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ORIGINAL ARTICLE

Preoperative predictors of postoperative pulmonary complications in neuromuscular scoliosis

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Abstract
Background Neuromuscular scoliosis (NMS) is associated with progressive restrictive lung disease and an increased risk of prolonged ventilation following surgery. This study reports the experiences of a single institution and evaluates whether preoperative pulmonary function tests (PFT) can predict the development of postoperative pulmonary complications.
Methods Correlations between preoperative PFT (forced expired volume in 1 s, FEV_1; forced vital capacity, FVC) findings and postoperative pulmonary complications were searched for among 74 NMS patients who underwent surgical correction at our medical center from 2002 to 2008.
Results Thirty-seven patients (50%) developed a pulmonary complication. The independent factors found to contribute to the development of a pulmonary complication were: FEV_1 <40% of the predicted value ($P = 0.007$), FVC <39.5% of the predicted value ($P = 0.005$), a larger Cobb angle (>69°) ($P = 0.002$), and older age (>16.5 years) ($P = 0.027$). Of these 37 patients, 6 needed postoperative ventilation. PFT findings found to be independently associated with the need for postoperative ventilation were: FEV_1 <40% of the predicted value ($P = 0.017$) and FVC <39.5% of the predicted value ($P = 0.015$).
Conclusions NMS patients with a preoperative FVC of <39.5% of the predicted value, an FEV_1 <40% of the predicted value, a Cobb angle of >69°, or age >16.5 years were found to be more likely to develop a postoperative pulmonary complication.

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Introduction

Scoliosis is associated with progressive restrictive lung disease, which increases the risks of pulmonary complications following surgical correction [1]. In addition to the restrictive lung deficit caused by the spinal deformity, neuromuscular scoliosis (NMS) impairs pulmonary function because of muscular weakness. Accordingly, NMS can lead to important pulmonary complications, including respiratory failure requiring prolonged ventilator support after surgery. As the Cobb angle (lateral curvature) progresses beyond 65°, lung volumes are reduced, and a ventilation/perfusion mismatch can occur. In severe cases (a Cobb angle of >100°), pulmonary hypertension and right ventricular hypertrophy may develop [2].

Pulmonary function testing is still widely used for preoperative pulmonary evaluation. However, it has been demonstrated that no specific factor can predict the need for postoperative ventilation, although an increased tendency was noted in patients with Duchenne muscular dystrophy (DMD) with a preoperative FVC (forced vital capacity) of <30% in children [3]. Another study demonstrated that an FEV_1 (forced expired volume in 1 s) of <40% of the predicted value predisposes the need for mechanical ventilation postoperatively in NMS children [4]. However, the ability of pulmonary function tests (PFT) to predict the risk of a postoperative pulmonary complication in NMS at any age group has not been determined.

Moreover, additional intraoperative factors, such as the duration and type of surgery, may influence the need for postoperative ventilation.

The objective of this study was to evaluate if PFT is useful for predicting a postoperative pulmonary complication or predicting the need for prolonged mechanical ventilation following neuromuscular scoliosis correction surgery, and to identify other factors that influence the risk of a postoperative pulmonary complication.

Methods

With institutional ethical review board approval, all patients with NMS undergoing spinal deformity surgery at our institute from 2002 to 2008 were enrolled in this retrospective analysis. Preoperative PFT was performed prior to posterior spinal fusion surgery. Surgeons routinely refer their scoliosis patients for a preoperative pulmonary evaluation and preoperative PFT 1–4 weeks prior to surgery. The main outcome measure was the incidence of postoperative pulmonary complications.

Charts were reviewed for the following information: (1) date of surgery; (2) age at time of surgery; (3) gender; (4) weight; (5) primary diagnosis of scoliosis; (6) preoperative PFT parameters (forced expired volume in 1 s, FEV_1; forced vital capacity, FVC; and FEV_1/FVC ratio); (7) preoperative chest X-ray findings; (8) duration of anesthesia, blood loss, blood transfusion volumes, and number of vertebrae fused; (9) date of extubation or the need for re-intubation and mechanical ventilator support; (10) any intra-operative or postoperative complications, such as pneumonia, effusions, atelectasis, infiltrates, or lung collapse. The following information was reviewed and correlated: preoperative PFT parameters (FEV_1, FVC, FEV_1/FVC ratio) or other factors, and the presence of a postoperative pulmonary complication.

Routine PFT was performed in the pulmonary physiology laboratory at our institute, which is located at sea level. FEV_1 and FVC were obtained from forced exhalation into a mass flow sensor. Results are reported as percentages of predicted values based on gender, arm-span, age, and weight.

All patients were anesthetized by one of three consultant anesthetists using a standardized technique. Briefly, anesthesia was induced with propofol 2–3 mg/kg, and rocuronium 0.6 mg/kg was used to facilitate endotracheal intubation. Anesthesia was then maintained with a remifentanil 0.05–0.4 μg/kg/min and propofol 30–150 μg/kg/min infusion or sevoflurane 0.6–0.7 MAC in a mixture of oxygen and air. Mean arterial pressure was maintained between 50 and 70 mmHg. Two large peripheral intravenous cannulae were inserted. In addition to standard general anesthetic monitoring, the bispectral index and invasive arterial pressure were monitored, and a urine catheter was inserted. A central venous catheter was also inserted to improve venous access for pressure monitoring and administering inotropic drugs. Temperature monitoring, intravenous fluid warmers, and warm air blankets were used throughout to maintain normothermia. Somatosensory-evoked potentials (SSEP) or motor-evoked potentials (MEP) were used to monitor the integrity of the spinal cord during surgery when necessary. All operations were performed by one spinal surgeon, and surgical procedures were performed via a posterior spinal fusion approach only. At the end of surgery, intravenous patient-controlled analgesia was started.

All patients received pulmonary toilet, and all chest radiographs taken within 3 days of surgery were reviewed for the presence of effusions, atelectasis, infiltrates, lung collapse, edema, pneumothorax, or hemothorax. Need and length of postoperative intubation with ventilator support and the occurrence of any pulmonary infectious complication that occurred until 3 months of surgery were also reviewed. Pneumonia was defined by the presence of a new or progressive localized infiltrate in chest radiographs within 3 months in the presence of two of the following: hypo/hyperthermia, an elevated white blood cell count, cough with purulent tracheal secretion/sputum, and decreased oxygenation. These criteria were adjusted by our hospital committee because no single set of reliable criteria is available to diagnose pneumonia, which requires clinical and radiographic methods, and laboratory support.

Statistical analysis

All values are reported as means (SD) or as numbers of patients. For univariate analysis, the *t* test was used to evaluate the effects of continuous variables (age, weight, PFT variables, Cobb angle, duration of anesthesia, blood loss, levels fused) on the development of a postoperative pulmonary complication or the need for postoperative ventilation. The chi-square test and Fisher's exact test were used to evaluate the associations among gender, diagnosis, preoperative chest X-ray findings, and dichotomized PFT variables and the development of a postoperative pulmonary complication or the need for postoperative ventilation. Pulmonary function test findings were evaluated as both continuous and dichotomous variables. Multivariate logistic regression analysis was used to evaluate the ability of variable combinations to predict the development of a postoperative pulmonary complication. Using the predicted probabilities from the logistic regression models, we constructed receiver-operating characteristic (ROC) curves. The ROC curve is a plot of sensitivity against (1-specificity) of a given marker, and an optimal cutoff, calculated from

Table 1 Postoperative pulmonary complication: patient demographics

	Pulmonary complication	No pulmonary complication	*P* value
N	37 (50%)	37 (50%)	
Age (years)	18.59 ± 7.73	16.16 ± 7.22	0.166
Weight	42.36 ± 10.71	42.84 ± 11.47	0.857
Cobb angle	77.11 ± 29.65	63.95 ± 26.67	0.048
Gender			
Males	23 (31%)	27 (36%)	n.s
Females	14 (19%)	10 (14%)	
Diagnosis			
Cerebral palsy	10 (14%)	6 (8%)	n.s
Duchenne muscular dystrophy	12 (16%)	18 (24%)	
Spinal muscular atrophy	5 (6%)	9 (12%)	
Neurofibromatosis	4 (5%)	2 (3%)	
Poliomyelitis	1 (1%)	1 (1%)	
Congenital muscular dystrophy	1 (1%)	0 (0%)	
Congenital myopathy	0 (0%)	1 (1%)	
Multiple sclerosis	1 (1%)	0 (0%)	
Marfan syndrome	1 (1%)	0 (0%)	
Prader Willi syndrome	1 (1%)	0 (0%)	
Post-traumatic spinal injury	1 (1%)	0 (0%)	

Values are mean ± SD or numbers (percentages) of patients

n.s Non-significant

the maximal sum of sensitivity and specificity, is presented. The sensitivity and specificity (with confidence interval) based on the optimal cutoffs were assessed with the bootstrap normal approximation method. The area under the curve (AUC) value can therefore be used as a summary of the predicted usefulness of a given model. The AUC was computed for each curve using numerical integration. Statistical significance was accepted for *P* values of <0.05.

Results

Data were available for a total of 104 neuromuscular scoliosis patients who underwent surgery at our institute from 2002 to 2008. Two patients were excluded due to inadequate records and progress notes. Of the remaining 102 patients, 74 patients (72.5%) underwent preoperative PFT, and therefore we analyzed the data of these patients. The demographics of these patients are shown in Table 1. Of 28 that did not undergo preoperative PFT, 27 patients had cerebral palsy with mental retardation, and 1 had meningomyelocele. Sixteen patients (57%) of these 28 who did not undergo PFT developed pulmonary complications (9 pleural effusion, 5 hemothorax/pneumothorax, 2 pulmonary edema, 3 atelectasis, 2 pneumonia). Some patients had more than one complication. The mean preoperative Cobb angle and the mean age of these 16 patients were 109.9° ± 17.7° and 23.6 ± 9.1 years, respectively, which was significantly different from those of the other 12 patients without a pulmonary complication. The respective mean preoperative Cobb angle and mean age of these 12 patients were 58.1° ± 15.2° and 15.9 ± 6.5 years ($P < 0.01$, unpaired *t* test).

Table 2 Numbers and percentages of pulmonary complication types among the 37 patients who developed a postoperative pulmonary complication

Pulmonary complication	Number	Frequency (%)
Pleural effusion	23	62
Bilateral	2	5
Ipsilateral	21	57
Pneumothorax/hemothorax	15	41
Prolonged intubation with mechanical ventilation	6	16
Pulmonary edema/congestion	16	43
Pneumonia	4	11
Atelectasis	8	22

Fourteen patients received closed thoracostomy: four before extubation in the operating room and the other ten after surgery

Of the 74 patients who underwent preoperative PFT, 37 (50%) developed a postoperative pulmonary complication. Pulmonary complication findings are shown in Table 2. Some patients had more than one complication. Eleven patients (15%) received closed thoracostomy in the operating room (2 cases), recovery room (1 case), or general ward/ICU (8 cases). Seventeen patients (23%) required postoperative intubation: 7 (41%) with DMD, 5 (29%) with cerebral palsy, 3 (17%) with spinal muscular atrophy, one (6%) with neurofibromatosis, and one with poliomyelitis. Six patients (8%) required intubation and ventilator support for more than 12 h (mean 49.5 ± 58.7 h) because of hemodynamic instability or poor respiratory effort, and these patients often required a longer period of ICU (intensive care unit) care than those who required ICU care without mechanical ventilator support (191 ± 212.4 vs. 24.6 ± 19.2 h, t test, $P < 0.05$). Details of ventilated patients are presented in Table 3.

Five patients (6.7%) showed radiographic abnormalities preoperatively. These abnormal findings were: mild cardiomegaly, diffuse hazy opacity, inactive pulmonary tuberculosis, a previous inflammatory scar, and subsegmental atelectasis, respectively. Of these, postoperative pulmonary complications were observed in two, but no patient needed postoperative ventilation.

Patient weight, gender, diagnosis, and preoperative chest X-ray findings were not found to be significantly related to the incidence of a postoperative complication or the need for postoperative ventilation. Numbers of vertebrae levels fused and mean anesthesia time were not found to be significantly related to the incidence of a postoperative complication or the need for postoperative ventilation. The AUC of the final prediction model in age was 0.631 (95% confidence interval 0.53–0.75; $P = 0.050$), and the AUC of the Cobb angle was 0.646 (95% confidence interval 0.52–0.77; $P = 0.030$; Fig. 1). The optimal (95% confidence interval) age cutoff for an elevated calculated risk score (see "Methods" for further description of ROC curve) was 16.5 and optimal Cobb angle cutoff was 69° (Fig. 2). A preoperative Cobb angle of >69° was found to be associated with the development of a postoperative pulmonary complication ($P = 0.002$), and a patient age of >16.5 years was found to be associated with the development of a postoperative pulmonary complication ($P = 0.027$). However, no significant differences were found between patients that required or did not require postoperative ventilation with respect to these factors. A larger mean blood loss to body weight ratio during surgery and more units of blood transfused were found to be associated with the development of a postoperative pulmonary complication, and a larger mean blood loss to body weight ratio was found to be associated with the need for postoperative ventilation ($P = 0.005$) (Table 4).

To access the relationship between preoperative PFT and complication development, optimum cutoff points were obtained (Tables 5, 6). The AUC of the final prediction model in FEV1% predicted was 0.669 (95% confidence interval 0.54–0.79; $P = 0.012$), and the AUC of FVC % predicted was 0.668 (95% confidence interval 0.54–0.79; $P = 0.012$; Fig. 1). The optimal (95% confidence interval) FEV1% predicted cutoff for an elevated

Table 3 Details of ventilated patients

No	Diagnosis	Age (years)	Cobb angle (°)	FVC (% pred)	Blood loss (ml/kg)	Transfusion (units)	Duration of operation (h)	Reason for ventilation	Duration of ventilation (h)	Inotropic support	Pulmonary complication (chest X-ray findings)
1	CP	25	55	28	91	13	5.8	Arterial desaturation	168	No	Pneumo/ede/cong
2	Polio	43	125	35	273	42	8	Hemodynamic instab	15	Dopa	Pneumo/hemo/eff
3	DMD	17	100	31	220	26	9.5	Hemodynamic instab	24	Dobu	Pneumo/eff/ede/atel
4	DMD	28	72	39	125	19	7.3	Hemodynamic instab	37	Dopa	Pneumo/hemo/eff
5	DMD	20	100	24	294	35	8	Hemodynamic instab	35	Dopa	Pneumo/ede/eff
6	DMD	13	83	23	52	8	4	Poor respiratory effort	18	Dopa	Ede/effu

FVC Forced vital capacity, *pred* predicted, *CP* cerebral palsy, *Polio* poliomyelitis, *DMD* Duchenne muscular dystrophy, *hemodynamic instab* hemodynamic instability, *dopa* dopamine, *dobu* dobutamine, *pneumo* pneumothorax, *ede* pulmonary edema, *cong* congestion, *hemo* hemothorax, *eff* effusion, *atel* atelectasis

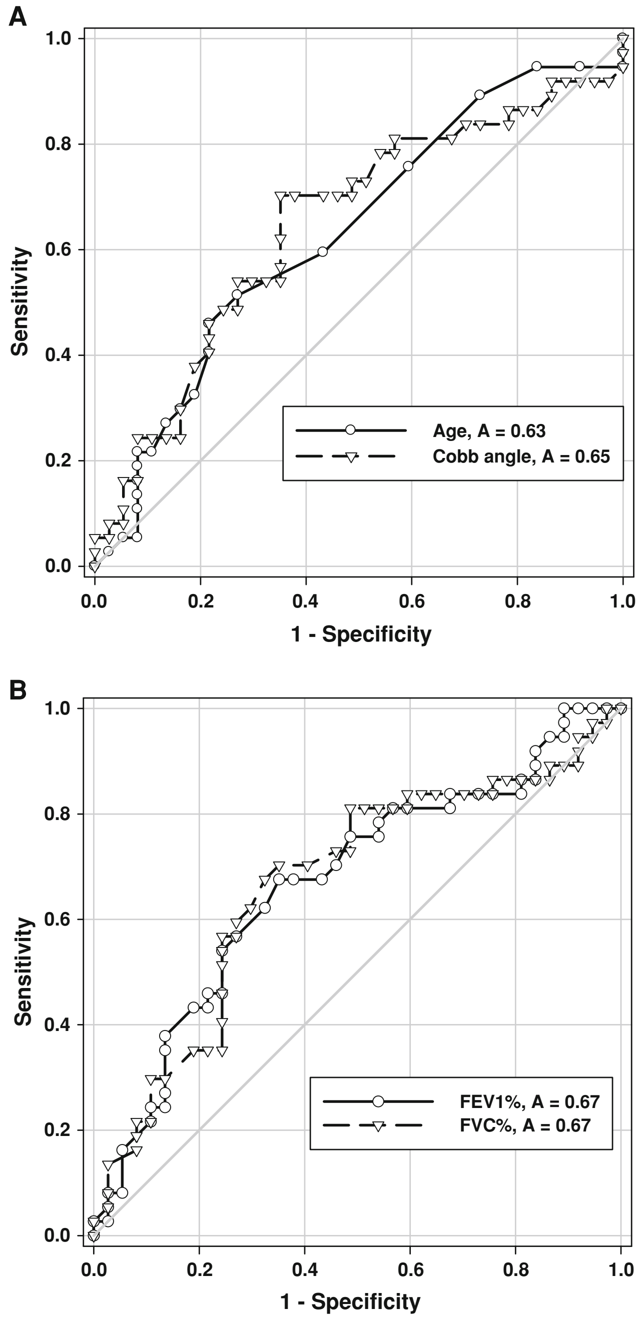

Fig. 1 **a** Receiver-operator characteristic (ROC) curve for the prediction of pulmonary complication by indexed age (area under the curve 0.6311, 95% confidence interval 0.5034–0.7588, $P = 0.05$) and by indexed Cobb angle (area under the curve 0.6465, 95% confidence interval 0.5186–0.7743, $P = 0.03$). **b** ROC curve for the prediction of pulmonary complication by indexed FEV1% predicted (area under the curve 0.6691, 95% confidence interval 0.5446–0.7936, $P = 0.012$) and by indexed FVC % predicted (area under the curve 0.6680, 95% confidence interval 0.5419–0.7941, $P = 0.012$)

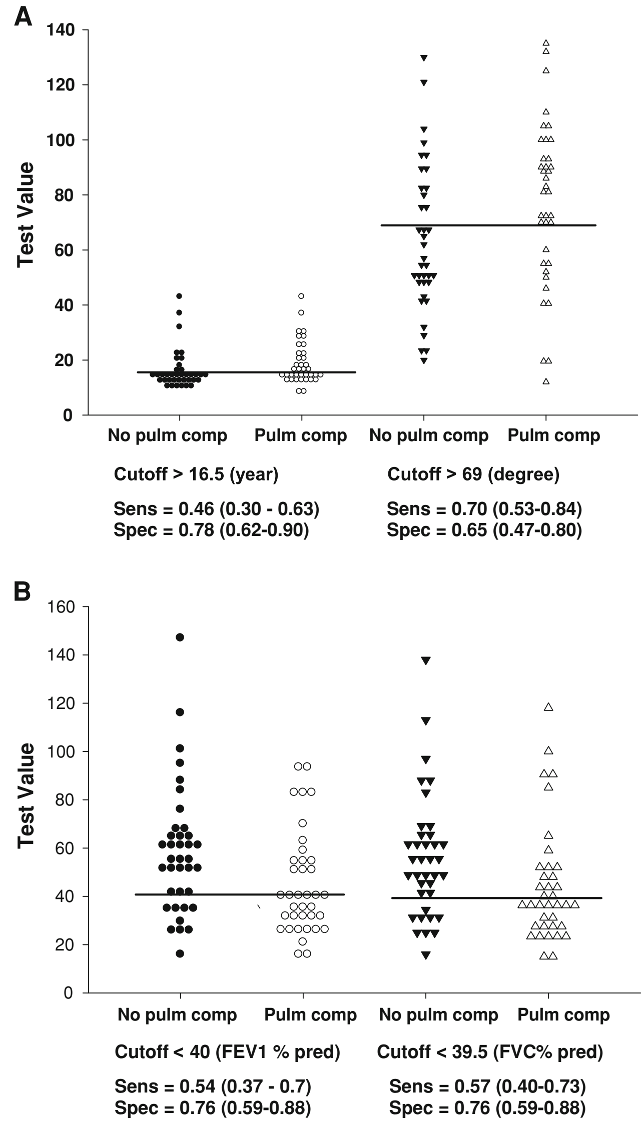

Fig. 2 Optimal cutoff values of each variable (**a** age, Cobb angle, **b** FEV1% predicted, FVC % predicted) were determined with receiver-operating characteristic curve (ROC) analysis for the prediction of a pulmonary complication and calculated from the Youden index (according to the highest specificity and sensitivity). Values are presented as sensitivity and specificity with 95% confidence intervals

calculated risk score (see "Methods" for further description of ROC curve) was 40 and optimal FVC % predicted cutoff was 39.5 (Fig. 2). Patients with a preoperative FEV_1 of <40% of the predicted value and/or FVC of <39.5% of the predicted value were found to be more likely to develop a postoperative pulmonary complication or to need postoperative mechanical ventilation. Regarding FEV_1/FVC ratios, we calculated relative risks and odds ratios for complication rates for all FEV_1/FVC ratio percentage points between 70 and 99%, and found that the FEV_1/FVC ratio was not correlated with the incidence of a postoperative pulmonary complication, because the majority of patients had a ratio of >93%.

Because of the large number of variables, such as preoperative and intraoperative risk factors, related to the

Table 4 Peri-operative characteristics of patients that developed a postoperative pulmonary complication

Total ($N = 74$)	Pulmonary complication ($n = 37$)	No pulmonary complication ($n = 37$)	P value
Level fused	13.49 ± 2.52	13.32 ± 2.59	0.786
Estimated blood loss (ml)	4751.35 ± 638.19	3140.54 ± 401.78	0.023
Estimated blood loss/kg body wt	117.75 ± 36.84	70.96 ± 22.06	0.008
Units of blood transfused	15.41 ± 5.47	9.81 ± 4.73	0.002
Length of anesthesia (min)	392.84 ± 110.65	348.62 ± 109.03	0.088
Total ($N = 74$)	Ventilated group ($n = 6$)	Non-ventilated group ($n = 68$)	P value
Level fused	14.50 ± 1.38	13.31 ± 2.61	0.274
Estimated blood loss (ml)	8033.33 ± 5299.68	3585.29 ± 2545.18	0.095
Estimated blood loss/kg body wt	175.8 ± 100.47	87.16 ± 39.26	0.005
Units of blood transfused	23.83 ± 13.05	11.62 ± 6.62	0.07
Length of anesthesia (min)	426.67 ± 115.87	365.79 ± 110.45	0.201

Values are mean ± SD. All patients of the ventilated group had pulmonary complications

Table 5 Postoperative pulmonary complication: preoperative pulmonary function test results

Total ($N = 74$)	Pulmonary complication ($n = 37$)	No pulmonary complication ($n = 37$)	P value
FEV_1 (% pred)	44.8 ± 20.5	58.1 ± 26.6	0.009
FVC (% pred)	44.3 ± 23.6	56.0 ± 25.5	0.01
FEV_1/FVC ratio	93.38 ± 7.22	93.76 ± 4.63	0.78
Total ($N = 74$)	Ventilated group ($n = 6$)	Non-ventilated group ($n = 68$)	P value
FEV_1 (% pred)	32.1 ± 7.6	52.4 ± 25.2	0.017
FVC (% pred)	30.0 ± 6.2	51.3 ± 25.8	0.015
FEV_1/FVC ratio	92.3 ± 8.7	93.7 ± 5.8	0.729
Pulmonary complication group ($n = 37$)	Ventilated group ($n = 6$)	Non-ventilated group ($n = 31$)	P value
FEV_1 (% pred)	32.1 ± 7.6	47.2 ± 21.3	0.058
FVC (% pred)	30.0 ± 6.2	47.1 ± 24.7	0.043
FEV_1/FVC ratio	92.3 ± 8.7	93.5 ± 7.0	0.398

Values are mean ± SD. FEV_1, forced expiratory volume in 1 s

FVC Forced vital capacity, *pred* predicted

Table 6 Postoperative pulmonary complication: predictive value of preoperative variables

	P value	Sensitivity	Specificity	PPV	NPV
FEV_1 <40% pred	0.007	54	76	69	62
FVC <39.5% pred	0.005	57	76	70	64
Cobb angle >69°	0.002	70	65	67	69
Age >16.5 years	0.027	46	78	68	59

FEV_1 Forced expiratory volume in 1 s, *FVC* forced vital capacity, *pred* predicted, *PPV* positive predicted value, *NPV* negative predicted value

development of a postoperative pulmonary complication, we performed multivariate logistic regression analysis of preoperative variables. PFT variables were considered as both continuous and dichotomous variables, like age and gender. The stepwise procedure revealed that a Cobb angle larger than 69° (odds ratio = 4.158, $P = 0.049$), an FEV_1 of <40% of predicted (odds ratio = 5.115, $P = 0.009$), and an FVC of <39.5% (odds ratio = 5.849, $P = 0.006$) independently placed patients at an elevated risk of a postoperative pulmonary complication (Table 7). Logistic regression analysis revealed that most of the associations between variables and the risk of a postoperative pulmonary complication were attributable to an age of >16.5 years (odds ratio = 3.081, $P = 0.027$), a Cobb angle of >69°, and an FVC of <39.5% of the predicted value. Table 8 shows clearly the additive effects of an FVC of <39.5% of predicted and a Cobb angle of >69° on the risk of a pulmonary complication. Furthermore, the risks posed by factors were found to be similar (age >16.5, 72%; Cobb angle of >69°, 67%; FVC of <39.5% of predicted, 70%), but when patients had two of these risk factors, the risk increased (age >16.5 plus a Cobb angle of >69°, 87%; age of >16.5 and an FVC of <39.5% of the predicted value, 86%; Cobb angle of >69° and FVC of <39.5% of the predicted value, 78%).

There were 39 patients with Cobb angle >69° and 35 patients with curve <69°. The mean postoperative curve improved 44.5° ± 18.1° (final follow-up, 48.3° ± 20.3°; preoperative curve >69° patients group) and 21.5° ± 10° (final follow-up, 22.8° ± 17°; preoperative curve <69° patients group), respectively, and the mean correction rate was 56.7%. Six patients who needed artificial ventilation postoperatively had improvement of their pulmonary problems thereafter. One of these six patients was a 43-year-old female with poliomyelitis who eventually required continued medical treatment for low back pain. The other five patients did not show complications that required any other treatment.

Discussion

This study shows that preoperative PFT values are useful for predicting the development of postoperative pulmonary complications, including prolonged postoperative ventilations, and the most sensitive PFT variable was found to be an FVC of <39.5% of the predicted value. Furthermore, during the analysis, patient age, preoperative Cobb angle, and an FVC of <39.5% of the predicted value were taken into account, and these three variables were found to contribute further information regarding the risk of a postoperative pulmonary complication.

Table 7 Multivariate logistic regression model findings regarding the prediction of a postoperative pulmonary complication

	Odds ratio	*P* value	95% confidence interval
Cobb angle >69°	4.158	0.049	1.469–11.768
FEV_1 <40% pred	5.115	0.009	1.312–16.180
FVC <39.5% pred	5.849	0.006	1.416–18.854

FEV_1 Forced expiratory volume in 1 s, *FVC* forced vital capacity, *pred* predicted

Only 6 of the 37 patients that developed a pulmonary complication needed postoperative ventilation, mainly for pleural problems such as pneumothorax, hemothorax, or pleural effusion. These problems occurred because of surgical technical problems with the posterior fusion method like in this study. Another possibility for the cause of these complications could also be surgery-induced hemodynamic instability, not pre-existing lung restriction or ventilator associated complications. Only 4 of the 37 patients that developed a pulmonary complication also developed pneumonia, which could have been related to an abnormal pulmonary function. However, these four patients did not need postoperative ventilator support.

The role of preoperative PFT in patients with idiopathic scoliosis is still controversial, [5–11] which is probably because these patients are otherwise healthy, whereas in addition to a restrictive lung deficit, neuromuscular scoliosis patients have impaired pulmonary function because of muscular weakness and recurrent chest infections as a consequence of poor cough and an impaired airway protective reflex. Usually vital capacity is referred to when assessing patients preoperatively to predict the need for postoperative assisted ventilation. In the present study, we found that a preoperative FVC of <39.5% of the predicted value was the most sensitive PFT variable for predicting the likelihood of a postoperative pulmonary complication and the need for postoperative ventilation. We also found that a preoperative FEV1 of <40% of the predicted value was a sensitive parameter for predicting the likelihood of postoperative pulmonary complications.

Yuan et al. [4] compared PFT variables and postoperative mechanical ventilation in 125 children with scoliosis, and found that an FEV_1 of <40% of the predicted value and a vital capacity of <60% of the predicted value correlated with the need for prolonged postoperative mechanical

Table 8 Observed percentages of occurrence of postoperative pulmonary complications with respect to age, Cobb angle, and FVC

	Cobb angle <69°		Cobb angle >69°	
	Age <16.5 years	Age >16.5 years	Age <16.5 years	Age >16.5 years
FVC >39.5% pred	3/19 (15.8%)	1/4 (25%)	7/14 (50%)	5/7 (71.4%)
FVC <39.5% pred	4/6 (66.7%)	3/6 (50%)	6/10 (60%)	8/8 (100%)
Total (Cobb angle)	11/35 (31.4%)		26/39 (66.7%)	

FVC Forced vital capacity, *pred* predicted ventilation following scoliosis repair. In the present study, an FVC of <39.5% of the predicted value was found to be related to the need for postoperative ventilation. However, there is a possibility that this finding was associated with patient age, because adults or adolescents were enrolled in addition to children in the present study.

According to Marsh et al. [12], preoperative risk is higher when FVC is <20–30% of the predicted value. Moore considered an FVC of <25% and a left ventricular ejection fraction of <50% a contraindication to elective surgery [13]. Two other interesting studies showed that FVC values of 30 or 60% less than predicted could increase preoperative risk [3, 14]. We consider that FEV_1 and FVC volumes of less than 40% of the predicted values are more intuitive than other cutoff points in neuromuscular scoliosis. Possibly, this difference is because they evaluated patients with only DMD, whereas we included patients with multiple diagnoses of neuromuscular scoliosis. Thus, we consider the accuracy of PFT in these compromised patients, especially those with DMD, differs from those of other types of NMS.

According to our analysis of other factors, a Cobb angle >69° is also a risk factor for predicting the development of a postoperative pulmonary complication. Sawahi et al. [15] reported postoperative complications in 12 of 14 patients with deformities of >100° as compared with 37 out of 97 with a deformity of <100°. In this previous study, the most common major complication was respiratory insufficiency (53%). It was concluded that a Cobb angle >100° is a risk factor for a postoperative complication. In the present study, we showed a correlation of pulmonary complications with a Cobb angle >69°. In addition, we found that postoperative ventilation was required in five of six patients with a curve of >69°. In contrast, Modi et al. [16] found that curve severity does not increase the complication rate or the need for an ICU stay. It is possible that their study is associated with overall postoperative complications. However, in the present study, we focused on the development of a postoperative pulmonary complication or the need for postoperative ventilation.

In this study, a pulmonary complication occurred in 17 of 25 patients older than 16.5 years and in 20 of 49 patients younger than 16.5 years (68 vs. 40%; $P < 0.05$). We also found that postoperative ventilation was required in four of six patients older than 17 years. Similarly, Yuan et al. [4] reported that children older than 13 (41 vs. 13%) were more likely to require postoperative mechanical ventilation. Patil et al. [17] showed that patients in the pediatric (0–17 years) age group had better short-term outcomes after scoliosis correction surgery than older patients. This difference is possibly due to a more severe scoliotic curve and more severe disease in adult scoliosis patients.

Other operative factors, such as a large amount of blood loss, could also be related to the need for postoperative ventilation support due to hemodynamic instability. Massive blood loss may lead to hemodynamic instability and the need for massive transfusions. This raises the question why are NMS patients susceptible to massive blood loss? Edler et al. [18] noted that more than 65% of their NMS children lost >50% of their estimated blood volume during scoliosis surgery and that this was primarily related to the number of vertebrae fused. Sarwahi et al. [15] concluded that a curve magnitude of >100° is a risk factor of a pulmonary complication, although this finding may have been associated with technical surgical problems. Nevertheless, massive transfusions could be an important predictor of a pulmonary complication and prolonged intubation. The requirement for a massive transfusion has also been associated with the development of a pulmonary complication, such as transfusion-related acute lung injury or ventilator-associated pneumonia [19, 20]. In the present study, five of six patients requiring ventilation postoperatively suffered from intraoperative hemodynamic instability requiring inotropic support. Furthermore, major blood loss can reduce preload, and this could have contributed in three of six of our postoperatively ventilated patients who developed intraoperative hypotension.

Based our findings, we suggest that the testing of respiratory function before surgery aids the primary surgeon by indicating the likelihood of a postoperative pulmonary complication. We conclude that an FEV_1 of <40% of the predicted value, an FVC of <39.5% of the predicted value, a Cobb angle larger than 69°, and age older than 16.5 years indicate a greater likelihood of the development of a postoperative pulmonary complication.

Conflict of interest The authors declare that they have no conflicts of interest to report.

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