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PERIOPERATIVE MANAGEMENT IN SCOLIOSIS SURGERY: SPINAL MUSCULAR ATROPHY TYPE II/III VERSUS ADOLESCENT IDIOPATHIC SCOLIOSIS

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ABSTRACT

Objective: Patients with spinal muscular atrophy (SMA) often require spinal surgery to slow pulmonary decline due to scoliosis restricting the pulmonary capacity. This study evaluated perioperative anesthetic management for scoliosis surgery in SMA patients and to compare it with adolescent idiopathic scoliosis (AIS).

Materials and Methods: After obtaining hospitals ethic committee approval, retrospective data between 2014 and 2023 were collected. The primary outcome measure was perioperative variables. The secondary outcome was to determine predictive factors for postoperative intensive care unit (ICU) admission.

Results: One hundred twenty five (66 female/59 male) ASA I-III patients (13.1±4.2 years) were included in the study. Of them, 49 had SMA (20 type II and 29 type III) and 76 had AIS. Forty-four SMA patients had mild to moderate restrictive lung disease and one patient was mechanical ventilation dependent. Mean age and body mass index (BMI) were lower and Cobb's angle was higher in SMA patients than in AIS patients ($p<0.05$). Instrumentation level (number of vertebrae fused) and the number of osteotomized vertebrae was higher in SMA patients ($p<0.05$). Mean duration of the surgery, estimated blood loss (EBL), EBL/total blood volume (TBV) ratio, and blood transfusion rate were higher in SMA patients ($p<0.05$). The ICU admission rate was higher in the SMA group (24.5%) compared to the AIS groups (24.5% >1.3%; $p<0.05$). Among SMA patients, five required postoperative mechanical ventilation. Hospital discharge time and complication rate was also higher in SMA patients ($p<0.05$). Receiver operation characteristics analysis revealed that preoperative poor respiratory function, prolonged surgery (>6 hours), multiple vertebral fusion (>6 levels), EBL/TBV >33%, massive transfusion, and low BMI were predictive for ICU admission.

Conclusion: SMA patients are at higher risk for major blood loss, massive transfusion, and ICU admission due to higher instrumentation level, longer operation time, and lower BMI. Preoperative risk analysis and preventive measures should be considered to enhance the success of the procedure in SMA patients due to respiratory compromise combined with complicated surgical procedures.

Keywords: Scoliosis, anesthesia, spinal muscular atrophy of childhood

INTRODUCTION

Spinal muscular atrophy (SMA) is a rare neuromuscular disorder with an incidence of 1 in 11,000 live births which is caused by homozygous deletion or mutation of the *survival motor neuron 1* gene. It is manifested by progressive muscle atrophy and muscle weakness due to denervation in the neuromuscular junction. Signs and symptoms can include floppiness in infancy, musculature weakness, weak cough, poor feeding, thrive failure, and respiratory distress depending on the severity of clinical manifestations[1]. In severe cases, feeding may be accomplished by a gastrostomy because of bulbar involvement and moreover, the patients may require noninvasive forms of supportive ventilation; ranging from non-invasive mask ventilation (continuous positive airway pressure or bilevel positive airway pressure) to mechanical ventilation dependence.

SMA is classified from type 0 to IV according to the onset age. The most common form, SMA type I accounts approximately 60% of all cases. The symptoms begin during the first 6 months after the birth and those patients cannot survive two years due to respiratory insufficiency. The patients with type II represent 20-30% of all cases and can sit independent but are not able to walk. They can survive 25 years with aggressive supportive treatments. Type III and IV SMA patients can walk independently and have a normal life expectancy[2]. SMA patients often require surgical interventions due to extremity contractures and kyphoscoliosis that limit pulmonary capacity resulting in restrictive pulmonary disease. SMA patients represent one of the most challenging surgical populations regarding anesthetic management. The problems mostly arise from the patient's poor condition combined with the difficulty of the surgical intervention[3]. Therefore, SMA patients often require intensive care at the postoperative period.

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Adolescent idiopathic scoliosis (AIS) is diagnosed in late childhood and adolescence. The patients have generally a normal health status and mild to moderate scoliosis does not cause movement or respiratory problems. Surgical treatment is recommended for patients whose curves are greater than 45° during growing, or are continuing to progress greater than 45° when growth stopped.

The aim of this study was to evaluate our anesthetic experience in pediatric scoliosis surgery, with particular focus on the SMA type II and III patients and to compare the results with healthy patients who underwent scoliosis surgery due to AIS. The primary outcome measure was perioperative variables. Secondary outcome measure was to identify the predictive factors for intensive care unit (ICU) admission in the postoperative period.

MATERIALS AND METHODS

After obtaining the Private Çankaya Hospital, Ethic Committee approval (decision no: 2023-02-01, date: 02.01.2023), a single center retrospective chart review was performed to include all children with SMA type II, type III, and AIS undergoing thoracolumbar spinal surgery including posterior spinal fusion or from 2014 to 2023. Data were retrospectively collected from the hospital's computerized database and medical files of patients. The medical records were reviewed to assess pre-operative, intraoperative and postoperative variables. The study has been carried out in accordance with The Code of Ethics of the World Medical Association (Declaration of Helsinki) and followed the strengthening the reporting of observational studies in epidemiology guidelines[4]. Obtaining informed consent from patients was waived due to the retrospective nature of the study. A total of 136 patients (55 SMA, 81 AIS) who underwent spinal surgery at our institution were identified. Patients whose surgery was not primary and elective thoracolumbar spinal surgery and with missing data were excluded from the study.

Anesthetic Technique

The routine anesthetic protocol for scoliosis surgery in our clinic was as follows: All patients were evaluated at the preoperative period (one week before the surgery) and invited to the hospital on the day of the surgery. Preoperative respiratory functions were evaluated by physical examination, radiological imaging (chest X-ray), respiratory function test, and pulmonology consultation. An otorhinolaryngology consultation was received for an anticipated difficult airway management.

At the day of the surgery, isotonic crystalloid that contains sodium with added glucose (e.g., 0.9% sodium chloride + 5% glucose) was intravenously (IV) given in the ward for pre-hydration during the fasting period, which lasted six hours for light meals and two hours for clear fluids. IV 1-2 mg midazolam was administered as premedication before the transfer to the operating room (OR). Time-out procedures were performed in the OR to ensure patient safety. The patients were monitored with non-invasive blood pressure (NIBP), pulse oximetry, and electrocardiogram (EKG). Anesthesia was induced using propofol (2.5 mg/kg) and fentanyl (1-2 µg/kg). After three minutes of mask-bag ventilation using 100% oxygen, endotracheal intubation was made under direct laryngoscopy using a cuffed and armored endotracheal tube. Ventilatory settings were adjusted to achieve normocapnia. Anesthesia was maintained using a propofol and remifentanil based total intravenous anesthesia (TIVA). The patients were monitorized with somatosensory evoked potentials (SSEP) and motor evoked potentials (MEP) by a neuro-monitorization technician. Therefore, neuromuscular blocking agents were not used in the maintenance phase as well as in the induction phase. A central venous catheter, an invasive arterial catheter, and a bladder catheter were inserted for hemodynamic monitorization, urine output measurement, and sampling. The rate of TIVA infusion was adjusted to ensure an anesthetic depth that does not interfere with SSEP and MEP. After anesthetic preparation, the patients were positioned prone on the operating table and made sure the pressure points of the body were supported. The body temperature was monitorized and the patients were warmed up using a forced-air warming system.

A hypotensive agent (nitroglycerine) infusion was IV administered to achieve a controlled hypotensive anesthesia in the intraoperative period which is defined as a reduction of mean arterial blood pressure (MAP) to a range of 60-70 mmHg or 30% reduction of baseline MAP[5]. It was combined with IV administration of tranexamic acid (10 mg/kg bolus followed by an infusion of 2 mg/kg h) to reduce blood loss in appropriate patients.

The amount of blood loss was assessed by collecting the gauzes saturated with blood and measuring the blood amount in the suction container. Total blood volume (TBV) was calculated using the following formula: TBV = body weight (kg) x 65-70 mL/kg. A packed red blood cell (PRBC) was transfused when estimated blood loss (EBL) was higher than 30% of TBV or hemoglobin level was reduced to <8 g/dL. When PRBC transfusion exceeded two units, fresh frozen plasma (FFP) was given in 1:1 ratio of FFP to PRBC. At the end of the surgery, an epidural catheter was inserted by the spine surgeon under direct vision, if applicable. An infusion was started via an epidural patient-controlled anesthesia (PCA) device containing a mixture of 20 mL of 0.5% bupivacaine (100 mg), 5 mL of 0.05% fentanyl (250 mcg) and 75 mL saline. The PCA protocol was as follows: infusion dose: 3-5 mL/h, bolus dose: 3-5 mL, lock-out time: 30 min and 4-hours limit: 40-60 mL. If an epidural catheter was not inserted, a tramadol intravenous PCA (infusion dose: 3-5 mg/h, bolus dose: 3-5 mg, lock-out time: 30 min, and 4-hours limit: 20-40 mg) was used for postoperative analgesia. Additionally, a local anesthetic wound infiltration using a mixture containing 1 mg/kg bupivacaine and 3 mg/kg lidocaine was made by the surgeon before the wound closure. IV paracetamol (10-15 mg/kg) was given for postoperative pain relief.

After the surgery, TIVA infusion was terminated. Extubation criteria were a) hemodynamic parameters: MAP >60 mmHg, heart rate: 80-120 beats min^{-1}, sinus rhythm, lactate <1 mmol/L b) respiratory parameters: SpO_2 >95, pO_2 >80 mmHg, pCO_2<40 mmHg, tidal volume ⩾8 mL/kg, respiratory rate: 14-20 min^{-1}. In addition, the patients with a modified Aldrete score ⩾9 who were cooperative, normothermic, did not receive massive blood transfusion, EBL was lower than 40% of TBV, and urine output >2 mL/kg h were discharged to the service after approximately 1 hour follow-up in the post-anesthesia care unit. The patients were monitorized in the ward with EKG, NIBP and pulse oximetry. The patients who did not meet the aforementioned criteria were transferred to the ICU. The follow-up observation in the ward was provided by the service nurses. The treatment orders were made by anesthesiologist and orthopedic surgeon. Pain intensity was evaluated using visual analogue scale (VAS) and a multimodal analgesic (MMA) regimen was used for postoperative pain relief. MMA included IV paracetamol 10-15 mg/kg with 6 hours intervals, ibuprofen pO 10 mg/kg with 8 hours intervals, and PCA (IV or epidural). IV tramadol (1 mg/kg) was given to appropriate patients as rescue analgesic. The patients were discharged from the hospital when hemodynamic parameters were stable, basic laboratory findings are within normal limits, VAS scores are lower than 3, and basic physiotherapy exercises were completed.

Data Collection

All medical data were reviewed in detail to obtain demographic characteristics including age, gender, body weight (kg), length (cm), body mass index (BMI), American Society of Anesthesiologists (ASA) score, and co-morbidities; intra-operative variables including the anesthetic preparation time (min), the operative time (min), numbers of vertebra fused (n), osteotomy (yes/no), EBL (mL), blood transfusion (unit), c) postoperative course: ICU admission (yes/no), ICU discharge time (hours), postoperative blood transfusion (unit), length of hospital stay (day), and in-hospital complications (n).

Statistical Analysis

The data were analyzed using the Statistical Packages for Social Sciences for Windows version 11.5 pocket program (IBM Corp., Chicago, IL, USA). For intergroup comparisons, the chi-square test and Fisher's exact test were used to analyze nominal data and the t-test for independent samples was used for quantitative data. Data were expressed as means ± standard deviation for continuous variables and numbers, and percentages for categorical variables. Univariate cox regression analyses were performed, including variables which were significantly differed in subgroup (patients who were admitted in the ICU or not) comparisons or variables that may be clinically relevant to overall ICU admission. A p value <0.05 was considered statistically significant.

RESULTS

A total of 136 patients were included into study. Eleven patients were excluded due to missing data (Figure 1). Of the remaining 125 patients, 66 patients were female (52.8%) and 59 were male (47.2%). Mean age was 13.1±4.2 (7-17) years. 49 (39.2 %) patients had SMA and 76 (60.8%) had AIS. Of 49 SMA patients, 20 (40.8%) patients were type II and 29 (59.2%) were type III SMA and 32 (65.3%) patients had mild (ASA II), 12 (24.5%) patients had moderate restrictive disease (ASA III), and one patient was mechanical ventilation dependent (ASA III). Among patients with AIS, 4 (5.2%) patients had asthma, 2 (2.6%) patients had diabetes mellitus, and 1 (1.3%) patient had mitral valve prolapsus without requiring therapy. When demographic data were compared, it was found that the mean age, height, weight, and BMI were lower in the SMA patients compared to patients with AIS ($p<0.05$). Also, the ratio of healthy patients (without co-morbidity) was higher in the AIS patients than the SMA patients ($p<0.05$). Preoperative Cobb's angle was greater in the SMA patients ($p<0.05$). Demographic data were listed in Table 1. Endotracheal intubation was performed using fiberoptic bronchoscope in two patients of SMA patients after failure with direct laryngoscopy.

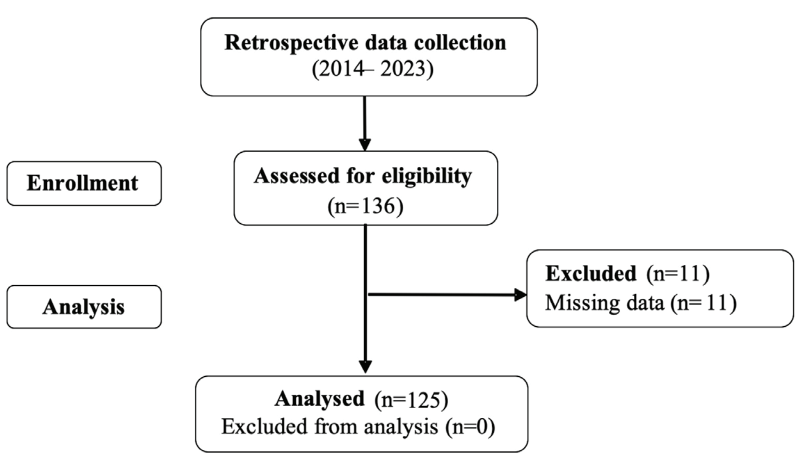

Figure 1. Study flow chart

Comparison of perioperative variables were listed in the Table 2. Instrumentation level (number of vertebrae fused), osteotomy ratio, and number of osteotomized vertebrae was higher in the SMA patients than the AIS patients ($p<0.05$). The mean duration of the surgery was longer, EBL, EBL/TBV ratio were higher also higher in the SMA patients. More patients required PRBC transfusion both in the intra- and postoperative period in the SMA patients compared to the AIS patients ($p<0.05$). The amount of PRBC transfusion was also higher ($p<0.05$). Twelve patients (24.5%) in the SMA group were required intensive care after surgery compared to 1 (1.3%) patient in the AIS group ($p<0.05$). Among SMA patients, four patients were required postoperative mechanical ventilation and extubated between 4-9 hours, and one patient was

Table 1. Demographic variables

	SMA patients (n=49)	AIS patients (n=76)	p
Gender (female/male)	26/23 (53.1/46.9)	40/36 (52.6/47.4)	0.208
Age (years)	11.1±1.2	14.8±3.4	0.04
Body weight (kg)	27.17±2.7	53.1±4.3	<0.01
Height (cm)	127.17± 5.3	155.1±3.0	0.03
BMI class (uw/n/ow/o) (n; %)	31/17/1/0 (63.3/34.7/2.0/0)	5/56/11/4 (6.6/73.7/14.5/5.2)	<0.01
ASA (I/II/III; %)	4/32/13 (8.2/65.3/26.5)	69/7/0 (90.8/9.2/0)	<0.01
Cobb's angle (°)	85.3±4.7	50.3±8.7	0.02

A p value <0.05 was considered statistically significant
SMA: Spinal muscular atrophy, AIS: Adolescent idiopathic scoliosis, BMI: Body mass index, uw: Underweight, n: Normal, ow: Overweight, o: Obese, ASA: American Society of Anesthesiologists

Table 2. Perioperative variables

Parameter/n=37	SMA (n=49)	Min-max	AIS (n=76)	Min-max	p
Instrumentation level (number of vertebrae fused)	12.5±0.4	7-14	10.4±2.1	5-13	0.02
Osteotomy ratio (n, %)	15 (30.6)	-	16 (21.1)	-	0.01
Number of osteotomized vertebrae	5	2-7	0.7	0-5	<0.01
Duration of the surgery (min)	308.24±19.6	205-510	230.8±14.3	180-315	0.01
Estimated blood loss (mL)	950.7±71.1	460-1930	865.2±40.8	640-2060	0.04
Estimated blood loss/total blood volume (%)	39.9±4.3	21.4-96.0	23.1±4.3	7.0-29.4	0.02
Intraoperative blood transfusion (n, %)	43 (87.8)	-	30 (39.4)	-	<0.01
Amount of intraoperative blood transfusion (U)	1.31±0.63	(1-4)	0.52±0.1	(1-2)	0.02
Postoperative blood transfusion (n, %)	11 (22.4)	-	12 (15.8)	-	0.03
Amount of postoperative blood transfusion (U)	0.30±0.1	(0-2)	0.18±0.1	(0-1)	0.03
Intensive care unit admission (n, %)	12 (24.5)	-	1 (1.3)	-	<0.01
Length of intensive care unit stay (h)	18.4±2.1	(18-47)	10.5	-	0.02
Hospital discharge time (day)	5.1±0.1	(4-8)	4.3±0.4	(4-6)	0.04
Postoperative complication (n, %)	5 (10.2)	-	1 (1.3)	-	<0.01

A p value <0.05 was considered statistically significant
SMA: Spinal muscular atrophy, AIS: Adolescent idiopathic scoliosis, Min-max: Minimum-maximum

Table 3. Summarizes ROC curve analysis results of numerical data which showed statistical difference in intergroup comparison

		%95 CI				
	AUC	Lower	Upper	p value	Sensitivity	Specifity
Number of vertebrae fused	0.715	0.647	0.903	**0.001**	0.807	0.501
Operative time	0.822	0.675	0.994	**<0.001**	0.711	1
Preoperative respiratory function	0.703	0.566	0.868	**0.004**	0.643	0.744
Blood loss	0.774	0.602	0.891	**0.001**	0.562	0.903
Blood transfusion	0.722	0.607	0.888	**0.002**	0.573	0.858
Body mass index	0.693	0.508	0.901	**0.002**	0.504	0.763

A p value <0.05 was considered statistically significant
ROC: Receiver operating characteristics, AUC: Area under curve, CI: Confidence interval

already mechanical ventilation dependent. The length of ICU stay and hospital discharge time were also longer in the SMA patients compared to AIS patients ($p<0.05$). Postoperative complication was observed in total 6 patients. Respiratory problems (atelectasis) were observed in 3 patients in the SMA group. One patient was transferred from the service to the ICU at the second postoperative day and treated due to the respiratory distress. Postural hypotension was observed in the remaining 3 patients. Complication rate was higher in the SMA group ($p<0.05$).

Prognostic Factors for ICU Admission

Table 3 summarizes ROC curve analysis results of numerical data which showed statistical difference in intergroup comparison. In univariate analysis, six variables of number of vertebrae fused ⩾6 ($p=0.001$), operative time >6 h ($p\leqslant0.001$), preoperative poor respiratory functions ($p=0.04$), blood loss >33.3% of TBV ($p=0.001$), blood transfusion >50% of TBV, and low BMI (underweight) ($p=0.002$) were identified.

DISCUSSION

The results of this retrospective study showed that the anesthetic management of scoliosis surgery was more complicated in patients with SMA compared to the patients with AIS. Scoliosis surgery has by itself several difficulties including prolonged duration of the surgery, intraoperative bleeding, prone positioning, major intravascular fluid shift, and the risk of neurologic complications. Blood loss may exceed 50% of patient's TBV and is related to the instrumentation level, osteotomy, increased intraabdominal pressure and engorgement of the epidural plexus, and consumption or dilution of the coagulation factors[6].

Neurologic complications may be catastrophic and neuro-monitorization with SSEP and MEP are mandatory to prevent or diagnose nerve injury in the intraoperative period. In several cases, intraoperative wake-up test may also be indicated. Prone positioning has a potential for pressure injuries that may result in pressure ulcer, optic nerve injury, corneal ulceration, inadequate peripheral venous return, and inadequate ventilation. Vulnerable areas should be supported by padding and joints and contractures should not be overstretched[7].

When physical condition of SMA patients is added to all challenges, from the point of view of anesthesia management, it should be admitted that this patient group may be considered one of the difficult patient populations in the orthopedic surgery. SMA patients are at risk for difficult airway management due to the limited mobility of cervical spine, limited mouth opening by mandibular joint ankylosis and oversized tongue that may require videolaryngoscope or flexible fiberoptic bronchoscope guided endotracheal intubation for airway safety[8].

The patients have generally increased sensitivity to non-depolarizing muscle blocking agents and their use is limited for prolonged effects. In the case of using non-depolarizing neuromuscular blockers, sugammadex may be a reliable choice to reverse the muscle relaxation. The patients are also at risk for succinylcholine-induced rhabdomyolysis and hyperkalemia[9]. There are no verified reports about malignant hyperthermia by volatile anesthetics, but volatile anesthetics may interfere with SSEP. Therefore, TIVA is considered to the best anesthetic option for maintenance. Extremity contractures may make intravenous access extremely difficult, and central venous catheterization is almost mandatory in scoliosis surgery. Nutritional status of the patients is generally poor caused by bulbar dysfunction and regurgitation and patients are underweight and flaccid due to the muscle weakness. Low muscle and fat mass may result in hypoglycemia in prolonged fasting. Blood glucose measurement should be repeated during the surgery. Perioperative cardiovascular complications are rare but cardiac malformations may be present among patients with severe SMA[10].

The most important problem is respiratory insufficiency which is caused by restrictive breathing pattern accompanied by scoliosis, weak cough and clearance of sputum. The patients are prone to pulmonary infections in the pre- and postoperative period that may rapidly progress to develop desaturation[11].

Scoliosis patients generally need critical care in the postoperative period. In our study, the ICU admission rate was 24.5% and we found that preoperative poor respiratory function, prolonged surgery (>6 hours), multiple vertebral fusion (>6 levels), intra-operative blood loss >33% of TBV, and massive transfusion are predictive for ICU admission. In a study by Akesen[12], it was reported that the ICU admission rate after scoliosis surgery in a mixed pediatric patient population was 15.3% and approximately 7% of patients required postoperative mechanical ventilation. It was found that ICU admission correlated significantly with lower body weight percentile, neuromuscular etiology, abnormal finding in chest X-ray, additional comorbidities, and estimated postoperative need for ICU in the preoperative evaluation[12]. The main difference between two studies was that our study population consisted of more SMA patients (49.2%) whereas only 23.5% of patients had neuromuscular disorder in Akesen's[12] study. When patients with neuromuscular disorders are compared, the ICU admission rate was lower in our study (24.5% vs 40%). In another study by Malik et al.[13], medical records of 1398 patients with idiopathic, congenital or neuromuscular scoliosis were reviewed who required ICU admission after correction of pediatric spine deformity. Patient and surgical factors which were associated with ICU admission were black/African American versus white race, anterior fusion, combined fusion, non-idiopathic scoliosis, preoperative ventilator dependence, asthma, having structural pulmonary abnormality, developmental delay, having a neuromuscular disorder, requiring nutritional support and a total operative time >270 minutes[13].

The results of other studies in the literature revealed that the ICU admission rate is related to the several variables such as patient's medical condition (neuromuscular disease, high Cobb angle), poor respiratory status, low body weight, extent of the surgery (number of vertebrae fused, osteotomy, prolonged surgery), intraoperative blood loss, massive transfusion, and poor nutritional status[14,15].

Therefore, we recommend several preventive measures to increase the procedural success: a) pre-operative anesthetic visit: pulmonary examination including pulmonary function test and pulmonary consultation, airway evaluation, nutritional status assessment, giving information to family about the possible complications ICU admission, and mechanical ventilation dependence[16]; b) intraoperative period: TIVA technique, tranexamic acid infusion, deliberate hypotensive anesthesia, avoiding neuromuscular blocking agents, invasive arterial blood pressure monitoring, large IV access (central venous catheterization), neuro-monitorization, MMA regimen, short acting opioids if necessary, careful fluid management, arterial blood gas analysis with short intervals, prevention of hypothermia, hypoglycemia, careful positioning, padding, and close communication with surgical team; c) postoperative period: establishing a postoperative care protocol that include extubation strategy and ICU admission criteria, postoperative non-invasive ventilation, and chest physiotherapy[17,18].

Study Limitations

This study has several limitations. First, the retrospective nature of the study may have recall and selection bias. To prevent this, same inclusion and exclusion criteria were used. The patients with missing data were excluded. The second limitation was that a comparison between a patient group with a neuromuscular disease and otherwise healthy subjects might most probably increase the bias risk. But the study focused mainly on the SMA patients. Therefore, the patients with AIS might be considered as a control group in a comparative study because all perioperative managements were same in both groups. Third, the data about hospital readmission after discharge does not exist because some patients were from out-of-town which might provide valuable information in the postoperative period.

CONCLUSION

This study showed that a structural preoperative planning including multi-disciplinary approach and postoperative care may provide a successful perioperative course in patients with SMA who underwent scoliosis surgery.

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Ethics

Ethics Committee Approval: This study was approved by the Private Çankaya Hospital Ethic Committee (decision no: 2023-02-01, date: 02.01.2023).

Informed Consent: Obtaining informed consent from patients was waived due to the retrospective nature of the study.

Peer-review: Externally peer-reviewed.

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