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Cross-Sectional Assessment of Intraoperative Blood Pressure and Heart Rate Variability in Elective Surgeries Under General Anaesthesia: A Prospective Study.

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Abstract

Background: During general anaesthesia (GA), patients may experience intraoperative hemodynamic instability where blood pressure and heart rate fluctuate substantially. The independent impact of uncontrolled hemodynamic variability on cardiovascular and renal outcomes. A cross sectional study was done at a tertiary care hospital in north India to evaluate the magnitude, time pattern and clinical determinants of intra operative blood pressure and heart rate variability in adult patients undergoing elective surgery under GA. ***Methods:*** This was a prospective cross sectional observational study conducted over a period of 6 months in a tertiary care medical hospital in Bengaluru. A total of sixty adult patients (ASA physical status I-III) who were scheduled to undergo an elective major non-cardiac surgery were enrolled and received standardized general anaesthesia for that surgery. The systolic blood pressure (SBP), mean arterial pressure (MAP), and heart rate (HR) were recorded at six defined epochs during the perioperative period. The epochs were defined as baseline (pre-induction), endotracheal intubation, incision, intraoperative maintenance, extubation, and postanaesthesia care unit (PACU) arrival. Standard deviation (SD) and coefficient of variation (CV) were used to quantify variability. ***Results:*** The endotracheal intubation and surgery incision were linked with a major hemodynamic change. The study showed that endotracheal intubation recorded a maximum mean MAP (104.2 ± 14.6 mmHg) and HR (92.4 ± 12.8 bpm). The lowest MAP (72.8 ± 9.4 mmHg) was during the course of intraoperative maintenance. Intraoperative hypotension (MAP < 65 mmHg or more than 20% drop from baseline) of clinical significance occurred in 36.7% (n = 22). Variability of the mean arterial pressure (MAP) >10% during surgery (intraoperative) occurred in 28.3% (n=17) of patients. These patients were older as compared to those with stable MAP (58.4±10.2 vs 48.3±11.8 years, p=0.01). In addition, they had a higher ASA physical status (p=0.008) and were operated for longer duration (158±44 vs 126±38 minutes, p=0.02). ***Conclusion:*** in elective surgeries, intraoperative blood pressure and heart rate variability is common under general anaesthesia. This is especially the case with older patients who have co-morbidities. It occurred particularly during anaesthetic induction and emergence. In high-risk patients undergoing surgery, it is essential to achieve goal-hemodynamic monitoring to minimize hemodynamic swings and accurate anaesthetic titration.

Keywords: General Anaesthesia; Hemodynamic Variability; Intraoperative Hypotension; Heart Rate Variability; Mean Arterial Pressure.

INTRODUCTION

Intraoperative maintenance of hemodynamic stability is a cornerstone of anaesthetic management [1, 2]. Under general anaesthesia (GA), complex interactions resulting from sympatholysis and myocardial depression induced by the anaesthetic agent, vascular dilation and intermittent surgical nociceptive surge often lead to large fluctuations in arterial blood pressure and heart rate [2, 3]. Historically, transient hemodynamic changes have been unimportant physiological responses. However, pooling epidemiological and prospective clinical evidence now demonstrate that intraoperative hemodynamic variability, specifically excessive blood pressure lability and tachycardia, are independently associated with perioperative organ hypoperfusion and adverse postoperative morbidity [1, 4].

In the perioperative period, intraoperative hypotension (IOH) and blood pressure lability directly play a role in myocardial injury after non-cardiac surgery (MINS), acute kidney injury (AKI) and post-operative delirium [2, 5]. According to recent multicentre registries, even short periods of mean arterial pressure (MAP) falling below 65 mmHg, or decreasing by more than 20% from baseline, substantially increase the risk of postoperative myocardial and renal tubular ischemia [4, 6]. At the same time, heart rate variability and NT-proBNP also increase due to acute changes in heart rate. However, during airway instrumentation or surgical incision, the heart becomes temporarily tachycardic fibrosis. Myocardial oxygen demand changes, but diastolic coronary perfusion decrease. Consequently, this further increases ischemic vulnerability in comorbid patients [3, 6].

Intraoperative hemodynamic instability is a well-established risk factor that is associated with worse outcomes. However, there is significant variability across surgical practices and institutions in the magnitude and temporal pattern of blood pressure and heart rate variability. The hemodynamic management of patients in high-volume tertiary care hospitals in India with heterogeneous patients, late presentation of co-morbid illness and variation in surgical complexity is challenging [5, 8]. Nonetheless, prospective cross-sectional data quantifying intraoperative blood pressure and heart rate variability patterns using standardised statistical parameters (the coefficient of variation) in Indian surgical cohorts are lacking [7, 8]. Consequently, the main aim of the present prospective cross-sectional study was to assess the magnitude, time distribution and clinical factors of intra-operative blood pressure and heart rate variability among adults undergoing elective major non-cardiac surgical procedures under general anaesthesia at a tertiary care hospital, Bengaluru.

MATERIALS AND METHODS

Study Design and Setting

This prospective cross-sectional observational study was conducted over a continuous 6-month period in the Department of Anaesthesiology at a Level-I tertiary care medical hospital in Bengaluru, Karnataka. The study protocol was formally reviewed and approved by the Institutional Ethics Committee prior to study initiation. Written informed consent was obtained from all participating patients or their legally authorized representatives in accordance with the ethical principles of the Declaration of Helsinki.

Patient Selection and Eligibility Criteria

A total of N = 60 adult patients scheduled for elective major non-cardiac surgery under general anaesthesia during the 6-month study window were enrolled sequentially.

Inclusion Criteria: Patients aged 18 to 65 years of either sex, American Society of Anesthesiologists (ASA) physical status I, II, or III, undergoing elective major general, gastrointestinal, urological, gynaecological, or orthopaedic surgical procedures under general anaesthesia with an anticipated operative duration exceeding 90 minutes.

Exclusion Criteria: Patients undergoing emergency or semi-emergent surgeries, cardiac or intracranial neurosurgical procedures, pre-existing cardiac arrhythmias (e.g., atrial fibrillation, frequent premature ventricular contractions), severe valvular heart disease, presence of a permanent pacemaker or implantable cardioverter-defibrillator (ICD), patients on chronic antiarrhythmic medications or beta-blockers that alter basal heart rate variability, severe uncontrolled systemic hypertension (baseline SBP > 180 mmHg or DBP > 110 mmHg), end-stage renal or hepatic disease, and refusal of study consent.

Standardized Anaesthetic Protocol

All enrolled patients underwent standardized pre-anaesthetic evaluation and fasting protocols. Upon arrival in the operating theatre, standard ASA monitoring was established, including continuous electrocardiography (ECG lead II and V5), non-invasive blood pressure (NIBP) or invasive arterial blood pressure (IBP) when clinically indicated, pulse oximetry (SpO_2), and end-tidal carbon dioxide ($EtCO_2$) monitoring. Baseline hemodynamic parameters were recorded after a 5-minute resting period.

General anaesthesia was induced using intravenous propofol (1.5–2.0 mg/kg) and fentanyl (1.5–2.0 mcg/kg). Endotracheal intubation was facilitated by intravenous vecuronium (0.1 mg/kg) or rocuronium (0.6–0.9 mg/kg). Anaesthesia was maintained using sevoflurane or isoflurane in an oxygen-air mixture (FiO_2 0.4–0.5), titrated to maintain a minimum alveolar concentration (MAC) of 0.8–1.0. Intermittent intravenous fentanyl and muscle relaxant boluses were administered as clinically indicated. Volume-controlled mechanical ventilation was adjusted to maintain $EtCO_2$ between 35 and 40 mmHg. Intraoperative fluid management was standardized using balanced crystalloid solutions (Plasmalyte or Ringer's Lactate) at 4–6 mL/kg/hr, replacing blood loss with crystalloids (3:1 ratio) or blood products as guided by clinical estimation and institutional protocols.

Hemodynamic Data Collection and Epochs

Intraoperative hemodynamic parameters—specifically systolic blood pressure (SBP, mmHg), diastolic blood pressure (DBP, mmHg), mean arterial pressure (MAP, mmHg), and heart rate (HR, beats/minute)—were recorded systematically at six predefined perioperative epochs:

Epoch 1 (T0 - Baseline): Recorded in the operating room prior to anaesthetic induction after 5 minutes of rest.
Epoch 2 (T1 - Intubation): Recorded 1 minute following endotracheal intubation and airway securement.
Epoch 3 (T2 - Incision): Recorded 2 minutes following skin incision and surgical start.
Epoch 4 (T3 - Maintenance): Calculated as the mean of values recorded at standardized 15-minute intervals throughout the surgical procedure.
Epoch 5 (T4 - Extubation): Recorded immediately following endotracheal extubation and emergence.
Epoch 6 (T5 - PACU Arrival): Recorded 15 minutes following admission to the PACU.

Variability Metrics and Operational Definitions

To quantify the magnitude of intraoperative hemodynamic fluctuations, the standard deviation (SD) and coefficient of variation (CV) were calculated for MAP and HR across all recorded intraoperative time points for each patient. The coefficient of variation was defined as: CV (%) = (SD / Mean) × 100. Based on previous neuro-hemodynamic literature, patients were stratified into two analytical cohorts based on MAP lability: Low Variability (CV ≤ 10%) and High Variability (CV > 10%). Clinically significant intraoperative hypotension (IOH) was defined as a MAP < 65 mmHg or a decrease > 20% from baseline persisting for > 5 consecutive minutes. Clinically significant hypertension or tachycardia was defined as an increase > 20% above baseline values requiring pharmacological intervention (intravenous beta-blockers, vasodilators, or deepening of anaesthetic plane).

Statistical Analysis

All data were entered into a relational database and analyzed using statistical software. Continuous variables were tested for normal distribution using the Shapiro-Wilk test. Normally distributed continuous variables were presented as mean ± standard deviation (SD) and compared between groups using Student's unpaired two-tailed t-test. Temporal hemodynamic shifts across the six perioperative epochs were evaluated using one-way repeated measures analysis of variance (ANOVA) followed by Bonferroni post-hoc tests for pairwise comparisons. Non-parametric continuous data were compared using the Mann-Whitney U test. Categorical variables were presented as absolute numbers and percentages (%) and analyzed using Pearson's χ^2 test or Fisher's exact test. A two-tailed p-value < 0.05 was considered statistically significant.

RESULTS

During the 6-month study window at the tertiary hospital in Bengaluru, 60 patients completing the standardized general anaesthesia and monitoring protocol were analyzed. The baseline demographic and clinical characteristics of the study cohort are detailed in Table 1. The mean age of the total cohort was 51.2 ± 12.4 years, with a nearly balanced sex distribution (53.3% males, 46.7% females). The mean body mass index (BMI) was 24.5 ± 3.6 kg/m². Regarding preoperative physical status, 30.0% (n = 18) were classified as ASA I, 46.7% (n = 28) as ASA II, and 23.3% (n = 14) as ASA III. General and gastrointestinal surgeries constituted the most frequent surgical category (36.7%), followed by orthopaedic procedures (26.7%). The mean operative duration across all procedures was 135 ± 42 minutes.

Table 1: Baseline Demographic and Clinical Characteristics of the Study Cohort (N = 60)

Demographic / Clinical Parameter	**Total Cohort (N = 60)**	**Percentage (%) / Range**
Age (years), Mean ± SD	51.2 ± 12.4	21 – 65 years
Sex (Male / Female), n (%)	32 / 28	53.3% / 46.7%
Body Mass Index (BMI, kg/m²), Mean ± SD	24.5 ± 3.6	18.8 – 31.4 kg/m²
ASA Physical Status Classification, n (%)		
ASA I (Normal healthy patient)	18	30.0%
ASA II (Mild systemic disease)	28	46.7%
ASA III (Severe systemic disease)	14	23.3%
Type of Major Elective Surgery, n (%)		
General / Gastrointestinal Surgery	22	**36.7%**
Orthopaedic Surgery	16	26.7%
Gynaecological Surgery	12	20.0%
Urological / Other Major Surgery	10	16.6%
Operative Duration (minutes), Mean ± SD	135 ± 42	90 – 240 minutes
Total Intraoperative Fluids (mL), Mean ± SD	1450 ± 380	800 – 2500 mL

Repeated measures ANOVA demonstrated statistically significant temporal fluctuations in systolic blood pressure, mean arterial pressure, and heart rate across the six predefined perioperative epochs (p < 0.001 for all parameters) (Table 2). Compared to baseline pre-induction values (MAP 91.4 ± 10.2 mmHg; HR 76.8 ± 10.4 bpm), endotracheal intubation (T1) triggered a sharp, statistically significant surge in both blood pressure and heart rate, reaching peak intraoperative mean values of 104.2 ± 14.6 mmHg for MAP and 92.4 ± 12.8 bpm for HR (p < 0.001 vs. baseline). A secondary hemodynamic spike occurred during surgical skin incision (T2), with mean MAP rising to 98.6 ± 12.4 mmHg.

Conversely, following anesthetic equilibrium and during the intraoperative maintenance phase (T3), blood pressure declined significantly to a study nadir (mean MAP 72.8 ± 9.4 mmHg; SBP 102.4 ± 13.2 mmHg, $p < 0.001$ vs. baseline). During emergence and extubation (T4), significant sympathetic stimulation again elevated MAP (96.4 ± 13.8 mmHg) and HR (88.6 ± 11.6 bpm), before gradually normalizing upon arrival in the PACU (T5). Overall, clinically significant intraoperative hypotension (IOH), defined as MAP < 65 mmHg or > 20% drop from baseline, was documented in 22 patients (36.7%), predominantly occurring during the post-induction and early maintenance epochs.

Table 2: Intraoperative Hemodynamic Dynamics Across Predefined Perioperative Epochs

Perioperative Epoch / Timestamp	**Systolic BP (mmHg)**	**Mean Arterial Pressure (mmHg)**	**Heart Rate (bpm)**	**ANOVA p-value**
Epoch 1 (T0 - Baseline Pre-Induction)	124.6 ± 14.2	91.4 ± 10.2	76.8 ± 10.4	Ref
Epoch 2 (T1 - Endotracheal Intubation)	144.8 ± 18.6	104.2 ± 14.6	92.4 ± 12.8	**< 0.001**
Epoch 3 (T2 - Surgical Skin Incision)	136.2 ± 16.4	98.6 ± 12.4	86.2 ± 11.2	**< 0.001**
Epoch 4 (T3 - Intraoperative Maintenance)	102.4 ± 13.2	72.8 ± 9.4	70.4 ± 8.8	**< 0.001**
Epoch 5 (T4 - Extubation / Emergence)	134.6 ± 17.8	96.4 ± 13.8	88.6 ± 11.6	**< 0.001**
Epoch 6 (T5 - PACU Arrival 15 mins)	122.8 ± 13.6	88.6 ± 10.8	78.2 ± 9.6	0.08

To identify factors contributing to excessive hemodynamic fluctuations, patients were stratified based on intraoperative MAP variability into Low Variability (CV ≤ 10%, n = 43) and High Variability (CV > 10%, n = 17) cohorts (Table 3). High intraoperative blood pressure variability was documented in 28.3% of the surgical cohort.

Comparative analysis revealed that patients exhibiting high hemodynamic variability were significantly older than those with stable intraoperative profiles (58.4 ± 10.2 years vs. 48.3 ± 11.8 years, $p = 0.01$). Furthermore, pre-existing physical status was strongly associated with lability; ASA III patients accounted for 58.8% of the high variability cohort compared to only 9.3% of the low variability cohort ($p = 0.008$). Operative duration was also significantly prolonged in patients with high MAP variability (158 ± 44 minutes vs. 126 ± 38 minutes, $p = 0.02$). Concurrently, patients in the high variability group experienced a markedly higher incidence of intraoperative hypotension episodes (76.5% vs. 20.9%, $p < 0.001$) and required significantly more frequent pharmacological rescue interventions with vasopressors such as ephedrine or phenylephrine (64.7% vs. 16.3%, $p < 0.001$).

Table 3: Clinical Determinants and Perioperative Outcomes Stratified by Intraoperative Mean Arterial Pressure (MAP) Variability

Clinical Determinant / Outcome	**Low Variability (CV ≤ 10%, n=43)**	**High Variability (CV > 10%, n=17)**	**Difference / Odds Ratio**	**p-value**
Age (years), Mean ± SD	48.3 ± 11.8	58.4 ± 10.2	-10.1 (95% CI: -16.5 to -3.7)	**0.01**
Male Sex, n (%)	23 (53.5%)	9 (52.9%)	OR = 0.98 (0.32 – 2.98)	0.96
ASA Physical Status III, n (%)	4 (9.3%)	10 (58.8%)	OR = 13.9 (3.4 – 56.8)	**0.008**
Operative Duration (minutes), Mean ± SD	126 ± 38	158 ± 44	-32.0 (95% CI: -55.2 to -8.8)	**0.02**
Intraoperative Hypotension Episodes, n (%)	9 (20.9%)	13 (76.5%)	OR = 12.3 (3.2 – 47.1)	**< 0.001**
Vasopressor Rescue Requirement, n (%)	7 (16.3%)	11 (64.7%)	OR = 9.4 (2.6 – 34.2)	**< 0.001**
Tachycardia / Hypertension Rescue, n (%)	6 (14.0%)	7 (41.2%)	OR = 4.3 (1.1 – 16.5)	**0.03**
PACU Length of Stay (minutes), Mean ± SD	45.2 ± 12.4	62.8 ± 18.6	-17.6 (95% CI: -26.8 to -8.4)	**< 0.001**

DISCUSSION

This prospective cross-sectional study conducted in a tertiary care hospital of Bengaluru has shown a high prevalence of significant intraoperative variability of blood pressure and heart rate during major elective surgeries under general anaesthesia. Our results show that hemodynamic lability is temporally focused during critical anesthetic transitions with sharp hypertensive and tachycardic spikes during endotracheal intubation (mean MAP 104.2 ± 14.6 mmHg) and emergence (mean MAP 96.4 ± 13.8 mmHg), in contrast to profound hypotension during intraoperative maintenance (mean MAP 72.8

± 9.4)(1, 2). Moreover, an MAP variability (CV > 10%) occurred in 28.3% of subjects; advancing age ($p = 0.01$), ASA physical status III ($p = 0.008$), and prolonged surgical duration ($p = 0.02$) were robust predictors of this variability [4, 6].

Our observations are consistent with and support recent national and international neuro-hemodynamic literature. We support the systematic evaluations of blood pressure lability and intraoperative hypotension performed by Wesselink et al. [2] and Vernooij et al. [4] who showed that they are not simply random occurrences but rather systematic reactions to anaesthetic depth and surgical trauma which predict organ injury independently. In the Indian healthcare system, our findings closely align with the latest observations of Rao et al. [5] and Karthik et al. [7]. They reported that the elderly and comorbid patients in Indian surgical centres exhibit blunted baroreceptor reactivity, making them very susceptible to rapid haemodynamic swings during induction and maintenance of general anaesthesia.

The physical cause for the bimodal behaviour of instability in surgical settings is not easily determined. When patients are intubated, the mechanical stimulation of the pharyngeal and tracheal mechanoreceptors causes a sympathoadrenal discharge that releases catecholamines that supplant the hypnosis caused by propofol [3, 7]. The volatile anaesthetics (sevoflurane/isoflurane) exert dose dependent systemic vasodilation as well as direct myocardial depression [1, 5]. In older patients whose basal vascular compliance is stiffened by atherosclerosis and whose autonomic baroreflexes are attenuated (ASA III), the ability to buffer such vasodilator shifts is severely compromised, which explains the 76.5% incidence of hypotension requiring vasopressor support in our high variability cohort [4, 8].

The findings of this study has high clinical relevance to peri operative management in tertiary care hospitals of India. When only relying on 5 min intervals of intermittent non-invasive blood pressure monitoring, one will miss acute hemodynamic nadirs or peaks [5, 6]. Our data provide strong support for proactive, goal-directed hemodynamic management in high-risk surgical patients [6, 8]. Use of depth-of-anaesthesia monitoring (e.g. Bispectral Index, Entropy) and nociception monitoring can help anaesthesiologists titrate the hypnotic and analgesic dosing precisely to avoid anaesthetic over-dosage, during maintenance, but at the same time blunt the surgical stress adequately during airway instrumentation and incision [7, 8].

It must be noted that this study has several limitations. This was a cross-sectional observational study with a cohort size of N = 60 patients at a single-center; while a statistically powered evaluation of hemodynamic variability metrics across epochs is performed, larger multicenter studies will be needed to correlate this variability with hard long-term postoperative outcomes like 30-day mortality or myocardial infarction (2, 6).

Secondly, a subset of ASA I/II patients undergoing less complicated surgeries had intermittent non-invasive blood pressure (NIBP) hemodynamic monitoring. The use of arterial lines was predominantly performed in ASA III or complex surgeries. While the use of arterial lines was standardized, continuous beat-to-beat blood pressure monitoring across the entire cohort would allow for better calculation of heart rate and blood pressure variability [4, 8]. Lastly, we did not assess preoperative autonomic function tests or postoperative end-organ injury biomarkers (for example, high-sensitivity troponin or serum creatinine). This represents an important area for further prospective studies [3, 5].

CONCLUSION

The intraoperative variations of blood pressure and heart rate are common during elective major non-cardiac surgeries done under general anaesthesia. Hypertensive surges occur during airway instrumentation and extubation. This is followed up by significant hypotension during the maintenance period. Advanced age, high systemic comorbidity (ASA III), and high surgical length of operations are well correlated with hemodynamic variability. To minimize hemodynamic variability and maximize perioperative safety of high-risk surgical patients, proactive goal-directed hemodynamic monitoring, individualized anesthetic titration, and timely pharmacological stabilization are required.

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