

CLINICAL ARTICLE

Anesthetic Management of Patients After Scoliosis Surgery: A Single-Center Retrospective Study

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Purpose: To evaluate the effect of anesthetic management on scoliosis surgery and review the incidence rate of perioperative adverse events.

Methods: This was a retrospective study and approved by the ethics committee. Patients who underwent scoliosis surgery from April 2011 to March 2018 in the Third Hospital of ChengDu were enrolled in this study. Characteristics of patients were obtained from the hospital's electronic records. The following information on patients was collected: preoperative assessment details, premedication, type of anesthesia and operation, the main postoperative outcome, and complications. Data were presented as the mean \pm standard deviations (SD) for normally distributed continuous variables and numbers for categorical variables. Statistical analyses were performed using SPSS version 22.0.

Results: In total, 513 patients were enrolled in the present study. The main preoperative complication was cardiopulmonary dysfunction (386 cases, 75.24%). Anesthesia induction was performed with conscious tracheal intubation after oral surface anesthesia. In total, the common postoperative complications involved anesthesia (24 cases, 4.68%), surgery (23 cases, 4.48%), the respiratory system (138 cases, 26.90%), and the gastrointestinal tract (nine cases, 1.75%). The majority of postoperative complications were postoperative hypoxemia and hypercapnia, caused by poor cardiopulmonary function. Rare and serious complications still occurred. Three patients died in hospital.

Conclusion: Our study demonstrated a high incidence of complications in scoliosis surgery, especially postoperative complications. Extreme postoperative vigilance is required and high-level monitoring of conditions is highly recommended.

Key words: Anesthetic management; Postoperative complication; Scoliosis surgery

Introduction

Scoliosis is a common thoracic deformity in children and adolescents, which is defined as a lateral curvature of more than 10°, including sequence abnormalities in coronal, sagittal, and axial positions. The incidence rate of scoliosis is approximately 1% to 4% all around world, while it ranges from 0.11% to 2.64% in China¹. Scoliosis affects not only the appearance of patients, but also the normal growth and

development of lung function, leading to irreversible impairment of lung function.

Some types of scoliosis may be structural, while others can be nonstructural. The latter can be caused by lower limb disorders resulting in limb length discrepancy or hip dysplasia, limb deficiency syndromes, and herniated discs in older children². Scoliosis has two types in terms of etiology: idiopathic and secondary. Idiopathic scoliosis is divided into

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three subtypes: infantile, juvenile, and adolescent types or early and late onset³. Secondary scoliosis is usually caused by congenital disorders, neuromuscular conditions, tumors, trauma, or syndromic conditions. It is also classified according to the side of occurrence into left- and right-sided curves.

In general, surgery treatment is one of the most effective ways to treat scoliosis. The basic aim of the surgical treatment is to prevent the curve and correct the deformity in the coronal and sagittal planes. In addition, the operation can also improve cosmetic appearance, achieve solid fusion, and prevent long-term disability.

However, the best anesthetic and perioperative strategies of scoliosis surgery remain unclear. Anesthetic and perioperative strategies of scoliosis surgery in our hospital were performed as a multidisciplinary intervention including the specialties of orthopaedics, anesthesiology, respiratory, cardiology, and intensive care. The aim of this study was to evaluate the effect of anesthetic management on scoliosis surgery and review the incidence rate of perioperative adverse events.

Methods

Patients

This was a single-center retrospective study. Patients who underwent scoliosis surgery from April 2011 to March 2018 in the Third Hospital of ChengDu were enrolled in this study. The inclusion criteria were as follows: (i) confirmation of severe scoliosis; and (ii) receiving scoliosis surgery during hospitalization. Patients with missing data on anesthetic and perioperative management were excluded. The study protocol was approved by the ethics committee of The Third Hospital of ChengDu.

Data Collection

Data of patients were extracted from electronic medical records. The following information of patients was collected: preoperative assessment details, premedication, type of anesthesia and operation, the main postoperative outcome, and complications. Preoperative assessment included basic cardiopulmonary function, 6-minute walk test, breath-hold test, and any other existing co-morbidity. We also recorded the preoperative blood pressure, heart rate, and oxygen saturation (SpO₂). Blood investigations included hemoglobin, white blood cell count, platelets, sodium, potassium, oxygen, and carbon dioxide content. Intraoperative data recorded included the drugs used for induction and maintenance of anesthesia and analgesia. Intraoperative blood loss, amount and types of intravenous fluids administered, use of tranexamic acid and cell salvage, and somatosensory evoked potentials (SSEP) were also recorded. Postoperatively, we recorded all complications as well as the number of days spent in high intensive care unit (ICU), days until discharge from hospital, and in-hospital mortality.

Surgery Process

Anesthesia and Position

The right internal jugular vein and right radial artery were punctured when the patient was awake. Since the neck is fixed by the external fixing bracket (head-basin ring) (Fig. 1B), the neck of the patients can hardly be tilted back and all patients have been intubated in awake state. After local oral mucosal anesthesia and cricothyroid membrane puncture anesthesia, tracheal intubation was performed.

Approach and Exposure

After taking the middle incision of the spine, echidna, vertebral plate, zygapophysis, transverse process, and partial of ribs were revealed layer by layer. A total of six to seven groups of vertebral root screws were implanted, confirmed by X-ray.

Resection and Fixation

The rib vertebrae and rib cross-sudden joints were loosened using detacher. The vertebrae was then resected through the small joint, and vertebral plates were overlapped, the width of which was related to the patient's side convex degree and spinal flexibility. Concave side protrusion and convex side pressure methods were used to correct the scoliosis.

Reconstruction

For razorback deformity, partial ribs were removed near the scoliosis, and the overlap of two sides were fixed with tendon sutures. Fixed sections were fused with the autogenous bones.

Monitoring Parameters

During the operation, we also monitored invasive arterial blood pressure, central venous pressure and pulse-indicated continuous cardiac output (PICCO). The bispectral index (BIS) monitor was used as a guide for anesthetic depth. Somatosensory evoked potentials (SSEPs) and myogenic motor evoked potentials (MMEPs) were monitored in all procedures, and data were recorded in all cases.

Invasive Arterial Blood Pressure

Invasive arterial blood pressure was directly measured through placing an arterial catheter into an artery, and could reflect the continuous dynamic change of blood pressure accurately and timely, with no influence from artificial pressure, sleeve width, and tightness.

Central Venous Pressure

Central venous pressure measured the pressure of right atrium and upper and lower cavity vein chest section, which could help assess the combined condition of blood volume, heart function, and vascular tension. When low blood pressure, central venous pressure below 5 cm H₂O suggested insufficient blood volume, 10–15 cm H₂O suggested obvious heart failure and a possibility of pulmonary edema.



Fig. 1 (A) Appearance of patients with server scoliosis; (B) The patient's condition before operation after traction of head-basin ring. It can be seen that the patient's head and neck are fixed and his head can hardly be tilted back; (C) Postoperative appearance of patients; (D) During surgery, the patient lies prone on a special foam pad to avoid eye and abdomen compression.

PICCO

PICCO was a single heart output measured by thermal dilution, and obtained by analyzing the area under the arterial pressure wave curve. This method could monitor the pre-load, post-load, and heart function in real time, and help anesthesia decision-making.

BIS

BIS was a mixture made by the power and frequency of EEG by dual-frequency analysis, ranging from 0 to 100. And a degree between 40° to 60° was the appropriate anesthetic depth.

SSEPs and MMEPs

Both were objective indicators for various sensory pathway lesions. SSEPs was estimated with body sensory function, after stimulating the sensory nerves at terminal part of the limb. The peripheral nerves, spinal cord, brain stem, thalamus, and cortical sensory regions could be assessed. MMEPs was measured

with a composite potential of muscle movement with a stimulation of motor cortex, which examined the transmission of motor nerves from the cortex to the muscle and the overall synchronization and integrity of the conduction pathway. Both of them could well monitor spinal cord function during the surgery, to avoid spinal cord damage caused by the operation.

Statistical Analysis

Statistical analyses were performed using SPSS version 22.0 (IBM, Armonk, New York, USA). Data were presented as the mean \pm standard deviations (SD) for normally distributed continuous variables and numbers for categorical variables.

Results

Baseline Characteristics

A total of 513 patients with severe scoliosis who underwent scoliosis surgery were enrolled in this study between 2013

and 2018. Demographic characteristics of patients were shown in Table 1. The mean age was 24 ± 8 years (range 16–32 years). The anesthesia management of all scoliosis surgery was conducted by experienced orthopaedic anesthetists and specialized spine surgeon consultants. The Cobb angle of the patient in our study is $127.5^\circ \pm 26.8^\circ$, a value representing the degree of scoliosis.

Preoperative Comorbidities

Preoperative comorbidities of patients were detailed in Table 2. Cardiopulmonary abnormalities were identified in 386 patients, including 326 cases of extreme pulmonary dysfunction, 136 cases of type 2 respiratory failure, 42 cases of pulmonary hypertension, and 43 cases of structural malformation of the heart. All of them were confirmed by echocardiography. Of the 513 patients, 186 (36.51%) had a history of respiratory failure defined as arterial oxygen tension (PaO_2) lower than 60 mmHg with a normal or high arterial carbon dioxide tension (PaCO_2), among which 84 patients

needed non-invasive ventilator therapy at home. Among the 513 patients, 32 (6.24%) were wheelchair-bound, 24 were able to stand but not walk, and eight could walk. No premedication was given to any of the patients.

Anesthesia and Surgical Process

After local oral mucosal anesthesia and cricothyroid membrane puncture anesthesia, tracheal intubation was performed. Four hundred and one (78.17%) patients were guided by fiberoptic bronchoscope, 82 (15.98%) were guided by visible light wand. Only total intravenous anesthesia (TIVA) was used with a variety of neuromuscular blocking

TABLE 1 Demographic characteristics and clinical features of patients

Parameter	Value
Age (years)	28.6 ± 3.7
Weight (kg)	37.5 ± 12.9
Cobb's angle ($^\circ$)	127.5 ± 26.8
Height (cm)	126.2 ± 13.8
Arm length (cm)	146.6 ± 19.1
HR (beats/min)	89.2 ± 26.1
BP (mm Hg)	123.5 ± 36.5
SpO_2 (%)	89.4 ± 7.8
Na^+ (mmol/L)	138.6 ± 2.4
K^+ (mmol/L)	3.9 ± 0.4
Blood urea nitrogen (BUN) (mmol/L)	4.7 ± 1.3
Creatinine ($\mu\text{mol/L}$)	42.5 ± 6.4
Hb (g/dL)	126.3 ± 11.4
WBC ($\times 10^9/\text{L}$)	8.4 ± 1.9
PLT ($\times 10^9/\text{L}$)	218.2 ± 31.7

Values are expressed as mean \pm SD

TABLE 2 Preoperative Comorbidities

Comorbidities	Number of patients
Ehler-danlas syndrome	5
Marfan syndrome	27
Ebstein's anomaly	4
Type 2 respiratory failure	136
Pulmonary hypertension	42
Hypertrophic obstructive cardiomyopathy	3
Neurofibromatosis	34
Extremely pulmonary dysfunction	326
Congenital polyarticular contracture	18
Atrial septal defect	26
Ventricular septal defect	13

TABLE 3 Induction, maintenance, analgesic and adjuvants administered

	Number of patients
Induction	
Sevoflurane	0
Propofol	122
Midazolam	426
Etomidate	364
N/A	
Maintenance	
Sevoflurane	0
Propofol	513
N/A	
Muscle relaxant	
Rocuronium	156
Cisatracurium	357
N/A	
Opioid	
Remifentanyl	513
Sufentanyl	513
Oxycodone	513
N/A	
Other	
Dexmedetomidine	513
Methylprednisolone	513
Tropisetron	286
Tranexamic acid	385

TABLE 4 Intraoperative blood loss and fluid replacement

Parameter	Value
Total blood loss (mL)	1783 ± 836
Fluids administered (mL)	
Crystalloids	1532 ± 359
Colloids	729 ± 286
Blood transfused	
Autologous blood transfused (mL)	326 ± 185
Allogenic red blood cells transfused (units)	4.6 ± 1.8
Allogenic plasma transfused (mL)	496 ± 246
Allogenic cryoprecipitation (units)(number of patients:368 of 513)	4.5 ± 2.6
Allogenic platelet(units)(number of patients 76 of 513)	1.8 ± 0.9

Values are expressed as mean \pm SD

TABLE 5 Main postoperative complications after scoliosis surgery

Complications	Number of patients
Pyrexia	39
Persistent vomiting	9
Pneumonia	12
Continuous positive airway pressure (CPAP) needed	126
Seizures	2
Tongue bite	3
Malignant hyperthermia	1
Inadequate pain control	18
Clotting disorders	4
Wound infection	13
Superior mesenteric artery syndrome	9
Abdominal aortic aneurysm formation	1
Brachial plexopathy and peripheral nerve injuries	2

agents, analgesics, and adjuvants administered intraoperatively (Table 3). Data on intraoperative blood loss and fluid replacement were presented in Table 4. The mean blood lost was 1783 ml, and the average administration of fluid was 1532 ml and 729 ml for crystalloids and colloids, respectively.

Postoperative Complications

The postoperative complications were described in Table 5. In total, the common postoperative complications were anesthesia-related (24 cases, 4.68%), surgical complications (23 cases, 4.48%), complications with the respiratory system (138 cases, 26.90%), and those with the gastrointestinal tract (nine cases, 1.75%).

All patients were electively admitted to ICU postoperatively. One hundred and twenty-six (24.56%) patients were electively ventilated after the surgical procedure, of which 58 used invasive ventilation and 68 used noninvasive ventilation. The mean time of mechanical ventilation was 2.6 ± 4.2 days (ranging from 1 to 6 days).

The respiratory issues occurred in 119 patients, with intraoperative blood loss in five patients, and intraoperative cardiac arrest in two patients, who regained spontaneous circulation after cardiopulmonary resuscitation (CPR). And 12 patients (2.34%) received re-intubation postoperatively due to postoperative respiratory failure. Tracheostomy was carried out in three patients (0.58%) and mean duration was 9.2 ± 2.7 days (ranging from 6 to 12 days). Three patients died on the 1st, 7th, and 14th postoperative days. The causes of death were postoperative tension pneumothorax fulminant liver failure (FLF), and acute respiratory distress syndrome (ARDS).

Discussion

The study showed that the main preoperative complication was cardiopulmonary dysfunction. The majority of

postoperative complications were postoperative hypoxemia and hypercapnia caused by poor cardiopulmonary function.

Anesthetic Management

Scoliosis surgery is a significant operation and requires thorough anesthetic planning. Congenital scoliosis accounts for the majority of our patients who can have sequelae resulting from a long-term deformity. Patients with these deformities can have organ dysfunction which will impact anesthetic management and so preoperative assessment is very important, with has a particular emphasis on cardiopulmonary function². A multidisciplinary approach is the key to successful treatment with the involvement of surgeons, anesthesiologists, intensivists, and specialist nurses. Positioning, potential haemorrhage, and the ability to monitor nerve function are important intraoperative considerations and, postoperatively, a multimodal analgesic regime and high level of monitoring are required.

Anesthetic evaluation of the patient with scoliosis is more difficult, as with surgical evaluation. The presence of learning difficulties may preclude those patients from giving a medical history or complying with preoperative testing. Scoliosis surgery places significant physiological stress on various organ systems in the body. Functional evaluation of the cardiovascular, pulmonary, renal, and endocrine systems, along with a careful search for any overt or latent comorbidities, is an essential part of preoperative patient work-up and optimization. Evaluation of the cardiopulmonary status is crucial in patients with scoliosis. Patients with a history of cardiopulmonary disease or other significant cardiac risk factors should undergo preoperative stress testing and further evaluation⁴, followed by optimization of cardiopulmonary function before elective spinal surgery. Usually, the breathing disorders along with the severe degree of scoliosis result in chronic restrictive airway disease^{5, 6}. This finding was confirmed in our study, as almost 80% of the patients suffered from restrictive airway dysfunction. Our medical history was as detailed as possible in an effort to identify every aspect of the pre-existing respiratory defects. More specific evaluation needing patients' cooperation remains challenging and mostly impossible.

Perioperative Management

In our perioperative management of these patients, we require them to walk up stairs, blow balloons, do singing exercises, and even use non-invasive ventilators during sleep for patients with type 2 respiratory failure. These exercises to minimize symptoms of airway obstruction in patients with chronic restrictive airway disease caused by scoliosis are beneficial for improving baseline pulmonary function^{7, 8}. Equally noteworthy is the reduction in postoperative pulmonary complication rate following cardiopulmonary exercises, a minimum of 3–4 months prior to surgery^{9, 10}.

From the cardiovascular point of view, 10% of patients had a pre-existing cardiac abnormality; most of them had atrial septal defect or ventricular septal defect, very few of

them had pre-existing pulmonary hypertension. In our series of patients, we did not notice any adverse event due to cardiac abnormalities in the perioperative period, but, conversely to other case series, some patients with pre-existing pulmonary hypertension even had pulmonary hypertension crisis and refractory right heart failure after operation^{11,12}. Respiratory dysfunctions are present in the majority of patients¹³. This finding was again confirmed in our study. Scoliosis causes a restrictive lung defect as it prevents normal lung expansion and reduces chest wall compliance. The impact of this can be evaluated by pulmonary function tests (PFTs), which provides information about the forced vital capacity and FEV1. In our patients whose Cobb angle was greater than 100°, there is a possibility of bronchial compression, so a spiral computed tomography (CT) can be useful. Cardiopulmonary exercise testing is currently routine practice in scoliosis surgery in our center.

The preoperative nutritional status, on the other hand, has an impact on the recovery process and should be assessed thoroughly before the planned surgery¹⁴. The consensus is that preoperative nutritional status should include body mass index, hemoglobin, electrolytes, albumin, and white blood cell count. However, dieticians who were part of the team also assessed all patients preoperatively in an attempt to optimize any nutritional deficits and minimize postoperative complications.

All the scoliosis patients received standard anesthetic monitoring involving a three-lead ECG, noninvasive blood pressure measurement, and oxygen saturations, but scoliosis surgery has specific considerations. There can be significant haemodynamic instability due to excessive bleeding and so an arterial line for invasive blood pressure monitoring and central venous catheter for rapid infusion is essential. In addition, placement of an arterial line facilitates more accurate monitoring of blood pressure throughout the procedure and is particularly useful in situations where hypotensive anesthesia is planned. An added advantage of intra-operative arterial line placement is the ease of obtaining samples for arterial blood gas analysis during surgery. Scoliosis patients, particularly those with connective tissue disorders or neuromuscular conditions, are more likely to have massive hemorrhage due to dysplasia or loss of muscular layer of arterial wall. In most scoliosis surgeries, a large-bore peripheral intravenous cannulae and a three-lumen central venous catheter provide adequate access. In some patients, we also monitored the patient's cardiac function through Pulse Contour Cardiac Output (PiCCO). Through PiCCO monitoring, we can prepare indexes such as cardiac output (CO), systemic vascular resistance index (SVRI), preload, and stroke volume variation (SVV) to provide convenience for intraoperative management of patients. Depth of anesthesia can be monitored using bispectral index (BIS) monitoring which works *via* electroencephalography (EEG) principles and provides some reassurance, particularly when using a TIVA technique. Monitoring of body temperature is also essential in addition to blood pressure, pulse oximetry, and other monitoring. Hypothermia can result from prolonged exposure to cold

environment in the operating room as well as infusion of cold intravenous fluids. The low body temperature can have an adverse impact on somatosensory evoked potential monitoring and can significantly delay emergence if a wake-up test is required. Hypothermia can also contribute to increased intraoperative blood loss by causing impairment in platelet function and hemostasis. Using external warming blankets, maintaining operating room temperatures within a comfortable range and warming intravenous fluids prior to infusion are some of the measures to prevent hypothermia.

A retrospective study showed promising results and good correlation between SSEPs, MEPs, and neurological injury^{15, 16}, so SSEPs and MEPs were monitored in all cases. In our study, the information provided by SSEPs and MEPs enables anesthesiologists and surgeons to quickly identify the spinal cord/nerve injury, even brachial plexus compression caused by posture.

Because of the head-pelvis ring, the neck of the patient can hardly move, therefore, all patients are operated on with conscious tracheal intubation. Intubation is carried out with an armored endotracheal tube to avoid kinking and thus obstruction when the patient is prone. Anesthesia is usually induced with an intravenous agent, such as propofol, along with a short-acting muscle relaxant or opiate bolus and maintained with total intravenous anesthesia (TIVA). We try our best to avoid the use of inhalation anesthetics during the operation because much literature reports that the incidence rate of malignant hyperthermia in scoliosis patients is higher than that in the general population, and inhalation anesthetics are one of the inducing factors of malignant hyperthermia^{17, 18}.

Placing the patient in the prone position on the surgical table can be challenging and calls for coordinated teamwork. Turning the patient interferes with monitoring and risks disrupting anesthesia and dislodgement of intravenous access and urinary catheters. We taped eyes and placed the face in a specifically designed foam pad carefully (Fig. 1D), ensuring that the eyes are free and there is no pressure on the orbit. Airway management in the prone, anesthetized patient is exceptionally difficult and would require the patient to be turned supine, in case of airway emergency. In order to avoid this from happening, endotracheal tubes are meticulously secured prior to turning in the prone position. In our case, three cases of tongue bite occurred, so a soft and firm dental pad is inserted to prevent the patients from experiencing tongue trauma and endotracheal tube damage during neuromuscular testing. Lying in the prone position exposes the patient to iatrogenic injury as a result of prolonged pressure. Due to the support of head-pelvis ring, damage to all pressure points, such as bony prominences and the development of pressure ulcers are avoided; meanwhile, it allows the abdomen to be free, preventing pressure injury to the abdominal organs. Abdominal compression can subsequently result in the compression of vena cava.

Intraoperative bleeding is always a risk in scoliosis surgery with high perioperative transfusion rates. We discussed

the risk of hemorrhage with the surgical team before the operation, and all cases used cell salvage in the operation room. Tranexamic acid was administered in all procedures, but the effect is not yet clear¹⁹. During the operation, we did not use controlled hypotension to avoid the hypoperfusion of spinal cord. Scoliosis Patients, particularly those with connective tissue disorders, neuromuscular conditions, or cardiac problems, need to have cross-matched red blood cells and products available as they are at greater risk of bleeding.

Scoliosis patients generally need critical care postoperatively, but through our intraoperative anesthesia management measures, 95% of them are extubated after the operation to permit assessment of neurological function. A multimodal analgesic regime is extremely important. Typically, patients receive non-steroidal anti-inflammatory drugs before operation. In the immediate postoperative period, patients receive regular opiate in the form of patient-controlled analgesia (PCA). Regional block has also been widely reported and applied in spinal surgery²⁰, but its clinical application in scoliosis surgery is still controversial. We have performed erector spinae plane block before operation, but it has an influence on SSEPs and MMEPs monitoring. However, it is certain that local anesthetic infiltration through subcutaneous incision is an effective analgesic method.

Similarly, in a case-control study by Toll, respiratory complications were the most common in scoliosis patients, comprising 61% of all major complications²¹. In our study, 126 patients were electively ventilated after the surgical procedure, of which 58 received invasive ventilation and 68 received noninvasive ventilation, and 12 of the total of 513 patients had to be reintubated due to low oxygen saturation associated with extremely pulmonary dysfunction. Strangely, there are two patients with brachial plexus injury in our case. After the analysis of our team, the surgical factors were

excluded and the reason caused by the right internal jugular vein puncture was finally determined. So far, we have completed the deep vein puncture of all patients under the guidance of ultrasound. Two patients bit their tongues during the operation. In MMEP monitoring, stimulation electrodes are placed on the scalp surface above the motor cortex, and electrical stimulation of about 400–500 V acts on the scalp. This stimulus can stimulate the contraction of masticatory muscles²². So, during the monitoring process, a mouth plug must be placed to prevent biting the tongue.

The limitation of our study is that it is a retrospective review of case notes and includes no control group. Unfortunately, the rarity and the characteristics of the scoliosis make the design of randomized controlled trials very difficult. Due to the retrospective nature of the study, some minor complications may have not been included in the patients' notes. However, even such studies can add valuable information to the current literature.

Conclusions

In summary, anesthesia for scoliosis surgery is a significant undertaking, as with the surgery itself, and success relies on the input of the multidisciplinary team. Careful preoperative planning with consideration to the cardiorespiratory function is essential. Positioning, hemorrhage control, and the ability to monitor nerve function are important intraoperative considerations and, postoperatively, a multimodal analgesic regime is required.

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