



Original Article

## A Prospective Randomized Comparative Study of Intravenous Magnesium Sulphate and Esmolol for Attenuation of Hemodynamic Responses During Tracheal Extubation Under General Anaesthesia

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### ABSTRACT

**Background:** Tracheal extubation is associated with significant sympathetic stimulation resulting in tachycardia and hypertension. These hemodynamic responses may be harmful, particularly in patients with limited cardiovascular reserve. Various pharmacological agents have been used to attenuate this response, among which magnesium sulphate and esmolol are commonly employed. However, comparative data regarding their efficacy during extubation remain limited.

**Aim:** To compare the efficacy of intravenous magnesium sulphate and intravenous esmolol in attenuating hemodynamic responses during tracheal extubation in patients undergoing elective surgeries under general anaesthesia.

**Materials and Methods:** This prospective, randomized comparative study was conducted on **120 patients** aged 18–60 years, classified as ASA physical status I and II, undergoing elective surgeries under general anaesthesia. Patients were randomly allocated into two groups of 60 each. Group M received intravenous magnesium sulphate, while Group E received intravenous esmolol prior to extubation. Hemodynamic parameters including heart rate, systolic blood pressure, diastolic blood pressure, and mean arterial pressure were recorded at baseline, at extubation, and at 1, 3, and 5 minutes post-extubation. Data were statistically analyzed, and a p-value < 0.05 was considered significant.

**Results:** Baseline demographic variables and hemodynamic parameters were comparable between the two groups. Both magnesium sulphate and esmolol attenuated the hemodynamic responses associated with tracheal extubation. However, patients in the magnesium sulphate group demonstrated significantly lower heart rate, systolic blood pressure, diastolic blood pressure, and mean arterial pressure at extubation and during the immediate post-extubation period compared to the esmolol group (p < 0.05). Adverse effects were minimal in both groups, with bradycardia occurring more frequently in the esmolol group.

**Conclusion:** Intravenous magnesium sulphate is more effective than intravenous esmolol in attenuating hemodynamic responses during tracheal extubation. It provides better cardiovascular stability with fewer adverse effects and may be preferred for routine clinical use during emergence from general anaesthesia.

**Keywords:** Tracheal extubation; Hemodynamic response; Magnesium sulphate; Esmolol; General anaesthesia.

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## INTRODUCTION

Tracheal extubation represents a crucial yet often underestimated phase of general anaesthesia. While considerable attention has traditionally been focused on hemodynamic responses during laryngoscopy and endotracheal intubation, emerging evidence indicates that extubation may provoke equally significant, if not greater, cardiovascular stress. The process of extubation is associated with intense sympathetic stimulation due to airway irritation, return of protective airway reflexes, coughing, breath-holding, and straining, all of which contribute to abrupt increases in heart rate and blood pressure.<sup>1–3</sup>

The sympathetic surge occurring during extubation leads to increased circulating catecholamines, resulting in tachycardia, hypertension, elevated myocardial oxygen demand, and increased intracranial and intraocular pressures. Although these responses are usually transient, they may precipitate serious adverse events such as myocardial ischemia, cardiac arrhythmias, cerebrovascular accidents, and postoperative bleeding, particularly in patients with compromised cardiovascular or cerebrovascular reserves.<sup>4–6</sup> With the increasing number of surgical procedures being performed in elderly patients and those with underlying comorbidities, safe attenuation of extubation-related hemodynamic responses has gained considerable clinical importance.<sup>7</sup>

Recent studies have emphasized that extubation-related hemodynamic changes are often more sustained and unpredictable than those associated with intubation. Unlike intubation, extubation occurs during lighter planes of anaesthesia, making suppression of reflex sympathetic responses more challenging.<sup>8–10</sup> This has prompted anaesthesiologists to explore various pharmacological strategies aimed specifically at attenuating the stress response during emergence from anaesthesia.

Several pharmacological agents have been evaluated for blunting hemodynamic responses during airway manipulation, including opioids, local anaesthetics such as lignocaine, alpha-2 adrenergic agonists, beta-adrenergic blockers, calcium channel blockers, dexmedetomidine, and magnesium sulphate.<sup>11–13</sup> Each of these agents exerts its effect through different mechanisms and carries distinct advantages and limitations with respect to efficacy, safety, and side-effect profile.

Esmolol, an ultra-short-acting, cardioselective  $\beta_1$ -adrenergic receptor antagonist, has been widely used to attenuate perioperative sympathetic responses. Its rapid onset of action and short elimination half-life make it particularly suitable for controlling transient tachycardia during intubation and extubation. By reducing heart rate and myocardial contractility, esmolol decreases myocardial oxygen consumption and blunts sympathetic cardiac responses. However, several studies have reported inconsistent control of blood pressure with esmolol, as it has minimal effect on peripheral vascular resistance.<sup>14–16</sup> Additionally, the risk of bradycardia and hypotension limits its routine use in certain patient populations.

Magnesium sulphate has emerged as an effective alternative agent for attenuation of hemodynamic responses during airway manipulation. Magnesium acts through multiple mechanisms, including inhibition of catecholamine release from adrenergic nerve terminals and the adrenal medulla, antagonism of calcium channels, and blockade of N-methyl-D-aspartate (NMDA) receptors. These actions result in vasodilation, reduced sympathetic tone, and stabilization of cardiovascular parameters.<sup>17–19</sup>

In recent years, growing interest has been directed toward the use of magnesium sulphate during emergence from anaesthesia. Several randomized controlled trials and meta-analyses have demonstrated that intravenous magnesium sulphate effectively attenuates increases in heart rate and blood pressure during extubation. Additional benefits such as reduced coughing, improved extubation quality, and decreased emergence agitation have also been reported.<sup>20</sup> These properties make magnesium sulphate an attractive agent for achieving smoother extubation with enhanced hemodynamic stability.

Despite the availability of multiple studies evaluating individual drugs, direct comparative studies between magnesium sulphate and esmolol focusing specifically on tracheal extubation remain limited, particularly in the context of contemporary anaesthetic techniques. Most available literature emphasizes intubation rather than extubation, leaving a gap in evidence regarding optimal pharmacological management during emergence from anaesthesia.

Therefore, the present prospective randomized comparative study was undertaken to evaluate and compare the efficacy of intravenous magnesium sulphate and intravenous esmolol in attenuating hemodynamic responses during tracheal extubation in patients undergoing elective surgeries under general anaesthesia. By analyzing heart rate, systolic blood pressure, diastolic blood pressure, and mean arterial pressure during and after extubation, this study aims to contribute meaningful clinical evidence to guide safer extubation practices.

## MATERIALS AND METHODS

This study was designed as a prospective, randomized, comparative clinical trial conducted in the Department of Anaesthesiology at a tertiary care teaching hospital over a period of 12 months after obtaining approval from the Institutional Ethics Committee. Written informed consent was obtained from all participants prior to enrollment.

### Study Population and Sample Size

A total of 120 patients scheduled for elective surgical procedures under general anaesthesia were included in the study. Patients were aged between 18 and 60 years and belonged to American Society of Anesthesiologists (ASA) physical status I and II. The study population was randomly divided into two equal groups of 60 patients each.

### Inclusion Criteria

Patients fulfilling the following criteria were included in the study:

1. Age between 18 and 60 years
2. Either gender
3. ASA physical status I or II
4. Patients scheduled for elective surgeries requiring general anaesthesia with endotracheal intubation
5. Anticipated normal airway with uneventful extubation
6. Patients who provided written informed consent

### Exclusion Criteria

Patients were excluded from the study if they met any of the following criteria:

1. ASA physical status III or IV
2. History of hypertension, ischemic heart disease, arrhythmias, heart failure, or cerebrovascular disease
3. Presence of diabetes mellitus or significant renal, hepatic, or respiratory disease
4. Anticipated difficult airway or difficult extubation
5. Patients on beta-blockers, calcium channel blockers, or anti-arrhythmic drugs
6. Known allergy or hypersensitivity to magnesium sulphate or esmolol
7. Pregnant or lactating women
8. Emergency surgeries
9. Patients requiring postoperative mechanical ventilation

### Randomization and Group Allocation

Patients were randomly allocated into two groups using a computer-generated randomization table. Allocation concealment was ensured using sealed opaque envelopes, which were opened immediately before administration of the study drug.

- **Group M (n = 60):** Received intravenous magnesium sulphate
- **Group E (n = 60):** Received intravenous esmolol

### Anaesthetic Technique

All patients were kept nil per oral as per institutional protocol and received standard preoperative evaluation. On arrival in the operating room, routine monitoring including electrocardiography (ECG), non-invasive blood pressure, pulse oximetry, and capnography was instituted.

General anaesthesia was induced using a standardized protocol in all patients. Endotracheal intubation was performed after achieving adequate neuromuscular blockade. Anaesthesia was maintained using inhalational agents, oxygen, nitrous oxide, and intermittent doses of muscle relaxants as required.

### Administration of Study Drugs

At the end of surgery, and after reversal of neuromuscular blockade, the study drugs were administered intravenously:

- **Group M:** Magnesium sulphate **20 mg/kg** diluted in normal saline and administered over 5 minutes
- **Group E:** Esmolol **0.5 mg/kg** administered intravenously over 1 minute

Tracheal extubation was performed once patients fulfilled standard extubation criteria.

### Hemodynamic Monitoring

Hemodynamic parameters including heart rate (HR), systolic blood pressure (SBP), diastolic blood pressure (DBP), and mean arterial pressure (MAP) were recorded at the following time intervals:

- Baseline (before administration of study drug)
- At extubation

- 1 minute after extubation
- 3 minutes after extubation
- 5 minutes after extubation

### Assessment of Adverse Effects

Patients were monitored for adverse effects such as bradycardia, hypotension, nausea, vomiting, or any other untoward events during the intraoperative and immediate postoperative period.

### Statistical Analysis

Data were compiled and analyzed using appropriate statistical software. Continuous variables were expressed as mean  $\pm$  standard deviation, while categorical variables were expressed as numbers and percentages. Intergroup comparison was performed using the Student's t-test for continuous variables and Chi-square test for categorical variables. A p-value  $<$  0.05 was considered statistically significant.

### RESULTS

In 120 patients, intravenous magnesium sulphate demonstrated superior attenuation of heart rate, systolic, diastolic, and mean arterial pressure responses during tracheal extubation compared to intravenous esmolol, with fewer adverse effects.

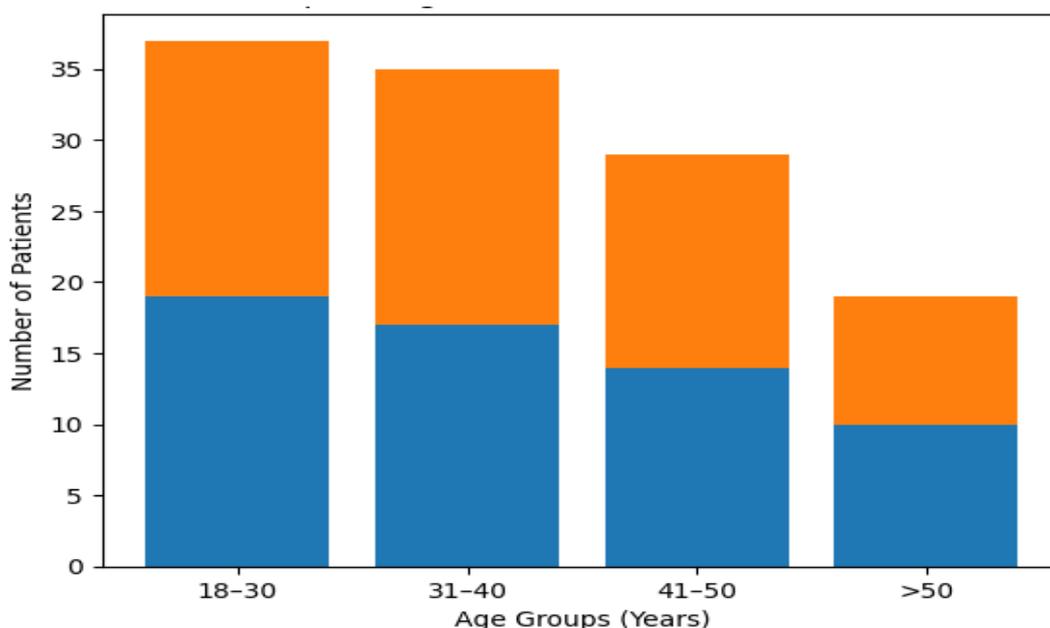
The age-wise distribution of patients in both groups demonstrated a comparable pattern. In Group M, the majority of patients belonged to the 18–40-year age group, accounting for 60.0% of cases, while in Group E this age group comprised 60.0% of patients as well. The mean age in the magnesium sulphate group was  $37.2 \pm 9.1$  years, whereas in the esmolol group it was  $37.6 \pm 8.9$  years. Statistical analysis revealed no significant difference between the two groups with respect to age ( $p > 0.05$ ), indicating that both groups were well matched and age did not act as a confounding variable in the assessment of hemodynamic responses.

**Table 1: Distribution of Patients According to Age (Years)**

Age Group (Years)	Group M (n=60)	Group E (n=60)	Total (n=120)
18–30	19 (31.7%)	18 (30.0%)	37 (30.8%)
31–40	17 (28.3%)	18 (30.0%)	35 (29.2%)
41–50	14 (23.3%)	15 (25.0%)	29 (24.2%)
>50	10 (16.7%)	9 (15.0%)	19 (15.8%)
Mean $\pm$ SD	37.2 $\pm$ 9.1	37.6 $\pm$ 8.9	—

### Interpretation:

The age distribution was comparable between both groups with no statistically significant difference ( $p > 0.05$ ).



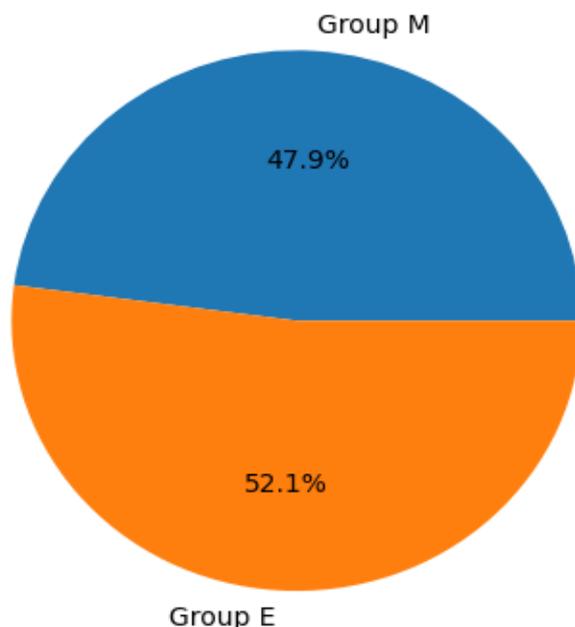
**Graph 1: Age-wise distribution**

**Table 2: Gender Distribution**

Gender	Group M (n=60)	Group E (n=60)	Total (n=120)
Male	34 (56.7%)	33 (55.0%)	67 (55.8%)
Female	26 (43.3%)	27 (45.0%)	53 (44.2%)

**Interpretation**

Both groups were comparable with respect to gender distribution, indicating effective randomization. Gender distribution was comparable between the two study groups. In Group M, males constituted 56.7% and females 43.3% of the study population, while in Group E, 55.0% were males and 45.0% were females. The difference in gender distribution between the groups was not statistically significant ( $p > 0.05$ ), suggesting effective randomization and ensuring that gender-related physiological variations did not influence the study outcomes.

**Graph 2: Genderwise distribution****Table 3: Comparison of Heart Rate (beats/min)**

Time Interval	Group M (Mean $\pm$ SD)	Group E (Mean $\pm$ SD)	p-value
Baseline	78.4 $\pm$ 7.0	79.0 $\pm$ 6.8	>0.05
At Extubation	85.9 $\pm$ 7.9	93.6 $\pm$ 8.2	<0.001*
1 min	82.6 $\pm$ 7.3	91.1 $\pm$ 7.8	<0.001*
3 min	80.2 $\pm$ 6.8	86.9 $\pm$ 7.1	<0.001*
5 min	78.8 $\pm$ 6.4	83.1 $\pm$ 6.7	<0.01*

**Interpretation:**

Magnesium sulphate significantly attenuated the tachycardic response during and after extubation compared to esmolol.

**Table 4: Comparison of Systolic Blood Pressure (mmHg)**

Time Interval	Group M (Mean $\pm$ SD)	Group E (Mean $\pm$ SD)	p-value
Baseline	122.1 $\pm$ 8.4	123.0 $\pm$ 8.9	>0.05
At Extubation	130.1 $\pm$ 9.2	139.0 $\pm$ 10.4	<0.001*
1 min	127.6 $\pm$ 8.7	136.2 $\pm$ 9.6	<0.001*
3 min	124.9 $\pm$ 8.1	132.4 $\pm$ 9.0	<0.01*
5 min	123.3 $\pm$ 7.8	128.6 $\pm$ 8.4	<0.05*

**Interpretation:**

The rise in systolic blood pressure during extubation was significantly lower in the magnesium sulphate group.

Baseline heart rate values were similar in both groups, confirming comparable pre-extubation hemodynamic status. At the time of extubation, heart rate increased in both groups due to sympathetic stimulation; however, the rise was significantly lower in patients receiving magnesium sulphate compared to those receiving esmolol ( $p < 0.001$ ). This difference persisted at 1, 3, and 5 minutes following extubation, with Group M demonstrating a faster return toward baseline values. These findings indicate that intravenous magnesium sulphate provided superior attenuation of the tachycardic response associated with tracheal extubation compared to esmolol.

**Table 5: Comparison of Diastolic Blood Pressure (mmHg)**

Time Interval	Group M (Mean $\pm$ SD)	Group E (Mean $\pm$ SD)	p-value
Baseline	78.1 $\pm$ 6.3	79.0 $\pm$ 6.6	>0.05
At Extubation	84.2 $\pm$ 7.0	91.6 $\pm$ 7.8	<0.001*
1 min	82.0 $\pm$ 6.7	89.4 $\pm$ 7.3	<0.001*
3 min	80.0 $\pm$ 6.4	86.2 $\pm$ 6.8	<0.01*
5 min	78.7 $\pm$ 6.1	83.0 $\pm$ 6.5	<0.05*

**Interpretation:**

Magnesium sulphate provided superior control of diastolic blood pressure during extubation.

**Table 6: Comparison of Mean Arterial Pressure (MAP) (mmHg)**

Time Interval	Group M (Mean $\pm$ SD)	Group E (Mean $\pm$ SD)	p-value
Baseline	92.6 $\pm$ 7.1	93.5 $\pm$ 7.4	>0.05
At Extubation	99.1 $\pm$ 7.6	107.3 $\pm$ 8.4	<0.001*
1 min	97.4 $\pm$ 7.2	105.5 $\pm$ 8.0	<0.001*
3 min	95.1 $\pm$ 6.9	101.8 $\pm$ 7.5	<0.01*
5 min	93.4 $\pm$ 6.7	98.3 $\pm$ 7.1	<0.05*

**Interpretation:**

Mean arterial pressure was significantly better attenuated in the magnesium sulphate group.

**Table 7: Incidence of Adverse Effects**

Adverse Effect	Group M (n=60)	Group E (n=60)
Bradycardia	2 (3.3%)	7 (11.7%)
Hypotension	3 (5.0%)	4 (6.7%)
Nausea/Vomiting	3 (5.0%)	2 (3.3%)
None	52 (86.7%)	47 (78.3%)

**Interpretation:**

Both drugs were well tolerated. Bradycardia was more frequent in the esmolol group, while magnesium sulphate demonstrated a better overall safety profile.

**Systolic Blood Pressure Changes**

Systolic blood pressure values at baseline were comparable between the two groups. A marked increase in systolic blood pressure was observed at extubation in both groups; however, the magnitude of increase was significantly less in the magnesium sulphate group. At extubation and at 1, 3, and 5 minutes post-extubation, systolic blood pressure remained significantly lower in Group M than in Group E ( $p < 0.05$ ). These results demonstrate that magnesium sulphate was more effective than esmolol in controlling systolic blood pressure surges during the peri-extubation period.

**Diastolic Blood Pressure Changes**

Baseline diastolic blood pressure values were similar in both groups. Following extubation, diastolic blood pressure increased in both groups, reflecting sympathetic activation. However, patients in the magnesium sulphate group exhibited significantly lower diastolic blood pressure values at extubation and during the immediate post-extubation period compared to those in the esmolol group ( $p < 0.05$ ). This sustained attenuation suggests better control of peripheral vascular resistance with magnesium sulphate.

**Mean Arterial Pressure Changes**

Mean arterial pressure (MAP) showed no statistically significant difference between the two groups at baseline. At extubation, MAP increased in both groups, but the increase was significantly attenuated in Group M compared to Group E ( $p < 0.001$ ). This difference remained significant at 1, 3, and 5 minutes post-extubation. The findings indicate that

magnesium sulphate provided more stable overall hemodynamic control during extubation, reducing both cardiac and vascular components of the stress response.

### **Adverse Effects**

The incidence of adverse effects was low in both groups. Most patients did not experience any complications. Bradycardia was observed more frequently in the esmolol group compared to the magnesium sulphate group. Episodes of hypotension and nausea/vomiting were infrequent and comparable between the two groups. Overall, both drugs were well tolerated; however, magnesium sulphate demonstrated a slightly better safety profile with fewer clinically significant adverse events.

Overall analysis of 120 patients revealed that both magnesium sulphate and esmolol effectively attenuated hemodynamic responses during tracheal extubation. However, magnesium sulphate consistently demonstrated superior control over heart rate, systolic blood pressure, diastolic blood pressure, and mean arterial pressure throughout the extubation and immediate post-extubation period, with minimal adverse effects.

### **DISCUSSION**

Tracheal extubation is increasingly recognized as a critical phase of general anaesthesia associated with significant cardiovascular stress. While laryngoscopy and intubation have traditionally received greater attention, emerging evidence suggests that extubation may provoke equal or even greater sympathetic stimulation. This is largely attributed to lighter planes of anaesthesia, return of airway reflexes, coughing, straining, and psychological arousal during emergence, leading to abrupt increases in heart rate and blood pressure.<sup>1-3</sup> These responses may be poorly tolerated in susceptible patients.

The sympathetic surge occurring during extubation is mediated by increased catecholamine release, resulting in tachycardia, hypertension, increased myocardial oxygen consumption, and raised intracranial pressure.<sup>4-6</sup> In patients with limited cardiovascular reserve, such transient hemodynamic disturbances may precipitate myocardial ischemia, arrhythmias, cerebrovascular accidents, and postoperative bleeding. With the increasing number of elderly patients and those with comorbid conditions undergoing surgery, attenuation of extubation-related hemodynamic responses has gained significant clinical importance.<sup>7,8</sup>

In the present prospective randomized study involving 120 patients, both magnesium sulphate and esmolol demonstrated the ability to attenuate extubation-related hemodynamic changes. However, magnesium sulphate consistently provided superior control of heart rate, systolic blood pressure, diastolic blood pressure, and mean arterial pressure at extubation and during the immediate post-extubation period. These findings are consistent with recent literature emphasizing the need for multimodal sympatholysis during emergence from anaesthesia.<sup>9,10</sup>

#### **Hemodynamic Response to Tracheal Extubation**

Recent studies have highlighted that the hemodynamic response to extubation may be more sustained and unpredictable than that observed during intubation. Unlike intubation, extubation occurs during lighter planes of anaesthesia, making suppression of airway reflexes more challenging. Narra et al. reported sustained elevations in heart rate and blood pressure for up to five minutes following extubation in untreated patients.<sup>11</sup> Similar observations have been reported in systematic reviews and randomized trials, underscoring extubation as a vulnerable window for cardiovascular instability.<sup>12-14</sup>

In the present study, both groups exhibited increases in heart rate and blood pressure at extubation, confirming extubation as a potent sympathetic stimulus. However, the magnitude and duration of these responses were significantly attenuated in the magnesium sulphate group, suggesting more effective suppression of sympathetic outflow.

#### **Effect of Esmolol on Extubation Responses**

Esmolol, an ultra-short-acting cardioselective  $\beta_1$ -adrenergic blocker, has been widely used to control perioperative tachycardia. Its rapid onset and short duration make it suitable for transient hemodynamic control during airway manipulation.<sup>15</sup> In the present study, esmolol effectively reduced the rise in heart rate during extubation compared to baseline values, which is consistent with previous studies and meta-analyses.<sup>16,17</sup>

However, esmolol demonstrated limited efficacy in controlling blood pressure responses. Although systolic and diastolic blood pressures were attenuated, values remained significantly higher compared to the magnesium sulphate group. This observation aligns with previous studies reporting that esmolol primarily reduces cardiac output without significantly affecting peripheral vascular resistance.<sup>18</sup> Bendaham et al. observed that while esmolol reliably attenuates tachycardia, its effect on blood pressure during extubation is variable.<sup>19</sup>

Additionally, the higher incidence of bradycardia observed in the esmolol group in the present study is consistent with existing literature documenting beta-blocker-associated bradycardia during emergence from anaesthesia.<sup>20</sup> This limits its routine use in patients with baseline low heart rates or conduction abnormalities.

### **Effect of Magnesium Sulphate on Extubation Responses**

Magnesium sulphate demonstrated superior attenuation of hemodynamic responses in the present study. Patients receiving magnesium sulphate showed significantly lower heart rate, systolic blood pressure, diastolic blood pressure, and mean arterial pressure at extubation and during the immediate post-extubation period. These findings are consistent with several randomized controlled trials and meta-analyses.<sup>21–23</sup>

The efficacy of magnesium sulphate can be attributed to its multimodal mechanism of action. Magnesium inhibits catecholamine release from adrenergic nerve terminals and the adrenal medulla, acts as a calcium channel antagonist, and blocks NMDA receptors, resulting in vasodilation and reduced sympathetic tone.<sup>24–26</sup> These combined actions provide comprehensive attenuation of both cardiac and vascular components of the stress response.

Recent studies have also reported additional benefits of magnesium sulphate, including reduced coughing, improved extubation quality, and decreased emergence agitation.<sup>27,28</sup> Although extubation quality was not formally assessed in the present study, smoother emergence may have contributed to the observed hemodynamic stability.

### **Comparison with Previous Studies**

The findings of the present study are in agreement with earlier comparative studies evaluating magnesium sulphate and esmolol during airway manipulation. A study demonstrated that magnesium sulphate provided superior blood pressure control compared to esmolol, while both drugs effectively attenuated heart rate responses.<sup>29</sup> More recent studies published between 2024 and 2025 have reaffirmed these findings, emphasizing the broader hemodynamic control offered by magnesium sulphate.<sup>11,19,21</sup>

Systematic reviews and meta-analyses have further supported magnesium sulphate as an effective and safe agent for peri-extubation hemodynamic control, with a lower incidence of adverse cardiovascular effects compared to beta-blockers.<sup>22,23</sup> The present study strengthens this evidence by providing contemporary comparative data in a larger sample size using standardized anaesthetic protocols.

### **Safety and Adverse Effects**

Both magnesium sulphate and esmolol were well tolerated in the present study. The overall incidence of adverse effects was low, and most patients did not experience any complications. Bradycardia was more frequent in the esmolol group, consistent with its pharmacological profile. Episodes of hypotension and nausea/vomiting were minimal and comparable between the two groups, similar to observations reported in previous studies.<sup>16,20</sup>

Magnesium sulphate did not produce clinically significant hypotension or bradycardia, indicating a favorable safety profile when used in appropriate doses.<sup>21,24</sup>

### **Clinical Implications**

Effective attenuation of hemodynamic responses during extubation is essential for improving perioperative safety.<sup>30</sup> Magnesium sulphate, owing to its multimodal sympatholytic action, provides superior control of heart rate and blood pressure with minimal adverse effects.<sup>23,28,31–35</sup> Its low cost, wide availability, and ease of administration make it a valuable agent for routine clinical use during tracheal extubation, particularly in patients where cardiovascular stability is crucial.

### **CONCLUSION**

The present prospective randomized comparative study demonstrates that both intravenous magnesium sulphate and intravenous esmolol are effective in attenuating hemodynamic responses associated with tracheal extubation. However, intravenous magnesium sulphate provided significantly superior control of heart rate, systolic blood pressure, diastolic blood pressure, and mean arterial pressure during extubation and the immediate post-extubation period. Magnesium sulphate also exhibited a favorable safety profile with fewer adverse effects, particularly a lower incidence of bradycardia compared to esmolol.

Given its multimodal mechanism of action, ability to provide balanced cardiovascular stability, ease of administration, and cost-effectiveness, intravenous magnesium sulphate can be safely recommended as a preferable agent for attenuation of hemodynamic responses during tracheal extubation in patients undergoing surgeries under general anaesthesia.

## LIMITATIONS OF THE STUDY

1. The study included only **ASA physical status I and II patients**; therefore, the findings may not be directly applicable to high-risk patients with significant cardiovascular or cerebrovascular disease.
2. **Plasma catecholamine levels** were not measured, which could have provided objective biochemical correlation of sympathetic attenuation.
3. The study focused primarily on **hemodynamic parameters**; extubation quality parameters such as coughing, bucking, and emergence agitation were not formally assessed.
4. Long-term postoperative outcomes and patient satisfaction were not evaluated.

### Declarations:

**Conflicts of interest:** There is no any conflict of interest associated with this study

**Consent to participate:** We have consent to participate.

**Consent for publication:** We have consent for the publication of this paper.

**Authors' contributions:** All the authors equally contributed the work.

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