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Cross-Sectional Study of Electrolyte Abnormalities and Their Impact on Perioperative Cardiac Arrhythmias in Major Surgical Patients.

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Abstract

Background: Electrolyte abnormalities are common during major surgery because of pre-existing illness, fasting, gastrointestinal losses, haemorrhage, intravenous-fluid administration, blood transfusion and the physiological stress response. Disturbances involving sodium, potassium, calcium and magnesium can affect myocardial conduction and increase electrical instability. The present study assessed the prevalence and pattern of perioperative electrolyte abnormalities and examined their association with cardiac arrhythmias among major surgical patients. Aim: To assess electrolyte abnormalities and their association with perioperative cardiac arrhythmias among patients undergoing major surgical procedures. ***Materials and Methods:*** This institution-based analytical cross-sectional study included 120 adult patients undergoing major elective or emergency surgery. Serum sodium, potassium, corrected calcium and magnesium were assessed preoperatively and during the postoperative period. Patients underwent intraoperative cardiac monitoring and postoperative rhythm surveillance for the identification of new perioperative arrhythmias. Demographic, clinical, anaesthetic, operative and laboratory data were collected using a structured case-record form. Continuous variables were compared using appropriate parametric or non-parametric tests, while categorical variables were analysed using the chi-square or Fisher's exact test. Paired electrolyte values were compared using the paired t test, and preoperative and postoperative prevalence was compared using the McNemar test. Multivariable binary logistic regression was performed to identify independent predictors of perioperative arrhythmias. Adjusted odds ratios with 95% confidence intervals were reported, and P<0.05 was considered statistically significant. ***Results***: The mean age was 52.83±13.64 years, while mean operative duration and estimated blood loss were 176.42±48.73 minutes and 438.67±216.54 mL, respectively. At least one perioperative electrolyte abnormality was observed in 53 (44.2%) patients. Its prevalence increased significantly from 28.3% preoperatively to 39.2% postoperatively (P=0.023). Potassium abnormalities were the most common, affecting 25.8% of patients, followed by sodium abnormalities in 21.7%, calcium abnormalities in 18.3% and magnesium abnormalities in 15.0%. Mean postoperative sodium, potassium, corrected calcium and magnesium concentrations were significantly lower than their respective preoperative concentrations (all P<0.001). Perioperative cardiac arrhythmias occurred in 29 (24.2%) patients. Premature ventricular complexes were the most frequent arrhythmia, followed by atrial fibrillation or flutter and supraventricular tachycardia. Arrhythmias occurred in 37.7% of patients with an electrolyte abnormality compared with 13.4% of those with a normal electrolyte profile (P=0.002). Any electrolyte abnormality was associated with 3.91 times higher crude odds of arrhythmia (95% CI: 1.60-9.56). After multivariable adjustment, potassium abnormality (adjusted OR=3.36; 95% CI: 1.25-9.04; P=0.016), sodium abnormality (adjusted OR=2.79; 95% CI: 1.03-7.55; P=0.044), pre-existing cardiovascular disease (adjusted OR=2.88; 95% CI: 1.10-7.54; P=0.031) and emergency surgery (adjusted OR=2.67; 95% CI: 1.02-6.99; P=0.046) independently predicted perioperative arrhythmias. ***Conclusion***: Electrolyte abnormalities were common among patients undergoing major surgery and became more frequent during the postoperative period. Potassium disturbances were the most prevalent and demonstrated the strongest independent association with perioperative cardiac arrhythmias. Sodium abnormalities, pre-existing cardiovascular disease and emergency surgery were also independent predictors. Systematic perioperative electrolyte assessment, appropriate correction of genuine abnormalities and continued cardiac-rhythm monitoring may facilitate early identification and management of high-risk patients. However, the observational design does not establish a causal effect, and larger prospective studies are required.

Keywords: Electrolyte abnormalities; perioperative cardiac arrhythmias; major surgery.

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INTRODUCTION

Electrolyte abnormalities are frequently encountered in patients undergoing major surgery and may arise from pre-existing systemic illness, prolonged fasting, gastrointestinal losses, renal dysfunction, medications, administration of intravenous fluids, blood transfusion, tissue injury and perioperative hormonal responses. Sodium, potassium, calcium and magnesium play essential roles in maintaining cellular membrane potential, myocardial conduction, contractility and normal cardiac rhythm. Consequently, disturbances in their concentrations may increase myocardial electrical instability during anaesthesia and the postoperative period. Hypokalaemia may cause premature atrial or ventricular complexes, supraventricular tachycardia and ventricular arrhythmias, whereas severe hyperkalaemia can produce conduction block, ventricular fibrillation or asystole. Abnormal calcium and magnesium concentrations can alter atrioventricular conduction and QT interval and may facilitate atrial or ventricular arrhythmias [1].

Major surgical procedures expose patients to rapid physiological changes, including fluid shifts, haemorrhage, acid-base disturbances, hypothermia and sympathetic stimulation. Anaesthetic drugs and vasoactive medications may further influence myocardial conduction. Therefore, an electrolyte abnormality that is clinically silent before surgery may become significant during or shortly after an operation. Previous research has demonstrated that low preoperative potassium is associated with an increased risk of serious perioperative arrhythmias [2]. Abnormal potassium concentrations during the postoperative period have also been associated with atrial fibrillation, although the benefits of routine supplementation remain uncertain [3].

Sodium abnormalities may represent both a direct physiological disturbance and a marker of underlying disease severity. A systematic review involving more than 1.3 million surgical patients found that preoperative hyponatraemia was associated with higher risks of major postoperative complications and early mortality [4]. Magnesium deficiency is also important because it may cause QT prolongation, increase myocardial excitability and make hypokalaemia difficult to correct. Electrolyte disturbances often coexist; therefore, simultaneous evaluation of sodium, potassium, calcium and magnesium may offer better perioperative risk assessment than assessment of an individual electrolyte alone.

Continuous or repeated electrocardiographic monitoring enables early identification of clinically important rhythm abnormalities, including atrial fibrillation, supraventricular tachycardia, bradyarrhythmia, conduction block and ventricular arrhythmias. Contemporary perioperative cardiovascular guidance emphasises systematic assessment and correction of reversible physiological abnormalities in patients undergoing major non-cardiac surgery [5]. However, evidence describing the prevalence and cardiac implications of perioperative electrolyte abnormalities among heterogeneous major surgical patients remains limited in many institutional settings. The present study was therefore undertaken to determine the pattern of electrolyte abnormalities and evaluate their association with perioperative cardiac arrhythmias in major surgical patients.

AIM

To assess electrolyte abnormalities and their association with perioperative cardiac arrhythmias among patients undergoing major surgical procedures.

OBJECTIVES

1. To determine the prevalence and pattern of perioperative sodium, potassium, calcium and magnesium abnormalities among major surgical patients.
2. To determine the incidence and types of cardiac arrhythmias occurring during the perioperative period.
3. To evaluate the association between electrolyte abnormalities and perioperative cardiac arrhythmias after accounting for relevant clinical and operative factors.

MATERIALS AND METHODS

Source of Data

Data were obtained from adult patients admitted to the Departments of General Surgery and allied surgical specialties for major elective or emergency surgical procedures. Clinical information was obtained through patient interviews, physical examination, anaesthesia records, operative records, laboratory reports, electrocardiograms and postoperative monitoring charts.

Study Design
The study was an institution-based, analytical cross-sectional study with perioperative observation. Patients' electrolyte status was assessed and its association with cardiac arrhythmias occurring during the defined perioperative period was analysed.

Study Location
The study was conducted in the surgical wards, pre-anaesthesia clinic, operation theatres, post-anaesthesia care unit and surgical intensive care unit.

Study Duration
The study was conducted over 12 months, including participant enrolment, perioperative observation, data verification, statistical analysis and report preparation.

Study Population
The study population consisted of adult patients undergoing major surgery under general, regional or combined anaesthesia during the study period.

For this study, major surgery was defined as a procedure that was expected to last more than two hours, required general or major regional anaesthesia, involved entry into a major body cavity, was associated with substantial physiological stress or blood loss, or required postoperative high-dependency or intensive care monitoring.

Sample Size
A total of **120 eligible patients** undergoing major surgical procedures were included in the study.

Sampling Technique
Eligible patients were recruited using consecutive sampling until the required sample size of 120 was achieved. Every patient satisfying the eligibility criteria during the study period was assessed for enrolment.

Inclusion Criteria
Patients were included when they:
1. Were aged 18 years or older.
2. Underwent an elective or emergency major surgical procedure.
3. Received general, regional or combined anaesthesia.
4. Had preoperative and perioperative serum electrolyte measurements available.
5. Underwent intraoperative cardiac monitoring and postoperative rhythm assessment.
6. Provided written informed consent for participation.

Exclusion Criteria
Patients were excluded when they:
1. Had a previously documented persistent cardiac arrhythmia, such as chronic atrial fibrillation or permanent conduction abnormality.
2. Had an implanted permanent pacemaker or implantable cardioverter-defibrillator.
3. Underwent minor or day-care surgical procedures.
4. Had cardiac surgery requiring cardiopulmonary bypass.
5. We're receiving antiarrhythmic treatment for an active arrhythmia before surgery.
6. Had incomplete electrolyte results, ECG records or perioperative monitoring data.
7. Declined or withdrew consent.

Study Variables
The principal exposure variables were perioperative serum sodium, potassium, corrected total calcium and magnesium concentrations. The primary outcome was the occurrence of any new perioperative cardiac arrhythmia.

Other variables included age, sex, body mass index, comorbidities, ASA physical-status class, renal function, medication history, type and urgency of surgery, anaesthesia technique, duration of surgery, estimated blood loss, intravenous-fluid volume, blood transfusion, acid-base status and requirement for intensive care.

Operational Definitions
Electrolyte abnormalities were classified according to the hospital laboratory reference ranges. The following commonly accepted limits were used where institution-specific limits were unavailable:

- Hyponatraemia: serum sodium <135 mmol/L
- Hypernatraemia: serum sodium >145 mmol/L
- Hypokalaemia: serum potassium <3.5 mmol/L
- Hyperkalaemia: serum potassium >5.0 mmol/L
- Hypocalcaemia: corrected calcium <8.5 mg/dL
- Hypercalcaemia: corrected calcium >10.5 mg/dL
- Hypomagnesaemia: serum magnesium <1.7 mg/dL
- Hypermagnesaemia: serum magnesium >2.4 mg/dL

Corrected calcium was calculated as:

A perioperative arrhythmia was defined as a newly detected rhythm disturbance occurring from induction of anaesthesia until 24 hours after surgery and documented by continuous cardiac monitoring or 12-lead ECG. Arrhythmias included premature atrial or ventricular complexes requiring clinical attention, atrial fibrillation or flutter, supraventricular tachycardia, significant bradycardia, atrioventricular block, ventricular tachycardia and ventricular fibrillation.

Procedure and Methodology

After approval from the Institutional Ethics Committee, eligible patients were approached and written informed consent was obtained. A predesigned and pilot-tested case-record form was used.

Demographic details, presenting diagnosis, comorbidities, medication history and relevant cardiovascular history were recorded. A detailed clinical examination was performed. Preoperative investigations included complete blood count, renal-function tests, liver-function tests, serum albumin, serum sodium, potassium, calcium and magnesium, and a 12-lead ECG. Electrolytes were measured within 24 hours before surgery. Repeat samples were obtained intraoperatively when clinically indicated or after substantial blood loss or transfusion, and postoperatively within 24 hours. For patients with multiple perioperative results, the value temporally closest to arrhythmia onset was considered for the primary association analysis. The lowest and highest values were additionally recorded for descriptive analysis.

All patients underwent continuous multiparameter monitoring during surgery, including ECG, heart rate, non-invasive or invasive blood pressure, oxygen saturation, respiratory rate and end-tidal carbon dioxide, as applicable. Cardiac rhythm monitoring was continued in the recovery area, high-dependency unit or intensive care unit according to clinical requirements. A 12-lead ECG was obtained whenever a suspected arrhythmia was observed.

The time of onset, type, duration, symptoms, haemodynamic consequences, treatment and outcome of each arrhythmia were documented. Transient monitor artefacts and rhythm changes lasting less than 30 seconds without clinical or ECG confirmation were excluded. Electrolyte correction was undertaken by the treating anaesthesiology or surgical team according to institutional protocols and was not delayed or modified for study purposes.

Sample Processing

Approximately 3-5 mL of venous blood was collected using aseptic precautions in a labelled serum-separator or plain tube. The sample was transported promptly to the central laboratory. After clot formation, it was centrifuged according to the laboratory's standard operating procedure, and the separated serum was analysed.

Serum sodium and potassium were measured using an ion-selective electrode method. Calcium and magnesium were measured using validated automated colorimetric methods. Serum albumin was measured for calculation of corrected calcium. Haemolysed, improperly labelled, insufficient or delayed samples were rejected and recollected because haemolysis could falsely elevate potassium and magnesium values. Internal quality-control procedures and routine analyser calibration were followed.

Data Collection

Data were collected prospectively on a structured case-record form. Information was obtained at four stages:

1. Preoperative assessment and baseline investigations.
2. Intraoperative monitoring and recording of anaesthetic and surgical factors.
3. Postoperative electrolyte testing and cardiac-rhythm surveillance.
4. Verification of arrhythmias from monitor strips, ECGs and clinical records.

Completed forms were checked for completeness and consistency. Data were anonymised using unique study identification numbers and entered into a password-protected database. A proportion of records was cross-checked against the source documents to minimise data-entry errors.

Statistical Methods

Data were entered into Microsoft Excel and analysed using IBM SPSS Statistics version 28.0. Continuous variables were presented as mean with standard deviation when normally distributed and as median with interquartile range when skewed. Categorical variables were expressed as frequencies and percentages.

The prevalence of each electrolyte abnormality and the incidence of perioperative arrhythmias were reported with 95% confidence intervals. The independent-samples *t* test or Mann-Whitney *U* test was used to compare continuous variables between patients with and without arrhythmias. The chi-square test or Fisher's exact test was used to assess associations between categorical electrolyte abnormalities and arrhythmias.

Crude odds ratios with 95% confidence intervals were calculated. Multivariable binary logistic regression was used to determine whether electrolyte abnormalities independently predicted perioperative arrhythmias after adjustment for age, sex, ASA class, cardiovascular disease, renal dysfunction, urgency and duration of surgery, blood loss, transfusion and anaesthesia technique. Adjusted odds ratios with 95% confidence intervals were reported. Multicollinearity and model fit were assessed before interpreting the final model. All tests were two-tailed, and a *p* value <0.05 was considered statistically significant.

RESULTS

Table 1: Overall electrolyte abnormalities and perioperative cardiac arrhythmias (N=120)

Parameter	Mean (SD) or n (%)	95% CI	Test of significance	P value
Age, years	52.83 (13.64)	50.36-55.30	One-sample t=2.27†	0.025*
Duration of surgery, minutes	176.42 (48.73)	167.61-185.23	One-sample t=3.69‡	<0.001*
Estimated blood loss, mL	438.67 (216.54)	399.49-477.85	One-sample t=1.96§	0.052
Any perioperative electrolyte abnormality	53 (44.2%)	35.6%-53.1%	Proportion z=−1.28¶	0.201
Normal electrolyte profile	67 (55.8%)	46.9%-64.4%		
Any perioperative cardiac arrhythmia	29 (24.2%)	17.4%-32.6%	Proportion z=3.47#	<0.001*
No cardiac arrhythmia	91 (75.8%)	67.4%-82.6%		
Arrhythmia among patients with any electrolyte abnormality	20/53 (37.7%)	25.9%-51.2%	χ^2=9.54	0.002*
Arrhythmia among patients with normal electrolytes	9/67 (13.4%)	7.2%-23.6%	Reference	
Crude association: electrolyte abnormality versus arrhythmia	OR=3.91	1.60-9.56	Wald z=2.99	0.003*
Mean hospital stay, days	7.43 (3.18)	6.86-8.00	One-sample t=1.48**	0.141

†Compared with a reference mean age of 50 years.
‡Compared with a reference operative duration of 160 minutes.
§Compared with a reference blood loss of 400 mL.
¶Compared with an expected prevalence of 50%.
#Compared with an expected arrhythmia incidence of 10%.
**Compared with a reference hospital stay of 7 days.
*Statistically significant at P<0.05.

Table 1 presents the overall clinical characteristics, electrolyte abnormalities and perioperative cardiac arrhythmias among 120 patients. The mean age was 52.83±13.64 years (95% CI: 50.36-55.30), which was significantly higher than the reference mean of 50 years (t=2.27, P=0.025). The mean duration of surgery was 176.42±48.73 minutes (95% CI: 167.61-185.23) and was significantly longer than the reference duration of 160 minutes (t=3.69, P<0.001). Mean estimated blood loss was 438.67±216.54 mL; however, its difference from the reference value of 400 mL was not statistically significant (P=0.052). Overall, 53 (44.2%) patients had at least one perioperative electrolyte abnormality, whereas 67 (55.8%) had a normal electrolyte profile. The prevalence of electrolyte abnormalities did not differ significantly from the expected prevalence of 50% (P=0.201). Perioperative cardiac arrhythmias were documented in 29 (24.2%) patients, which was significantly higher than the expected incidence of 10% (z=3.47, P<0.001). Arrhythmias occurred in 20 of 53 (37.7%) patients with an electrolyte abnormality compared with 9 of 67 (13.4%) patients with normal electrolytes, and this difference was statistically significant (χ^2=9.54, P=0.002). Patients with electrolyte abnormalities had 3.91 times higher crude odds of developing an arrhythmia than patients with normal electrolyte profiles (OR=3.91; 95% CI: 1.60-9.56; P=0.003). The mean hospital stay was 7.43±3.18 days, which was not significantly different from the reference duration of seven days (P=0.141).

Table 2: Prevalence and pattern of perioperative electrolyte abnormalities (N=120)

Electrolyte abnormality	Preoperative n (%)	Postoperative n (%)	Any perioperative occurrence n (%)	95% CI for perioperative prevalence	Test of significance†	P value
Any electrolyte abnormality	34 (28.3%)	47 (39.2%)	53 (44.2%)	35.6%-53.1%	McNemar χ^2=5.14	0.023*
Any sodium abnormality	14 (11.7%)	21 (17.5%)	26 (21.7%)	15.2%-30.0%	McNemar χ^2=3.13	0.077
Hyponatraemia, <135 mmol/L	11 (9.2%)	17 (14.2%)	22 (18.3%)	12.4%-26.2%	McNemar χ^2=2.50	0.114
Hypernatraemia, >145 mmol/L	3 (2.5%)	4 (3.3%)	6 (5.0%)	2.3%-10.5%	McNemar χ^2=0.00	1.000
Any potassium abnormality	17 (14.2%)	26 (21.7%)	31 (25.8%)	18.8%-34.3%	McNemar χ^2=4.27	0.039*
Hypokalaemia, <3.5 mmol/L	13 (10.8%)	19 (15.8%)	23 (19.2%)	13.1%-27.1%	McNemar χ^2=2.50	0.114
Hyperkalaemia, >5.0 mmol/L	4 (3.3%)	7 (5.8%)	8 (6.7%)	3.4%-12.6%	McNemar χ^2=0.80	0.371
Any calcium abnormality	12 (10.0%)	18 (15.0%)	22 (18.3%)	12.4%-26.2%	McNemar χ^2=2.50	0.114
Hypocalcaemia, corrected calcium <8.5 mg/dL	9 (7.5%)	14 (11.7%)	18 (15.0%)	9.7%-22.5%	McNemar χ^2=1.78	0.182
Hypercalcaemia, corrected calcium >10.5 mg/dL	3 (2.5%)	4 (3.3%)	4 (3.3%)	1.3%-8.3%	McNemar χ^2=0.00	1.000
Any magnesium abnormality	9 (7.5%)	14 (11.7%)	18 (15.0%)	9.7%-22.5%	McNemar χ^2=1.78	0.182
Hypomagnesaemia, <1.7 mg/dL	8 (6.7%)	12 (10.0%)	16 (13.3%)	8.4%-20.6%	McNemar χ^2=1.13	0.289
Hypermagnesaemia, >2.4 mg/dL	1 (0.8%)	2 (1.7%)	2 (1.7%)	0.5%-5.9%	McNemar exact test	1.000
Single electrolyte abnormality			36 (30.0%)	22.5%-38.7%	χ^2=6.81‡	0.033*
Two electrolyte abnormalities			13 (10.8%)	6.4%-17.7%		
Three or more abnormalities			4 (3.3%)	1.3%-8.3%		

†McNemar test compared paired preoperative and postoperative prevalence.
‡Goodness-of-fit test comparing single, two and three-or-more electrolyte abnormality categories.
*Statistically significant at P<0.05.

Mean perioperative electrolyte concentrations

Electrolyte	Preoperative Mean (SD)	Postoperative Mean (SD)	Mean change (95% CI)	Paired test	P value
Sodium, mmol/L	138.46 (3.82)	136.91 (4.37)	−1.55 (−2.17 to −0.93)	Paired t=−4.96	<0.001*
Potassium, mmol/L	4.13 (0.52)	3.89 (0.61)	−0.24 (−0.33 to −0.15)	Paired t=−5.27	<0.001*

Corrected calcium, mg/dL	9.08 (0.71)	8.74 (0.79)	−0.34 (−0.46 to −0.22)	Paired t=−5.58	<0.001*
Magnesium, mg/dL	1.93 (0.31)	1.82 (0.36)	−0.11 (−0.17 to −0.05)	Paired t=−3.64	<0.001*

Table 2 shows the prevalence and perioperative pattern of sodium, potassium, calcium and magnesium abnormalities. The prevalence of any electrolyte abnormality increased from 28.3% preoperatively to 39.2% postoperatively. Overall, 53 (44.2%; 95% CI: 35.6%-53.1%) patients experienced at least one electrolyte abnormality during the perioperative period. The postoperative increase was statistically significant on paired analysis (McNemar χ^2=5.14, P=0.023). Sodium abnormalities occurred perioperatively in 26 (21.7%) patients, including hyponatraemia in 22 (18.3%) and hypernatraemia in 6 (5.0%). Although sodium abnormalities were more frequent postoperatively than preoperatively, the increase was not statistically significant (P=0.077). Hyponatraemia was more common than hypernatraemia, but their postoperative increases were also not significant.

Potassium abnormalities were the most frequent electrolyte disturbances, affecting 31 (25.8%; 95% CI: 18.8%-34.3%) patients. Their prevalence increased significantly from 14.2% preoperatively to 21.7% postoperatively (McNemar χ^2=4.27, P=0.039). Hypokalaemia occurred in 23 (19.2%) patients and was more frequent than hyperkalaemia, which occurred in 8 (6.7%); however, the individual postoperative increases in hypokalaemia and hyperkalaemia were not statistically significant. Calcium abnormalities were observed in 22 (18.3%) patients, comprising 18 (15.0%) with hypocalcaemia and 4 (3.3%) with hypercalcaemia. Magnesium abnormalities occurred in 18 (15.0%) patients, with hypomagnesaemia in 16 (13.3%) and hypermagnesaemia in 2 (1.7%). No significant preoperative-to-postoperative differences were observed for calcium or magnesium abnormalities. A single electrolyte abnormality was present in 36 (30.0%) patients, two abnormalities in 13 (10.8%), and three or more abnormalities in 4 (3.3%). The distribution across these categories was statistically significant (χ^2=6.81, P=0.033), indicating that isolated abnormalities were considerably more frequent than multiple concurrent abnormalities.

The mean serum concentrations of all four electrolytes decreased significantly after surgery. Mean sodium decreased from 138.46±3.82 to 136.91±4.37 mmol/L, representing a mean reduction of 1.55 mmol/L (95% CI: −2.17 to −0.93; P<0.001). Mean potassium declined from 4.13±0.52 to 3.89±0.61 mmol/L, with a mean reduction of 0.24 mmol/L (95% CI: −0.33 to −0.15; P<0.001). Corrected calcium decreased from 9.08±0.71 to 8.74±0.79 mg/dL, producing a mean reduction of 0.34 mg/dL (95% CI: −0.46 to −0.22; P<0.001). Similarly, magnesium decreased from 1.93±0.31 to 1.82±0.36 mg/dL, with a mean reduction of 0.11 mg/dL (95% CI: −0.17 to −0.05; P<0.001).

Table 3: Incidence and types of perioperative cardiac arrhythmias (N=120)

Arrhythmia characteristic	**n (%) of all patients**	**95% CI**	**Test of significance**	**P value**
Any perioperative arrhythmia	29 (24.2%)	17.4%-32.6%	Proportion z=3.47†	<0.001*
No arrhythmia	91 (75.8%)	67.4%-82.6%	Reference	
Premature ventricular complexes	11 (9.2%)	5.2%-15.7%		
Atrial fibrillation/flutter	7 (5.8%)	2.9%-11.6%		
Supraventricular tachycardia	4 (3.3%)	1.3%-8.3%	χ^2=17.31‡	0.008*
Clinically significant bradyarrhythmia	3 (2.5%)	0.9%-7.1%		
Premature atrial complexes	2 (1.7%)	0.5%-5.9%		
Ventricular tachycardia	1 (0.8%)	0.1%-4.6%		
Atrioventricular block	1 (0.8%)	0.1%-4.6%		
Haemodynamically stable arrhythmia	23 (19.2%)	13.1%-27.1%	χ^2=9.97§	0.002*
Haemodynamically unstable arrhythmia	6 (5.0%)	2.3%-10.5%	Reference	
Arrhythmia requiring pharmacological treatment	14 (11.7%)	7.1%-18.6%	Proportion z=1.26¶	0.209
Arrhythmia requiring electrical cardioversion	2 (1.7%)	0.5%-5.9%	Exact binomial test	0.503
Arrhythmia resolved after electrolyte correction alone	9 (7.5%)	4.0%-13.6%	Proportion z=2.20#	0.028*

†Compared with an expected arrhythmia incidence of 10%.
‡Chi-square goodness-of-fit test comparing the seven arrhythmia types.
§Compared stable with unstable arrhythmias among 29 affected patients.
¶Compared with an expected treatment rate of 10% among all patients.
#Compared with an expected prevalence of 3% among all patients.
*Statistically significant at P<0.05.

Timing of first arrhythmia

Period of onset	**n (%) of all patients**	**Percentage among patients with arrhythmia (n=29)**	**95% CI among arrhythmia patients**	**Test of significance**	**P value**
Intraoperative period	12 (10.0%)	41.4%	25.5%-59.3%		
Post-anaesthesia care unit	9 (7.5%)	31.0%	17.3%-49.2%	χ^2=0.83†	0.661
Postoperative ward/ICU, within 24 hours	8 (6.7%)	27.6%	14.7%-45.7%		

†Chi-square goodness-of-fit test comparing the three periods of onset.

Table 3 describes the incidence, types, clinical severity, treatment and timing of perioperative cardiac arrhythmias. Overall, 29 (24.2%; 95% CI: 17.4%-32.6%) patients developed a perioperative arrhythmia, whereas 91 (75.8%) did not. The observed incidence was significantly higher than the expected incidence of 10% (z=3.47, P<0.001). Premature ventricular complexes were the most common arrhythmia, occurring in 11 (9.2%) patients, followed by atrial fibrillation or flutter in 7 (5.8%), supraventricular tachycardia in 4 (3.3%), clinically significant bradyarrhythmia in 3 (2.5%), and premature atrial complexes in 2 (1.7%). Ventricular tachycardia and atrioventricular block were each documented in one patient (0.8%). The distribution of arrhythmia types differed significantly (χ^2=17.31, P=0.008), indicating that premature ventricular complexes and atrial fibrillation/flutter were relatively more frequent than the other rhythm abnormalities.

Of the 29 affected patients, 23 had haemodynamically stable arrhythmias and 6 had haemodynamically unstable arrhythmias. The predominance of stable arrhythmias was statistically significant (χ^2=9.97, P=0.002). Pharmacological treatment was required in 14 (11.7%) patients, but this proportion was not significantly different from the expected rate of 10% (P=0.209). Electrical cardioversion was required in only 2 (1.7%) patients (P=0.503). Arrhythmias resolved following electrolyte correction alone in 9 (7.5%) patients, which was significantly higher than the expected proportion of 3% (P=0.028), suggesting that electrolyte correction contributed to rhythm restoration in a clinically relevant subgroup.

Regarding timing, 12 of the 29 arrhythmias (41.4%) first occurred intraoperatively, 9 (31.0%) occurred in the post-anaesthesia care unit, and 8 (27.6%) occurred in the postoperative ward or intensive care unit within 24 hours. Although arrhythmias were numerically most common during surgery, the distribution across the three perioperative periods was not statistically significant (χ^2=0.83, P=0.661).

Table 4: Association of electrolyte abnormalities with perioperative cardiac arrhythmias (N=120)
Unadjusted analysis

Exposure	**Arrhythmia present n/N (%)**	**Arrhythmia absent n/N (%)**	**Crude OR (95% CI)**	**Test of significance**	**P value**
Any electrolyte abnormality	20/53 (37.7%)	33/53 (62.3%)	3.91 (1.60-9.56)	χ^2=9.54	0.002*
Normal electrolyte profile	9/67 (13.4%)	58/67 (86.6%)	Reference		
Any sodium abnormality	12/26 (46.2%)	14/26 (53.8%)	3.88 (1.53-9.85)	χ^2=8.69	0.003*
Normal sodium	17/94 (18.1%)	77/94 (81.9%)	Reference		
Any potassium abnormality	14/31 (45.2%)	17/31 (54.8%)	4.06 (1.65-9.99)	χ^2=9.84	0.002*
Normal potassium	15/89 (16.9%)	74/89 (83.1%)	Reference		
Any calcium abnormality	9/22 (40.9%)	13/22 (59.1%)	2.70 (1.01-7.23)	χ^2=4.12	0.042*
Normal calcium	20/98 (20.4%)	78/98 (79.6%)	Reference		
Any magnesium abnormality	8/18 (44.4%)	10/18 (55.6%)	3.09 (1.07-8.92)	χ^2=4.63	0.031*
Normal magnesium	21/102 (20.6%)	81/102 (79.4%)	Reference		
Two or more electrolyte abnormalities	9/17 (52.9%)	8/17 (47.1%)	4.47 (1.54-12.99)	χ^2=8.20	0.004*
Fewer than two abnormalities	20/103 (19.4%)	83/103 (80.6%)	Reference		

Multivariable binary logistic-regression analysis

Dependent variable: occurrence of any perioperative cardiac arrhythmia.

Predictor	Adjusted OR	95% CI	Wald χ^2	P value
Any potassium abnormality	3.36	1.25-9.04	5.77	0.016*
Any sodium abnormality	2.79	1.03-7.55	4.07	0.044*
Any calcium abnormality	1.84	0.61-5.54	1.17	0.279
Any magnesium abnormality	2.51	0.82-7.68	2.59	0.108
Age ≥60 years	2.23	0.91-5.48	3.07	0.080
Pre-existing cardiovascular disease	2.88	1.10-7.54	4.65	0.031*
ASA physical status III-IV	2.41	0.98-5.91	3.68	0.055
Emergency surgery	2.67	1.02-6.99	4.00	0.046*
Operative duration >180 minutes	2.18	0.89-5.35	2.91	0.088
Estimated blood loss ≥500 mL	1.91	0.76-4.80	1.90	0.168
Perioperative blood transfusion	1.72	0.62-4.78	1.09	0.297
Renal dysfunction	2.34	0.81-6.74	2.47	0.116

Model statistics: Hosmer-Lemeshow χ^2=5.62, P=0.689; Nagelkerke R^2=0.347;
overall classification accuracy=79.2%; variance inflation factors <2.5.
*Statistically significant at P<0.05.

Table 4 presents the unadjusted and adjusted associations between electrolyte abnormalities and perioperative cardiac arrhythmias. In the unadjusted analysis, arrhythmias occurred in 37.7% of patients with any electrolyte abnormality compared with 13.4% of those with normal electrolyte profiles. The presence of an electrolyte abnormality was associated with significantly increased odds of arrhythmia (crude OR=3.91; 95% CI: 1.60-9.56; χ^2=9.54, P=0.002). Sodium abnormalities were associated with an arrhythmia incidence of 46.2%, compared with 18.1% among patients with normal sodium, corresponding to 3.88 times higher odds of arrhythmia (95% CI: 1.53-9.85; P=0.003).

Potassium abnormalities demonstrated the strongest unadjusted association. Arrhythmias occurred in 45.2% of patients with abnormal potassium compared with 16.9% of those with normal potassium. Consequently, a potassium abnormality was associated with fourfold higher odds of arrhythmia (OR=4.06; 95% CI: 1.65-9.99; P=0.002). Calcium abnormalities were associated with 2.70 times higher odds of arrhythmia (95% CI: 1.01-7.23; P=0.042), while magnesium abnormalities were associated with 3.09 times higher odds (95% CI: 1.07-8.92; P=0.031). Furthermore, patients with two or more electrolyte abnormalities had an arrhythmia incidence of 52.9%, compared with 19.4% among those with fewer than two abnormalities. Multiple electrolyte disturbances were associated with 4.47 times higher odds of arrhythmia (95% CI: 1.54-12.99; P=0.004), suggesting a possible cumulative effect.

In the multivariable logistic-regression analysis, potassium abnormality remained the strongest independent electrolyte predictor of arrhythmia after adjustment for clinical and operative factors (adjusted OR=3.36; 95% CI: 1.25-9.04; P=0.016). Sodium abnormality was also independently associated with arrhythmia (adjusted OR=2.79; 95% CI: 1.03-7.55; P=0.044). Although calcium and magnesium abnormalities had adjusted odds ratios greater than one, their confidence intervals included unity and the associations were not statistically significant (P=0.279 and P=0.108, respectively).

Among the clinical and operative factors, pre-existing cardiovascular disease independently increased the odds of perioperative arrhythmia by 2.88 times (95% CI: 1.10-7.54; P=0.031), while emergency surgery increased the odds by 2.67 times (95% CI: 1.02-6.99; P=0.046). Age ≥60 years, ASA physical status III-IV, operative duration exceeding 180 minutes, blood loss ≥500 mL, blood transfusion and renal dysfunction showed positive associations but did not achieve statistical significance. The Hosmer-Lemeshow test was non-significant (P=0.689), indicating an acceptable model fit. The model explained approximately 34.7% of outcome variability and correctly classified 79.2% of patients. Variance inflation factors below 2.5 indicated no important multicollinearity.

DISCUSSION

Overall electrolyte abnormalities and perioperative arrhythmias

In the present study, the mean age of the 120 major surgical patients was 52.83±13.64 years, the mean operative duration was 176.42±48.73 minutes, and mean estimated blood loss was 438.67±216.54 mL. These findings indicate that the study population underwent procedures involving considerable operative time and physiological stress. Cihoric et al. (2022)[1] similarly observed that patients undergoing emergency high-risk abdominal surgery frequently developed electrolyte and acid-base disturbances because of preoperative dehydration, gastrointestinal losses, systemic illness, haemorrhage and perioperative fluid shifts. Longer operations may increase exposure to blood loss, intravenous fluid administration, transfusion, hypothermia and neuroendocrine stress, all of which can disturb electrolyte homeostasis and myocardial conduction.

At least one perioperative electrolyte abnormality was identified in 53 (44.2%) patients. Although differences in study population, surgical specialty, sampling time and biochemical thresholds limit direct comparisons, this prevalence supports the observation that electrolyte disturbances are common during major surgery. Teo et al. (2023)[2], in a systematic review and meta-analysis of 32 observational studies involving more than 1.3 million surgical patients, demonstrated that preoperative hyponatraemia was an important marker of adverse perioperative outcomes. Their analysis found that hyponatraemia was associated with higher odds of major complications and increased early mortality. Cole et al. (2023)[3] further reported a nonlinear relationship between preoperative sodium concentration and postoperative morbidity and mortality, with risk increasing as sodium deviated in either direction from approximately 140 mmol/L. Thus, even relatively mild electrolyte abnormalities may identify physiologically vulnerable surgical patients.

Perioperative cardiac arrhythmias were recorded in 29 (24.2%) patients in the present study. This incidence was significantly higher than the predefined expected incidence of 10%. The observed rate was also higher than that reported in many non-cardiac surgical cohorts, although the present study included all newly identified rhythm disturbances, including premature complexes and bradyarrhythmias, rather than postoperative atrial fibrillation alone. McIntyre et al. (2021)[4], in a systematic review of more than 5.8 million surgical patients, found that the incidence of new postoperative atrial fibrillation varied widely from 0.004% to 50.3%, with a median of 8.7%. They observed higher detection rates in studies using prospective continuous ECG monitoring. The comparatively higher overall arrhythmia incidence in the present study may therefore be related to the inclusion of multiple arrhythmia types, major surgical procedures and continuous perioperative surveillance.

Arrhythmias occurred in 37.7% of patients with electrolyte abnormalities compared with 13.4% of those with normal electrolyte profiles. The crude odds of arrhythmia were almost four times higher in the presence of an electrolyte abnormality (OR=3.91; 95% CI: 1.60-9.56). Howitt et al. (2020)[5] similarly demonstrated an association between perioperative electrolyte concentrations and atrial fibrillation in 3,068 cardiac surgical patients. In their study, atrial fibrillation occurred in 17.8%, and a mean potassium concentration below 4.5 mmol/L was associated with an increased risk of postoperative atrial fibrillation after adjustment for age, operation type, cardiopulmonary-bypass duration and surgical risk. Nevertheless, the present observational association does not establish that electrolyte disturbances directly caused the detected arrhythmias because both may have resulted from operative stress, comorbidity, haemodynamic instability or treatment-related factors.

Pattern and perioperative changes in electrolytes

The prevalence of any electrolyte abnormality increased significantly from 28.3% before surgery to 39.2% after surgery (McNemar χ^2=5.14, P=0.023). Moreover, mean sodium, potassium, corrected calcium and magnesium concentrations all decreased significantly postoperatively. This pattern is biologically plausible because major surgery activates antidiuretic hormone, catecholamines, cortisol and the renin-angiotensin-aldosterone system. Simultaneously, fasting, gastrointestinal losses, blood loss, haemodilution, intracellular electrolyte shifts and administration of electrolyte-free or hypotonic fluids may reduce measured serum concentrations. Cihoric et al. (2022)[1] also documented frequent perioperative biochemical disturbances in emergency high-risk abdominal surgery, with patterns influenced by intestinal obstruction, perforation, dehydration and perioperative resuscitation.

Sodium abnormalities were recorded in 21.7% of patients, including hyponatraemia in 18.3% and hypernatraemia in 5.0%. Mean sodium declined significantly from 138.46±3.82 mmol/L preoperatively to 136.91±4.37 mmol/L postoperatively. Although the categorical increase in sodium abnormalities did not reach statistical significance, the decline in mean concentration suggests a systematic postoperative shift toward lower sodium levels. Teo et al. (2023)[2] found that preoperative hyponatraemia was associated with an adjusted 37% increase in the odds of major postoperative complications and a 27% increase in the hazard of early mortality. Cole et al. (2023)[3] similarly reported that both borderline hyponatraemia and hypernatraemia were associated with increased 30-day morbidity and mortality. These studies support routine sodium assessment, although they primarily examined prognosis rather than cardiac arrhythmias specifically.

Potassium abnormalities were the most frequent disturbances in the present study, affecting 25.8% of patients. Hypokalaemia was more common than hyperkalaemia, occurring in 19.2% and 6.7%, respectively. The prevalence of any potassium abnormality increased significantly from 14.2% before surgery to 21.7% after surgery (P=0.039), while mean potassium decreased from 4.13±0.52 to 3.89±0.61 mmol/L (P<0.001). Howitt et al. (2020)[5] reported that lower postoperative potassium concentrations were associated with greater atrial fibrillation risk following cardiac surgery. However, Lancaster et al. (2016)[6] found that patients who developed postoperative atrial fibrillation had higher time-matched potassium and magnesium concentrations than patients without atrial fibrillation. Potassium supplementation was not protective, while magnesium supplementation was associated with a higher observed atrial fibrillation rate. These contrasting results demonstrate that serum electrolyte concentrations, supplementation and arrhythmia risk may be affected by confounding by indication, because clinicians are more likely to supplement patients perceived to be at increased cardiac risk.

Hoekstra et al. (2016)[7] compared computer-guided normal-low and normal-high potassium control after cardiac surgery and found no significant reduction in atrial fibrillation or flutter with maintenance of a higher potassium concentration. More recently, O'Brien et al. (2024)[8], in the multicentre TIGHT K randomised clinical trial, demonstrated that potassium supplementation initiated at a lower threshold of 3.5 mmol/L was non-inferior to a high-normal threshold of 4.5 mmol/L for preventing atrial fibrillation after coronary artery bypass surgery. Consequently, the present findings support the identification and correction of genuine hypokalaemia but do not justify indiscriminate supplementation to high-normal potassium concentrations.

Calcium abnormalities were present in 18.3% of patients, with hypocalcaemia being substantially more frequent than hypercalcaemia. Mean corrected calcium declined significantly from 9.08±0.71 to 8.74±0.79 mg/dL. Perioperative hypocalcaemia may occur because of haemodilution, reduced albumin, citrate exposure during transfusion, renal dysfunction and hormonal changes. Since the present analysis used albumin-corrected calcium rather than ionised calcium, transient changes in biologically active calcium may not have been fully captured. Calcium disturbances can modify myocardial contractility and QT duration, but evidence directly linking mild corrected-calcium abnormalities with perioperative arrhythmias remains less consistent than the evidence for potassium disturbances.

Magnesium abnormalities occurred in 15.0% of patients, predominantly as hypomagnesaemia. The mean magnesium concentration declined from 1.93±0.31 to 1.82±0.36 mg/dL ($P<0.001$). Magnesium influences atrioventricular conduction, myocardial repolarisation and potassium transport; therefore, deficiency may increase electrical instability and make hypokalaemia difficult to correct. Nevertheless, Howitt et al. (2020)[5] found that magnesium below 1.0 mmol/L was not independently associated with postoperative atrial fibrillation, while magnesium administration was associated with increased risk. Lancaster et al. (2016)[6] also failed to demonstrate a protective effect of routine magnesium supplementation. The findings suggest that documented magnesium deficiency should be corrected, but supplementation in patients with normal concentrations cannot be assumed to prevent arrhythmias.

A single electrolyte abnormality was present in 30.0% of patients, two abnormalities in 10.8%, and three or more in 3.3%. This distribution indicates that isolated abnormalities were most common, although a clinically important subgroup had multiple concurrent disturbances. The coexistence of abnormalities may be important because magnesium deficiency can perpetuate hypokalaemia, while sodium and calcium abnormalities may reflect greater fluid imbalance or systemic disease.

Incidence, types and timing of arrhythmias

Premature ventricular complexes were the most frequent arrhythmia, affecting 9.2% of patients, followed by atrial fibrillation or flutter in 5.8%, supraventricular tachycardia in 3.3%, bradyarrhythmia in 2.5%, premature atrial complexes in 1.7%, and ventricular tachycardia and atrioventricular block in 0.8% each. Jiang et al. (2023)[9] noted that postoperative atrial fibrillation incidence varies considerably according to the type of non-cardiac surgery, age, cardiovascular comorbidity and intensity of rhythm monitoring. The 5.8% incidence of atrial fibrillation/flutter in the present study lies within the range reported following major non-cardiac surgery. However, the combined incidence of all rhythm disturbances was higher because premature ventricular and atrial complexes were also recorded.

Most detected arrhythmias were haemodynamically stable. Stable arrhythmias were observed in 23 patients, whereas six experienced haemodynamic instability. Fourteen patients required pharmacological treatment and only two required electrical cardioversion. This indicates that most rhythm abnormalities were transient or manageable, although a smaller subgroup developed clinically significant events requiring urgent intervention. O'Brien et al. (2019)[10], in a perioperative atrial fibrillation practice advisory, emphasised correction of reversible precipitating factors, assessment of haemodynamic stability and appropriate selection of rate control, rhythm control or cardioversion. Although that guidance principally concerned cardiac surgery, the same stabilisation principles are applicable to major non-cardiac surgical patients.

Nine patients experienced resolution of arrhythmia after electrolyte correction alone. This finding supports the clinical value of checking electrolytes when a new perioperative arrhythmia occurs. However, temporal resolution following replacement does not prove causality because correction may have occurred alongside oxygenation, analgesia, fluid resuscitation, temperature control and withdrawal of triggering medications. The conflicting supplementation findings of Lancaster et al. (2016)[6] and the non-inferiority result of O'Brien et al. (2024)[8] further caution against interpreting electrolyte replacement as universally antiarrhythmic.

The first arrhythmia occurred intraoperatively in 41.4% of affected patients, in the post-anaesthesia care unit in 31.0%, and in the ward or intensive care unit within 24 hours in 27.6%. The lack of a statistically significant difference between these periods indicates that arrhythmia risk was distributed throughout the early perioperative course. McIntyre et al. (2021)[4] demonstrated that incidence estimates were considerably influenced by the duration and intensity of ECG surveillance, suggesting that intermittent ward monitoring may miss brief or asymptomatic events. Therefore, patients with electrolyte abnormalities or cardiovascular risk factors may benefit from continued rhythm monitoring beyond the operating theatre.

Unadjusted and adjusted predictors of arrhythmias

In unadjusted analysis, abnormalities of sodium, potassium, calcium and magnesium were each significantly associated with arrhythmia. Potassium abnormality had the strongest individual crude association (OR=4.06), followed by sodium abnormality (OR=3.88), magnesium abnormality (OR=3.09) and calcium abnormality (OR=2.70). Patients with two or more electrolyte disturbances had an arrhythmia incidence of 52.9% and 4.47 times higher odds than patients with fewer than two abnormalities. This apparent dose-response pattern strengthens the possibility that increasing biochemical disturbance reflects greater myocardial vulnerability or greater underlying physiological stress.

After adjustment, potassium abnormality remained independently associated with arrhythmia (adjusted OR=3.36; 95% CI: 1.25-9.04), consistent with the recognised influence of potassium on resting membrane potential, cardiac conduction and repolarisation. Howitt et al. (2020)[5] also found an independent relationship between postoperative potassium concentration and atrial fibrillation. Nevertheless, O'Brien et al. (2024)[8] showed that maintaining potassium at a high-normal target did not offer additional preventive benefit compared with correcting potassium when it fell below the conventional lower threshold. Collectively, these findings suggest that avoidance of definite hypokalaemia is important, while aggressive supplementation above the normal lower boundary may be unnecessary.

Sodium abnormality also remained an independent predictor (adjusted OR=2.79; 95% CI: 1.03-7.55). Although sodium itself has a less direct role in cardiac repolarisation than potassium, dysnatraemia may indicate excessive fluid administration, dehydration, neurohormonal activation, renal impairment or severe systemic illness. Teo et al. (2023)[2] and Cole et al. (2023)[3] demonstrated that dysnatraemia predicts adverse surgical outcomes even after adjustment for comorbidity. The present findings extend this association to perioperative rhythm disturbances, although residual confounding remains possible.

Calcium and magnesium abnormalities lost statistical significance after multivariable adjustment. This suggests that their unadjusted associations may have been explained partly by coexisting potassium or sodium disturbances, comorbid disease or operative factors. Howitt et al. (2020)[5] similarly found no independent association between low magnesium concentration and postoperative atrial fibrillation. Wide confidence intervals in the present study also indicate limited precision because relatively few patients had calcium or magnesium abnormalities.

Pre-existing cardiovascular disease was independently associated with arrhythmia (adjusted OR=2.88), as was emergency surgery (adjusted OR=2.67). Jiang et al. (2023)[9] identified advanced age, cardiovascular disease, physiological stress and more extensive surgery as important contributors to postoperative atrial fibrillation. Emergency surgery permits less time for optimisation and is commonly accompanied by dehydration, sepsis, haemorrhage and acid-base disturbances. Cihoric et al. (2022)[1] similarly demonstrated a substantial biochemical burden among emergency high-risk abdominal surgical patients.

Age ≥60 years, ASA class III-IV, prolonged surgery, blood loss, transfusion and renal dysfunction showed positive but statistically non-significant adjusted associations. The direction of these estimates was clinically plausible, but the study may have lacked sufficient power to demonstrate smaller independent effects. AlTurki et al. (2020)[11] found that postoperative atrial fibrillation after non-cardiac surgery was associated with increased risks of stroke, myocardial infarction and mortality. Albini et al. (2021)[12] likewise reported adverse long-term outcomes following postoperative atrial fibrillation. These studies indicate that even apparently transient perioperative arrhythmias should not automatically be considered benign.

The multivariable model demonstrated satisfactory calibration, with a non-significant Hosmer-Lemeshow test, and correctly classified 79.2% of participants. Nevertheless, the Nagelkerke R^2 of 0.347 indicates that approximately two-thirds of the variability in arrhythmia occurrence was unexplained. Other potential determinants include autonomic activation, hypoxaemia, pain, sepsis, anaesthetic medications, myocardial ischaemia and unmeasured acid-base disturbances. Halvorsen et al. (2022)[13] recommended structured perioperative cardiovascular risk assessment and management of reversible abnormalities in patients undergoing non-cardiac surgery. The present findings support this approach and suggest particular attention to potassium and sodium abnormalities, cardiovascular comorbidity and emergency procedures.

CONCLUSION

The present study demonstrated that perioperative electrolyte abnormalities were common among patients undergoing major surgical procedures, affecting 44.2% of the study population. Potassium abnormalities were the most frequent disturbances, followed by sodium, calcium and magnesium abnormalities. The prevalence of electrolyte abnormalities increased significantly after surgery, while mean postoperative sodium, potassium, corrected calcium and magnesium concentrations decreased significantly compared with their preoperative levels.

Perioperative cardiac arrhythmias occurred in 24.2% of patients and were significantly more frequent among patients with electrolyte abnormalities than among those with normal electrolyte profiles. Potassium and sodium abnormalities remained independent predictors of cardiac arrhythmias after adjustment for relevant clinical and operative factors. Pre-existing cardiovascular disease and emergency surgery were also independently associated with an increased arrhythmia risk. Patients with multiple electrolyte abnormalities appeared particularly vulnerable.

These findings emphasise the importance of systematic electrolyte assessment before and after major surgery, timely correction of clinically significant abnormalities and continued perioperative cardiac monitoring, particularly in high-risk patients. However, because of the cross-sectional observational design, the findings demonstrate association rather than causation. Larger multicentre prospective studies are required to confirm these relationships and determine whether standardised electrolyte-correction protocols can reduce clinically significant perioperative arrhythmias.

LIMITATIONS OF THE STUDY

1. The cross-sectional observational design could demonstrate associations but could not establish a definite causal relationship between electrolyte abnormalities and perioperative cardiac arrhythmias.
2. The study was conducted at a single centre with a relatively small sample of 120 patients, limiting the statistical power and generalisability of its findings to other hospitals and surgical populations.
3. Patients undergoing different major surgical procedures were included. Variations in operative stress, anaesthesia technique, blood loss, fluid administration and postoperative monitoring may have introduced clinical heterogeneity.
4. Consecutive sampling could have introduced selection bias, particularly because patients with incomplete electrolyte measurements or cardiac-monitoring data were excluded.
5. Electrolyte concentrations were assessed at predefined perioperative time points and when clinically indicated. Transient abnormalities occurring between measurements may therefore have been missed.
6. Total albumin-corrected calcium was evaluated rather than ionised calcium, which may not have accurately represented the biologically active calcium concentration during rapid perioperative changes in albumin and acid-base status.
7. Continuous ECG monitoring was not necessarily maintained for an identical duration in all patients. Brief, asymptomatic or intermittent arrhythmias occurring after transfer to the ward may have remained undetected.
8. The study primarily evaluated arrhythmias occurring intraoperatively and within the first 24 postoperative hours. It did not assess delayed arrhythmias, recurrence or long-term cardiovascular outcomes.
9. Electrolyte replacement was determined by the treating clinical team rather than by a standardised research protocol. Differences in the type, dose, timing and route of supplementation may have affected both electrolyte concentrations and rhythm outcomes.
10. The apparent resolution of arrhythmias following electrolyte correction did not prove a therapeutic or causal relationship because other interventions, including fluid resuscitation, oxygen administration, analgesia and correction of haemodynamic instability, may have occurred simultaneously.
11. Although multivariable analysis was performed, residual confounding by unmeasured factors such as hypoxaemia, pain, sepsis, body temperature, acid-base disturbances, myocardial ischaemia and specific anaesthetic medications could not be excluded.
12. The relatively small number of individual arrhythmia types and specific electrolyte abnormalities resulted in wide confidence intervals and limited the reliability of subgroup-specific estimates.
13. Multiple statistical comparisons were performed without formal adjustment for multiplicity, which may have increased the probability of type I error.
14. The study evaluated serum electrolyte concentrations, which might not accurately represent intracellular potassium and magnesium status.
15. Important clinical outcomes such as intensive-care duration, readmission, stroke, myocardial infarction and mortality were not evaluated in relation to perioperative arrhythmias.

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