Original Article

Complications of three deep sedation methods for magnetic resonance imaging

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Abstract

Background: Propofol and pentobarbital are commonly used to sedate children undergoing magnetic resonance imaging (MRI). Aim/Objective: To compare the safety of three types of sedation: intravenous propofol (PROP), mixed pentobarbital/propofol (PENT), and mixed pentobarbital group requiring supplemental sedation (PENT SUPP) regimens in pediatric patients following deep sedation (DS) for noncardiac MRI.

Materials and Methods: We conducted a case-control study matching 619 cases with complications with 619 controls using data from our institution's sedation database for children deeply sedated for noncardiac MRI. Cases were defined as patients with any complication and we characterized complications from cases, and used a conditional logistic regression model to assess the association between three DS methods and occurrence of complications after adjusting for confounding variables.

Results: We found that complications occurred in association with 794 (10.1%) of the 7,839 DSs performed for MRI between 1998 and 2008. Of the 794 cases, 619 cases met inclusion criteria for the study. Among the 619 cases that met inclusion criteria, 24 (0.3% of 7,839 DSs total) were associated with major complications. Type of sedation was significantly associated with the occurrence of complications, and the PENT group was associated with decreased odds of complications when compared to the PROP regimen (OR 0.68; 95% CI 0.46, 0.98; P=0.040) and compared to the PENT SUPP group (OR 0.60; 95% CI 0.31, 0.89; P<0.0001).

Conclusions: DS with a pentobarbital technique was associated with decreased odds for complications when compared to a propofol-based technique or a pentobarbital technique requiring supplemental sedation.

Key words: MRI in infants and children, pediatric sedation, pentobarbital, propofol

Introduction

Propofol, pentobarbital, dexmedetomidine, and other agents are commonly used to induce deep sedation (DS) in children undergoing magnetic resonance imaging (MRI) scanning to minimize motion artifacts. Studies have shown that propofol's rapid distribution and plasma clearance increase the need for repeated boluses and continuous infusion to maintain the level of sedation. Use of propofol for sedation has been associated with respiratory depression that may lead to hypoxia.[1-3] Nonetheless, a study of 49,836 propofol sedation/anesthesia cases found that the technique is unlikely to result in serious adverse outcomes in institutions with organized sedation services.[4] Propofol also permits faster onset and recovery and has comparable efficacy to a pentobarbital/midazolam/fentanyl regimen.[5] Pentobarbital has also been shown to be safe and effective when used with midazolam or fentanyl for sedation during pediatric diagnostic imaging.[6,7] Dexmedetomidine sedation was associated with a 16% incidence of bradycardia; however, mean arterial blood pressures and oxygen saturations were reported to be within normal limits for these patients.[8]

At Oregon Health and Science University (OHSU), children are sedated for diagnostic imaging with intravenous (IV) propofol (PROP) or mixed pentobarbital/propofol (PENT) regimens. Patients sedated with the PENT regimen but then required supplemental sedation, defined as an additional dose of pentobarbital and/or propofol by bolus or infusion

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more than 20 min after the initial dose of pentobarbital, were categorized under a third sedation method called the PENT SUPP group. In addition, airway devices such as laryngeal mask airways (LMAs) or endotracheal tubes (ETTs) are very rarely used. It was not known whether these different types of sedation are associated with different incidence of complications. Therefore, the aim of this study was to compare the safety among the PROP, PENT, and PENT SUPP regimens in patients receiving noncardiac MRI. We hypothesized that the type of sedation is a significant predictor of complications.

Materials and Methods

This case-control study used data on pediatric patients deeply sedated by attending pediatric anesthesiologists between 1998 and 2008 for noncardiac MRI scanning and recorded in our institution's Sedation Quality Improvement (SQI) database to compare the safety of propofol and pentobarbital regimens. The study protocol was approved by the OHSU Institutional Review Board.

The SQI database is administered by the Department of Anesthesiology and Peri-operative Medicine at our institution and populated by sedation nurses based on information recorded on a paper pediatric sedation form by attending anesthesiologists performing the DSs. The SQI database includes data on demographics, procedural details, sedation techniques, and outcomes including side effects and complications. In addition to data collection from the SQI database, one of the authors manually searched through original paper sedation charts for corroboration of data with the SQI database and to obtain data missing from the SQI database, when available. Data collected from both the SQI database and/or the paper sedation charts were populated in a Microsoft Excel® spreadsheet for further analysis.

The sedation form also includes specific check boxes for each of the predefined major and minor complications. In particular, major complications were defined as aborted procedure, aspiration, cardiac arrest, dysrhythmia, hypotension with more than a 30% decrease from baseline, unplanned admission to ICU, unplanned admission to ward, and unplanned intubation. Minor complications were defined as airway obstruction without intervention, airway obstruction with intervention, apnea without intervention, apnea with intervention, coughing, desaturation (oxygen saturation below 92%) with or without intervention, drug error, inadequate sedation, IV infiltration, multiple IV sticks (>3 tries), nausea and/or vomiting, poststudy agitation (paradoxical reaction), excessive secretions complicating airway management, and unplanned admission to PACU. In addition, the form includes specific inquires on whether an unplanned admission to PACU, Ward or PICU, or an aborted procedure occurred.

Patients who received MRI that was not cardiac MRI were categorized as noncardiac patients, and only noncardiac MRI pediatric patients who were deeply sedated between 1998 and 2008 for MRI scanning were eligible to be considered in this analysis. Patients who received cardiac MRI were excluded from this study due to cardiovascular compromise that creates potential for increased problems with DS. In addition, we excluded all patients of one of the attending anesthesiologists who utilized a unique loading dose of propofol (LDP) method of sedation (large propofol bolus over 10–15 min and no infusion). The LDP method may have significantly different physiological effects that would invalidate any comparison with patients sedated with propofol using the "usual" method (typical induction bolus followed by infusion). Patients who received chloral hydrate were also excluded from the study. Patients who were administered either midazolam and/or ketamine premedication were included in the study. During DS, ketamine is administered as a synergistic agent prior to administration of either propofol or pentobarbital; it also has minimal respiratory depressant effects at low doses. Ketamine is widely used in pediatric sedation in emergency departments, burns units, and pediatric sedation units.

The SQI database had a total of 7,839 pediatric patients deeply sedated for MRI from 1998 to 2008 including cardiac, noncardiac, and LDP patients. We reviewed data from the SQI database and identified 619 eligible noncardiac patients who experienced one or more complications as cases. We matched each case with an eligible noncardiac MRI patient without complication (control) from the SQI database based on American Society of Anesthesiologists (ASA) Physical Status Classification, weight, and age. The patient with the same ASA classification, and weight and age within 20% of the corresponding case patient was selected as the control. For each case and control, additional data were collected from original paper sedation charts and scanned paper records stored on the Electronic Health Record (Epic, Epic Systems Corporation), including gender, additional complications, the type and doses of premedication and sedation used, sedation duration, recovery time, airway interventions used, anesthesiologist, and patient diagnoses, when available.

The type of DS was the primary predictor variable. In addition to type of DS, other potential confounding variables considered in the multiple conditional logistic regression model included premedication, anesthesiologist, and gender.

DS Techniques

Three methods of DS were used during the study period:

propofol (PROP), mixed pentobarbital (PENT), and mixed pentobarbital group requiring supplemental sedation (PENT SUPP). For the PROP group, midazolam premedication was given [intravenous (IV) 0.02–0.21 mg/kg, intramuscular (IM) 0.08–0.12 mg/kg, per os (PO) 0.18–1.00 mg/kg, or intranasal (IN) 0.24–0.40 mg/kg], and in other cases both midazolam and ketamine (IM 2–8 mg/kg, IV 0.48–2.78 mg/kg, or IN 4.44 mg/kg). Next, a propofol bolus for induction (0.6–20 mg/kg) was given, followed by a propofol infusion (50–200 mcg/kg/min). Propofol bolus for induction was based on doses of propofol recorded on the chart within the first 5 min of the case.

For the PENT group, midazolam premedication was given (IM 0.1–0.13 mg/kg, IV 0.02–1.00, IN 0.20–0.32, GT 0.40–0.80) and in other cases ketamine (IM or PO 3–4 mg/kg or IN 3.1 mg/kg). Next, IV pentobarbital (0.5–6 mg/kg) was given, usually followed by a single dose of propofol (0.3–7.1 mg/kg).

Finally, the PENT SUPP group included patients who were sedated for MRI with the PENT regimen as described above, but then required supplemental sedation, defined as an additional dose of pentobarbital and/or propofol by bolus or infusion more than 20 min after the initial dose of propofol or pentobarbital was given to induce sedation. Propofol alone was used as supplemental sedation when the total pentobarbital dose reached 5 mg/kg.

We used descriptive statistics to summarize patient characteristics. Multiple conditional logistic regression was applied to identify predictors of complications using matched data from cases and controls, and to investigate whether type of sedation was associated with complications after adjusting for potential confounders. Variables included in the model included type of sedation, whether premedication was given, the anesthesiologist performing the DS, and gender of patient. A P value of 0.05 was considered significant. All analyses were conducted using SAS 9.1.3 (Cary, NC, USA).

The ASA approved a continuum of depth of sedation that defines general anesthesia and levels of sedation/analgesia.[9] The four levels include minimal sedation (anxiolysis), moderate sedation/analgesia (also called conscious sedation), DS/analgesia, and general anesthesia. The definitions are taken from this continuum. The first level, minimal sedation (anxiolysis) is a drug-induced state during which patients respond normally to verbal commands. Although cognitive function and physical coordination may be impaired, airway reflexes, and ventilatory and cardiovascular functions are unaffected. The second level, moderate sedation/analgesia ("conscious sedation") is a drug-induced depression of consciousness during which patients respond purposefully to verbal commands, either alone or accompanied by light tactile stimulation. Reflex withdrawal from a painful stimulus is not considered a purposeful response. No interventions are required to maintain a patent airway, and spontaneous ventilation is adequate. Cardiovascular function is usually maintained. The third level, DS/analgesia is a drug-induced depression of consciousness during which patients cannot be easily aroused but respond purposefully following repeated or painful stimulation. The ability to independently maintain ventilatory function may be impaired. Patients may require assistance in maintaining a patent airway, and spontaneous ventilation may be inadequate. Cardiovascular function is usually maintained. Patients in our study were undergoing DS as defined here. The fourth level on the continuum, general anesthesia is a drug-induced loss of consciousness during which patients are not able to be aroused, even by painful stimulation. The ability to independently maintain ventilatory function is often impaired. Patients often require assistance in maintaining a patent airway, and positive pressure ventilation may be required because of depressed spontaneous ventilation or drug-induced depression of neuromuscular function. Cardiovascular function may be impaired.

Patients were monitored with pulse oximetry, noninvasive blood pressure, and end-tidal carbon-dioxide monitoring ($EtCO_2$) continuously from induction to full recovery. In addition, the patients were directly observed by the anesthesiologist prior to placement in the scanner and following removal from the scanner. Blow-by oxygen or oxygen by nasal prongs was only used when deemed necessary based on patients' response to sedation, not as a routine, even in patients with congenital heart disease. Recovery from DS was assessed using a modified Ramsey Sedation Scale: 1. fully awake or nonmedicated; 2. drowsy but cooperative/anxiety free (corresponds to minimal sedation); 3. asleep but arousable to voice/gentle touch (corresponds to moderate sedation); 4. asleep but arousable to painful stimulation (corresponds to DS); 5. no response to painful stimulation (corresponds to general anesthesia).[10] All patients involved in the study were observed and monitored postoperatively until they resumed oral intake, could stay awake spontaneously, and were back to baseline levels of consciousness and motor function, or essentially returned to level one on the Ramsey Sedation Scale.

Results

Results of demographic characteristics, ASA Physical Status Classification, sedation regimen, and sedation times for both the case and control group are presented in Table 1. Cases

and controls were matched well on ASA classification, and weight and age, and similar in gender distribution.

Complications occurred in 794 (10.1%) of all 7,839 DSs performed for MRI in the database. The distribution of the type of MRI performed for the 619 eligible noncardiac cases and controls is reported in Table 2. The distribution was similar, with 86.1% of cases and 83.4% of controls completing MRI of the brain and/or spine; and with 8.2% of cases and 7.1% of controls completing MRI of the chest/abdomen/pelvis. Among the 619 eligible noncardiac cases with complications, 595 (96.1%) experienced minor complications, and 24(3.9%) had major complications. The vast majority of the minor complications were airway obstruction requiring intervention and transient oxygen de-

Table 1: Demographic and clinical characteristics

Variable	Noncardiac MRI	
	Cases (%)	Controls (%)
N	619¶	619
Age (years)†	5.0 + 4.6	5.0 + 4.6
Weight (kg)†	20.8 + 15.7	21.5 + 17.0
Gender*		
Male	347 (56.4)	338 (54.6)
Female	268 (43.6)	281 (45.4)
ASA physical status*		
I	57 (9.2)	57 (9.2)
II	304 (49.1)	304 (49.1)
III	250 (40.4)	250 (40.4)
IV	8 (1.3)	8 (1.3)
Bolus dose† (mg/kg)		
Propofol bolus dose (PROP Group)	3.73 + 2.99 (*n* = 102)	3.59 + 2.26 (*n* = 91)
Pentobarbital dose (PENT Group)	2.81 + 1.14 (*n* = 298)	2.70 + 0.81 (*n* = 356)
Pentobarbital dose (PENT SUPP Group)	2.77 + 0.86 (*n* = 212)	2.70 + 0.81 (*n* = 142)
Total propofol dose† (mg/kg)		
PROP group	12.46 + 8.69 (*n* = 107)	12.51 + 6.52 (*n* = 96)
PENT group	2.24 + 1.85 (*n* = 298)	2.06 + 2.77 (*n* = 356)
PENT SUPP group	6.21 + 4.58 (*n* = 208)	5.64 + 5.18 (*n* = 142)
Total pentobarbital dose† (mg/kg)		
PENT Group	2.82 + 1.15 (*n* = 298)	2.74 + 1.00 (*n* = 356)
PENT SUPP Group	3.15 + 1.07 (*n* = 212)	3.11 + 1.13 (*n* = 142)
Type of Sedation*		
PROP Regimen	105 (17.2)	96 (16.2)
PENT Regimen	298 (48.5)	356 (59.9)
PENT SUPP Regimen	212 (34.5)	142 (23.9)
Times†		
Overall Sedation Time (minutes)	75.8 + 50.1	
Sedation Time (minutes)	77.1 + 45.1 (*n* = 612)	74.6 + 54.8 (*n* = 587)
Time to Discharge (minutes)	41.0 + 35.6 (*n* = 617)	37.2 + 60.1 (*n* = 616)

**Data are numbers, with percentages in parentheses. †Continuous data are means + standard deviations. ¶N = 615 for gender in case group*

Table 2: Region of magnetic resonance imaging scan for deep sedations performed*

Regions	Cases (%)	Controls (%)
Brain	413 (66.7)	350 (56.5)
Brain and spine	28 (4.5)	56 (9.0)
Spine	92 (14.9)	111 (17.9)
Cardiac	0 (0.0)	0 (0.0)
Chest/abdomen/pelvis	51 (8.2)	44 (7.1)
Extremities	29 (4.7)	30 (4.8)
Head/skull/neck/face/eye/orbits/cochlear study	3 (0.48)	26 (4.2)
Seizure protocol	1 (0.16)	2 (0.32)
Not recorded	2 (0.32)	0 (0.0)

**Data are number of events, with percentages in parentheses*

Table 3: Complications of Noncardiac MRI group*

Variable sedation cases total	PENT 298 (%)	PENT SUPP 212 (%)	PROP 105 (%)
Major complications			
Aborted procedure	6 (2.0)	6 (2.8)	3 (2.9)
Aspiration	0 (0.0)	0 (0.0)	1 (1.0)
Cardiac arrest	0 (0.0)	0 (0.0)	0 (0.0)
Dysrhythmia	0 (0.0)	0 (0.0)	1 (1.0)
Hypotension	1 (0.3)	0 (0.0)	1 (1.0)
Unplanned admission ICU	0 (0.0)	0 (0.0)	0 (0.0)
Unplanned admission Ward	1 (0.3)	0 (0.0)	0 (0.0)
Unplanned intubation	1 (0.3)	0 (0.0)	3 (2.9)
Minor Complications			
Airway obstruction, no intervention	0 (0.0)	0 (0.0)	0 (0.0)
Airway obstruction w/ intervention	92 (30.9)	90 (42.5)	39 (37.1)
Apnea, no intervention	3 (1.0)	1 (0.5)	0 (0.0)
Apnea with intervention	13 (4.4)	27 (12.7)	12 (11.4)
Coughing	50 (16.8)	46 (21.7)	22 (21.0)
Desaturation, no intervention	8 (2.7)	4 (1.9)	0 (0.0)
Desaturation with intervention	177 (59.4)	113 (53.3)	48 (45.7)
Drug error	0 (0.0)	2 (0.9)	0 (0.0)
Inadequate sedation	0 (0.0)	1 (0.5)	0 (0.0)
IV infiltration	4 (1.3)	2 (0.9)	1 (1.0)
Multiple IV sticks (>3 tries)	17 (5.7)	13 (6.1)	14 (13.3)
Nausea and/or vomiting	3 (1.0)	2 (0.9)	4 (3.8)
Post-study agitation	28 (9.4)	19 (9.0)	2 (1.9)
Excessive secretions	26 (8.7)	30 (14.2)	24 (22)
Unplanned admission to PACU	4 (1.3)	2 (0.9)	0 (0.0)

**Data are number of events, with percentages in parentheses, MRI = Magnetic resonance imaging; PACU = Post anesthesia care unit*

Table 4: Association between predictors and complications from the multivariable model

Variables	OR (95% CI)	*P* value
Gender		
Female vs. Male	0.91(0.71,1.17)	0.474
Premedication		
Yes vs. No	0.67 (0.45, 1.01)	0.055
Type of sedation		0.0002
PENT vs. PROP	0.68 (0.46, 0.98)	0.040
PENT SUPP vs. PROP	1.23 (0.83, 1.83)	0.300
PENT vs. PENT SUPP	0.60 (0.31, 0.89)	<0.0001
Anesthesiologists	NA*	0.566

**It is not meaningful to present ORs to compare individual anesthesiologists. Also there are too many anesthesiologists to present ORs.*

saturation requiring [Table 3]. The major complications included 15 (62.5%) aborted procedures, 4 (16.6%) unplanned intubations, 2 (8.3%) episodes of hypotension, and 1 (4.1%) instance each of pulmonary aspiration, dysrhythmia, and unplanned ward admission. The overall distribution of major and minor complications and the distribution for each regimen are presented in Table 3. There were no instances of cardiac arrest or unplanned ICU admission. Of the aborted procedures, seven were due to airway obstruction, oxygen desaturation, and/or difficulty maintaining airway; five were due to coughing and secretions complicating airway management; one was due to persistently blurred images secondary to motion artifacts; one was due to patient movement; and one was due to inability to accommodate resedation.

In the multivariate model, premedication, anesthesiologist, and gender were not significant predictors for the occurrence of complications [Table 4]. After adjusting for other variables in the model, the type of sedation was a significant predictor for the occurrence of complications ($P = 0.0002$). The PENT regimen was significantly associated with a lower risk of complications when compared to the PROP regimen (OR 0.68; 95% CI 0.46, 0.98; $P = 0.040$), and compared to the PENT SUPP group (OR 0.60; 95% CI 0.31, 0.89; $P < 0.0001$). There was no significant difference in association with complications when comparing the PROP regimen to the PENT SUPP group ($P = 0.300$).

Discussion

In our study, complications occurred in 794 (10.1%) of all 7,839 DSs performed for MRI in the database. A study by Hoffman *et al.* indicated an adverse event rate of 9.2% associated with DS, though with a much smaller sample size of only 65.[11] A study of 30,037 pediatric sedation patients reported a 5.3% incidence of complications but included all levels of sedation including anxiolysis and moderate sedation, as opposed to DS only, which is likely to explain the difference in incidence.[12]

The PENT regimen was associated with a significantly lower risk of complications than the PROP regimen in noncardiac MRI patients. Several studies have shown that short-acting barbiturates are safe and effective for sedation during pediatric diagnostic imaging.[6,7,13-15] One study showed that although oral pentobarbital and oral chloral hydrate are equally effective, the incidence of adverse events with oral pentobarbital sedation (0.5%) was significantly lower in infants younger than 2 years during MRI and CT than with chloral hydrate sedation (2.7%) ($P < 0.001$).[6] Propofol has also been associated with a significantly greater incidence of adverse respiratory events and more frequent physiologic changes than pentobarbital during pediatric diagnostic imaging procedures.[16,17]

Propofol has significant advantages as well. The study by Zgleszewski *et al.* showed that patients in the propofol group had a faster recovery than patients in the pentobarbital group (34 min +/- 17 *vs.* 100 min +/- 30, $P < 0.001$).[15] Pershad *et al.* reported that a pentobarbital regimen was associated with prolonged sedation in six patients (20%), emergence agitation in two patients (6.7%), and one episode of delayed agitation after discharge from the hospital.[5] Pentobarbital has been associated with undesirable side effects in some children, including prolonged recovery, nausea, vomiting, ataxia, agitation, and unplanned admission.[15,17-19]

Mallory *et al.* also described the spectrum of complications with pentobarbital for diagnostic imaging which are typically different from those of propofol, such as inadequate sedation, prolonged recovery, allergic complications, unplanned admission, and vomiting.[17] Unlike their study, we did not find the use of pentobarbital was associated with inadequate sedation, probably as a result of our practice of using a small bolus of propofol in association with pentobarbital to alleviate the excitement that often accompanies pentobarbital administration.

Respiratory complications such as apnea can be life-threatening, and few studies have attempted to elucidate the effects of anesthetics on upper airway muscles.[20-22] During deep anesthesia, increasing doses of pentobarbital have been shown to increase the phasic genioglossus electromyogram, which theoretically increases the size of the airway and decreases collapsibility.[20] Our study did find that apnea with intervention occurred at a lower incidence in the pentobarbital group than in the propofol group. Eikermann *et al.* also showed that genioglossus activity is maintained at the same levels that are observed during natural non-REM sleep, and in

fact exceeds the activity level observed during REM sleep.[20] Further study is necessary to elucidate whether pentobarbital's effect on the genioglossus activity could contribute to a more stable airway in a clinically meaningful way, such as when DS is required for patients with a compromised airway. Sedation with a mixed pentobarbital technique may be associated with less physiological derangement as demonstrated in our study by the decreased odds of complications when this technique is used instead of a propofol-based technique.

The regression analysis also indicates that the PENT SUPP group was associated with a significantly increased risk of complications than the PENT group. The PENT SUPP group includes patients who were sedated for MRI with the mixed pentobarbital regimen, but then required a resedation known as "supplemental" sedation 20 min or more after the initial sedation. The increased risk of complications in this group may be a result of the need for additional sedative agents (propofol or pentobarbital) on top of existing residual effects of barbiturate and benzodiazepine, with resultant synergy that could result in adverse physiologic effects such as airway obstruction, apnea, and hypoxia.

Sanborn *et al.* concluded that the use of multidrug sedation regimens should be avoided, as their study found that all patients who require airway resuscitation had undergone a multidrug sedation regimen.[23] It is important to note that Sanborn's study included chloral hydrate, fentanyl, pentobarbital, and midazolam, but did not include propofol. A landmark study in 2000 found that adverse events were commonly associated with drug interactions and synergistic effects.[24] Similarly, patients in the PENT SUPP group received some combination of pentobarbital and low-dose propofol, followed by supplemental sedation with propofol, and sometimes pentobarbital as well. Our results indicate that for longer scans, avoiding multiple drugs and using a single-drug regimen such as propofol alone may result in improved outcomes since the favorable recovery profile of propofol compared to pentobarbital is likely to result in fewer side effects such as nausea, vomiting, dizziness, and prolonged somnolence following sedation.

Despite prospective data collection, the retrospective analysis has inherent limitations. We had to rely on the accuracy of written record and there is potential reporting bias and missing or incomplete documentation. Not all confounding variables were captured in the database and data abstraction and there was always the potential for residual confounding. However, we excluded patients who received cardiac MRI, and patients who received a unique LDP method of sedation, and matched cases and controls based on three clinically relevant variables to minimize confounders. In addition, gender was also evenly distributed for the case and control groups. The finding that the anesthesiologist was not a significant predictor variable helped adjust for minor variations in practice between anesthesiologists. Data from this study came from one site with a highly experienced sedation service, thus generalizability of the study may be limited.

To conclude, in our study, the use of a pentobarbital technique was found to be associated with a lower incidence of complications during sedation in noncardiac MRI patients compared to a propofol technique or a pentobarbital technique requiring supplemental sedation. The vast majority of complications in our study were airway obstruction and transient oxygen desaturation.

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