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Preoperative Base Excess as a Predictor of Perioperative Complications in Patients with Nonidiopathic Scoliosis who Have High Risk Associated with General Anesthesia

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Abstract:

Introduction: Patients with nonidiopathic scoliosis often have a high risk associated with general anesthesia because of cardiac or pulmonary dysfunction secondary to underlying diseases. Base excess has been reported as a predictor in the management of trauma and cancer, although not yet in scoliosis. This study was performed to clarify the surgical outcomes and the association of perioperative complications with base excess in patients with nonidiopathic scoliosis who have a high risk associated with general anesthesia.

Methods: Patients with nonidiopathic scoliosis who were referred to our institution from 2009 to 2020 because of their high risk associated with general anesthesia were retrospectively enrolled. High-risk factors for anesthesia were determined by a senior anesthesiologist and categorized into circulatory or pulmonary dysfunction. Perioperative complications were analyzed using the Clavien-Dindo classification; severe complications were defined as grade ≥III. We investigated high-risk factors for anesthesia, underlying diseases, preoperative and postoperative Cobb angle, surgery-related factors, base excess, and postoperative management. These variables were statistically compared between patients with and without complications.

Results: Thirty-six patients (mean age, 17.9 years old; range, 11-40 years old) were enrolled (two patients declined surgery). High-risk factors were circulatory dysfunction in 16 patients and pulmonary dysfunction in 20 patients. The mean Cobb angle improved from 85.1° (36°-128°) preoperatively to 43.6° (9°-83°) postoperatively. Three intraoperative complications and 23 postoperative complications occurred in 20 (55.6%) patients. Severe complications occurred in 10 (27.8%) patients. All patients underwent postoperative intensive care unit management after posterior all-screw construction. A large preoperative Cobb angle (p=0.021) and base excess outliers (>3 or <−3 mEq/L) (p=0.005) were significant risk factors for complications.

Conclusions: Patients with nonidiopathic scoliosis who have a high risk associated with general anesthesia have a higher complication rate. Preoperative large deformity and base excess (>3 or <−3 mEq/L) could be predictors of complications.

Keywords:

syndromic scoliosis, neuromuscular scoliosis, nonidiopathic scoliosis, postoperative complication, high risk associated with general anesthesia, circulatory dysfunction, pulmonary dysfunction, base excess

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Introduction

Scoliosis associated with various systemic diseases, such as Marfan syndrome, neurofibromatosis, and Prader-Willi syndrome, is categorized as syndromic scoliosis[1,2)]. Scoliosis associated with neuromuscular diseases, such as cerebral palsy and muscular dystrophy, is categorized as neuromuscular scoliosis. Although these types of nonidiopathic (syndromic/neuromuscular) scoliosis often progress quickly and require corrective surgery; few reports have comprehensively discussed the surgical outcomes of patients with nonidiopathic scoliosis[1)].

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Patients with nonidiopathic scoliosis often have cardiac and pulmonary dysfunctions due to underlying systemic disease[3]. Consequently, such patients are likely to have a high risk associated with general anesthesia. Furthermore, the progression of scoliosis leads to postural imbalance and decreased respiratory function. The clinical course of nonidiopathic scoliosis depends on the severity of the underlying disease and the magnitude of the spinal deformity. Surgery for nonidiopathic scoliosis can maximize residual physical function by preventing or delaying secondary respiratory complications. Specifically, surgical treatment can be lifesaving in addition to improving patients' quality of life. Despite the highly invasive nature of corrective surgery, a successful surgical outcome is hugely beneficial to patients with nonidiopathic scoliosis[4-7].

However, serious unexpected complications often occur intraoperatively or postoperatively, and these serious complications occasionally become fatal. The risk of perioperative complications is higher in patients with nonidiopathic than idiopathic scoliosis[2,8]. Moreover, the mortality rate of neuromuscular scoliosis surgery (0.3%) is higher than that of idiopathic scoliosis surgery (0.02%)[8]. The perioperative risk is assumed to further increase in patients who have a high risk associated with general anesthesia. When determining the surgical indications in patients with nonidiopathic scoliosis, patients who have a high risk associated with general anesthesia should be more carefully considered in terms of whether they should undergo corrective surgery. However, few studies have focused on the surgical outcomes and intraoperative/postoperative complications of patients with nonidiopathic scoliosis who have a high risk associated with general anesthesia.

Base excess (BE) has been shown to be a predictor of mortality in patients in the intensive care unit (ICU) after severe trauma[9] and cardiac surgery[10] and a predictor of morbidity after cancer surgery[11]. However, the association of perioperative complications with BE in patients with nonidiopathic scoliosis remains unclear. Therefore, this retrospective study was conducted to clarify the clinical outcomes and the association of perioperative complications with BE in patients with nonidiopathic scoliosis who have a high risk associated with general anesthesia.

Material and Methods

Patients and surgical procedure

Thirty-eight consecutive patients with syndromic/neuromuscular scoliosis who were referred to our institution from 2009 to 2020 because of high anesthetic risk were retrospectively enrolled. Informed consent was obtained from all patients and/or their legal guardians. Patients who declined surgery were excluded. High-risk factors for anesthesia, determined by a senior anesthesiologist, included circulatory dysfunction (poor exercise tolerance before surgery as indicated by <4 metabolic equivalents [METs], or severe valvular heart disease) and pulmonary dysfunction (use of positive airway pressure because of obstructive sleep apnea, pulmonary hypertension, or use of home oxygen therapy because of chronic hypoxic respiratory conditions). When patients met the criteria for both circulatory and pulmonary dysfunctions, they were categorized as having pulmonary dysfunction because the primary cause of circulatory dysfunction is pulmonary dysfunction. All operations were performed by a single surgeon with posterior all-screw construction. Spinopelvic fixation was performed using iliac screws or S2 alar-iliac screws. Ponte osteotomies were performed on six periapical intervertebral segments. No two-stage surgery was performed. Neither anterior surgery nor combined surgery was performed. Intraoperative monitoring of spinal cord function was conducted by motor evoked potentials. Cell savers were used in all cases.

The demographic and clinical factors analyzed were age, sex, high-risk factors for general anesthesia, preoperative hemoglobin (Hb) concentration, and underlying diseases. Surgery-related factors were the operating time; blood loss; blood transfusion, including preoperative autologous blood donation and intraoperative blood salvage; preoperative and postoperative Cobb angle, C7 minus central sacral vertical line (C7-CSVL) and the sagittal vertical axis; correction rate, and number of fused vertebrae. Radiographic parameters were measured in the standing position for ambulators and in the sitting position for nonambulators. BE was measured preoperatively from arterial blood. Based on previous reports[9,12], an outlier was defined as BE of >3 or <−3 mEq/L. To assess postoperative management, we investigated the length of ICU stay, duration of postoperative intubation, and duration of hospitalization. Decisions regarding discharge from the ICU and extubation were made by an anesthesiologist. Intraoperative and postoperative complications were analyzed. The Clavien-Dindo classification[13] was used to evaluate postoperative complications. Postoperative complications were defined as grade ≥II, and severe complications were defined as grade ≥III.

Statistical analysis

All statistical analyses were performed using SPSS 23.0 (IBM Corp., Armonk, NY, USA) with significance set at p of <0.05. Values are expressed as mean and range or median and interquartile range. In the comparisons of patients with and without complications, the unpaired t-test or the Mann-Whitney U test was used for continuous variables and Fisher's exact test was used for categorical variables.

Results

Among the initial 38 patients, two patients who declined surgery were excluded after receiving an explanation of the risks of general anesthesia by a senior anesthesiologist. Consequently, 36 patients were enrolled. All patients were followed up for more than 2 years. The mean age at surgery was 17.9 years old (range, 11-40 years old). The patients

Table 1. Demographics and Clinical Outcomes.

Variables	
Age (mean [range]) (y)	17.9 [11 to 40]
Gender; *n*, (%)	
Male	23 (63.9)
Female	13 (36.1)
High-risk factor for anesthesia; *n*, (%)	
Circulatory dysfunction	16 (44.4)
Pulmonary dysfunction	20 (55.6)
Ambulatory ability; *n*, (%)	
Ambulator	11 (30.6%)
Nonambulator	25 (69.4%)
Preoperative Cobb angle (mean [range]) (°)	85.1 [36 to 128]
Postoperative Cobb angle (mean [range]) (°)	43.6 [9 to 83]
Correction rate (mean [range]) (%)	50.5 [8.0 to 85.0]
Preoperative C7-CSVL (mean [range]) (mm)	2.1 [−97.2 to 103.2]
Postoperative C7-CSVL (mean [range]) (mm)	−5.9 [−60.2 to 57.7]
Preoperative SVA (mean [range]) (mm)	51.5 [−53.6 to 220.3]
Postoperative SVA (mean [range]) (mm)	48.5 [−24.2 to 150.3]
Operative time (mean [range]) (min)	522 [303 to 1008]
Preoperative Hb (mean [range]) (g/dL)	13.3 [8.3 to 17.8]
Blood loss (mean [range]) (g)	2378 [50 to 9980]
Blood transfusion (mean [range]) (ml)	2068 [0 to 9855]
Number of fused vertebrae (median [IQR])	14.5 [13 to 16]
Base excess; *n*, (%)	
Outliers (>3mEq/L, or<−3mEq/L)	8 (22.2)
Inliers (−3mEq/L to 3mEq/L)	28 (77.8)
Length of ICU stay (median [IQR]) (d)	4 [4 to 5.75]
Length of intubation (median [IQR]) (d)	2 [0 to 4.75]
Hospitalization (median [IQR]) (d)	25.5 [20.25 to 41.5]

C7-CSVL, C7 minus the central sacral vertical line
SVA, sagittal vertical axis
Hb, hemoglobin
ICU, intensive care unit
IQR, interquartile range

Table 2. Underlying Diseases.

	n (%)
Muscular dystrophy	12 (33.3)
Cerebral palsy	8 (22.2)
Marfan syndrome	4 (11.1)
Congenital heart disease	2 (5.6)
Freeman-Sheldon syndrome	1 (2.8)
Loeys–Dietz syndrome	1 (2.8)
Rett syndrome	1 (2.8)
West syndrome	1 (2.8)
Sotos syndrome	1 (2.8)
Congenital myopathy	1 (2.8)
Escobar syndrome	1 (2.8)
Arthrogryposis multiplex congenita	1 (2.8)
Alternating hemiplegia	1 (2.8)
Prune belly syndrome	1 (2.8)

comprised 23 (63.9%) men and 13 (36.1%) women. Circulatory dysfunction was observed in 16 (44.4%) patients and pulmonary dysfunction in 20 (55.6%). Eleven patients were ambulators and 25 were nonambulators (Table 1). The most common underlying disease was muscular dystrophy (33.3%). Table 2 lists the other underlying diseases.

The mean Cobb angle improved from 85.1° (range, 36°-128°) preoperatively to 43.6° (range, 9°-83°) postoperatively. The mean correction rate was 50.5% (range, 8.0%-85.0%). The mean operating time was 522 min (range, 303-1008 min). The preoperative Hb value was 13.3 g/dL (range, 8.3-17.8 g/dL). The mean blood loss was 2378 g (range, 250-9980 g). The median number of fused vertebrae was 14.5 (interquartile range, 13-16). Allogeneic blood transfusion excluding autologous blood transfusion was performed in 26 (63.9%) patients. The mean total blood transfusion volume was 2068 mL (range, 0-9855 mL) (Table 1).

All patients underwent postoperative ICU management, and the median length of ICU stay was 4.0 days (interquartile range [IQR], 4-5.75 days). Postoperative ventilator management was required in 24 (66.7%) patients, and the median intubation period was 2.0 days (IQR, 0-4.75 days). All patients returned home, and the median hospitalization duration was 25.5 days (IQR, 20.25-41.5 days) (Table 1).

Three intraoperative complications and 23 postoperative complications occurred in 20 (55.6%) patients. Of the three intraoperative complications, two (8.7%) patients required emergency intervention because of a rapid decrease in blood pressure. The first patient, a 25-year-old woman with cerebral paralysis and BE of −2.2 mEq/L, had persistent hypotension during surgery and subsequently developed cardiac arrest on the way to the ICU; she recovered by cardiopulmonary resuscitation. The other was a 22-year-old patient with congenital myopathy and BE of −8.6 mEq/L who also developed persistent hypotension intraoperatively. In a 16-year-old male patient with Duchenne muscular dystrophy with a BE of 0.9 mEq/L, the motor evoked potential waveform disappeared during correcting manipulation and the operation was discontinued after rod removal. Because the patient's paraplegia immediately improved, *in situ* fusion was conducted after 3 weeks. Although all intraoperative complications were very serious, no permanent disability remained after surgery. Twenty-three postoperative complications occurred in 20 (55.6%) patients, including circulatory dysfunction in eight patients and pulmonary dysfunction in 12. The most common complication was pneumonia (n=12, 33.3%). The other complications are listed in Table 3. Severe postoperative complications, defined as Clavien-Dindo grade ≥III complications, occurred in 10 (27.8%) patients. Of these patients, five developed severe pneumonia, two of whom stayed in the ICU for 2 months or longer. In addition, two patients developed ileus, and one patient developed large-volume hematemesis. These patients underwent surgical or endoscopic treatment. One patient required reoperation because of a surgical site infection, and one patient required reintubation and ventilator management in the ICU because of airway obstruction by sputum. Nine of these 10 patients with severe complications had neuromuscular syndrome. All patients with severe complications are listed in Table 4.

The comparison between patients with and without complications revealed that the length of ICU stay (p=0.003), duration of intubation (p=0.039), and hospital stay (p=0.001) were significantly longer in patients with than without complications. The preoperative Cobb angle was significantly larger in patients with than without complications (p=0.021). In addition, BE outliers (>3 or <−3 mEq/L) had a higher risk of complications (p=0.005; odds ratio, infinity) than BEs ranging from −3 to 3 mEq/L. The type of high-risk factor for general anesthesia was not associated with complications (p=0.737) (Table 5). We also compared the rate of severe complications between patients with grade ≥III (n=10) and grade ≤II complications (n=26). Severe complications occurred in four of eight patients with BE outliers. There was a significant difference not in the BE (p=0.179; odds ratio, 3.67) but in the preoperative Cobb angle (p=0.046). The severity of complications may depend on the preoperative Cobb angle rather than the preoperative BE.

Table 3. Postoperative Complications.

	n
Pneumonia	12
Ileus	4
Surgical site infection	2
Surgical wound dehiscence	1
Urinary tract infection	1
Hematemesis	1
Hyperkalemia	1
Respiratory arrest	1
Total	23

Discussion

Surgical treatment of nonidiopathic scoliosis has many advantages in improving posture balance and quality of life[4,7], reducing the burden on care providers[5,6], and preventing deterioration of pulmonary function[4]. However, patients with nonidiopathic scoliosis frequently have physical disability with a small body; rigid, severe deformity; and sometimes low bone quality. They also often have visceral disorders, including cardiac and pulmonary dysfunctions. Consequently, nonidiopathic scoliosis surgery has orthopedic surgical risks and anesthetic risks due to the presence of underlying diseases. However, despite the high complication rate, optimal assessment of perioperative risk in patients with

Table 4. Case Series with Severe Complications (Clavien–Dindo Classification Grade ≥3).

Age (y)	Gender	High-risk factor for anesthesia	Underlying disease	Preoperative Cobb angle (°)	Base excess (mEq/mL)	Complication
16	Male	Circulatory dysfunction	Congenital heart disease	62	9.4	Ileus
25	Female	Circulatory dysfunction	Cerebral palsy	120	−2.2	Pneumonia
22	Male	Pulmonary dysfunction	Congenital myopathy	73	−8.6	Pneumonia
17	Male	Circulatory dysfunction	Duchenne muscle dystrophy	89	1.1	Hematemesis
15	Male	Pulmonary dysfunction	Duchenne muscle dystrophy	86	−3.9	Ileus
17	Male	Pulmonary dysfunction	Cerebral palsy	103	2.7	Pneumonia
21	Male	Pulmonary dysfunction	Alternating hemiplegia	115	−1.7	Pneumonia
15	Male	Circulatory dysfunction	Duchenne Muscle dystrophy	103	−0.6	Pneumonia
16	Female	Pulmonary dysfunction	Cerebral palsy	115	−2	Respiratory arrest
19	Male	Pulmonary dysfunction	Cerebral palsy	109	−3.2	Surgical site infection

Table 5. Comparison between Patients with Complications and without Complications.

Variables	With complications *n*=20	Without complications *n*=16	*p*-value
Age (mean [range]) (y)	18.7 [14 to 35]	16.9 [11 to 40]	0.366†
Gender; *n*, (%)			0.493*
Male	14 (70.0)	9 (56.3)	
Female	6 (30.0)	7 (43.7)	
High-risk factor for anesthesia; *n*, (%)			0.737*
Circulatory dysfunction	8 (40.0)	8 (50.0)	
Pulmonary dysfunction	12 (60.0)	8 (50.0)	
Ambulatory ability; *n*, (%)			0.159*
Ambulator	4 (20.0)	7 (43.7)	
Nonambulator	16 (80.0)	9 (56.3)	
Preoperative Cobb angle (mean [range]) (°)	93.0 [52 to 128]	75.3 [36 to 116]	0.021†
Postoperative Cobb angle (mean [range]) (°)	49.2 [9 to 75]	36.5 [10 to 83]	0.059†
Correction rate (mean [range]) (%)	47.9 [8 to 83]	53.7 [12.0 to 85.0]	0.335†
Preoperative C7-CSVL (mean [range]) (mm)	−6.4 [−97.2 to 103.2]	12.7 [−56.1 to 85.1]	0.276†
Postoperative C7-CSVL (mean [range]) (mm)	−13.1 [−60.2 to 50.1]	3.2 [−27.1 to 57.7]	0.067†
Preoperative SVA (mean [range]) (mm)	67.7 [36.2 to 175.6]	31.3 [−53.6 to 220.3]	0.131†
Postoperative SVA (mean [range]) (mm)	58.8 [12.9 to 150.3]	35.6 [−19.8 to 136.2]	0.089†
Operative time (mean [range]) (min)	516 [366 to 785]	530 [303 to 1008]	0.853†
Preoperative Hb (mean [range]) (g/dL)	13.5 [8.7 to 17.8]	13.2 [9.3 to 17.6]	0.696†
Blood loss (mean [range]) (g)	2803 [50 to 9980]	1848 [560 to 5280]	0.767†
Blood transfusion (mean [range]) (ml)	2387 [0 to 9855]	1668 [250 to 5311]	0.307†
Number of fused vertebrae (median [IQR])	15 [14 to 16]	14 [12.25 to 15.75]	0.178‡
Base excess; *n*, (%)			0.005*
Outliers (>3mEq/L, or<−3mEq/L)	8 (40.0)	0 (0)	
Inliers (−3mEq/L to 3mEq/L)	12 (60.0)	16 (100.0)	
Length of ICU stay (median [IQR]) (d)	5 [4 to 10.75]	4 [3 to 4.75]	0.003‡
Length of intubation (median [IQR]) (d)	3 [0.25 to 8.75]	1 [0 to 2]	0.039‡
Hospitalization (median [IQR]) (d)	35 [24.25 to 54.0]	21.5 [19.25 to 26.25]	0.001‡

C7-CSVL, C7 minus the central sacral vertical line
SVA, sagittal vertical axis
Hb, hemoglobin
ICU, intensive care unit
IQR, interquartile range
*Fisher's exact test
†Unpaired t-test
‡Mann–Whitney U-test

nonidiopathic scoliosis has not been established[8,14].

We focused on BE, which has been reported as a predictor of mortality in patients in the ICU. BE of ≤−6.0 mEq/mL has been shown to be associated with increased mortality, significant injuries, and major complications after severe trauma[9]. In cardiac surgery, BE of <−6.7 mEq/mL was identified as the single predictor of ICU mortality[10]. In another study, abnormal BE (>3 or <−3 mEq/L) increased the risk of 30-day mortality in patients with acute kidney injury[15]. Although standard BE is provided by most commercial blood gas analyzers worldwide, many spine surgeons are unaware of its relevance and how to make use of this marker[16]. In fact, the relationship between perioperative complications and BE is still unclear in patients with nonidiopathic scoliosis. Interestingly, BE outliers had a higher risk for complications in the current study. This may be because chronic pulmonary dysfunction leads to respiratory alkalosis and a compensatory increase in BE, and circulatory dysfunction leads to metabolic acidosis and progressive base deficit. BE may thus be an appropriate indicator of the ability of patients with nonidiopathic scoliosis with cardiac or pulmonary dysfunction to tolerate major scoliosis surgery. To reduce complications, it might be effective to ameliorate the acid-base imbalance with preoperative breathing training in patients with respiratory alkalosis[17]. Furthermore, it would be useful to implement multidisciplinary screening to prevent surgeons from overlooking BE outliers, leading to a reduction in mortality[18].

In the current study, we also shed light on a high risk associated with general anesthesia. According to the American College of Cardiology/American Heart Association guideline, perioperative risk of major adverse cardiac events is associated with the presence of an active cardiac condition, poor functional capacity (<4 METs), and the Revised Car-

diac Risk Index[19]. In addition, patients with heart failure or valvular heart disease require special consideration[19]. Pulmonary complications, including obstructive sleep apnea, pulmonary hypertension, and chronic hypoxic respiratory conditions, also contribute to perioperative morbidity and mortality to a magnitude similar to that of cardiac complications[20]. Based on these considerations and the specific background of the patients in the current study, we judged high anesthetic risk according to the following criteria: circulatory dysfunction (poor exercise tolerance [<4 METs] or severe valvular heart disease) and pulmonary dysfunction (use of positive airway pressure because of obstructive sleep apnea, pulmonary hypertension, or use of home oxygen therapy because of chronic hypoxic respiratory conditions).

The perioperative complication rate is reportedly higher in patients undergoing surgery for nonidiopathic scoliosis than for idiopathic scoliosis[2,8]. However, the complication rates among previous individual studies show moderate to high variability[21]. These studies were heterogeneous in their methodology and outcome types; therefore, we used the Clavien-Dindo classification[13], which is closely associated with the postoperative course[22,23], to accurately assess the postoperative complications. This grading system has been established as a standardized system and applied in many fields of surgery. This system is also suitable for objectively judging the postoperative course of patients with nonidiopathic scoliosis, who require a multidisciplinary approach involving specialties such as pediatrics and anesthesiology. In addition, we defined grade ≥III complications as severe complications because they are highly disadvantageous to the patients and result in extended hospitalization and increased medical costs.

As expected, the patients with nonidiopathic scoliosis who had a high risk associated with general anesthesia in the current study had higher overall complication rates (55.6%), even compared with syndromic/neuromuscular scoliosis surgery[2,8]. A retrospective study of 1071 patients with syndromic scoliosis demonstrated that 27 (2.7%) patients developed major complications and 439 (41.0%) developed minor complications[2]. Additionally, a retrospective review of 19360 patients with neuromuscular scoliosis showed a complication rate of 17.9%[8]. Specifically, one-third of patients developed pneumonia, and the most common severe complication was severe pneumonia, most of which occurred in patients with neuromuscular scoliosis. A systematic meta-analysis of neuromuscular scoliosis surgery showed that pulmonary complications were the most common (22.7%)[21], supporting our results. In addition, severe cerebral paralysis and Duchenne's muscular dystrophy are associated with a high risk of pulmonary complications secondary to their disease pathology[24,25]. However, another retrospective review showed that the rate of pulmonary complications in patients with neuromuscular scoliosis was 1.9%[8]. This discrepancy may indicate that the pulmonary complication rate depends on the individual patient's cardiopulmonary function as well as the underlying disease. Spirometry is usually used to evaluate preoperative lung function. Generally, patients with a forced vital capacity of <30% are at high risk for complications of neuromuscular scoliosis surgery[26,27]. In fact, it is often difficult to accurately perform spirometry in patients with nonidiopathic scoliosis. Physicians have recently been reluctant to perform spirometry because of the coronavirus pandemic. Thus, the definition of pulmonary dysfunction in the current study may be simple and useful. Ileus was the second most common complication in the current study, but few reports have described this complication. One retrospective study showed that ileus after scoliosis surgery occurred in 13.6% of patients[28]. Another study showed that paralytic ileus occurred in 6.0% of patients with neuromuscular scoliosis[29]. The incidence of ileus in our study was similar to these reports. In one retrospective review[21], implant-related complications, including screw loosening and rod breakage, was the second most common (12.5%) type of complication in patients with neuromuscular scoliosis. However, no implant failure occurred in the current study. This may have been related to the low activity of patients in this study or the surgical techniques used (*e.g.*, avoidance of overcorrection).

The comparison of patients with and without complications showed that patients with preoperative large deformity and BE outliers were at higher risk for complications. Master et al.[30] reported that a preoperative curve magnitude of ≥60° was directly associated with an increased risk of major complications. Considering that patients with nonidiopathic scoliosis have progressive cardiopulmonary dysfunction and deformity, early intervention may reduce complications and preoperative BE outliers. In fact, some authors recommended early intervention[4,30].

This study has several limitations. First, this study was a retrospective clinical analysis at a single institution. Second, patients without high anesthetic risk were excluded. Third, this study included a relatively small number of patients, and confounding factors were present. Given the rarity of patients with nonidiopathic scoliosis who have high anesthetic risk, multicenter trials with a large number of patients would be desirable to identify independent risk factors using a multivariate analysis.

In conclusion, patients with nonidiopathic scoliosis who had a high risk associated with general anesthesia were at high risk for complications, including severe complications. Preoperative large deformity and BE outliers could be predictors of complications.

Conflicts of Interest: The authors declare that there are no relevant conflicts of interest.

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Ethical Approval: This study was conducted under the approval and guidance of the Institutional Review Board (IRB) at Kobe University Graduate School of Medicine (No. B190002, 04/16/2019 approval).

Informed Consent: Written informed consent was obtained from all individual participants and/or their legal guardians included in the study. The study was conducted in concordance with the principles of the Declaration of Helsinki and with the laws and regulations of Japan.

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