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ELECTROLYTE DERANGEMENTS IN PATIENTS UNDERGOING CARDIAC SURGERY VERSUS NON-CARDIAC THORACIC VASCULAR SURGERY

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ABSTRACT

Objective: Electrolyte disturbances are common in patients undergoing cardiac surgery, largely due to cardiopulmonary bypass (CPB), hypothermia and hemodilution. These alterations can predispose patients to life-threatening arrhythmias and postoperative complications.

Aim: We aimed to estimate and compare perioperative serum sodium, potassium, calcium, magnesium and phosphorus levels in patients undergoing cardiac surgery versus non-cardiac thoracic vascular surgery.

Methods: This case–control study included 50 cardiac surgery patients (study group) and 50 non-cardiac thoracic vascular surgery patients (control group). Serum electrolytes (Na^+, K^+, Ca^{2+}, Mg^{2+}, P) were measured one day before surgery and one day after surgery.

Results: Preoperative electrolyte levels did not differ significantly between the groups. Postoperatively, potassium and calcium showed highly significant depletion in cardiac surgery patients ($p = 0.001$). Magnesium was also significantly depleted in the study group ($p = 0.05$). Sodium and phosphorus levels did not defer significantly between the groups.

Conclusion: Cardiac surgery patients are at substantially higher risk of postoperative potassium, calcium and magnesium depletion. Vigilant monitoring and prophylactic electrolyte supplementation especially for potassium, calcium and magnesium are essential during and after cardiac surgery.

Keywords: electrolytes, cardiac surgery, cardiopulmonary bypass, potassium depletion, calcium depletion, arrhythmia, thoracic surgery

INTRODUCTION

Patients undergoing Cardiac Surgeries are very much prone to develop tachyarrhythmias, especially in intraoperative and postoperative periods. Detection of mechanism and frequency of electrolyte disorders in Cardiac Surgery patients were main objective of present study. Electrolyte Disorders (ES) have important role in ventricular and supraventricular arrhythmias as well as other complications in the intensive care unit (ICU).[1] Serum Potassium (K^+) levels are usually measured frequently in Cardiac Surgery patients, as it is a well-known fact that sharp decline of Potassium levels are seen immediately after Cardio Pulmonary Bypass (CPB) surgeries. Other electrolytes such as Calcium (Ca++), Magnesium (Mg^{++}), Phosphorus (P) and Sodium (Na^+) are measured less frequently. We hypothesize that patients undergoing cardiac surgical procedures might be at risk for electrolyte depletion, The present study was conducted to explore the electrolyte levels in cardiac surgery patients and compare the electrolyte derangements with non-cardiac thoracic vascular surgery patients. In Cardiac surgery patients undergoing surgery are usually cooled (hypothermia) to reduce the metabolic rate and tissue oxygen demand.[2] The hypothermia was maintained much longer in the cardiac surgery patients than non-cardiac surgeries. The sustained hypothermia in cardiac surgery patients caused Potassium depletion which occurred mainly due to hemodilution in CPB and urinary excretion.

Cardioplegic solutions are specialized pharmacological formulations used during cardiac surgeries to temporarily and reversibly arrest cardiac activity. Cardioplegic solutions contains complex fluids composed of several key elements, each contributing to the cardioprotective effect. These components are carefully balanced to preserve cellular homeostasis, prevent arrhythmias and maintain tissue viability during the surgical procedure. Potassium rich Cardioplegic Solution (16-29.6 mEq/L) induces diastolic arrest by depolarizing cardiac myocytes, inactivating voltage-gated sodium channels and halting action potential propagation. This depolarized arrest mimics hyperkalemia, preventing further contractions and reducing oxygen demand.[3] High content of Magnesium (18-32 mEq/L) in Cardioplegic Solution acts as a calcium antagonist by inhibiting calcium influx through voltage-dependent channels.

Magnesium stabilizes the myocardial membrane, prevents arrhythmias and helps to conserve ATP.

Role of sodium in cardiac surgery

Sodium is a key determinant of extracellular fluid (ECF) volume and osmotic pressure. It governs the distribution of water between the intracellular and extracellular compartments by creating osmotic gradients across semipermeable membranes. During cardiac surgery, maintaining fluid balance is critical to ensure adequate perfusion of vital organs, including the heart and brain. Adequate sodium levels support blood volume and vascular tone, contributing to stable blood pressure during anesthesia and surgical manipulation.[4] The depolarization phase of the action potential in cardiomyocytes is driven primarily by the rapid influx of sodium ions through voltage-gated sodium channels. The deranged sodium concentrations are important factor of disturbance in sinus rhythm and conduction blocks or arrhythmias.[5]

Sodium is essential for the effective contraction and relaxation of cardiac and skeletal muscles. Sodium contributes to the regulation of acid-base balance through its interactions with buffer systems and renal function.[6] Sodium is essential for maintaining intracellular ionic composition. Sodium-potassium ATPase regulates intracellular potassium and sodium levels, maintaining the electrochemical gradient and cellular integrity. Sodium supports the secondary active co-transport of glucose, calcium and amino acids, all of which influence myocardial performance and recovery.

Role of potassium in cardiac surgery

Potassium is primarily an intracellular electrolyte, the concentration differential of Sodium and Potassium across the cell membrane is maintained by the Na+/K+ ATPase.[7] Potassium homeostasis plays a critical role in maintaining cardiac rhythm and myocardial contractility. It also influences vascular activity and the regulation of vascular smooth muscle proliferation. In the cardiac surgery patients hyperkalemic and hypothermic cardioplegic solutions (CS) are usually used for induction of cardiac arrest.

Potassium derangement usually occur during and after Cardio Pulmonary Bypass (CPB). Immediately following CPB, patients frequently experience a sharp decline in blood Potassium levels. This drop of potassium can be due to increased urinary excretion and shift into cells, both of which are exacerbated by extracorporeal

circulation and sustained hypothermia during surgery.[8] The hypothermic state, which is protective, contributes to enhanced electrolyte excretion and cellular uptake of potassium, predisposing the patients to hypokalemia. Additionally, the routine administration of insulin to many cardiac surgery patients further drives potassium into cells, worsening hypokalemia.

Role of calcium in cardiac surgery

Calcium is a fundamental ion in human physiology, particularly critical in cardiovascular function. During cardiac surgery, maintaining calcium homeostasis is essential for preserving cardiac performance, ensuring hemodynamic stability and supporting recovery. The multifaceted role of calcium in myocardial contractility, vascular tone regulation, coagulation and intracellular signaling each of which is vital during the preoperative, intraoperative and postoperative phases of cardiac surgery. Calcium plays a pivotal role in the excitation-contraction coupling of cardiac muscle.[9] It facilitates the interaction between actin and myosin filaments in cardiomyocytes, which is necessary for myocardial contraction. During cardiac surgery, especially procedures involving cardiopulmonary bypass (CPB), fluctuations in calcium levels can impair contractility, leading to reduced cardiac output and hemodynamic instability. Maintaining appropriate calcium levels helps stabilize the cardiac rhythm and reduce the incidence of perioperative arrhythmias such as atrial fibrillation and ventricular tachycardia.

Role of magnesium in cardiac surgery

Magnesium is a vital mineral involved in a wide array of physiological processes and its role in cardiac surgery is particularly critical. In the cardiac surgery patients magnesium plays cardioprotective, antithrombotic, electrophysiological, metabolic and anti-inflammatory benefits. Magnesium has potent cardioprotective properties, particularly in the ischemic-reperfusion injury. During cardiac surgeries, such as valve replacement and bypass grafting periods of ischemia followed by reperfusion can lead to significant myocardial damage. Magnesium mitigates this ischemic-reperfusion injury by stabilizing cell membranes, reducing calcium influx into myocardial cells, which can otherwise trigger cell death. Magnesium promotes vasodilation, thereby improving coronary perfusion and decreasing myocardial oxygen demand during and

after surgery. These effects collectively reduce infarct size and preserve myocardial function during and after surgery.[10]

Role of phosphorus in cardiac surgery

Phosphorus plays a critical role in numerous physiological processes, making it an essential element in the perioperative management of the patients undergoing cardiac surgery. Its biological importance is primarily attributed to its involvement in energy metabolism, acid-base balance, membrane integrity and signaling pathways each of which is vital in maintaining normal cardiac function.[11] Phosphorus is a fundamental component of adenosine triphosphate (ATP), the primary energy currency of cells. During cardiac surgery, especially during periods of ischemia or cardiopulmonary bypass, myocardial energy demands may exceed supply. In such conditions, maintaining adequate phosphorus levels becomes essential to ensure sufficient ATP production. Depleted phosphorus stores can lead to impaired energy metabolism, resulting in reduced myocardial contractility and poor cardiac output during and after surgery.

AIMS AND OBJECTIVES

To estimate the levels of Serum Electrolytes (Sodium, Potassium, Calcium, Magnesium and Phosphorous) in the patients undergoing Cardiac Surgery as well as Non-cardiac Surgery. Secondly to compare the derangement of Serum Electrolytes level in the post operative patients who have undergone Cardiac Surgery vs Non-cardiac Thoracic Surgery (Lung Lobectomy, Pneumectomy etc.).

MATERIALS AND METHODS

This case control study was conducted in the Department of Biochemistry on the 50 patients undergoing Cardiac Surgery (Study Group) and 50 patients undergoing Non-cardiac Thoracic Vascular Surgery (Control Group) referred by Department of Cardio-thoracic and Vascular Surgery of Rajindra Hospital, Patiala. The blood samples of the patients were analyzed for Serum Sodium, Potassium, Calcium, Magnesium and Phosphorus one day prior to surgery (Preoperative samples) and also one day after surgery (Postoperative samples). We compared the derangement of levels of Serum Sodium, Potassium, Calcium, Magnesium and Phosphorus in the patients undergoing Cardiac Surgeries versus Non-cardiac Thoracic Vascular Surgeries.

INCLUSION CRITERIA:

Patients undergoing elective On-pump or Off-pump cardiac surgery having Left ventricular ejection fraction (LVEF)> 50% for Cardiac cases and Patients Age > 18 years of age.

EXCLUSION CRITERIA:

Patients Age < 18 years, LVEF < 50% for Cardiac cases, Patients End stage renal disease, Pregnancy and Infection/Sepsis patients

SPECIAL SERUM ELECTROLYTE INVESTIGATIONS

Sample Collection: Fresh 2 ml blood sample was taken in red vial (Allow to clot) by venipuncture mainly from Cephalic/Median cubital vein present in antecubital fossa of the arm. Proper centrifugation for separation of serum was at 2000 rpm for approximately 20 minutes done. Serum electrolytes estimation is not analyzed in hemolyzed blood sample, because hemolyzed sample gives abnormal electrolyte readings.

1. **Estimation of Serum Na^+ and K^+**

Principle: Serum Sodium and Potassium were estimated by Electrolyte Analyzer which is based on principle Potentiometry and Ion-Selective Electrodes (ISE). [12]

Normal reference range of Serum Sodium: 135 to 155 mEq/L

Normal reference range of Serum Potassium: 3.5 to 5.2 mEq/L

2. **Estimation of Serum Calcium:**

Principle: Serum Calcium is estimated by reagent Arsenazo lll. Content of Arsenazo lll reagent is Arsenazo lll 0.20 mmol/L and Buffer (ph 6.5±0.1) 100 mmol/L.

Reagents Arsenazo lll combine with calcium ions at pH 6.5 to form a coloured chromophore, the absorbance of which is measured at 650 nm in Autoanalyzer. Precautions must be taken to avoid calcium contamination. The use of the plastic tubes or cuvettes are strongly recommended.[13]

Normal reference range of Serum Calcium in adult: 8.6 to 10.2 mg/dl

3. **Estimation of Serum Magnesium:**

Principle: Serum Magnesium is estimated with Magnesium Reagent. The content of Reagent is Xylidyl Blue (1) 100 µmol/L, Ethanolamine 1 mol/L and GEDTA 60 µmol/L. Mg^{++} reacts with Xylidyl Blue to form a colored compound in alkaline solution. The intensity of color formed is proportional to the Mg^{++}concentration in the sample. It is estimated in Autoanalyzer.[14]

Normal reference range of Serum Magnesium in adult: 1.6 to 2.6 mg/dl.

4. **Estimation of Serum Phosphorus:**

Principle: Serum phosphorus is estimated by U V Molybdate method. The composition of Phosphorus reagents are Ammonium molybdate 0.43 mmol/L, Sulfuric acid 213 mmol/L and Surfactant 0.2%.

Inorganic phosphorous combines with ammonium molybdate in the presence of strong acid to form phosphomolybdate. The formation of reduced phosphomolybdate is measured at 340 nm in Autoanalyzer.[15]

Normal reference range of Serum Phosphorus in adult: 2.5 to 4.5 mg/dl

RESULTS AND OBSERVATIONS

Table 1 Preoperative Mean Electrolytes Levels in Study Group vs Control Group

Pre-Operative	Groups	Mean	SD	Std. Error Mean	p value
Sodium (Na+)	Study group	139.08	4.48	0.63	0.681 (NS)
	Control group	139.42	3.74	0.53	
Potassium (K+)	Study group	4.26	0.52	0.07	0.336(NS)
	Control group	4.16	0.47	0.07	
Calcium (Ca+)	Study group	9.02	0.41	0.06	0.532 (NS)
	Control group	8.97	0.35	0.05	
Phosphorus (Pho)	Study group	3.51	0.53	0.07	0.149 (NS)
	Control group	3.32	0.76	0.11	
Magnesium (Mg2+)	Study group	1.97	0.23	0.03	0.448 (NS)
	Control group	1.94	0.22	0.03	

Study Group = Cardiac Surgery, Control Group = Non-cardiac Thoracic Surgery

Comparison of Pre-Operative Mean Electrolytes Level in Study and Control Group

In the present study the Table 1 shows the mean pre-operative Serum Electrolyte levels of Sodium 139.08 mEq/L, potassium 4.26 mEq/L, Calcium 9.02 mg/dl, Magnesium 1.97 mg/dl, Phosphorus 3.51 mg/dl in Study group and Sodium 139.42 mEq/L, Potassium 4.16 mEq/L, Calcium 8.97 mg/dl, Magnesium 1.94 mg/dl, Phosphorus 3.32 mg/dl in Control group respectively. The p Values were non-significant for all electrolytes. Hence there were no significant difference observed in mean Serum Electrolytes Levels in Pre-operative Study and Control Group.

Table 2 Postoperative Mean Electrolytes Levels in the Study Group vs Control Group

Post-Operative	Groups	Mean	SD	Std. Error Mean	p value
Sodium (Na+)	Study group	135.12	6.35	0.90	0.168 (NS)
	Control group	136.58	3.87	0.55	
Potassium (K+)	Study group	3.53	0.60	0.09	0.001 (HS)
	Control group	4.15	0.53	0.08	
Calcium (Ca+)	Study group	8.48	0.43	0.06	0.001 (HS)
	Control group	8.87	0.41	0.06	
Phosphorus (Pho)	Study group	3.08	0.57	0.08	0.611 (NS)
	Control group	2.99	1.08	0.15	
Magnesium (Mg2+)	Study group	1.70	0.27	0.04	0.239 (NS)
	Control group	1.76	0.24	0.03	

Study Group = Cardiac Surgery, Control Group = Non-cardiac Thoracic Surgery

Comparison of Post-Operative Mean Electrolytes level in Study and Control Group

In the present study the Table 2 shows the mean Postoperative levels of Serum Sodium, Magnesium, phosphorus 135.12 mEq/L, 1.70 mg/dl, 3.08 mg/dl respectively in Study Group and 136.58 mEq/L, 1.76 mg/dl, 2.99 mg/dl respectively in Control Group. The p values of Sodium is 0.168, Magnesium 0.239 and Phosphorus 0.611 respectively, hence there were no significant difference in Serum Sodium, Magnesium and Phosphorus levels in Postoperative Study and Control Group.

Postoperative mean levels of Serum Potassium, Calcium, 3.53 mEq/L, 8.48 mg/dl respectively in Study Group and 4.15 mEq/L, 8.87 mg/dl respectively in Control Group. The p values of both Potassium and Calcium are 0.001 highly significant, hence there were highly significant depletion of Serum Potassium and Calcium levels in Study Group as compared to Control Group.

Table 3 : Comparison of the Mean difference in pre-operative and post-operative Electrolyte Levels in Study Group vs Control Group

Pre & Post-Operative	Groups	Mean difference in pre and post operative electrolytes	Mean Difference between Study and Control Group	p value
Sodium (Na+)	Study group	3.96 mEq/L	1.12 mEq/L	0.253 (NS)
	Control group	2.84 mEq/L		
Potassium (K+)	Study group	0.73 mEq/L	0.72 mEq/L	0.001 (HS)
	Control group	0.01 mEq/L		
Calcium (Ca+)	Study group	0.54 mg/dl	0.43 mg/dl	0.001 (HS)
	Control group	0.11 mg/dl		
Phosphorus (Pho)	Study group	0.43 mg/dl	0.10 mg/dl	0.409 (NS)
	Control group	0.33 mg/dl		
Magnesium (Mg2+)	Study group	0.27 mg/dl	0.09mg/dl	0.050 (S)
	Control group	0.18 mg/dl		

Study Group = Cardiac Surgery, Control Group = Non-cardiac Thoracic Surgery

Comparison of Mean difference in pre-operative vs post-operative Electrolytes level in Study vs Control Group

In the present study the Table 3 shows the difference of mean depletion in Sodium level is 1.12 mEq/L and the p value 0.253 (NS) and Phosphorus level is 0.10 mg/dl and the p value 0.409 (NS). Hence there were no significant difference in mean depletion of Serum Sodium and Phosphorus levels in Study vs Control Group.

The difference of mean depletion of Potassium level is 0.72 mEq/L and Calcium 0.43 mg/dl the p values of both Electrolytes are 0.001 (HS). Hence there were highly significant difference in mean depletion of Serum Potassium and Calcium levels in Study vs Control Group.

The difference of mean depletion of Magnesium level is 0.09 mg/dl the p value 0.050 (S). Hence there was significant difference in mean depletion of Serum Magnesium levels in Study vs Control Group.

DISCUSSION

The present case-control study was conducted at the Govt. Medical College and Rajindra Hospital Patiala, enrolling 50 patients undergoing Cardiac Surgery as Study Group and 50 patients undergoing Non-cardiac Thoracic Vascular Surgery as Control Group. The primary objective was to evaluate and compare the derangement of five key serum electrolytes Na+, K+, Ca++, Mg++ and Phosphorus one day prior and one day after surgery.

Pre-operative Electrolyte Profile

Preoperative mean serum levels of Sodium is 139.08 mEq/L vs. 139.42 mEq/L and p value 0.681, Potassium is 4.26 mEq/L vs. 4.16 mEq/L and p value 0.336, Calcium is 9.02 mg/dl vs 8.97 mg/dl and p value 0.532, Magnesium is 1.97 mg/dl vs 1.94 mg/dl and p value 0.448, Phosphorus is 3.51 mg/dl vs 3.32 mg/dl and p value 0.149 in the study and control group respectively which were statistically non-significant between these groups. This homogeneity confirms that all patients commenced surgery with a normal electrolyte profile, ensuring that observed postoperative derangements are attributable to the surgical intervention and associated physiological changes, particularly the use of Cardiopulmonary Bypass (CPB).

Post-operative Electrolyte Profile

Electrolytes with Significant Difference

Potassium

The mean difference between Pre and Postoperative Potassium level in Study Group is 0.73 mEq/L and in Control group is 0.01 mEq/L, resulting in a mean difference is 0.72 mEq/L with the p value 0.001 (Highly Significant) between Study and Control group. This Highly Significant difference is consistent with the findings of Polderman KH et al[1] The hypokalemia is primarily attributed to the effects of CPB (i) Hypothermia-induced diuresis leads to renal loss (ii) Elevated catecholamine levels from surgical stress stimulate the ATPase pump, driving into the skeletal muscle cells (iii) Metabolic shifts during acid-base disturbances post-CPB promote cellular uptake. This deficit is clinically important, as imbalance is a major cause of postoperative ventricular and supraventricular arrhythmias.

Calcium

The mean difference between Pre and Postoperative Calcium level in Study group is 0.54 mg/dl and in Control Group is 0.11 mg/dL, resulting in a mean difference is 0.43 mg/dl with the p value 0.001 (Highly Significant) between Study and Control Group. This Highly Significant difference is consistent with the finding of Polderman KH et al[1]. The greater depletion of Calcium in the Study group than in Control Group is strongly linked to CPB factors. The underlying mechanisms include (i) Hemodilution by the CPB priming solution, which dilutes circulating calcium concentration (ii) Citrate Chelation by the blood products transfused during CPB, which binds the biologically active ionized calcium. The risk of hypocalcemia contributing to hypotension, arrhythmia and coagulopathy necessitates rigorous Calcium monitoring in cardiac surgical patients.

Magnesium

The mean difference between Pre and Postoperative Magnesium level in Study Group is 0.27 mg/dl and in Control Group is 0.18 mg/dl, resulting in a mean difference is 0.09 mg/dl with the p value 0.050 (Significant) between Study and Control Group. This Significant difference is corresponding with the pattern of Polderman KH et al[1]. The more depletion of Calcium in Study Group than in Control Group is strongly linked to CPB factors. The underlines mechanisms include (i) Hemodilution by the CPB

priming solution which dilute circulating Magnesium concentration. (ii) Hemodilution due to Cardioplegic Solution with low Magnesium. (iii) Ultrafiltration during CPB. The risk of Hypomagnesemia is associated with arrhythmia, myocardial infarction and hypertension

Electrolytes with Non- significant Difference

Sodium

The mean difference between Pre and Postoperative Serum Sodium level in Study Group is 3.96 mEq/L and in Control Group is 2.84 mEq/L, resulting in a mean difference is 1.12 mEq/L with the p value 0.168 (Non-Significant) between the Study and Control Groups. This Non-significant depletion between both group is consistent with finding of Polderman KH et al.[1]

Phosphorus

The mean difference between Pre and Postoperative Serum Phosphorus level in Study Group is 0.43 mg/dl and in Control Group is 0.33 mg/dl, resulting in a mean difference is 0.10 mg/dl with the p value 0.409 (Non-significant) between Study and Control Group. This Non-significant finding is inconsistent with the dramatic results reported by Polderman KH et al[1], who found highly significant derangements in the Study Group than Control Group. This divergence may reflect advances in clinical protocols since earlier studies. The current study's non-significant result may be due to the widespread adoption of proactive, standardized perioperative care, supplementation in the cardiac surgery setting, effectively mitigating the difference between the two surgical groups.

CONCLUSION

In this study we observed that Serum Potassium and Calcium were Highly Significant depleted in Cardiac Surgery patients in comparison to Non-Cardiac Thoracic Surgery patients. Serum Magnesium was Significantly depleted in Cardiac Surgery patients in Comparison to Non-Cardiac Thoracic Surgery patients. The derangement of Serum Sodium and Phosphorus has no significant difference in Cardiac Surgery (Study Group) and in Non-cardiac Thoracic Surgery (Control Group) patients.

LIMITATION OF STUDY:

This Study was conducted in the department of Cardio-vascular Surgery and sample of the patients were taken one day prior to surgery (Preoperative) and one day after surgery (Postoperative). Between the collection of Preoperative and Postoperative sample any supplements of Electrolytes were not included in the study.

CONFLICT OF INTEREST: Nil

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