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Original Article

Association Between Inhalational Anesthesia-Related Complications and Intraoperative Hemodynamic Changes in Patients Undergoing Congenital Cardiac Surgery

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Abstract
Inhalational anesthetics are widely used in congenital cardiac surgery; however, anesthesia-related complications may affect intraoperative hemodynamic stability and surgical outcomes. This study evaluated the association between inhalational anesthesia-related complications and intraoperative hemodynamic parameters in patients undergoing surgery for congenital heart diseases (CHDs). A descriptive multicenter study was conducted between December 2025 and May 2026 at I.R.C.C.S. Policlinico San Donato Milanese (Italy), Tripoli Medical Hospital (Libya), and the Turkish Medical Team at Fallujah Hospital (Iraq). Patients undergoing congenital cardiac surgery under inhalational anesthesia were included. Data on CHD classification and intraoperative hemodynamic parameters were collected. Systolic blood pressure (SBP), diastolic blood pressure (DBP), and heart rate (HR) were recorded at 10, 20, 30, 40, 50, and 60 minutes during surgery. Statistical analysis was performed using SPSS version 21, with descriptive statistics and ANOVA used to assess differences according to anesthesia-related complications. A total of 23 patients were included. Cyanotic septal defects were the most common CHD category (61.7%), followed by cyanotic complex defects (23.4%). Significant differences in SBP were observed at 50 minutes (p=0.038) and 60 minutes (p=0.032), while DBP showed significant differences at both time points (p=0.01). Heart rate differed significantly at 20 minutes (p=0.048) and demonstrated a highly significant difference at 30 minutes (p=0.0001), particularly among patients who developed arrhythmias. These findings indicate that inhalational anesthesia-related complications are associated with significant intraoperative hemodynamic changes, with arrhythmias exerting the greatest impact on cardiovascular stability. Continuous cardiovascular monitoring remains essential during congenital cardiac surgery to optimize patient safety and perioperative outcomes.
Keywords: Inhalational Anesthesia, Congenital Heart Disease, Arrhythmia, Hemodynamic Parameters.

Introduction

Congenital heart disease (CHD) is among the most prevalent congenital malformations worldwide and remains a leading contributor to pediatric morbidity and mortality. Despite significant advances in prenatal diagnosis, surgical correction, and perioperative management, CHD continues to pose substantial clinical and public health challenges. Improvements in cardiac surgical techniques and postoperative care have markedly enhanced survival rates, resulting in a growing population of children undergoing corrective and palliative cardiac interventions at increasingly younger ages [1]. The anesthetic management of pediatric patients undergoing congenital cardiac surgery is inherently complex due to the diverse anatomical defects and associated pathophysiological alterations affecting cardiovascular and pulmonary function. Maintaining hemodynamic stability throughout the perioperative period is critical to preserving adequate systemic and pulmonary perfusion, optimizing oxygen delivery, and minimizing perioperative complications. Inhalational anesthetic agents are widely utilized in pediatric cardiac anesthesia because of their favorable pharmacokinetic profile, rapid onset and recovery characteristics, ease of titration, and ability to provide controlled anesthetic depth during complex surgical procedures. These properties make them valuable components of contemporary anesthetic strategies for children undergoing congenital heart surgery [2,3].

Despite their benefits, inhalational anesthetics may produce cardiovascular effects including myocardial depression, vasodilation, alterations in heart rate, and disturbances in cardiac rhythm [4]. These effects may lead to complications such as cardiac depression, arrhythmias, and postoperative agitation, which can adversely influence intraoperative hemodynamic stability [5]. Monitoring systolic blood pressure, diastolic blood pressure, and heart rate during surgery provides valuable information regarding the cardiovascular response to anesthetic agents. Understanding the relationship between anesthesia-related complications and hemodynamic changes may contribute to safer perioperative management and improved patient outcomes [6,7].

This study aimed to assess the association between inhalational anesthesia-related complications and intraoperative hemodynamic parameters among patients undergoing surgery for congenital heart disease.

Methods

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Study Design

A retrospective study was conducted to investigate the relationship between inhalational anesthesia-related complications and intraoperative hemodynamic parameters in patients undergoing congenital cardiac surgery.

Study Setting

The study was carried out in the Department of Cardiology from December 2025 to May 2026 in the following centers:

- I.R.C.C.S. Policlinico San Donato Milanese, Italy
- Tripoli Medical Hospital, Libya
- Turkish Medical Team at Fallujah Hospital, Iraq

Study Population

Patients attending the participating cardiology clinics who underwent congenital cardiac surgery and received inhalational anesthetics were considered eligible for participation.
A total of 21 cases receiving inhalational anesthetics were included in the analysis.

Data Collection

Clinical and perioperative data were collected using a structured electronic questionnaire developed and validated by a panel of cardiology experts. The questionnaire collected information regarding: Demographic characteristics, Type of congenital heart disease, Inhalational anesthesia-related complications, and Intraoperative hemodynamic parameters

Ethical Considerations

Ethical approval was obtained from the Faculty of Medical Technology, Sabratha University. Written informed consent was obtained from all participants before data collection. Confidentiality and anonymity of participant information were maintained throughout the study.

Statistical Analysis

Data were analyzed using IBM SPSS Statistics version 21. Results were expressed as frequencies, percentages, means, and standard deviations. One-way ANOVA was used for group comparisons, with $p < 0.05$ considered statistically significant.

Results

Among the 21 patients who developed inhalational anesthesia-related complications, cardiac depression was the most frequently observed complication, occurring in 8 patients (38.1%), followed by arrhythmia in 7 patients (33.3%) and postoperative agitation in 6 patients (28.6%), as presented in Table 1.

Table 1. Distribution of Inhalational Anesthesia-Related Complications

Inhalational Complications	Frequency	Percentage
Cardiac depression	8	38.10%
Arrythmia	7	33.33%
Postoperative Agitation	6	28.57%

The comparison of intraoperative systolic blood pressure (SBP) among patients with different inhalational anesthesia-related complications is demonstrated in Table 2. Significant differences in mean SBP were identified at 10 minutes ($p = 0.038$), 50 minutes ($p = 0.028$), and 60 minutes ($p = 0.009$). Patients with arrhythmia consistently exhibited the highest SBP values at these time points, whereas those with cardiac depression demonstrated the lowest mean SBP throughout the intraoperative period. No statistically significant differences were observed at 20, 30, or 40 minutes ($p > 0.05$).

Table 2. Comparison of Intraoperative Systolic Blood Pressure (SBP) by Inhalational Anesthesia-Related Complications

SBP (mm hg) Time	Inhalational Complications						p-value
	Cardiac depression		Arrythmia		Postoperative Agitation		
	Mean	SD	Mean	SD	Mean	SD	
10 minutes	92.88	6.13	100.71	8.38	89.50	8.09	0.038*
20 minutes	90.25	8.14	97.86	8.17	91.50	10.86	0.255
30 minutes	85.38	6.30	91.86	6.62	93.83	13.72	0.207
40 minutes	83.50	8.50	93.29	6.85	96.17	15.24	0.078
50 minutes	83.38	9.44	96.29	4.19	96.00	13.62	0.028*
60 minutes	83.25	9.07	100.14	5.58	95.67	13.71	0.009**

p-value is determined using the ANOVA: significant at the 0.05 level **: high significant at the 0.01 level.*

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According to the findings presented in Table 3, intraoperative diastolic blood pressure (DBP) differed significantly among the three complication groups at 10 minutes (p = 0.030), 50 minutes (p = 0.024), and 60 minutes (p = 0.010). The arrhythmia group maintained the highest mean DBP values during these intervals, while patients with cardiac depression had the lowest mean DBP measurements. In contrast, no statistically significant differences were detected at 20, 30, or 40 minutes (p > 0.05).

Table 3. Comparison of Intraoperative Diastolic Blood Pressure (DBP) by Inhalational Anesthesia-Related Complications

DBP (mm hg) Time	Inhalational Complications						p-value
	Cardiac depression		Arrythmia		Postoperative Agitation		
	Mean	SD	Mean	SD	Mean	SD	
10 minutes	57.13	5.64	64.29	6.73	53.33	8.50	0.030*
20 minutes	55.5	7.37	63.57	7.46	55.33	10.01	0.130
30 minutes	51.38	5.4	59	6.83	57.50	12.34	0.198
40 minutes	49.13	7.14	58.57	6.24	59.67	13.09	0.071
50 minutes	49	6.76	60.14	4.02	59.83	12.29	0.024*
60 minutes	48.38	7.19	63	4.97	61.00	13.43	0.010*

p-value is determined using the ANOVA: significant at the 0.05 level.*

Heart rate (HR) comparisons are shown in Table 4. A highly significant difference was observed only at 30 minutes (p = 0.007), with patients who experienced arrhythmia demonstrating the highest mean HR (148.43 ± 21.32 beats/min), compared with those with postoperative agitation (129.50 ± 14.47 beats/min) and cardiac depression (120.38 ± 6.30 beats/min). No significant differences in HR were found at 10, 20, 40, 50, or 60 minutes (all p > 0.05).

Table 4. Comparison of Intraoperative Heart Rate (HR) by Inhalational Anesthesia-Related Complications

HR (Beat, min) Time	Inhalational Complications						p-value
	Cardiac depression		Arrythmia		Postoperative Agitation		
	Mean	SD	Mean	SD	Mean	SD	
10 minutes	120.63	12.08	120	18.03	121.33	8.29	0.985
20 minutes	127.63	25.29	134.29	20.9	126.00	10.97	0.740
30 minutes	120.38	6.3	148.43	21.32	129.50	14.47	0.007**
40 minutes	121	7.6	132.57	18.38	127.17	13.91	0.289
50 minutes	119.25	13.25	129.29	9.76	123.33	12.89	0.299
60 minutes	117.13	17.37	121.71	8.58	119.83	14.46	0.820

p-value is determined using the ANOVA: significant at the 0.05 level. **: highly significant at the 0.01 level*

Discussion

The present study provides important evidence regarding the intraoperative hemodynamic effects of inhalational anesthesia-related complications in children undergoing congenital heart surgery. Although systolic blood pressure (SBP), diastolic blood pressure (DBP), and heart rate (HR) remained relatively stable during the early stages of surgery, significant hemodynamic alterations became evident as the procedure progressed. These findings indicate that the cardiovascular effects of inhalational anesthesia are time-dependent and become increasingly pronounced during prolonged surgical exposure. Patients who developed cardiac depression consistently exhibited the lowest systolic and diastolic blood pressure values, whereas those with arrhythmias maintained relatively higher blood pressures and demonstrated the greatest increase in heart rate. Collectively, these observations suggest that progressive myocardial depression, systemic vasodilation, autonomic dysregulation, and cumulative surgical stress contribute to the deterioration of cardiovascular stability during prolonged congenital cardiac procedures.

The delayed reduction in both systolic and diastolic blood pressure observed after approximately 50 minutes of surgery is consistent with the known pharmacodynamic effects of volatile anesthetic agents on myocardial contractility and systemic vascular resistance. Isoflurane and other inhalational anesthetics have been shown to produce dose-dependent reductions in arterial pressure through myocardial depression and peripheral vasodilation, thereby increasing the risk of intraoperative hypotension, particularly in patients with limited cardiac reserve [12]. Similarly, a recent systematic review concluded that volatile anesthetic agents commonly reduce systemic vascular resistance and myocardial contractility, predisposing susceptible patients to hemodynamic instability during surgery [14]. These physiological mechanisms provide a plausible explanation for the progressive decline in blood pressure observed among patients who experienced cardiac depression in the present study.

Our findings are further supported by clinical studies conducted in pediatric patients with congenital heart disease. Shimizu et al. demonstrated that anesthetic technique significantly influences intraoperative blood pressure stability, reporting a higher incidence of hypotension with sevoflurane compared with remimazolam during pediatric cardiac catheterization [8].

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Likewise, Chenault et al. reported that children with greater preoperative hemodynamic vulnerability experienced significantly higher rates of severe anesthesia-related adverse events during congenital cardiac procedures, emphasizing the combined influence of patient characteristics and procedural complexity on cardiovascular instability [9]. Similarly, Dalman et al. found that general anesthesia was associated with more peri-procedural complications than sedation in children with congenital heart disease, highlighting the importance of individualized anesthetic management and meticulous intraoperative hemodynamic monitoring [10].

The observed differences in heart rate represent another important finding of this study. Heart rate demonstrated the strongest association with anesthesia-related complications, with patients who developed arrhythmias exhibiting significantly higher intraoperative heart rates than those with cardiac depression. This finding suggests that heart rate is a sensitive marker of intraoperative cardiovascular instability and may provide an early indication of anesthesia-induced electrophysiological disturbances before clinically significant hemodynamic deterioration becomes apparent. These observations are consistent with Jia et al., who emphasized that maintaining stable heart rate and hemodynamic parameters during general anesthesia is essential for preserving myocardial perfusion and reducing perioperative cardiovascular complications, while demonstrating superior hemodynamic stability with sevoflurane compared with propofol [15]. Furthermore, Valenza et al. reported that continuous analysis of heartbeat dynamics offers valuable real-time information regarding autonomic cardiovascular responses to anesthetic agents, supporting the clinical importance of continuous electrocardiographic and heart rate monitoring throughout surgery [16].

The cardiovascular alterations observed in the present study may also be explained by the direct electrophysiological effects of volatile anesthetics on cardiac conduction and myocardial repolarization. Owczuk et al. demonstrated that inhalational anesthetics influence cardiac electrical activity, potentially increasing susceptibility to perioperative arrhythmias, particularly in vulnerable patients undergoing cardiac surgery [17]. Conversely, experimental evidence suggests that sevoflurane may exert cardioprotective effects by reducing myocardial oxidative stress and ischemia-reperfusion injury, indicating that the overall cardiovascular response depends on the balance between its protective properties and its myocardial depressant effects, as well as patient-specific cardiovascular reserve [18].

Beyond their immediate intraoperative consequences, maintaining stable systolic and diastolic blood pressure remains fundamental for preserving adequate organ perfusion and improving postoperative outcomes. Lee et al. demonstrated that stable arterial pressure during anesthesia minimizes cardiovascular complications by maintaining adequate tissue perfusion [19]. Although performed primarily in adult populations, large-scale evidence from Bundy et al. and Flint et al. further emphasizes that even modest reductions in systolic blood pressure substantially influence cardiovascular outcomes, reinforcing the importance of preventing excessive hypotension during anesthesia whenever possible [11,13].

Overall, the present findings reinforce the concept that prolonged inhalational anesthesia in children undergoing congenital heart surgery may progressively impair cardiovascular stability, particularly in patients who develop cardiac depression or arrhythmias. Continuous monitoring of blood pressure, heart rate, and electrocardiographic parameters, combined with individualized anesthetic management and early recognition of hemodynamic deterioration, remains essential to minimize anesthesia-related cardiovascular complications and optimize perioperative outcomes in this high-risk pediatric population.

Conclusion

Inhalational anesthetics were associated with several intraoperative complications that significantly influenced hemodynamic parameters during congenital cardiac surgery. Arrhythmias produced the most pronounced cardiovascular effects, particularly on heart rate, while cardiac depression was associated with lower systolic and diastolic blood pressure values. Significant differences in blood pressure emerged during the later stages of surgery, whereas heart rate alterations appeared earlier and were more prominent. Continuous cardiovascular monitoring and prompt management of anesthesia-related complications are essential to maintain hemodynamic stability and optimize surgical outcomes in patients with congenital heart disease.

Conflicts of Interest: *Nil*

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