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ORIGINAL RESEARCH **PEDIATRIC ANESTHESIA**

Impact of spontaneous vs. controlled ventilation with laryngeal mask airway in pediatric cataract surgery

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Abstract

Background & objective: Anesthetic management of pediatric cataract surgery is special as most of these surgeries have to be completed under general anesthesia, and airway management and adequate ventilation take precedence and special care. We compared spontaneous ventilation vs. controlled ventilation, using laryngeal mask airway (LMA) with or without muscle relaxation showing their impact on different parameters in pediatric cataract surgery.

Methodology: This prospective study included 150 ASA-I and II children, who underwent elective cataract surgery. The patients were randomly divided into three groups: Group-A, B and C to receive spontaneous ventilation, unparalyzed controlled and paralyzed controlled ventilation through LMA, respectively. Evaluation of the effect of ventilation on position of the eyes during surgery in relation to depth of anesthesia, intra-ocular pressure (IOP), surgeon's satisfaction, consumption of sevoflurane, emergence agitation, respiratory parameters and intra-operative hemodynamic stability were the main outcome measures registered.

Results: Pressure-controlled ventilation using laryngeal mask improved dynamic compliance with statistically significant lower incidence of eye movements ($p = 0.001$) and lower IOP measurements despite decreased sevoflurane consumption and higher BIS values ($p < 0.001$). It led to better surgeon satisfaction and less postoperative agitation ($p < 0.001$) without any statistically significant differences in hemodynamic parameters or $EtCO_2$, in comparison to spontaneous ventilation.

Conclusion: Pressure-controlled ventilation through laryngeal mask airway with low-dose muscle relaxants and titrated anesthesia under bispectral index monitoring is an acceptable safe clinical practice. However, ventilation without neuromuscular blockade could be an alternative with adequate monitoring.

Abbreviations: LMA – laryngeal mask airway; $EtCO_2$ – End-tidal carbon dioxide level; BIS – Bispectral index; IOP – Intra-ocular pressure;

Key words: Ventilation; Laryngeal Mask Airway; Eye Movement; Positive-Pressure Respiration; Child; Humans; Lens Capsule, Crystalline / surgery; Pediatrics / methods

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1. Introduction

The goals of anesthetic management in pediatric cataract surgery are to provide an immobile operative field without an increase in intra-ocular pressure (IOP), and to maintain a hemodynamically stable child, adequate depth of anesthesia with less anesthetic consumption and a low incidence of peri-operative complications. [1-2]

Intra-operative awareness during anesthesia in children can have long-term behavioral and psychological effects. [3] The bispectral index (BIS) is considered a good general measure of the depth of anesthesia. BIS is widely used in pediatric anesthesia and several studies have validated its utility for precise titration of volatile anesthetic agents, and found it better than the usual clinical parameters to provide earlier awakening and better recovery profile. [4-6]

Laryngeal mask airway (LMA) has been successfully used as an alternative device to endotracheal intubation in general anesthesia of short duration ophthalmic procedures with spontaneous or assisted ventilation. [7-8] Spontaneous breathing is a popular mode of ventilation with LMA with several beneficial effects, such as improved hemodynamics and ventilation-perfusion matching, without any chance of ventilator-induced lung injury. [9] However, it provides less effective gas exchange than positive pressure ventilation. [10]

Congenital cataract may be associated with other anomalies such as myopathies, which can be affected by using muscle relaxants, so these drugs are better avoided. Controlled ventilation without muscle relaxation using LMAs is an attractive option. [11]

We compared the impact of spontaneous ventilation vs. controlled ventilation with or without muscle relaxation in pediatric cataract surgery under general anesthesia regarding the position of the eye in relation to depth of anesthesia as guided by BIS, and the intraocular pressure. The surgeons' satisfaction, sevoflurane consumption, emergence agitation and peri-operative hemodynamic parameters were the secondary objectives.

It was hypothesized that unparalyzed controlled ventilation would be advantageous to other modes in providing satisfactory surgical conditions with adequate depth of anesthesia and a better recovery profile.

2. Methodology

This prospective, randomized, comparative study was conducted after getting approval from Institutional Review Board (No. MD.19.12.264), and was registered in clinicaltrials.gov (No. NCT04241653). Informed written consent was obtained from parents of all patients. The study was conducted in compliance with the ethical principles of Declaration of Helsinki (2013).

The eligible 150 patients were randomly assigned into three equal groups (n = 50 in each group) according to computer-generated table of random numbers. Group-A patients received spontaneous ventilation, Group-B had controlled ventilation without relaxants and Group-C was paralyzed controlled ventilated. A single investigator assessed the patients for eligibility. However, the observer anesthesiologist was not blinded in view of the need to monitor and manage patients intra-operatively.

The inclusion criteria were; children of ASA-I and II, of both genders, aged between 1 and 5 y, scheduled for elective cataract surgery. Exclusion criteria were parental refusal of consent, contraindication to use of LMA, hyper reactive airway or respiratory disease, children with mental or neurological disorders, bleeding or coagulation diathesis, history of known sensitivity to the used anesthetics, and previous surgery in the same eye.

All patients were kept fasting prior to surgery, and no premedication was used. Upon arrival to the operating room, basic monitors were applied and baseline values were recorded. BIS monitor (Covidien Ireland limited, Mansfield, USA) was used. Anesthesia was induced by face mask with 8% sevoflurane in 100% oxygen, and peripheral intravenous cannula was inserted. Then LMA (Ambu, Glen Burnie, USA) was inserted after adequate jaw relaxation achieved by giving propofol 2 mg/kg and capnograph was connected. All children received ketorolac 0.5 mg/kg IV for analgesia.

LMA positioning was checked clinically by manual chest expansion, equal bilateral breath sounds, and the presence of CO_2 wave on capnography. All cases were performed on Datex-Ohmeda GE anesthesia machines (Madison, USA). If LMA insertion failed, the child was intubated and excluded from the study.

In Group-A, spontaneous breathing was maintained with a pressure support of 10 cmH_2O to obtain expiratory tidal volume of 8 mL/kg. In Groups B and C, mechanical ventilation was applied with pressure controlled ventilation (PCV); the flow was adjusted to 2 L/min, the pressure was adjusted to obtain a volume of 8 mL/kg up to 20 cmH_2O with a PEEP of 4 cmH_2O, and a fixed inspiratory: expiratory ratio of 1:2. The set respiratory rate was 15 breaths/min, adjusted to achieve the end tidal CO_2 ($EtCO_2$) levels between 30 and 40 mmHg as measured by capnography.

Thereafter, anesthesia was maintained with sevoflurane in air/oxygen mixture of 40%. Sevoflurane concentration was titrated to achieve adequate depth of anesthesia and maintain immobilization of the eyeball as guided by vital signs and BIS. Ringer solution was infused to all subjects in the study as maintenance fluid.

At the end of surgery, sevoflurane was discontinued and LMA was removed and children were transferred to the post-anesthesia care unit (PACU).

In Group-C, neuromuscular blockade with atracurium 0.5 mg/kg was used for induction. Residual muscle relaxation was reversed with neostigmine 0.05 mg/kg and atropine 0.02 mg/kg to achieve adequate spontaneous breathing and purposeful motor movements.

All patients were monitored for heart rate and mean arterial blood pressure before and immediately after insertion of the LMA, at 5 min intervals, then after removal of LMA. Hypotension was defined as a MAP 25% below baseline value, a bolus of ephedrine 0.1 mg/kg IV was given if needed and its occurrence was recorded.

$EtCO_2$ was recorded every 5 min and dynamic compliance was recorded twice; after stabilization of ventilation then at the end of the procedure.

All children were monitored for any upward or downward deviation of the vision axis. Incidence, type and corresponding BIS values of eye movements during surgery were recorded. This was managed by increasing sevoflurane concentration by 0.5 % each time as guided by BIS.

BIS values and sevoflurane concentrations were recorded after insertion at every 5 min till the end of the procedure. Then, mean sevoflurane consumption during the whole procedure was calculated. [12]

Usage of sevoflurane (mL) was calculated as follows;

Dialed concentration (%) x fresh gas flow (2 L/min) x duration at that concentration (min) x molecular weight (200 mg) divided by 2412 x density (1.52 g/mL)

Intra-ocular pressure was measured; baseline, after induction, immediately after insertion of LMA, and at the end of the surgery, using Schiotz-tonometer (Gulden Ophthalmics™, Pennsylvania, USA).

Postoperative emergence agitation was assessed using Cravero scale (1 - obtunded with no response to stimulation. 2 - asleep but responsive to movement or stimulation. 3 - awake and responsive. 4 - crying for 3 min. 5 - thrashing behavior that requires restraint) every 5 min from awakening for half an hour. If the child was agitated (score 4 / 5), propofol 1 mg/kg was given as a rescue medication. [13]

The ophthalmologist was questioned regarding the quality of surgical field, the eye position, akinesia of eye, blood loss and IOP (0 - not achieved 1- partially achieved 2 - fully achieved). [14]

Statistical analysis

The collected data were analyzed using SPSS version 22. Normality of numerical data distribution was tested by Kolmogorov-Smirnov test. Normally distributed numerical data are presented as mean + standard deviation and compared in different groups using one-way ANOVA with post-hoc Bonferroni test. Non-normally distributed numerical data are presented as median (range) and compared non-parametrically using Kruskal-Wallis test followed by Mann-Whitney U test. Categorical data are presented as number (percentage) and their comparison is performed using Chi-square test. $P \leq 0.05$ was considered statistically significant.

A Priori G-power analysis was done to estimate the study sample size which was based on previous study. [2] Assuming α (type 1 error) = 0,05 and β (type 2 error) = 0,2 (power =80 %), 46 patients per group were sufficient to detect a 20% difference of incidence in eye movements among the groups. A drop out of 10% of cases were expected. Therefore, 50 patients were required in each group to detect this difference.

3. Results

A total of 161 patients were assessed for eligibility in the current study from February 2020 to February 2021. Eleven patients were excluded and the remaining 150 patients were enrolled and analyzed (Figure 1).

Patients in the three studied groups were comparable with respect to the demographic data, durations of surgery and anesthesia (P > 0.05) (Table 1).

According to the hemodynamic parameters (Figures 2 and 3) and $EtCO_2$ (Figure 4), no statistically significant differences were detected among the studied groups throughout the intra-operative period.

Table 1: Demographic data, durations of surgery and anesthesia.

Parameter		Group-A n = 50	Group-A n = 50	Group-A n = 50	P-value
Age (y)		3.5 ± 1.7	3.1 ±1.2	3.2 ±1.2	0.23
Gender	(Male)	29 (58 %)	31 (62 %)	32 (64%)	0.82
	(Female)	21 (42 %)	19 (38 %)	18 (36 %)	
Weight (kg)		15.2 ± 2.5	14.6 ± 2.6	14.9 ± 2.4	0.45
Duration of surgery (min)		29.9 ± 4.9	30.3 ± 7.3	32.3 ± 7.6	0.16
Duration of anesthesia (min)		37.4 ± 4.9	37.5 ± 7.9	40 ± 7.7	0.11

Data presented as mean ± SD or number (%); min = minutes

Table 2: Intra-operative dynamic compliance, peri-operative intra-ocular pressure and mean sevoflurane consumption through the surgery.

Parameter	Group-A n = 50	Group-A n = 50	Group-A n = 50	P-value
Dynamic compliance after stabilization of ventilation (ml / cmH_2O)	18.3 ± 1.2	22.5 ± 1.9 *	23 ± 2.4 *	< 0.001
Dynamic compliance at end of procedure (ml / cmH_2O)	17.9 ± 1.1	22.7 ± 1.7 *	23.6 ± 2.6 *	< 0.001
Basal IOP (mmHg).	15.7 ± 1.7	15.5 ± 1.9	15.1 ± 2.3	0.40
After induction IOP (mmHg).	14.1 ±1.5	13.9 ± 1.3	12.9 ± 1.5 * †	< 0.001
After insertion IOP (mmHg).	15.4 ± 1.7	15 ± 1.5	13.6 ± 1.6 * †	< 0.001
At end of surgery IOP (mmHg).	14.5 ± 1.9	12.8 ±1.1 *	12.5 ± 0.9 *	< 0.001
Mean sevoflurane consumption (mL)	11.1 ± 1.8	9.1 ± 1.9 *	7.4 ± 1.3 * †	< 0.001

Values are presented as mean ± SD; IOP = intra-ocular pressure.
** marks statistical significance relative to Group-A.*
†: marks statistical significance relative to Group-B.

Table 3: Incidence of eye movement through the surgery, number of patients who required intervention and postoperative surgeons satisfaction.

Parameter	Group-A n = 50	Group-A n = 50	Group-A n = 50	P-value
Incidence of eye movement	41	18*	7*	0.001
Number of patients	18 (36%)	9 (18%) *	6 (12%) *	0.01
Surgeons satisfaction	6 (4-8)	8 (7-8) *	8 (7-8) *	< 0.001

Values are presented as number (%) and range (median)
** marks statistical significance relative to Group-A.*

Table 4: Carvalo score and number of patients with score 4 and 5.

Parameter		Group-A n = 50	Group-A n = 50	Group-A n = 50	P-value
Carvalo score	5 min	3-5 (5)	3-5 (4) *	1-5 (3) *†	< 0.001
	10 min	3-5 (4)	3-5 (3.5) *	1-5 (2) *†	< 0.001
	15 min	1-5 (3)	2-4 (3) *	1-3 (2) *†	< 0.001
	20 min	1-3 (3)	1-3 (2) *	1-3 (2) *	< 0.001
	25 min	1-3 (3)	1-3 (2) *	1-2 (2) *	< 0.001
	30 min	1-3 (2)	1-3 (2) *	1-2 (2) *	< 0.001
Score = 4		17 (34%)	21 (42%) *	6 (12%) * †	< 0.001
Score = 5		20 (40 %)	7 (14 %) *	4 (8 %) * †	

Values are presented as median (range) and number (%). min, minute.
** marks statistical significance relative to group A.*
†: marks statistical significance relative to group B.

Regarding intra-operative dynamic compliance, there were statistically significant higher values after ventilation stabilization and at the end of the procedure in Groups B and C, relative to Group-A (Table 2).

There were statistically significant lower IOP values in Groups B and C relative to Group-A at the end of surgery, and in Group-C in comparison to Groups A and B after induction and insertion of LMA (Table 2).

Patients in Group-A showed statistically significant lower BIS values and higher sevoflurane values relative to the other two groups through the surgery (Figures 5 and 6). Also, Group-B had significantly more sevoflurane consumption compared to Group-C (Table 2).

The incidence of eye movements was significantly higher in Group-A. All movements were in upward direction, except downward movements in 3 patients of Group-A, whilst BIS was less than 40. Otherwise, upward movements were 1 (BIS: 50-54), 4 (BIS: 55-59), 18 (BIS: 60-64) and 40 (BIS > 65). Furthermore, akinesia of the eye was fully achieved in all, but 18 (36%), 9 (18%), 6 (12%) patients in Groups A, B and C respectively (Table 3). The surgeon’s satisfaction was significantly higher in Groups B and C than Group-A (Table 3).

Significantly lower agitation scores were observed in Groups B and C compared to Group-A, and in Group-C compared to Group-B, for the first 15 min (Table 4).

No adverse effects such as hypotension, respiratory depression, nausea, vomiting, or allergic reactions were noted in our study.

4. Discussion

This study was conducted to evaluate effects of different strategies of ventilation on pediatric cataract surgery. According to our study pressure-controlled ventilation either with or without muscle relaxant was associated with lower incidence of intra-operative eye movements, in comparison to spontaneous ventilation. Eye movements were predominantly in upward direction and more than half of them occurred at BIS 65. Three

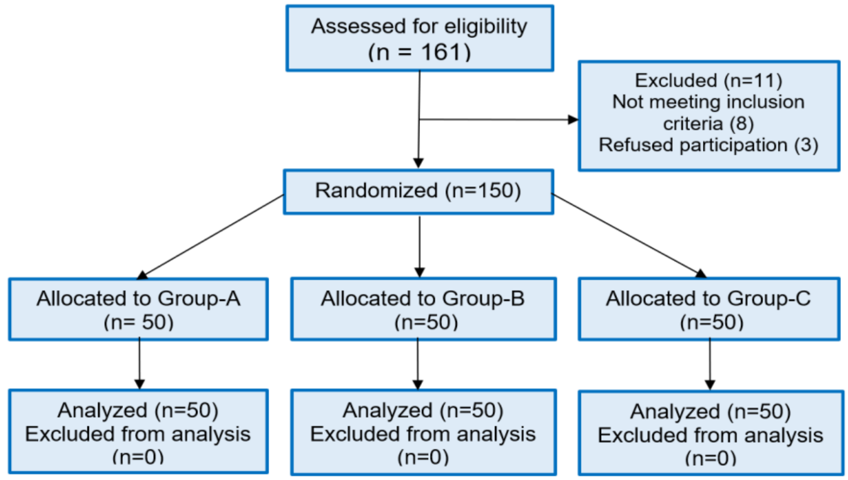

Figure1: Study flow diagram

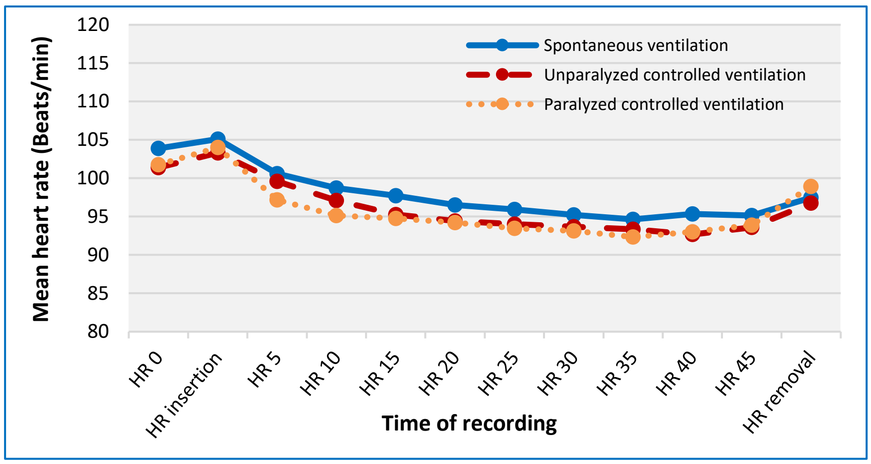

Figure 2: Mean values for peri-operative heart rate (HR) (beat/min)

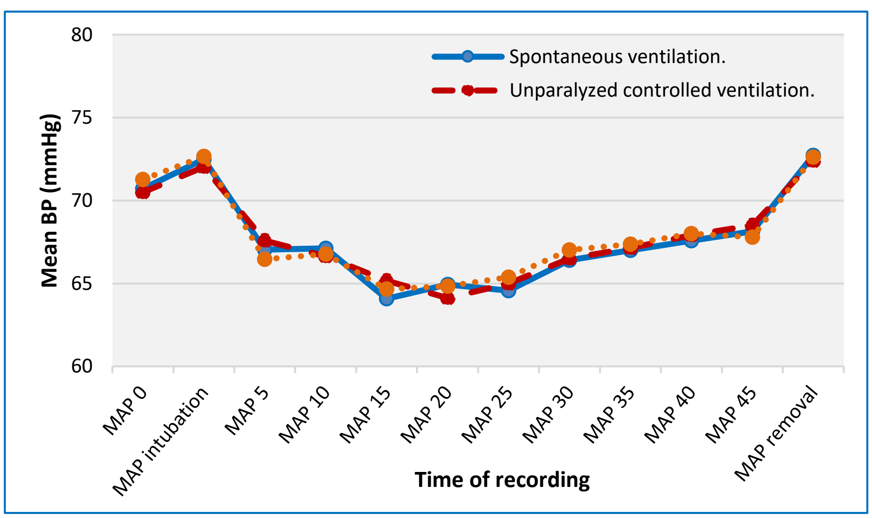

Figure 3: Mean values of peri-operative (MAP) (mmHg)

downward movements occurred with BIS less than 40. The deviations could easily be corrected by increasing depth of anesthesia. In addition, eccentric elevation in muscle relaxant group can be explained by the short duration of muscle relaxant and the fact that it was given once only at induction.

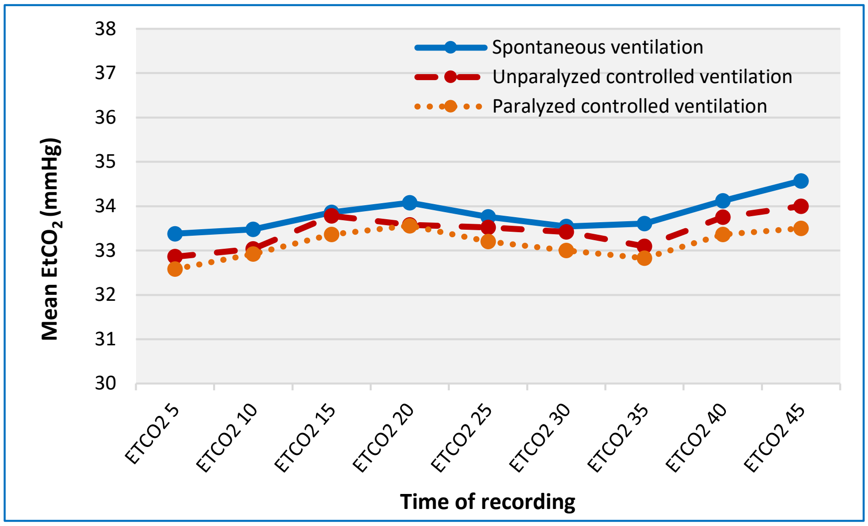

Figure 4: Mean values of end tidal CO_2 ($EtCO_2$) through the surgery.

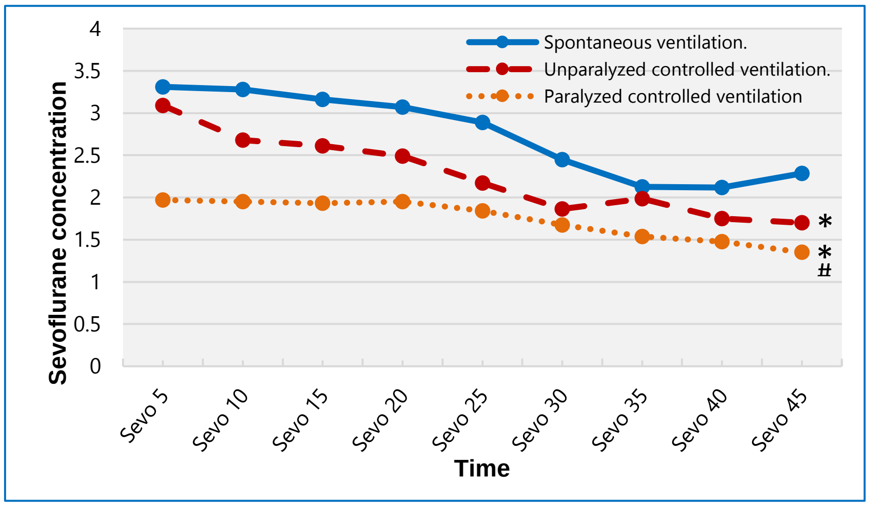

Figure 5: Mean sevoflurane concentration through the surgery

** Significance relative to group A at all time intervals.*
 # Significance relative to group B at all time intervals.

Other studies discussed issues related to horizontal divergence and focused on the correlation between clinical preoperative divergence with ocular alignment under anesthesia. [15] However, few studies evaluated the incidence of eccentric ocular position in patients under anesthesia for intra-ocular surgery.

The quality of immobilization was investigated by other researchers during eye surgery and the incidence of eccentric ocular position was 8%, which increased to 18% without the use of muscle relaxants. However, in most cases muscle relaxation is maintained only at the start of surgery until reliable immobilization is reached by volatile anesthetics. The authors reported that an eccentric ocular position was mor e likely during the light planes of general anesthesia. [16]

Similarly, in another study done in adults, using laryngeal mask without neuromuscular blockade was associated with an increased incidence of upward eye deviations during anesthesia in comparison with intubation; no clinically relevant difference was revealed in quality of eye immobilization between groups. [2]

In the current study, eccentric eye elevation had occurred more frequently with concurrent elevation of BIS values during surgery. However, it cannot explain why patients with similar BIS values had significant differences in ocular deviation. Individual differences in BIS monitoring or variation of eye movements are one potential explanation.

The BIS value has been shown to correlate well with sevoflurane concentration during anesthesia. It does not differ significantly with age, but there may be individual differences in encephalogram patterns in young children due to different maturation rates. [17] On the other hand, the pediatric BIS value has been shown to have a significant negative correlation with anesthetic depth and may even be misleading. If anesthesia is adopted to BIS, the concentration of volatile anesthetics may be lowered to the MAC-awake and below MAC, thus jeopardizing immobilization. [2] Asynchronous events were accompanied by a transient increase in BIS values which required an increase in sevoflurane concentration to keep BIS value at 40–60. [18]

According to the present study, spontaneous mode of ventilation seemed to make more consumption of sevoflurane than controlled mode to achieve adequate depth of anesthesia. This could be referred to improved ventilator-patient synchrony, reduced work of breathing and eventually decreased anesthetic drug consumption by controlled ventilation. In contrast to our results, Moharana et al. proved that pressure support ventilation decreases anesthetic consumption. It decreases emergence time and improves oxygenation index too in children undergoing ambulatory surgery as compared with the pressure-controlled ventilation according to them. [19]

This current study had documented that controlled ventilation appeared to achieve better dynamic compliance than spontaneous ventilation. It controls inspiratory pressure and allows the inspired tidal volume to vary with changes in pulmonary compliance and airway resistance. Findings that were proved by other studies as well. [20]

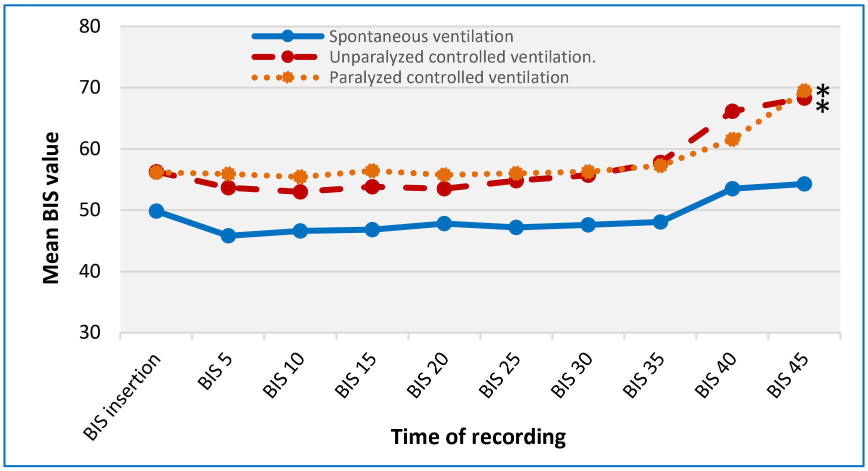

Figure 6: Mean values of intra-operative bispectral index (BIS).

** Significance relative to group A at all time intervals.*

Von Geodecke and his colleagues concluded in 2005 that pressure support ventilation through LMA had improved gaseous exchange and reduced work of breathing in anesthetized pediatric patients, in comparison with continuous positive airway pressure. [21] However, our study differed because we used an anesthesia machine instead of an ICU ventilator as in the previous study.

The results of current study revealed that hemodynamic parameters remained equivalent among the three groups in spite of the slight increase which was noticed clinically after insertion and removal of LMA and was attributed to the pressure exerted by the inflated cuff on the pharyngeal walls.

A significant difference in IOP values was noted between controlled and spontaneous groups at the end of the surgery which can be referred to the effect of reduction in $EtCO_2$ level by controlled ventilation. Furthermore, this significance was also observed after induction and insertion of LMA in muscle relaxant group in relation to their impact on IOP. However, changes of IOP seemed to be clinically irrelevant in pediatric cataract surgery.

Emergence agitation in the results of this study was more frequent in the spontaneous group than two controlled groups, perhaps due to more sevoflurane consumption. It may be explained by temporary neurological dysfunction associated with sevoflurane anesthesia, rapid early awakening in an unfamiliar environment and visual disturbances resulting in a dissociative state. [22]

Cataract surgery is one of the minimally invasive procedure with slight postoperative pain so postoperative pain is not a factor which influenced the emergence behavior of the children. [23]

In the current study, surgeon's satisfaction was high in controlled groups than spontaneous group which is in concurrence with eye movements which may have interfered with their work.

5. Limitations

The data were collected over a short period with a maximum duration of 45 min; hence, this study cannot represent the effects of prolonged anesthesia on the lung compliance. Second, complete blinding was not possible.

6. Conclusion

In pediatric cataract surgery, controlled ventilation using low-dose muscle relaxants is an acceptable safe clinical practice. BIS monitored anesthesia using pressure-controlled ventilation through LMA without neuromuscular blockade achieved good dynamic compliance to guarantee a well satisfactory surgical field with clinically irrelevant upward eye deviations. So, it may be used as an alternative provided that adequate depth of anesthesia must be assured to avoid unwanted injuries during surgery.

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8. Conflict of interest

The authors did not declare any conflict of interests.

9. Data availability

Numerical data relaated to this study is available with the instittutional department of anesthesia.

10. Authors contribution

SME: Concept, write and manuscript editing

AHD: Conduc of the study work, manuscript writing

WMG, OMI, MMM: Manuscript editing

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