No difference in age, sex, no. of fusion levels, or graft materials; blood loss (621 ml in ACDF, 1011 ml in ACCF, p = 0.001); operative duration (186 min in ACDF, 268 min in ACCF, p = 0.024)	Hardware related, pseudarthrosis, dysphagia, hoarseness, donor-site pain, graft related, dural tear	No significant difference in hardware-related complications (p = 0.408), pseudarthrosis (p = 0.537), dysphagia (p = 0.436), hoarseness (p = 0.742), donor-site pain (p = 0.092), graft-related complications (p = 0.158), or dural tear (p = 0.688)

(continued)

TABLE 5. Comparative surgical studies reporting differences in complication rates (*continued*)

Authors & Year (class)	Allocation, Diagnosis, & Surgical Procedure	Similarities & Differences Btwn Groups	Complications	Results
Laminoplasty vs laminectomy				
Chen et al., 2012 (III)	Cervical alignment; OPLL (n = 164); ACCF (n = 91), LMP (n = 41), LMF (n = 32)	No difference in age, sex, occupying rate, or no. of intervertebral levels; preop JOA score (10.2 in LMP vs 9.1 in LMF, $p < 0.05$); all patients in LMF group had cervical kyphosis; all patients in LMP group had cervical lordosis	C-5 palsy; axial pain	No difference in axial pain btwn LMP & LMF; higher incidence of C-5 radiculopathy in LMF compared to LMP ($p < 0.001$)
Fehlings et al., 2012 (III)	Discretion of surgeon; CSM (n = 302); LMP (n = 34), LMF (n = 82)	No significant difference in age & baseline severity; operative duration (150 min in LMP vs 225 min in LMF, $p < 0.001$); EBL (198 ml in LMP vs 476 ml in LMF, $p < 0.001$)	Minor &/or major complications; major complications, wound infection, C-5 radiculopathy, dysphagia	No significant difference in rates of minor &/or major complications ($p = 0.14$), major complications ($p = 1.00$), wound infections ($p = 0.43$), C-5 radiculopathy ($p = 0.50$), or dysphagia ($p = 0.32$)
Woods et al., 2011 (III)	Discretion of surgeon; CSM (n = 121); LMF (n = 82), LMP (n = 39)	No difference in preop alignment	Complications, neck pain	No significant difference in complication rates ($p = 0.087$) or neck pain at final follow-up ($p = 0.066$)
Yang et al., 2013 (III)	Discretion of surgeon; CSM (n = 141); LMF (n = 66), LMP (n = 75)	No difference in age, sex, baseline severity score, no. of operative levels, cervical curvature, ROM, or preop area of dural sac; blood loss (284.53 ml in LMP vs 310.91 ml in LMF, $p = 0.003$); operative duration (145.07 min in LMP vs 173.79 min in LMF, $p = 0.000$)	C-5 radiculopathy, CSF leakage, kyphosis, wound infection, restenosis & axial pain	No significant difference in CSF leakage ($p = 0.252$), kyphosis ($p = 0.756$), wound infection ($p = 0.285$), or restenosis ($p = 0.448$); higher incidence of C-5 radiculopathy ($p = 0.022$) & axial pain ($p = 0.001$) in LMF group
Laminoplasty techniques				
Hosono et al., 2006 (III)	Pts were treated w/ C3-7 LMP if they had cord compression at C-6/C-7 or lower levels; CSM (n = 65); C3-6 (n = 37), C3-7 (n = 28) LMP	No difference in age, sex, or blood loss; operative duration (113 min in C3-6 vs 129 min in C3-7 group, $p = 0.0082$)	C-5 palsy, early & late axial pain	No significant difference in C-5 palsy ($p = 0.63$); higher incidence of early & late axial pain in C3-7 group ($p = 0.006$, $p = 0.015$)
Hosono et al., 2007 (III)	Quasi-randomized; CSM (n = 65), OPLL (n = 21), CDH (n = 5); left-opened C3-7 (n = 37), C3-6 (n = 31), right-opened C3-6 (n = 23) LMP	No difference in age, sex, preop JOA	Early & late axial pain	Higher incidence of early & late axial pain in left-opened C3-7 group compared to the C3-6 groups ($p = 0.0008$, $p = 0.0036$)
Kaneyama et al., 2010 (III)	Quasi-randomized; CSM (n = 108), OPLL (n = 31), CDH (n = 7); open-door (n = 73), double-door (n = 73) LMP	No difference in sex, age, diagnosis, preop JOA, or no. of opened laminae	C-5 palsy	Higher incidence of C-5 palsy in open-door group ($p < 0.05$)

(continued)

TABLE 5. Comparative surgical studies reporting differences in complication rates (*continued*)

Authors & Year (class)	Allocation, Diagnosis, & Surgical Procedure	Similarities & Differences Btwn Groups	Complications	Results
<i>Laminoplasty techniques (continued)</i>				
Katsumi et al., 2012 (III)	Quasi-randomized; CSM (n = 238), OPLL (n = 42), CDH (n = 2); LMP (NFG, n = 141), LMP w/ C4/5 foraminotomy (FG, n = 141)	No difference in age, sex, diagnosis, blood loss, or no. of decompressed levels; operative duration (129 min in FG vs 102 min in NFG, p < 0.0001)	C-5 palsy	Higher incidence of C-5 palsy in NFG (p < 0.05)
Kawaguchi et al., 2003 ³⁹ (III)	Quasi-randomized; CSM (n = 56); modified LMP (n = 28)*, original LMP (n = 28)	No difference in EBL, preop cervical alignment, ROM, or space available for cord; operative duration (130 min in modified group vs 162 min in original group, p = 0.001)	Axial pain	Lower incidence of axial pain & neck stiffness in modified group (p = 0.0019)
Komagata et al., 2004 (III)	Allocation undefined; CSM (n = 197), OPLL (n = 108); ELAP (230 w/ foraminotomy)	NR	C-5 palsy	Lower incidence of C-5 palsy in concurrent foraminotomy (p < 0.05)
Park et al., 2012 (III)	Quasi-randomized; CSM (n = 45), OPLL (n = 55); mid-splitting (n = 21) or unilateral single-door (n = 79) LMP	No difference in age, sex, preop JOA, diagnosis, or surgical level	Aggravated neck pain, C-5 palsy, other complications	No significant differences in aggravated neck pain (p = 0.34), C-5 palsy (p = 0.34), or other complications (p = 1.00)
Sakaura et al., 2008 (III)	Segregated into 2 groups according to funicular section of nuchal ligament on MRI; CSM (n = 37); C-6+C-7 (n = 19), C-7 preserving (n = 18) C3-6 LMPT	No difference in age, sex, preop JOA, sagittal alignment, or segmental alignment at C-6/C-7.	Early & late axial pain†	No differences in axial neck pain (p > 0.05)
Sakaura et al., 2010 (III)	Quasi-randomized; CSM (n = 36); C3-6 open-door LMP: preserved bilateral subaxial deep extensor muscles (n = 18), non-preserved muscles (n = 18)	No difference in age, sex, or preop JOA	Early & late axial pain,‡ postop kyphosis	No difference in axial pain or postop kyphosis (p > 0.05)
Tsuji et al., 2007 (III)	CSM (n = 64); selective ELAP§ (n = 42), C3-7 ELAP (n = 22)	No difference in age, sex, JOA score, stenotic level, C2-7 angle, ROM, or no. of expanded laminae	C-5 palsy	Incidence of C-5 palsy significantly lower in selective ELAP group compared w/ C3-7 ELAP group (p = 0.037).
Xia et al., 2011 (II)	Randomized; CSM (n = 102); EOLP (n = 57), narrow-open group (n = 45)¶	No difference in age, operative duration, or EBL	C-5 palsy	No significant differences in C-5 palsy (p = 0.17)
<i>Other</i>				
Caroom et al., 2013 (III)	CSM (n = 112); vancomycin (n = 40), control (n = 72); posterior decompression & instrumentation (n = 112)	No difference in age, diabetes, preop severity, BMI, operative duration, EBL, or no. of levels instrumented	Surgical site infection	Higher incidence in control group (p = 0.007).

(continued)

TABLE 5. Comparative surgical studies reporting differences in complication rates (*continued*)

Authors & Year (class)	Allocation, Diagnosis, & Surgical Procedure	Similarities & Differences Btwn Groups	Complications	Results
Other (<i>continued</i>)				
Yoshida et al., 2012 (III)	CSM (n = 31), controls (n = 30); ELAP C3-7 (n = 31), lumbar decompression (n = 30)	No difference in age, sex, ASA, or operative duration; blood loss (165 ml in LMP vs 257 in lumbar decompression, p = 0.0132)	Complications	Higher incidence in LMP group (p = 0.0183)

ACCF = anterior cervical corpectomy and fusion; ASA = American Society of Anesthesiologists; ASF = anterior spinal fusion; ELAP = expansive open-door laminoplasty; EOLP = expansive open-door laminoplasty; FG = foraminotomy group; LMF = laminectomy and fusion; LMP = laminoplasty; NDI = Neck Disability Index; NFG = nonforaminotomy group; NR = not reported; QoL5 = EuroQoL-5D; SF-36 = 36-Item Short Form Health Survey.

* Modified group: 1) bone grafts in the open gap were placed at 3 levels, 2) bone grafting in the hinged side was not performed, 3) the neck collar was worn for only 1 month, and 4) patients were advised to perform early posterior neck muscle exercises.

† C-6+C-7 group: funicular section of the nuchal ligament attached only to the C-7 spinous process was preserved; C-7 group: funicular section of the nuchal ligament attached only to the C-7 spinous process was preserved (not attached to C-6 process on MRI).

‡ Early axial pain: more than a week, less than a month; late axial pain: persisting for more than 1 month.

§ In selective ELAP, open-door laminoplasty was performed only at stenosis levels; partial laminectomy of the upper half of lamina at the most inferior stenosis level was combined with laminoplasty.

¶ Wide group: the hinge trough was positioned at the inner margin of the lateral mass; narrow group: the hinge trough was positioned at one-third outside the lamina and 2-3 mm more inward than the wide-open method.

OPLL are at a greater risk of developing upper extremity palsy or C-5 palsy postoperatively.

Low to moderate evidence suggests no association between surgical approach, number of levels, estimated blood loss, laminoplasty and corpectomy, and perioperative complications. Longer operative duration is predictive of overall perioperative complications (moderate evidence) but not of major complications (low evidence).

Based on moderate evidence, there are higher rates of neck pain in laminoplasty compared with anterior spinal fusion and higher rates of dysphagia in ACDF than in Bryan disc. With respect to laminoplasty techniques, there is no difference in rates of C-5 palsy between wide and open-door laminoplasty (moderate evidence). Low evidence reports a lower incidence of C-5 palsy in laminoplasty with concurrent foraminotomy compared with no foraminotomy.

Discussion

This review summarizes important clinical and surgical predictors of postoperative complications. This knowledge will allow clinicians to identify high-risk patients and institute rigorous prevention strategies. Furthermore, surgeons can use this information to objectively discuss surgical risks with their patients. This, together with outcome prediction, will enable patients to make more informed decisions during the surgical-consent process and will also aid in expectation management. Finally, from an economic standpoint, health care providers will be able to appropriately allocate resources and predict future hospital utilization costs for each surgical patient.

Based on this review, age is a significant predictor of postoperative complications. This is consistent with previous lumbar spine studies that have shown significant adverse events in elderly patients following surgery.^{5,14} As CSM is a progressive disease, older patients are likely to have substantial degenerative pathology and will require a more complex surgery.¹⁹ In addition, the elderly can be less tolerant to surgery due to poorer overall general health status, comorbidities, and reduced physiological reserves.

There is controversy in the literature surrounding the predictive value of comorbidities. The number of comorbidities was significantly associated with perioperative complications in a study by Boakye et al.³ This finding was based on a large retrospective analysis of 58,115 patients undergoing spinal fusion at a single hospital. Furlan et al., on the other hand, reported no relationship between the number of ICD-9 codes and perioperative complications.²¹ This insignificant multivariate association may be due to a potential interaction between older age and number of comorbidities. Patients with diabetes, particularly uncontrolled or Type I, are at a greater risk of perioperative complications and may require a longer length of stay and more hospital resources. These findings are consistent with results from previous lumbar spine studies that concluded diabetes is a significant risk factor of wound infections and nonunions.^{2,17,23,62}

With respect to surgical factors, a longer operative duration is associated with greater perioperative complication rates. Duration of surgery may be a surrogate for case

TABLE 6. Evaluation of overall body of evidence using GRADE

Characteristic	Strength of Evidence	Conclusions/Comments	Baseline*	Upgraded† (levels)	Downgraded‡ (levels)
KQ1: Are there clinical or imaging factors that can predict perioperative complications?					
Age	High	Associated w/ perior complications: as reported by 3 studies (2 prospective, 1 retrospective), older patients are at a greater risk of perior complications	High		
	Low	Associated w/ axial pain: a single retrospective study reported that older age decreased the risk of postop axial pain	Low	LES (2)	Consistency UK, imprecise (-2)
	Low	Not associated w/ UE/C-5 palsy: 2 studies (1 prospective, 1 retrospective) reported no association between age & UE/C-5 palsy	High		Inconsistent, indirect (-2)
	Insufficient	There is insufficient evidence from a single retrospective study that age predicts major intraop blood loss	Low		Consistency/precision UK (-2), indirect (-1)
Comorbidities	Low	Not associated w/ perior complications: 2 (prospective) out of 3 studies found no association between comorbidities & perior complications	High		Inconsistent, precision UK (-2)
	Low-insufficient	There is insufficient evidence from a single retrospective study that diabetes (compared to no diabetes) is associated w/ cardiac complications & that uncontrolled diabetes (compared to controlled diabetes) is related w/ cardiac complications, hematomas, & postop infection	Low	LES (+1-2)	Consistency UK, imprecise (-2)
Sex	Moderate	Not associated w/ perior complications: as reported by 2 prospective studies, sex is not related w/ perior complications	High		Precision UK (-1)
	Insufficient	There is insufficient evidence from a single prospective study that sex predicts C-5 palsy	High		Consistency/precision UK, sparse (-3)
	Insufficient	There is insufficient evidence that sex predicts intraop blood loss (1 retrospective) & axial pain (1 retrospective)	Low		Indirect (-1) &/or consistency UK, imprecise or precision UK (-2)
BMI	Low	Not associated w/ perior complications: there is evidence from single prospective studies that BMI, duration of symptoms, & smoking status are not related to perior complications	High		Consistency/precision UK (-2)
Smoking status	Insufficient	There is insufficient evidence from a single retrospective study that duration of symptoms predicts axial pain	Low		Consistency UK, imprecise (-2)
Duration of symptoms	Insufficient	Not associated w/ perior complications: a single prospective study reported no association between baseline severity & perior complications	High		Consistency/precision UK (-2)
Baseline severity	Low	There is insufficient evidence that baseline severity predicts C-5 palsy (1 prospective) & axial pain (1 retrospective)	Low		Sparse (-1) &/or consistency UK, imprecise (-2)
Diagnosis	Low	Associated w/ UE or C-5 palsy: 2 studies (1 prospective, 1 retrospective) reported an association between a diagnosis of OPLL & postop UE or C-5 palsy	High	LES (+2)	Inconsistent, indirect, imprecise/precision UK, risk of bias (-4)

(continued)

TABLE 6. Evaluation of overall body of evidence using GRADE (*continued*)

Characteristic	Strength of Evidence	Conclusions/Comments	Baseline*	Upgraded† (levels)	Downgraded (levels)
KQ1: Are there clinical or imaging factors that can predict perioperative complications? (<i>continued</i>)					
Size of OPLL	Insufficient	There is insufficient evidence from a single retrospective study that size of OPLL & type of OPLL are predictive of intraop blood loss	Low		Consistency/precision UK, indirect (–3)
Preop Alignment	Insufficient	There is insufficient evidence from a single retrospective study that preop alignment & ROM predict axial pain	Low		Consistency UK, imprecise (–2)
Preop ROM	Insufficient	There is insufficient evidence from a single retrospective study that cervical alignment, no. of compressed segments, position of the superior articular process, cord inclination, & high intensity on T2-WI are predictive of C-5 palsy	High		Consistency UK, imprecise, sparse (–3)
Cervical alignment					
No. of compressed segments					
Position of articular process					
Cord inclination					
SI on T2-WI					
Occupying ratio	Insufficient	There is insufficient evidence from a single retrospective study that occupying ratio is predictive of UE paresis	Low		Consistency UK (–1)
	Insufficient	There is insufficient evidence from a single retrospective study that occupying ratio is predictive of intraop blood loss	Low	LES (+1)	Consistency UK, imprecise, indirect (–3)
KQ1: Are there surgical factors that can predict perioperative complications?					
No. of levels	Moderate	Not associated w/ periop complications: based on 2 prospective studies, the no. of levels is not associated w/ periop complications	High		Precision UK (–1)
	Insufficient	There is insufficient evidence that no. of opened lamina is predictive of C-5 palsy	High		Consistency UK, imprecise, sparse (–3)
	Insufficient	There is insufficient evidence from a single retrospective study that long fusion predicts UE paresis	Low		Consistency UK, imprecise, indirect (–3)
Surgical approach	Moderate	Not associated w/ periop complications: as reported by 2 prospective studies, surgical approach is not related to periop complications	High		Precision UK (–1)
Operative duration	Moderate	Associated w/ periop complications: based on a single prospective study, a longer operative duration is associated w/ periop complications	High		Consistency UK (–1)
	Low	Not associated w/ major periop: as reported by a single prospective study, operative duration is not associated w/ major periop complications	High		Consistency/precision UK (–2)
	Insufficient	There is insufficient evidence from single retrospective studies that operative duration is predictive of axial pain & UE paresis	Low		Consistency UK/imprecise (–2); indirect, consistency UK (–2)
No. of stages	High	Associated w/ major periop complications: based on a single prospective study, a 2-stage procedure is a risk factor for major periop complication development	High	LES (+2)	Consistency UK, imprecise (–2)
	Low	Not associated w/ periop complications: based on a single prospective study, no. of stages was not related w/ periop complications	High		Consistency/precision UK (–2)
Operative blood loss	Low	Not associated w/ periop complications: a single prospective study reported no association between operative blood loss & periop complications	High		Consistency/precision UK (–2)
	Insufficient	There is insufficient evidence from single retrospective studies that operative blood loss is predictive of axial pain & UE paresis	Low		Consistency UK (–1)

(continued)

TABLE 6. Evaluation of overall body of evidence using GRADE (*continued*)

Characteristic	Strength of Evidence	Conclusions/Comments	Baseline*	Upgrade† (levels)	Downgrade‡ (levels)
KQ1: Are there surgical factors that can predict perioperative complications? (<i>continued</i>)					
Laminoplasty, corpectomy	Low	Not associated w/ periop complications: a single prospective study reported no association between laminoplasty or corpectomy & periop complications	High		Consistency/precision UK (-2)
KQ2: Are there differences in rates of surgical complications between procedures?					
Anterior vs posterior	Insufficient	There is insufficient evidence from 4 studies (3 prospective, 1 retrospective) that complications differ between anterior & posterior surgery	Low		Risk of bias (-1)
Anterior corpectomy vs laminoplasty	Insufficient	There is insufficient evidence from 1 retrospective study that complication rates differ between anterior corpectomy & laminoplasty	Low		Consistency UK (-1)
Anterior decompression vs laminoplasty	Moderate	Higher rates of neck pain in laminoplasty: a single prospective study reported a higher incidence of neck pain in laminoplasty compared to ASF	High		Consistency UK (-1)
	Insufficient	There is insufficient evidence that rates of complications, C-5 radiculopathy, bone graft complications, axial pain, & postop kyphosis differ between anterior decompression & laminoplasty	Low		Risk of bias &/or consistency UK/inconsistent (-1)
ACDF vs Bryan disc	Moderate	Higher rates of dysphagia in ACDF: a single RCT reported a higher rate of dysphagia in ACDF than in Bryan disc surgery	High		Consistency UK (-1)
ACCF vs ACDF	Insufficient	There is insufficient evidence from 2 retrospective studies that complication rates differ between ACCF & ACDF	Low		Risk of bias &/or inconsistency (-1/-2)
LMF vs laminoplasty	Insufficient	There is insufficient evidence from 3 studies (1 prospective, 2 retrospective) that complication rates differ between LMF & laminoplasty	Low		Risk of bias &/or inconsistency (-1/-2)
Laminoplasty techniques	Moderate	No difference in rates of C-5 palsy between wide & narrow open-door laminoplasty: as reported by 1 RCT, hinge position did not affect rates of C-5 palsy	High		Consistency UK (-1)
	Low	Lower incidence of C-5 palsy in laminoplasty w/ concurrent foraminotomy: 2 studies (1 prospective, 1 retrospective) reported a lower incidence of C-5 palsy in a concurrent FG compared to the NFG	Low		
	Insufficient	There is insufficient evidence from 3 studies (1 prospective, 1 retrospective, 1 case-control) that rates of axial pain & C-5 palsy differ between C3-6/selective laminoplasty & C3-7 laminoplasty	Low		Consistency UK (-1) &/or risk of bias (-1)
	Insufficient	There is insufficient evidence from 2 prospective studies that rates of axial pain & postop kyphosis differ between muscle-preserving & muscle-disrupting groups	Low		Consistency UK, risk of bias (-2)
	Insufficient	There is insufficient evidence from single studies (2 prospective, 1 retrospective) that rates of C-5 palsy differ between open-door & double-door laminoplasty; rates of axial pain & neck stiffness differ between modified & original laminoplasty; & rates of aggravated neck pain, C-5 palsy, & other complications differ between midsplitting & unilateral single-door laminoplasty	Low		Consistency UK, risk of bias (-2)
Vancomycin	Insufficient	There is insufficient evidence from a single study that rates of infection differ between a vancomycin & a control group	Low		Consistency UK (-1)

LES = large effect size; RCT = randomized control trial; UK = unknown.

* Baseline quality: high = majority of article Level III/II; low = majority of articles Level III/IV.

† Upgrade: large magnitude of effect (1 or 2 levels); dose response gradient (1 level); plausible confounding decrease magnitude of effect (1 level).

‡ Downgrade: inconsistency of results (1 or 2 levels); indirectness of evidence (1 or 2 levels); imprecision of effect estimates (1 or 2 levels); risk of bias (1 or 2 levels); failure to specify subgroup analysis a priori (1 level); reporting bias (1 level).

complexity. Therefore, we do not recommend surgeons speed up surgery to prevent complications but rather identify complex cases, anticipate complications and plan accordingly. A 2-stage anteroposterior surgery is predictive of major complications; similarly, this factor may reflect greater degenerative pathology and increased case complexity.

The second objective of this review was to compare complication rates between various surgical techniques. Based on the results of KQ1, studies had to control for age and operative duration to be classified as good quality cohort studies. Unfortunately, the majority of the literature included in this review did not adjust for these 2 confounders, preventing accurate comparisons between groups.

There was low to moderate evidence, however, suggesting differences in complication rates between ACDF and laminoplasty, ACDF and Bryan's disc, narrow and wide-hinge laminoplasty, and presence and absence of concurrent foraminotomy. Postoperative neck pain is frequently encountered following laminoplasty and rates are significantly higher than following anterior spinal fusion.

Current hypotheses for intra- or postoperative C-5 nerve root palsy include traumatic surgical procedure, edema of the spinal cord, or tethering of the root. Yonenobu et al. suggested that C-5 palsy is more common following wide-open door laminoplasty due to excessive backward shift of the spinal cord.^{73,74} The hinge position determines how open the door is and an inward shift of the hinge restricts excessive backward shift and overstretching of the nerve roots.⁷¹ Although no patients in the narrow-group experienced C-5 palsy and 3 cases were seen in the wide group, this difference did not reach statistical significance. However, there was a lower incidence of this complication following laminoplasty with concurrent foraminotomy, suggesting that another potential cause of C-5 palsy is existing C-4/C-5 foraminal stenosis.³⁸

Strengths and Limitations

This is the first systematic review exploring important clinical, imaging, and surgical predictors of complications. It has highlighted some of the key knowledge gaps in the literature, including a lack of high-quality prospective prognostic studies and poor control of confounding variables in comparative studies. Our study has its limitations. First, our search was restricted to studies published in English, and as a result, some relevant abstracts were excluded. Second, although we analyzed the studies based on type of complication, we could not separate based on timing of complications. Third, articles that dichotomized a predictor might have done it differently (e.g., age). Finally, since the review process and critical appraisal does require scientific judgment, there is potential for discrepancy among reviewers and bias.

Evidence-Based Clinical Recommendations

Recommendation 1: While surgeons should not discriminate on the basis of age, they should be informed that older patients are at a higher risk of complications and are less likely to achieve a modified Japanese Orthopaedic Association (JOA) score ≥ 16 . We therefore recommend surgeons discuss these risks with their patients, plan and

institute rigorous preventative strategies, and closely monitor their patients in the perioperative period. Furthermore, health care systems should anticipate higher associated costs and allocate resources accordingly.

Strength of Statement: Moderate

Recommendation 2: Longer operative duration and 2-stage surgery are important predictors of complications. However, both likely reflect substantial degenerative pathology and increased case complexity. We therefore recommend surgeons identify these cases preoperatively, anticipate complications, and plan both preventative and postoperative management strategies.

Strength of Statement: Moderate

Consensus Statement 1: We suggest that results from this study guide the development of future complication prediction rules. Furthermore, we suggest that analyses in comparative complication studies control for operative duration and age.

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Disclosure

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author Contributions

Conception and design: Fehlings, Tetreault, Ibrahim. Analysis and interpretation of data: Tetreault, Ibrahim, Côté, Singh. Drafting the article: all authors. Critically revising the article: all authors. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Fehlings.

Correspondence

Michael G. Fehlings, The Toronto Western Hospital, University Health Network, Rm. 4W-449, 399 Bathurst St., Toronto, ON M5T 2S8, Canada. email: michael.fehlings@uhn.on.ca.