A Clinical Prediction Model to Determine Outcomes in Patients with Cervical Spondylotic Myelopathy Undergoing Surgical Treatment

Data from the Prospective, Multi-Center AOSpine North America Study

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Background: Cervical spondylotic myelopathy is a progressive spine disease and the most common cause of spinal cord dysfunction worldwide. The objective of this study was to develop a prediction model, based on data from a prospective multi-center study, relating a combination of clinical and imaging variables to surgical outcome in patients with cervical spondylotic myelopathy.

Methods: Two hundred and seventy-eight patients diagnosed with cervical spondylotic myelopathy treated surgically were enrolled at twelve different sites in the multi-center AOSpine North America study. Univariate analyses were performed to evaluate the relationship between outcome, assessed with the modified Japanese Orthopaedic Association (mJOA) score, and various clinical and imaging predictors. A set of important candidate variables for the final model was selected on the basis of author consensus, literature support, and statistical findings. Logistic regression was used to formulate the final model.

Results: Univariate analyses demonstrated that the odds of a successful outcome decreased with a longer duration of symptoms (odds ratio [OR] = 0.80, 95% confidence interval [CI] = 0.65 to 0.98, p = 0.030); a lower baseline mJOA score (OR = 0.74, 95% CI = 0.65 to 0.84, p < 0.0001); the presence of psychological comorbidities (OR = 0.51, 95% CI = 0.29 to 0.92, p = 0.024); the presence of broad-based, unstable gait (OR = 2.72, 95% CI = 1.47 to 5.06, p = 0.0018) or other gait impairment (OR = 3.56, 95% CI = 1.75 to 7.22, p = 0.0005); and older age (OR = 0.96, 95% CI = 0.93 to 0.98, p = 0.0004). The dependent variable, the mJOA score at one year, was dichotomized for logistic regression: a ''successful'' outcome was defined as a final score of ≥16 and a ''failed'' outcome was a score of <16. The final model included age (OR = 0.97, 95% CI = 0.94 to 0.99, p = 0.0017), duration of symptoms (OR = 0.78, 95% CI = 0.61 to 0.997, p = 0.048), smoking status (OR = 0.46, 95% CI = 0.21 to 0.98, p = 0.043), impairment of gait (OR = 2.66, 95% CI = 1.17 to 6.06, p = 0.020), psychological comorbidities (OR = 0.33, 95% CI = 0.15 to 0.69, p = 0.0035), baseline mJOA score (OR = 1.22, 95% CI = 1.05 to 1.41, p = 0.0084), and baseline transverse area of the cord on magnetic resonance imaging (OR = 1.02, 95% CI = 0.99 to 1.05, p = 0.19). The area under the receiver operator characteristic curve was 0.79, indicating good model prediction.

Conclusions: On the basis of the results of the AOSpine North America study, we identified a list of the most important predictors of surgical outcome for cervical spondylotic myelopathy.

Level of Evidence: Prognostic Level II. See Instructions for Authors for a complete description of levels of evidence.

Cervical spondylotic myelopathy is the most common cause of spinal cord dysfunction worldwide. It is a progressive disease caused by the degeneration of various components of the vertebra, including the vertebral body, the intervertebral disc, the supporting ligaments, and the facet joints[1]. Various static factors and anatomical changes in the

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spine may lead to narrowing of the spinal canal and potentially to mechanical compression of the neural elements[2]. Long-standing compression of the spinal cord can lead to irreversible damage including demyelination and necrosis of the gray matter[3]. Surgery has been used for the treatment of cervical spondylotic myelopathy to arrest its progression, prevent further neurological disability, and improve clinical status[4].

The multi-center AOSpine North America cohort study was undertaken primarily to evaluate the impact of surgery on functional, quality-of-life, and disability outcomes and to assess the value of surgery across the full range of myelopathy severity. The results of that study suggested that surgery has a positive effect on all outcome measures and that it is useful for the treatment of mild to severe myelopathy, as discussed in the companion paper by Fehlings et al. in this issue. A secondary objective of the AOSpine North America study was to create a clinical prediction model relating the best combination of clinical and imaging factors to postoperative outcome.

An extensive systematic review of the literature on surgical treatment of cervical spondylotic myelopathy revealed duration of symptoms, baseline modified Japanese Orthopaedic Association (mJOA) score, and age to be the clinical factors most commonly reported as predictors of surgical outcome[5-7]. In addition to these three factors, it is important to consider smoking status, sex, signs and symptoms, and comorbidities as potential predictors in the model[8]. As the diagnosis of cervical spondylotic myelopathy is confirmed through imaging, it is also critical to assess whether magnetic resonance imaging (MRI) is a valuable prognostic tool and whether spinal cord properties or canal dimensions are more important. A systematic review by Karpova et al. revealed that a smaller transverse spinal cord area, multisegmental signal changes on a T2-weighted image, and the presence of a combination of T1 and T2 signal changes are all predictive of a poor surgical outcome[9].

The aim of the present study was to design a clinical prediction model relating imaging and clinical variables to surgical outcome, utilizing high-quality, prospectively collected data on 272 patients enrolled in the AOSpine North America study at twelve different North American sites. To our knowledge, this is the largest prospective multi-center analysis evaluating important predictors of surgical outcome in patients with cervical spondylotic myelopathy.

Materials and Methods

Subjects

From December 2005 to September 2007, 278 patients with clinically diagnosed and imaging-confirmed cervical spondylotic myelopathy were enrolled at twelve participating sites across North America. Patients were asked to participate in the study if they satisfied the inclusion criteria of (1) an age of eighteen years or older, (2) presentation of symptomatic cervical spondylotic myelopathy with at least one clinical sign of myelopathy, and (3) an absence of previous cervical spine surgery. Patients with asymptomatic cervical spondylotic myelopathy, active infection, neoplastic disease, rheumatoid arthritis, ankylosing spondylitis, and concomitant lumbar stenosis were excluded.

All enrolled patients underwent surgical decompression combined with instrumented fusion. The surgical approach (anterior and/or posterior) and the number of operated segments were determined by the surgeon. Patients treated anteriorly underwent cervical discectomy and fusion, corpectomy and fusion, or a combination of procedures. Posterior procedures included laminectomy and fusion, laminoplasty, or a combination of these techniques. Extensive data for each participating subject (including demographic information, a surgical summary, symptomatology, medical history, neurological and imaging assessment, and patient-assessed quality of life) were collected at baseline and at six, twelve, and twenty-four months. Data at the one-year follow-up visit were used to assess important predictors of outcome as the follow-up rate was substantially higher than at two years.

The MRI scans were acquired prior to surgery with use of a 1.5-T General Electric instrument (Milwaukee, Wisconsin) and a standardized imaging protocol. Radiologists analyzed the images with use of digital software without knowledge of the patient's clinical and neurological status. Cord compression was assessed on T2-weighted MRI by measuring the transverse area at maximal compression and the midsagittal spinal cord diameter.

Primary Outcome Measure

The mJOA score (see Appendix) for each patient was determined preoperatively and at each follow-up visit. The mJOA score was selected as the primary outcome measure for this analysis as it is a widely accepted standard for assessing the functional status of patients with cervical spondylotic myelopathy. This 18-point scale was modified from the validated JOA scale by Benzel et al. and separately addresses upper and lower extremity motor function, sensory function, and sphincter function[10]. The mJOA score, evaluated at the one-year follow-up visit, was dichotomized for logistic regression; a successful outcome was defined as a final mJOA score of ≥16, and a failed outcome was a score of <16. The cutoff of 16 points was deemed clinically appropriate by all authors as it was within the range of mild impairment according to the criteria used in the AOSpine North America study.

Analytical Methods

Descriptive statistics were calculated for all relevant variables in the AOSpine North America study database with use of only true, not imputed, data. Continuous predictors including age, duration of symptoms, and baseline mJOA score were described with use of means, standard deviations, and ranges. Categorical variables such as sex, smoking status, and comorbidities were described with use of frequencies. The duration of symptoms could not be transformed without having remaining outliers and was categorized into five groups: up to three months, more than three months to six months, more than six months to twelve months, more than twelve months to twenty-four months, and more than twenty-four months. Missing follow-up data and missing MRI or computed tomography measurements were assumed to be missing at random and were replaced with a set of plausible values derived using a multiple imputation procedure with ten iterations. As suggested by the U.S. Food and Drug Administration (FDA), multiple imputation is the preferred method for handling missing data in a therapeutic trial. Use of this procedure is likely to yield results that are less susceptible to bias and is more efficient than removing patients with incomplete data[11-13].

Simple logistic regression analyses were conducted with use of the imputed data to evaluate the association between surgical outcome and various clinical and imaging factors. Predictors that yielded a p value of <0.05 in univariate analyses were included in a multivariate analysis[14]. In addition, variables that had a p value of >0.05 but were considered to be clinically important by author consensus were also assessed in the multivariate analysis.

Collinearity of all variables was evaluated by calculation of tolerance. Manual backward stepwise regression was used to determine the best combination of predictors. Variables were included if they were either significant ($p < 0.05$) or considered to be clinically relevant. Logistic regression was used to determine the odds ratios (ORs) and the parameter estimates of the intercept and covariates. The prediction equation is given by:

$$\log \frac{P_i}{1 - P_i} = \beta_0 + \sum_{j=1}^{p} \beta_j X_{ij}$$

where P_i is the probability of outcome i, the term on the left side of the equation is the logarithm of the odds of the outcome, β_0 is the estimate of the intercept, and the β_j values are the parameter estimates of the predictor variables X_j.

Secondary Analysis

Given the non-normal distribution of the data and the limitations of the mJOA scale, logistic regression analysis was identified as the best statistical model for this study. Similar steps, however, were taken to also create a multiple linear regression model relating the most important predictors to the one-year mJOA score, treated as a continuous variable.

Source of Funding

Collection of the prospective outcomes data was supported by a grant provided by AOSpine North America.

Results

A total of 278 patients met all inclusion criteria and were treated surgically. Six of these patients had a perfect preoperative mJOA score (18 out of 18) and were therefore excluded; the remaining 272 patients were included in the analysis (Table I). All patients underwent a preoperative evaluation including determination of the baseline mJOA score. Fifty-five (20%) of the 272 patients did not complete the one-year follow-up assessment because they had withdrawn from the study, did not attend the scheduled appointment, or had died; data for these patients were imputed. The remaining 217 patients completed the one-year follow-up assessment. Transverse spinal cord area measurements were missing for 132 patients (49%) and were also imputed.

The study cohort consisted of 112 women and 160 men, with ages ranging from twenty-nine to eighty-six years (mean [and standard deviation], 56.5 ± 11.5 years). The patients had a wide range of preoperative severity (baseline mJOA score, 3 to 17; mean, 12.71 ± 2.60). The duration of symptoms ranged from 0.50 to 432 months.

The most common symptoms were numb and clumsy hands, gait impairment, and weakness. Most patients also presented with hyperreflexia. The primary sources of stenosis were spondylosis and disc herniation, with many patients presenting with both.

Univariate Analyses

The variables that were significantly associated ($p < 0.05$) with the binary response variable (mJOA score) in the univariate analyses were the presence of psychological comorbidities ($p = 0.024$); age ($p = 0.0004$); baseline mJOA score ($p < 0.0001$); broad-based, unstable gait ($p = 0.0018$); impairment of gait ($p = 0.0005$); and duration of symptoms ($p = 0.030$) (Table II). The relationships between the final mJOA score and the presence of cardiovascular comorbidities ($p = 0.076$), smoking status ($p = 0.057$), the number of levels ($p = 0.12$), transverse spinal cord area ($p = 0.11$), and weakness ($p = 0.18$) had p values of <0.2

TABLE I Characteristics of the 272 Patients with Surgically Treated Cervical Spondylotic Myelopathy

General characteristics	
Age* *(yr)*	56.5 ± 11.5 (29-86)
Sex *(M/F)*	160/112
Symptom duration, n = 271* *(mo)*	23.8 ± 34.6 (0.5-432)
Baseline mJOA score*	12.71 ± 2.6 (3-17)
1-year mJOA score, n = 217*	15.7 ± 2.5 (6-18)
Smoking *(Y/N)*	71/201
Symptoms, n = 271 *(Y/N)*	
Numb hands	242/29
Clumsy hands	213/58
Impairment of gait	206/65
Bilateral arm paresthesias	141/130
L'hermitte phenomena	85/186
Weakness	238/33
Signs, n = 271 *(Y/N)*	
Corticospinal motor deficits	136/135
Atrophy of hand muscles	108/163
Hyperreflexia	199/72
Positive Hoffmann sign	172/99
Upgoing plantar response	77/194
Lower limb spasticity	105/166
Broad-based, unstable gait	142/129
Comorbidities, n = 272 *(Y/N)*	
Cardiovascular	128/144
Respiratory	38/234
Endocrine	59/213
Gastrointestinal	48/224
Renal	12/260
Psychiatric	66/206
Rheumatologic	24/248
Neurological	26/246
Diagnosis†	
Spondylosis	214
Disc herniation	189
Ossification of posterior longitudinal ligament	24
Hypertrophy of ligamentum flavum	61
Congenital stenosis	43
Subluxation	13
Other	7
Transverse area, n = 139* *(mm²)*	45.9 ± 14.1 (16.0-84.5)
Surgical approach	
Anterior	169
Posterior	95
Combined	14

*The values are given as the mean and the standard deviation, with the range in parentheses. †A patient could have more than one diagnosis.

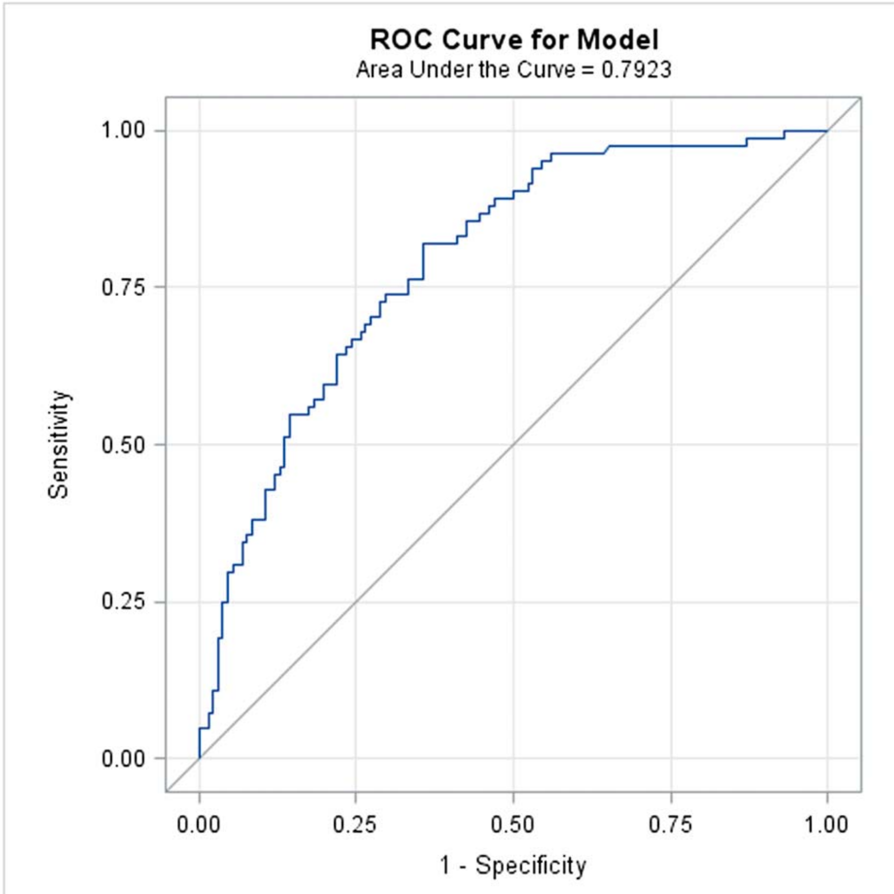

Fig. 1

ROC curve for the logistic regression clinical prediction model. An ROC curve plots the true-positive rate (sensitivity) against the false-positive rate (1 − specificity). The predictive performance of this model can be quantified by calculating the area under the ROC curve. An area of 1 indicates a perfect test (100% specific and 100% sensitive), whereas an area of 0.5, indicated by the diagonal line, indicates no discriminative value. The displayed area of 0.79 suggests that this model had good discrimination (with good defined as an area of between 0.70 and 0.80).

and were also included in the multivariate model. It was our consensus that no additional clinical or imaging factors should be examined further.

Manual Backward Stepwise Regression

Assessment of tolerance indicated collinearity between the symptom of impairment of gait and the sign of broad-based, unstable gait. Broad-based, unstable gait was therefore excluded from the multivariate analysis. The logistic regression model that was created with use of manual backward stepwise regression consisted of six significant clinical variables and one imaging variable deemed clinically relevant (Table III). The area under the receiver operator characteristic (ROC) curve was 0.79 (Fig. 1). According to the final model, the odds of a successful outcome (mJOA score ≥ 16) were greater when the patient had a higher preoperative mJOA score (OR = 1.22, p = 0.0084), did not smoke (OR = 0.46, p = 0.043), did not have psychological comorbidities (OR = 0.33, p = 0.0035), did not have impaired gait (OR = 2.66, p = 0.020), was younger in age (OR = 0.97, p = 0.017), had a shorter duration of symptoms (OR = 0.78, p = 0.048), and had a larger transverse spinal cord area (OR = 1.02, p = 0.19). Impairment of gait was assigned a value of 0 for presence or 1 for absence, the baseline mJOA value was scored continuously from 0 to 18, smoking status was assigned a value of 0 for no and 1 for yes, duration of symptoms was assigned a value of 1 through 5 as described in the Materials and Methods, and psychological comorbidities were assigned a value of 0 for absence or 1 for presence. This resulted in the following final logistic regression model: Log(odds of success) = −0.028 – 0.25(duration of symptoms) + 0.20(baseline mJOA) − 1.12(psychological comorbidities) – 0.78(smoking) – 0.035(age) + 0.98(impairment of gait) + 0.020(transverse area).

Specifically, the odds of a successful outcome (1) decreased by 22% when the duration of symptoms increased from three months or less to at least three but less than six months, (2) were 1.22 times greater for every one-point increase in the preoperative mJOA score, (3) decreased by 3% for

TABLE II Univariate Analysis of the Relationship of Clinical and Imaging Factors with the Odds of a Successful Outcome

Variable*	β Estimate	P Value	OR	95% CI† of OR
General characteristics				
Baseline mJOA	−0.30	<0.0001	0.74	0.65 to 0.84
Age in yr	−0.045	0.0004	0.96	0.93 to 0.98
Symptom duration	−0.22	0.030	0.80	0.65 to 0.98
Smoking status	−0.64	0.057	0.53	0.27 to 1.30
Comorbidities				
Psychological	−0.67	0.024	0.51	0.29 to 0.92
Cardiovascular	−0.48	0.076	0.62	0.36 to 1.05
Signs				
Broad-based gait	1.00	0.0018	2.72	1.47 to 5.06
Symptoms				
Impairment of gait	1.27	0.0018	3.56	1.75 to 7.22
Weakness	−0.58	0.18‡	0.56	0.24 to 1.30
Imaging				
Transverse area in mm^2	0.021	0.11‡	1.02	0.995 to 1.05
No. of levels	−0.17	0.12‡	0.84	0.68 to 1.04

*Baseline mJOA: 1 to 18. Symptom duration: 1 = ≤3 mo, 2 = >3 but ≤6 mo, 3 = >6 but ≤12 mo, 4 = >12 but ≤24 mo, 5 = >24 mo. Smoking and psychological and cardiovascular comorbidities: 0 = no, 1 = yes. Broad-based gait, impairment of gait, and weakness: 0 = yes, 1 = no. ‡Although p was not <0.05, the variable was included in the multivariate analysis because p was <0.2. †CI = confidence interval.

every one-year increase in age, (4) were approximately half as great for patients who smoked compared with nonsmokers, (5) were 2.66 times greater for patients without impaired gait than for those with this symptom, (6) were 67% lower for patients with psychological comorbidities, and (7) were 1.02 times greater for every one-point increase in transverse area (Table III).

Secondary Analysis

A secondary analysis using multiple linear regression yielded results similar to those of the logistic regression: the same set of predictors was identified as the most clinically and statistically important (Table IV). The model had an R^2 value of 0.26 and is given by the following equation: Final mJOA = 14.34 + 0.96(impairment of gait) + 0.21 (baseline mJOA) – 0.022(age) − 0.73(smoking) + 0.024(transverse area) − 0.31(duration of symptoms) – 1.23(psychological comorbidities).

As with the logistic regression equation, a higher final mJOA score was associated with an absence of impaired gait (p = 0.0062), absence of psychological comorbidities (p = 0.0005), higher baseline mJOA score (p = 0.002), younger age (p = 0.084),

TABLE III Final Logistic Regression Model Relating the Best Combination of Clinical and Imaging Predictors to the Dichotomized Postoperative mJOA Score

Variable*	β Estimate	P Value	OR	95% CI† of OR
Intercept	−0.028	—	—	—
Psychological comorbidities	−1.12	0.0035	0.33	0.15 to 0.69
Baseline mJOA	0.20	0.0084	1.22	1.05 to 1.41
Age in yr	−0.035	0.017	0.97	0.94 to 0.99
Impairment of gait	0.98	0.020	2.66	1.17 to 6.06
Smoking	−0.78	0.043	0.46	0.21 to 0.98
Symptom duration	−0.25	0.048	0.78	0.61 to 0.997
Area in mm^2	0.020	0.19	1.02	0.99 to 1.05

*Psychological comorbidities and smoking: 0 = no, 1 = yes. Baseline mJOA: 0 to 18. Impairment of gait: 0 = yes, 1 = no. Symptom duration: 1 = ≤3 mo, 2 = >3 but ≤6 mo, 3 = >6 but ≤12 mo, 4 = >12 but ≤24 mo, 5 = >24 mo. †CI = confidence interval.

TABLE IV Final Multiple Linear Regression Model Relating the Best Combination of Clinical and Imaging Predictors to the Continuous Postoperative mJOA Score

Variable*	β Estimate	95% CI† of β Estimate	P Value
Intercept	14.34	—	—
Psychological comorbidities	−1.23	−1.92 to −0.55	0.0005
Baseline mJOA	0.21	0.076 to 0.34	0.0020
Symptom duration	−0.31	−0.53 to −0.091	0.0057
Impairment of gait	0.96	0.27 to 1.64	0.0062
Smoking	−0.73	−1.45 to −0.015	0.045
Area in mm^2	0.024	−0.0031 to 0.050	0.081
Age in yr	−0.022	−0.047 to 0.0030	0.084

*Psychological comorbidities and smoking: 0 = no, 1 = yes. Impairment of gait: 0 = yes, 1 = no. Symptom duration: 1 = ≤3 mo, 2 = >3 but ≤6 mo, 3 = >6 but ≤12 mo, 4 = >12 but ≤24 mo, 5 = >24 mo. †CI = confidence interval.

nonsmoking status (p = 0.045), a larger transverse area (p = 0.081), and a shorter duration of symptoms (p = 0.0057).

Discussion

To our knowledge, this is the first study evaluating important predictors of surgical outcome with use of a multi-center, prospectively collected database of patients with symptomatic cervical spondylotic myelopathy. In addition, we believe that it represents the largest study of its kind, with a sample size of 272 patients. Since the study cohort had a wide range of ages and baseline severities and included a substantial percentage of patients presenting with various signs and symptoms and comorbidities, the results of this study should be generally applicable to future patients diagnosed with cervical spondylotic myelopathy and treated surgically.

The primary findings of this study were that a lower preoperative mJOA score (greater severity), smoking, older age, psychological comorbidities, longer duration of symptoms, smaller transverse spinal cord area, and presence of impaired gait were all associated with a decreased probability of a successful outcome. These variables made up the logistic regression equation relating the most important clinical and imaging factors to the dichotomized postoperative mJOA score.

The multiple linear regression equation consisted of the same seven predictors as the logistic regression equation. All of the variables except for transverse area were significant ($p < 0.05$); area approached significance and was deemed clinically relevant. This model is more clinically useful as it permits the prediction of an exact postoperative mJOA score instead of the odds of having a score greater of ≥16. Statistically speaking, however, this model violates a key assumption of multiple linear regression as the response variable was not normally distributed: 50% of the patients had a final mJOA score of 17 or 18, with 35% of the patients achieving a perfect score of 18.

Several previous studies have confirmed that both the baseline severity score and duration of symptoms are important predictors of the surgical outcome[15-22]. The rationale behind these two findings is that both severe and chronic, long-standing compression of the spinal cord may lead to irreversible damage due to demyelination and necrosis of the gray matter.

Controversy remains regarding the significance, strength, and direction of the relationship between surgical outcome and age. The current study demonstrated that age was a predictor and that older patients had decreased odds of a favorable outcome. Although most surgeons will not discriminate on the basis of age, they should be aware that elderly patients are not able to translate neurological recovery to functional improvement as well as a younger population can. There are several potential explanations for this discrepancy: (1) the elderly experience age-related changes in the spinal cord including a decrease in the number of γ-motoneurons, number of anterior horn cells, and number of myelinated fibers in the corticospinal tracts and posterior funiculus, (2) older patients are more likely to have unassociated comorbidities that may affect outcome, or (3) the elderly may not be able to conduct all of the activities on a functional scale as a result of these comorbidities[7,23-26]. The significant association between age and surgical outcome in the present study should help confirm that age does affect surgical results at one year postoperatively.

The present study revealed that a patient who smokes is less likely to have a successful outcome compared with a nonsmoker. It has previously been suggested that smoking negatively affects the outcome of lumbar spine surgery, as smoking was correlated with lower rates of fusion and higher rates of wound infections. Hilibrand et al. investigated the impact of smoking in patients with cervical spondylotic myelopathy treated with multilevel anterior cervical decompression with autogenous bone-grafting and determined that the rate of solid osseous union was higher in nonsmokers than in smokers[27]. Because of increased fusion rates, better outcomes were observed in the nonsmoking population. Although the patients in our study who smoked had a lower probability of a successful outcome compared with the nonsmokers, we do not believe that this was due to a lower fusion rate: only two of the seventy-one current smokers experienced pseudarthrosis or a nonunion, compared with five of the 201 nonsmokers (Fisher exact test, p = 1.0).

Impaired gait and the presence of psychological comorbidities have previously been reported, in one study each, as having a negative effect on surgical results. Wang and Green studied a series of patients who underwent revision laminectomy following failed anterior cervical discectomy and fusion[28]. Patients with more severe gait impairment had a poorer surgical outcome as assessed with the Nurick score. The impact of emotional and psychological issues on outcome was evaluated by Kumar et al.[29], who found a significantly greater occurrence of depression, as evaluated by the Short Form-36 (SF-36), in the group with a poor outcome than in the group with a good outcome. However, Kumar et al. also noted the difficulty in drawing conclusions regarding the predictive value of psychological comorbidities on the basis of patient-generated outcome measures, such as the SF-36. To our knowledge, the present study is the first to find a significant and a strong negative association between the presence of impaired gait or psychological comorbidities and the final mJOA score.

The last predictor included in the model was the transverse spinal cord area. Four of the five equations formulated in previous studies included various imaging factors as predictors, suggesting that it was necessary to take MRI features into account when developing the model. The relationship between transverse area and outcome was not significant in the univariate logistic regression analysis. However, this variable was still included in the final model as it was identified as a clinically important predictor by all authors on the basis of past experience and findings from the literature. Okada et al. reported an association between preoperative transverse area and recovery rate in patients with either ossification of the posterior longitudinal ligament of the spine or cervical spondylotic myelopathy[30]. This finding is consistent with other studies that also suggest a relationship between transverse area and the recovery percentage or functional score at the time of long-term follow-up[16,31]. Since there is adequate support from the literature and since the association between outcome and transverse area approached significance, it was included in the final model.

Study Strengths and Limitations

The data used for this analysis were collected prospectively at twelve different sites across North America. Since there were multiple recruitment centers, we were able to accrue a sample of 278 patients; to our knowledge, this is more than three times the size of any previously conducted study on the prediction of surgical outcomes of patients with cervical spondylotic myelopathy. Since the patients enrolled were treated surgically at hospitals across the continent, the findings from the present study should be more generalizable and more applicable to future populations than conclusions from previous single-center studies would be. One of the major limitations of this study involves the 20% loss to follow-up at one year and 49% missing data for transverse spinal cord area. The missing data were accounted for with use of a multiple imputation procedure with ten iterations, in accordance with statistical recommendations. Another limitation is the violation of normality in the response variable, which could affect the results of multiple linear regression. Since the predictors were identical in the logistic regression and the multiple linear regression, it is likely that either equation could be used to successfully predict the surgical outcome. This model will need to be validated on a second external data set to determine its predictive ability in future populations.

Appendix

eA A table outlining the mJOA scale is available with the online version of this article as a data supplement at jbjs.org. ■

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