

Atrial fibrillation and changes in serum and urinary electrolyte levels after coronary artery bypass grafting surgery

Milda Švagždienė, Edmundas Širvinskas, Rimantas Benetis¹, Laima Ralienė, Violeta Šimatonienė²

Institute for Biomedical Research, ¹Heart Center,

²Department of Physics, Mathematics and Biophysics, Kaunas University of Medicine, Lithuania

Key words: atrial fibrillation; coronary artery bypass grafting surgery; serum electrolyte balance; magnesium supplements; hypomagnesemia.

Summary. *Objective.* Our study was designed to assess the incidence of atrial fibrillation, changes in serum electrolyte concentrations and urinary electrolyte excretion following coronary artery bypass grafting surgery.

Material and methods. A total of 165 patients who underwent elective coronary artery bypass grafting surgery at the Department of Cardiac Surgery (Heart Center) during the period of 2004–2005 were enrolled. Serum K^+ , Na^+ , Mg^{2+} , Ca^{2+} , Cl^- , and P^- concentrations were measured before cardiopulmonary bypass (CPB), on the arrival to an intensive care unit, and 15–18 hours after the surgery. Urinary excretion of K^+ , Na^+ , Mg^{2+} , Ca^{2+} , Cl^- , and P^- was estimated 24 hours before the surgery, during the surgery, and 24 hours after the surgery. Cardiac rhythm was monitored throughout the study. All patients randomly were divided into the group 1 ($n=55$), which received magnesium sulphate infusion, and group 2 ($n=110$), which did not receive magnesium sulphate.

Results. The overall incidence of atrial fibrillation was 27.4%. The patients in the group 1 had significantly higher levels of serum magnesium before CPB and serum chloride after the surgery. Urinary magnesium and calcium excretion was significantly higher in the group 1 during and after the surgery. Before the surgery and 24 hours after the surgery, phosphate excretion was significantly higher in the group 1.

Conclusions. The incidence of atrial fibrillation after myocardial revascularization surgery remains high (27.4%). Serum electrolyte concentrations after myocardial revascularization varied within normal ranges. Magnesium sulphate infusion did not decrease the rate of postoperative atrial fibrillation during the early postoperative period in normomagnesemic patients.

Introduction

Postoperative atrial fibrillation (AF), despite an intense interest of the scientists, remains an outstanding problem after cardiac surgery with cardiopulmonary bypass (CPB). A lot of risk factors and the multicomponential character of pathogenesis are established, various schemes for prophylactic means are designed (the use of magnesium supplements, β -blockers, Cordarone, electrical stimulation, etc.), but the problem still exists (1). The incidence of postoperative AF remains up to 30% (2).

It is difficult to explain why some of the patients with no risk factors develop postoperative AF. Some authors noticed that there are changes in electrolyte balance after cardiac surgery with CPB. The changes in serum magnesium level and their relation with the

rate of postoperative AF usually are analyzed by most publications (3, 4). The opinion that magnesium supplementation is helpful to reduce the rate of postoperative AF is predominant. However, there is some evidence suggesting that administration of magnesium may be detrimental. Parikka et al. (5) suggested that correction of postoperative decline of magnesium by 70 mmol on the first two days following cardiac surgery did not reduce the incidence of atrial fibrillation. The authors reported that patients with high serum magnesium levels had a higher incidence of AF and that supra-physiological concentrations of magnesium led to slowing of sinus rhythm rate that could predispose to AF. Inhibition of the sinus node by magnesium is most probably offset by inhibition of acetylcholine release at the vagal nerve terminals.

Our study was designed to assess the changes of serum electrolytes and their urine excretion and the effects of magnesium sulphate infusion on these changes and the rate of postoperative AF during the CABG surgery with CPB.

The aim of the study was to estimate the relationship of the rate of postoperative AF and the changes in serum electrolyte concentration and their urinary excretion as well as to evaluate the effects of intraoperatively infused magnesium sulphate on the incidence of postoperative atrial fibrillation in the early postoperative period after CABG surgery with CPB.

Materials and methods

A prospective cohort randomized study was carried out at the Heart Center, the Department of Cardiac Surgery (Hospital of Kaunas University of Medicine), during 2004–2005. After approval of the Kaunas Region Ethics Committee for Biomedical Research and written informed consent of the patients, 165 patients who underwent elective coronary artery bypass grafting surgery were enrolled. Patients' enrolment criteria were as follows: male sex, age of 50–75 years, left ventricular ejection fraction of >0.3 , controlled arterial hypertension without dysfunction of other organs, NYHA class of $<III$, normal liver, pulmonary, and renal function, no diabetes or other metabolism disorders, normal serum cholesterol values, no atrial fibrillation in the past, serum electrolytes (K^+ , Na^+ , Mg^{2+} , Ca^{2+} , Cl^- , P^-) concentrations within normal ranges before the surgery, the preoperative status of $\leq IV$ ASA class.

All the patients were randomly divided into two groups: group 1 ($n=55$, received 40 mg/kg of $MgSO_4$

after anesthesia induction and 500 mg/h maintenance infusion) and group 2 ($n=110$, did not receive magnesium sulphate) (6–8).

Patients' exclusion criteria were as follows: unstable hemodynamic and the need for vasopressors, increased mediastinum drainage of >100 mL/kg, ST interval or T changes on ECG, no sinus rhythm (AV rhythm, bradyarrhythmic AF) restoration at the end of CPB, and the need for electric heart stimulation. According to the exclusion criteria, 3 patients from the group 1 and 4 patients from the group 2 were excluded from the study after the surgery. So finally, the data of 158 patients ($n=52$ in the group 1 and $n=106$ in the group 2) were analyzed.

The preparation of the patients before the surgery, premedication, general anesthesia, cardiopulmonary bypass, cardioplegia, surgical technique, and the treatment after the surgery were the same for all patients. The conventional methods established at the Heart Center, Department of Cardiac Surgery (Kaunas University of Medicine), were used.

Demographic characteristics and presurgical data of the patients of both groups are shown in Table 1.

Patients were treated before the surgery according to the planned order. Echocardiography, coronary angiography, fibrogastroduodenoscopy, chest x-ray, nephrogram, biochemical and morphological blood analyses were performed.

The standardized premedication (10 mg of morphine, 0.1 mg/kg of oral midazolam, and half of the used dose of metoprolol were prescribed one hour before the surgery) and general standardized anesthesia (1–2 μ g/kg of fentanyl, 0.05 mg/kg of midazolam, 1–3 mg/kg of thiopentone, and 0.08–0.1 mg/kg

Table 1. Demographic and presurgical data of the patients

Parameter	Group 1 ($n=52$)	Group 2 ($n=106$)	<i>P</i>
Age, years	64.95 $\pm$ 1.34	65.29 $\pm$ 0.96	0.818
Body mass index, kg/m ²	30.95 $\pm$ 0.71	29.44 $\pm$ 0.54	0.064
Left ventricular ejection fraction, %	46.48 $\pm$ 0.78	43.79 $\pm$ 1.04	0.072
Left atrial index	19.23 $\pm$ 0.30	19.80 $\pm$ 0.27	0.143
CVP, mm Hg	6.64 $\pm$ 0.30	5.88 $\pm$ 0.26	0.072
ASA class, %			
II	83	72	0.135
III	4	11	0.100
IV	13	19	0.396

The data are presented as mean $\pm$ standard error of the mean.

ASA, American Society of Anesthesiologists; CVP, central venous pressure.

of pipecuronium for induction and 3 µg/kg/h of fentanyl, 1–4 mg/h of midazolam, and 1.5–2.0% MAC of sevoflurane for anesthesia maintenance) were applied.

All patients received Ringer's acetate solution according to their clinical needs. Serum potassium was examined and corrected if needed after induction of anesthesia, at the beginning of CPB, every 15 min during the CPB, and at the end of the surgery after disconnection of CPB. Calcium and phosphate supplementation was not used during the study.

The cardiopulmonary bypass machine was filled with Ringer's acetate solution containing 10 000 units of heparin. A roller pump with membrane oxygenator (Dideco D703, Mirandola) and a reservoir were used. Cold (temperature, 2–4°C), crystalloid cardioplegia with St. Thomas solution was employed for the protection of myocardium. Cardioplegia was repeated every half an hour using the half of the initial dose.

Surgeries were made through the section of a middle sternotomy. A standard surgical technique for the formation of the coronary anastomoses was used. The surgical data of both groups are presented in Table 2.

After the surgery, the patients were transferred to the intensive care unit (ICU). All patients received Ringer's acetate solution (Na⁺, 131.0 mmol/L; K⁺, 4.0 mmol/L; Mg²⁺, 1.0 mmol/L; Cl⁻, 111 mmol/L; acetate, 30 mmol/L) according to their clinical needs for the infusion therapy. Serum potassium was kept at the level not lower than 4.3–4.5 mmol/L and corrected if needed by 3 g of KCl (sol. KCl 7.45%, 40 mL) intravenously. Calcium, magnesium, and phosphate supplementation was not used in the ICU.

The standardized monitoring (ECG, invasive arterial blood pressure, SpO₂, central venous pressure, urine output) using Siemens 900 monitors was applied throughout the study.

The serum K⁺, Na⁺, Mg²⁺, Ca²⁺, Cl⁻, P⁻ concent-

rations were examined before the CPB, immediately after the surgery, after arrival to the ICU, and on the next morning after the surgery (15–18 hours after the surgery). Urine excretion of electrolytes was estimated by detecting urine concentration of electrolytes (mmol/L) and diuresis (mL) during a certain period (24 hours before the surgery, the time of the operation, and 24 hours after the surgery). The absolute amount of excreted electrolyte (in mmol) was calculated according to the formula:

$$\text{Amount of electrolyte (mmol)} = \text{diuresis (mL)} \times \text{urine concentration of electrolyte (mmol/L)}.$$

At the ICU, cardiac rhythm was monitored using Siemens 900 monitors, and the episodes of AF were documented in the memory of the monitor. Any episode of an irregular rhythm with the presence of *f* waves of variable morphology and amplitude was considered atrial fibrillation.

The patients of study group (group 1) were divided into subgroups as follows: 1A (AF⁺) subgroup included patients with postoperative AF (n=15) and 1B (AF⁻) patients without postoperative AF (n=37).

The patients of control group (group 2) were divided into subgroups 2A (AF⁺) (n=28) and 2B (AF⁻) (n=78) analogically.

Statistical data analysis was performed using the SPSS 12.0 (Statistical Package for Social Science) package. All data are presented as the mean and standard error of the mean. The analyzed parameters were described using the general statistical status, distribution, and symmetry. The comparison of quantitative variables was performed using Student *t* test. The Kolmogorov-Smirnov test was used to check the normal data distribution. The Mann-Whitney *U* test was used for the evaluation of the difference between two independent groups. When statistical hypothesis were verified, the *P* level of <0.05 was used, where *P* is the marginal level of statistical significance in hypothesis verification.

Table 2. Surgical data

Parameter	Group 1 (n=52)	Group 2 (n=106)	<i>P</i>
Number of grafts	3.62±0.10	3.49±0.95	0.392
Duration of CPB, min	99.10±3.47	93.30±3.35	0.269
Duration of aorta cross-clamping, min	52.33±1.99	47.39±1.94	0.104
Total amount of cardioplegic solution, mL	1576.19± 68.92	1504.88±35.44	0.230
Total amount of CPB priming solution, mL	2268.10±42.89	2188.85±37.49	0.089
Total amount of solutions for infusion therapy in ICU, mL	2020.24±178.33	2312.44±101.89	0.088

The data are presented as mean ± standard error of the mean.
CBP, cardiopulmonary bypass; ICU, intensive care unit.

Results

The data of 158 patients (52 in the group 1 and 106 in the group 2) were analyzed. Demographic, presurgical (Table 1), and surgical (Table 2) data did not differ between the groups. Before the surgery, all patients received β -blockers, ACE inhibitors, and nitrates. There were no differences in the mean medication doses between the groups. The proportions of patients using these medications did not differ comparing the groups. More than half (58.71%) of the patients in the group 1 and 80.49% of the patients in the group 2 ($P=0.421$) used metoprolol, 71.43% of patients in the group 1 and 54.66% in the group 2 ($P=0.056$) used ramipril, and all patients in both the groups (100%) used nitrates.

The overall rate of postoperative AF in our study was 27.4% (43 patients). Less than one-fifth (17.6%) of patients had AF on the first postoperative day, 52.9% of patients on the second, and 29.4% of patients on the third postoperative day. Majority (91.3%) of the patients had tachyarrhythmic AF, and 8.7% of patients had normoarrhythmic AF. No bradyarrhythmic AF was detected during the study. The duration of the AF episode varied from 10 min to 150 min, averaging to 67.94 (SD, 6.94) min. The AF episode discontinued itself in 20.6% of cases. In other cases, it was interrupted by 5 mg/kg per 30 min infusion of Cordarone. There were no cases of unstable hemodynamics due to AF.

The rate of postoperative AF between the groups did not differ ($P=0.690$): 28.85% ($n=15$) of patients in the group 1 and 26.42% ($n=28$) in the group 2 ex-

perienced postoperative AF. The character of AF did not differ between the groups as well.

Comparison of serum electrolyte concentration changes between study and control groups. Changes in serum electrolyte levels during the study are presented in Table 3.

There were no significant differences in serum potassium, sodium, ionized calcium, and phosphate concentrations between the groups before CPB, during the surgery, and 15–18 h after the surgery. Serum level of these electrolytes remained within normal ranges during the study.

Before CPB, serum magnesium levels were within normal ranges in both the groups, but it was significantly higher in the group 1 ($P<0.01$). Immediately after the surgery, there was no difference in serum magnesium concentration between the groups ($P=0.726$), but it significantly exceeded the normal ranges (95% CI, 1.28–1.42 in the group 1; 95% CI, 1.31–1.41 in the group 2).

Immediately after the surgery, 2.4% ($n=2$) of patients in the group 2 were hypomagnesemic (<0.7 mmol/L). More than three-fourths (80.8%, $n=74$) of patients in the group 2 and 73.08% ($n=38$) of patients in the group 1 were hypermagnesemic. Serum magnesium concentration was significantly higher in the group 1 15–18 h after the surgery ($P<0.001$). Hypermagnesemia was detected in 30.9% ($n=13$) of patients in the group 1 and in 13.4% ($n=11$) of patients in the group 2.

Serum chloride concentration was within normal ranges during the study in both the groups. Before CPB, it did not differ between the groups ($P=0.157$)

Table 3. Serum electrolyte concentrations in the group 1 (study) and group 2 (control)

Ion	Group	Before CPB	After the surgery	15–18 h after the surgery
K ⁺ , mmol/L	1	4.53±0.06	4.60±0.03	4.58±0.05
	2	4.53±0.04	4.58±0.05	4.56±0.04
Na ⁺ , mmol/L	1	136.86±0.40	136.00±0.31	137.05±0.36
	2	134.24±2.30	136.46±0.40	137.32±0.40
Mg ²⁺ , mmol/L	1	1.03±0.02*	1.35±0.03	1.02±0.02*
	2	0.90±0.01*	1.37±0.04	0.92±0.02*
Ca ²⁺ , mmol/L	1	0.98±0.01	0.99±0.01	0.98±0.01
	2	0.99±0.01	0.99±0.01	0.99±0.01
Cl ⁻ , mmol/L	1	107.57±0.39	109.38±0.40*	106.79±0.40
	2	106.73±0.38	106.98±0.70*	107.11±0.40
P ⁻ , mmol/L	1	0.98±0.03	1.01±0.03	0.95±0.02
	2	0.95±0.02	1.06±0.02	0.95±0.02

The data are presented as mean ± standard error of the mean. CBP, cardiopulmonary bypass.

* $P<0.05$ between the groups.

but after arrival to the ICU, serum chloride was significantly higher in the group 1 ($P=0.011$). Later on, it did not differ again ($P=0.582$).

Comparison of urine electrolyte excretion between study and control groups. The data of electrolyte excretion in both the groups are presented in Table 4. Diuresis did not differ between the groups before the surgery ($P=0.212$), during the surgery ($P=0.903$), and after the surgery ($P=0.511$).

Potassium, sodium, and chloride urine excretion varied within normal ranges and did not differ between the groups.

Magnesium urine excretion in both the groups exceeded normal range after the surgery (95% CI, 18.14–25.48 in the group 1; 95% CI, 11.62–15.08 in the group 2). Before the surgery, it was within normal ranges and did not differ between the groups ($P=0.891$). However, during the surgery and after the surgery, magnesium excretion was significantly higher in the group 1 than in the group 2 ($P<0.01$).

Calcium urine excretion varied within normal ranges in both the groups during the study. There was no significant difference between the groups before the surgery ($P=0.065$). During the surgery, calcium excretion was significantly higher in the group 1 than in the group 2 ($P=0.017$). The same difference remained after the surgery as well ($P=0.007$).

Before the surgery, phosphate excretion was significantly higher in the group 1 ($P=0.013$). It did not differ between the groups during the surgery ($P=0.90$)

and during the first 24 h after the surgery ($P=0.082$).

Analysis of data of the study group in respect of atrial fibrillation. Changes in serum electrolyte concentrations in the subgroups 1A (AF^+) and 1B (AF^-) are presented in Table 5.

Serum potassium, sodium, chloride concentration remained within normal ranges during the study in both the subgroups. Before CPB, serum potassium level was significantly lower in the subgroup 1A (AF^+) than in the subgroup 1B (AF^-) ($P=0.001$). Later on, during the study period, there was no significant difference either at arrival to the ICU ($P=0.134$) or 15–18 h after the surgery ($P=0.136$).

Serum magnesium concentration was significantly lower in the subgroup 1A (AF^+) than subgroup 1B (AF^-) before CPB ($P<0.01$). There were no hypomagnesemic patients before CPB. Serum magnesium level was found to be higher than 1.05 mmol/L in 37.84% ($n=14$) of patients in the subgroup 1B (AF^-). In the subgroup 1A (AF^+), there were no cases of hypermagnesemia before CPB ($P=0.007$).

Immediately after the surgery, on arrival to the ICU, serum magnesium level did not differ between the subgroups ($P=0.561$). Hypermagnesemia was found in 66.67% ($n=10$) of patients in the subgroup 1A (AF^+) and in 64.86% ($n=24$) of patients in the subgroup 1B (AF^-) ($P=0.891$). After 15–18 h following surgery, serum magnesium concentration became significantly higher ($P<0.01$) in the subgroup 1A (AF^+) again. At that period, no cases of hypomagnesemia were re-

Table 4. Diuresis and electrolyte excretion in the group 1 (study) and group 2 (control)

Parameter	Group	24 h before the surgery	During the surgery	24 h after the surgery
Diuresis, mL	1	1734.52±89.71	728.57±33.34	2110.00±95.41
	2	1881.22±81.53	738.29±58.51	2025.61±74.71
K^+ , mmol	1	60.87±3.90	29.67±2.41	135.24±15.28
	2	61.88±3.11	27.52±1.73	115.18±6.10
Na^+ , mmol	1	109.77±8.98	73.62±4.79	274.04±34.83
	2	108.75±8.22	67.88±5.93	241.60±14.34
Mg^{2+} , mmol	1	3.36±0.21	9.67±0.45*	21.81±1.54*
	2	3.40±0.21	5.02±0.37*	13.35±0.98*
Ca^{2+} , mmol	1	3.13±0.30	2.12±0.12*	7.98±1.28*
	2	2.62±0.16	1.68±0.12*	4.67±0.33*
Cl^- , mmol	1	128.80±8.17	94.67±5.15	309.31±25.37
	2	123.28±5.90	80.99±5.52	317.65±17.11
P^- , mmol	1	21.18±1.25*	4.41±0.47	29.93±3.99
	2	17.91±0.82*	4.50±0.46	23.06±1.30

The data are presented as mean ± standard error of the mean.

* $P<0.05$ between the groups.

Table 5. Serum electrolyte concentrations in the subgroups 1A (AF⁺) and 1B (AF⁻)

Ion	Subgroup	Before CPB	After the surgery	15–18 h after the surgery
K ⁺ , mmol/L	1A (AF ⁺)	4.17±0.09*	4.63±0.05	4.46±0.09
	1B (AF ⁻)	4.68±0.09*	4.53±0.06	4.68±0.09
Na ⁺ , mmol/L	1A (AF ⁺)	135.67±1.10	136.00±0.70	135.33±0.77
	1B (AF ⁻)	137.73±0.62	136.00±0.56	136.73±0.62
Mg ²⁺ , mmol/L	1A (AF ⁺)	0.93±0.15*	1.39±0.10	0.90±0.02*
	1B (AF ⁻)	1.07±0.03*	1.34±0.04	1.07±0.03*
Ca ²⁺ , mmol/L	1A (AF ⁺)	0.898±0.06*	1.04±0.01	0.88±0.02*
	1B (AF ⁻)	1.01±0.03*	0.99±0.02	1.02±0.01*
Cl ⁻ , mmol/L	1A (AF ⁺)	104.08±0.90*	108.67±0.23	105.25±1.32
	1B (AF ⁻)	108.97±0.50*	109.67±0.77	107.40±0.58
P ⁻ , mmol/L	1A (AF ⁺)	0.92±0.05	0.99±0.05	0.81±0.08*
	1B (AF ⁻)	1.01±0.06	1.02±0.05	1.00±0.04*

The data are presented as mean ± standard error of the mean. CPB, cardiopulmonary bypass.

* $P<0.05$ between the subgroups.

gistered in all group 1. Hypermagnesemia was detected in 35.14% ($n=13$) of patients in the subgroup 1B (AF⁻); patients in the subgroup 1A (AF⁺) did not have hypermagnesemia at that period of the study ($P=0.011$).

Ionized serum calcium concentration remained within normal ranges during the study in the subgroup 1B (AF⁻). In the subgroup 1A (AF⁺), it was subnormal before CPB (95% CI, 0.85–0.95) and in the next morning after the surgery (95% CI, 0.84–0.92). Before CPB, ionized serum calcium level in the subgroup 1A (AF⁺) was significantly lower in comparison with the subgroup 1B (AF⁻) ($P=0.003$). After the surgery, at the ICU, there was no difference in serum ionized calcium concentration between the groups ($P=0.458$). After 15–18 h following surgery, it was significantly lower in the subgroup 1A (AF⁺) again ($P<0.01$).

Serum chloride concentration was significantly lower in the subgroup 1A (AF⁺) before CPB ($P<0.01$). It did not differ between the subgroups after arrival to the ICU ($P=0.370$) and 15–18 h after the surgery ($P=0.060$).

Serum phosphate concentration remained within normal ranges in the subgroup 1B (AF⁻) during the study period (normal range, 0.87–1.45 mmol/L). In the subgroup 1A (AF⁺), it was subnormal (95% CI, 0.68–0.95) in the next morning after the surgery. There was no significant difference between the subgroups before CPB ($P=0.237$) and immediately after the surgery ($P=0.701$). But 15–18 h after the surgery, serum phosphate concentration was significantly higher in the subgroup 1B (AF⁻) ($P=0.006$).

The data of electrolyte excretion in the subgroups 1A (AF⁺) and 1B (AF⁻) are presented in Table 6.

Sodium, calcium, chloride, and phosphate urine excretion varied within normal ranges and did not differ between the subgroups during the study period.

Potassium urine excretion varied within normal ranges, but it was significantly lower in the subgroup 1A (AF⁺) before the surgery ($P<0.01$).

Magnesium urine excretion varied within normal ranges before the surgery and during the surgery in both the subgroups. There was no difference in it between the subgroups before the surgery ($P=0.982$). During the surgery, magnesium excretion was significantly lower in the subgroup 1A (AF⁺) ($P<0.01$). After the surgery, magnesium excretion did not differ between the subgroups again ($P=0.062$), but in both the subgroups, it exceeded normal ranges (95% CI, 8.25–23.83 in the subgroup 1A; 95% CI, 8.55–39.69 in the subgroup 1B).

Analysis of the data of control group in respect of atrial fibrillation. Changes in serum electrolyte concentrations in the subgroups 2A (AF⁺) and 2B (AF⁻) are presented in Table 7.

Serum potassium and sodium concentration remained within normal ranges and did not differ between the subgroups during the study.

Serum magnesium concentration did not differ between the subgroups before CPB ($P=0.269$), immediately after the surgery ($P=0.613$), and 15–18 h after the surgery ($P=0.764$). Immediately after the surgery, serum magnesium level in all group 2 exceeded normal ranges (95% CI, 1.31–1.41), but at 15–18 h after the

Table 6. Urine excretion of electrolytes and diuresis in the subgroups 1A (AF⁺) and 1B (AF⁻)

Parameter	Group	24 h before the surgery	During the surgery	24 h after the surgery
Diuresis, mL	1A (AF ⁺) 1B (AF ⁻)	1708.33±210.05 1745.00±96.08	866.67±112.37 773.33±46.72	2451.67±380.20 1973.33±110.87
K ⁺ , mmol	1A (AF ⁺) 1B (AF ⁻)	39.89±5.88* 69.27±4.04*	38.84±9.99 26.00±2.58	184.84±70.72 115.40±11.35
Na ⁺ , mmol	1A (AF ⁺) 1B (AF ⁻)	88.27±12.83 118.37±11.21	90.75±14.63 66.77±7.33	414.31±156.72 317.94±27.47
Mg ²⁺ , mmol	1A (AF ⁺) 1B (AF ⁻)	3.35±0.47 3.36±0.24	6.43±0.82* 10.96±0.71*	16.04±2.25 24.12±2.84
Ca ²⁺ , mmol	1A (AF ⁺) 1B (AF ⁻)	3.14±0.29 3.13±0.40	2.40±0.15 2.01±0.23	13.25±5.99 6.87±0.79
Cl ⁻ , mmol	1A (AF ⁺) 1B (AF ⁻)	108.30±17.09 136.99±8.92	111.58±14.05 87.91±8.42	368.24±96.91 285.74±32.97
P ⁻ , mmol	1A (AF ⁺) 1B (AF ⁻)	21.92±3.32 20.88±1.20	3.30±0.89 4.85±0.86	47.08±18.24 33.07±2.73

The data are presented as mean ± standard error of the mean.

**P*<0.05 between the subgroups.

Table 7. Serum electrolyte concentrations in the subgroups 2A (AF⁺) and 2B (AF⁻)

Ion	Subgroup	Before CPB	After the surgery	15–18 h after the surgery
K ⁺ , mmol/L	2A (AF ⁺) 2B (AF ⁻)	4.63±0.10 4.48±0.07	4.63±0.11 4.57±0.05	4.73±0.04 4.60±0.09
Na ⁺ , mmol/L	2A (AF ⁺) 2B (AF ⁻)	137.36±0.60 133.09±3.13	136.36±0.88 136.50±0.43	137.00±0.77 137.43±0.40
Mg ²⁺ , mmol/L	2A (AF ⁺) 2B (AF ⁻)	0.88±0.03 0.91±0.02	1.34±0.07 1.38±0.05	0.93±0.05 0.92±0.01
Ca ²⁺ , mmol/L	2A (AF ⁺) 2B (AF ⁻)	1.00±0.01 0.99±0.01	0.99±0.01 1.00±0.02	0.97±0.01* 1.00±0.01*
Cl ⁻ , mmol/L	2A (AF ⁺) 2B (AF ⁻)	107.45±0.78 106.47±0.43	111.91±0.96* 105.17±0.74*	108.68±0.65 106.53±0.42
P ⁻ , mmol/L	2A (AF ⁺) 2B (AF ⁻)	0.94±0.04 0.96±0.03	0.98±0.03* 1.09±0.02*	0.81±0.03* 0.99±0.03*

The data are presented as mean ± standard error of the mean. CPB, cardiopulmonary bypass.

**P*<0.05 between the subgroups.

surgery, it was within normal ranges again.

Ionized serum calcium concentration remained within normal ranges in both the subgroups during the study. It did not differ between the subgroups either before CPB (*P*=0.415) or after the surgery (*P*=0.545). At 15–18 h after the surgery, in the subgroup 2A (AF⁺), serum ionized calcium level was significantly lower than in the subgroup 2B (AF⁻) (*P*=0.011).

Serum chloride concentration did not differ significantly between the subgroups before CPB (*P*=0.198).

Immediately after the surgery, on arrival to the ICU, it was significantly higher in the subgroup 2A (AF⁺) in comparison with the subgroup 2B (AF⁻) (*P*<0.01). It remained significantly higher at 15–18 h after the surgery as well (*P*=0.003). During the whole study period, serum chloride varied within normal ranges.

Serum phosphate concentration did not differ between the subgroups (*P*=0.687) before CPB. On the arrival to the ICU, serum phosphate level was significantly lower (*P*=0.007) in the subgroup 2A (AF⁺).

The difference remained significant at 15–18 h after the surgery as well ($P=0.034$). Before the surgery, 21.43% ($n=6$) of the patients in the subgroup 2A (AF^+) and 28.21% ($n=22$) of the patients in the subgroup 2B (AF^-) had hypophosphatemia (within the range of 0.58–0.86 mmol/L) ($P=0.471$). Immediately after the surgery, the rate of hypophosphatemia decreased to 10.26% ($n=10$) of patients in the subgroup 2B (AF^-). The rate of hypophosphatemia did not change in the subgroup 2A (AF^+) ($P=0.139$). At 15–18 h after the surgery, the rate of hypophosphatemia increased again. The rate was significantly higher ($P=0.01$) in the subgroup 2A (AF^+) (14 patients, 50% of cases) in comparison with the subgroup 2B (AF^-) (13 patients, 16.67% of cases). Severe hypophosphatemia (<0.48 mmol/L) was not detected.

The data of electrolyte excretion in the subgroups 2A (AF^+) and 2B (AF^-) are presented in Table 8.

Diuresis was significantly lower during 24 h before the surgery ($P=0.019$) and during the surgery ($P=0.005$) in the subgroup 2A (AF^+). During the first 24 h after the surgery, diuresis did not differ between the subgroups ($P=0.08$). Excretion of all measured electrolytes varied within normal ranges in both the subgroups during the study period. No significant difference was detected in potassium urine excretion between subgroups.

There was no significant difference in sodium urine excretion before the surgery ($P=0.071$). During the

surgery, it was significantly lower in the subgroup 2A (AF^+) ($P=0.006$). Sodium urine excretion did not differ after the surgery between the subgroups ($P=0.262$).

Magnesium urine excretion was significantly lower in the subgroup 2A (AF^+) than in the subgroup 2B (AF^-) before the surgery ($P=0.013$). It did not differ between the subgroups during the surgery ($P=0.287$) and during the first 24 hours after the surgery ($P=0.689$).

Calcium urine excretion was significantly lower in the subgroup 2A (AF^+) before the surgery ($P=0.02$) and during the surgery ($P=0.04$). But after the surgery, it did not differ between the subgroups ($P=0.09$).

Chloride urine excretion did not differ before the surgery ($P=0.06$). During the surgery, it was significantly lower in the subgroup 2A (AF^+) ($P=0.007$). And again, there was no significant difference in chloride excretion between the subgroups after the surgery ($P=0.377$).

Before the surgery, phosphate urine excretion was significantly lower in the subgroup 2A (AF^+) in comparison with the subgroup 2B (AF^-) ($P=0.01$). There was no significant difference during the surgery ($P=0.101$) and after the surgery ($P=0.305$).

Discussion

Despite normal serum electrolyte levels, relatively good perioperative status, the usage of beta-blocking agents before and early after the surgery, the incidence

Table 8. Urine excretion of electrolytes and diuresis in the subgroups 2A (AF^+) and 2B (AF^-)

Parameter	Group	24 h before the surgery	During the surgery	24 h after the surgery
Diuresis, mL	2A (AF^+) 2B (AF^-)	1602.73±160.10* 1983.33±92.03*	500.00±50.97* 825.67±74.85*	1833.64±53.11 2096.00±98.95
K ⁺ , mmol	2A (AF^+) 2B (AF^-)	54.86±5.06 65.19±3.72	25.83±3.23 28.14±2.05	117.33±8.27 114.38±7.74
Na ⁺ , mmol	2A (AF^+) 2B (AF^-)	87.04±9.99 116.71±10.48	44.28±4.78* 76.54±7.64*	217.97±14.73 250.26±18.78
Mg ²⁺ , mmol	2A (AF^+) 2B (AF^-)	2.65±0.27* 3.67±0.26*	4.44±0.52 5.24±0.47	13.93±1.31 13.14±1.25
Ca ²⁺ , mmol	2A (AF^+) 2B (AF^-)	2.08±0.20* 2.82±0.20*	1.33±0.18 1.81±0.14	3.85±0.32 4.98±0.43
Cl ⁻ , mmol	2A (AF^+) 2B (AF^-)	106.87±9.71 129.29±7.12	59.55±6.10* 88.85±6.96*	295.42±14.47 325.80±22.75
P ⁻ , mmol	2A (AF^+) 2B (AF^-)	14.05±0.83* 19.32±1.03*	6.03±0.84 4.52±0.54	25.02±3.18 22.34±1.35

The data are presented as mean ± standard error of the mean.

* $P<0.05$ between the subgroups.

of AF was high in our study.

Most of the studies, designed to evaluate changes in electrolyte levels after CPB, find enhanced electrolyte depletion and electrolyte balance disorders. Hemodilution and the use of diuretics are considered to be the main causes of enhanced electrolyte depletion (9, 10). Anyway, in our study, we did not find any severe electrolyte disorders during the whole study period. Measured serum electrolyte (potassium, sodium ionized magnesium, ionized calcium, chloride, and phosphate) levels were within normal ranges. Serum magnesium concentration was significantly increased before CPB in the group 1, which is explained by magnesium infusion immediately after the anesthesia induction in this group. Amaya et al. (11) in their study added 16 mmol/L of ionized magnesium into cardioplegic solution. After the surgery, serum ionized magnesium levels did not change without additional supplementation of magnesium. In our study in both groups, we used St. Thomas solution for cardioplegia, containing 13.54 mmol/L of magnesium. After the surgery on arrival to the ICU, ionized serum magnesium levels were similar in both the groups and exceeded normal ranges. Patients in both the groups received extra magnesium with cardioplegic solution, and patients in the group 1 received more extra magnesium from magnesium sulphate infusion. Anyway, there was no significant difference in the level of serum magnesium between the groups due to the increased magnesium excretion in the group 1. However, serum magnesium level still remained higher in the group 1 on the first postoperative day.

The relationship between hypomagnesemia and AF after cardiac surgery suggests that serum magnesium levels should be kept within normal ranges. The question still remains whether normomagnesemic patients need extra magnesium.

Not surprisingly, magnesium excretion was increased after the surgery and during the first postoperative day in the group 1 comparing to the group 2. It correlates well with increased serum magnesium levels before the CPB and on the second postoperative day. During the surgery, calcium excretion in the group 1 increased as well, and it may be related to increased serum magnesium levels during the surgery due to continuous magnesium sulphate infusion. The relation between calcium and magnesium metabolism is so close that an increase in serum magnesium levels increases calcium excretion. It is hypothesized that increases in magnesium concentration in the peritubular interstitium inhibit transcellular calcium absorption. Anyway, the mechanisms still remain un-

clear. In addition, hypermagnesemia suppresses the secretion of parathyroid hormone and decreases renal tubular reabsorption (12).

In our study, other measured electrolytes (serum sodium, potassium, ionized calcium, chloride, and phosphate) also remained within normal ranges and did not differ between the groups, except chloride, which though remaining within normal ranges, was higher after the surgery in the group 1. High volume of chloride-rich solutions for intravenous infusion and cardiopulmonary bypass priming may alter serum chloride level, but most of the data show that hyperchloremic acidosis is mild and at the end does not need treatment (13). In our study, despite a high volume of solutions used, serum chloride levels were within normal ranges, though it was higher in the group 1 after the surgery. Anyway, it is not clear why the difference appeared between the groups following the surgery.

In our study, serum potassium levels remained steady. According to the conventional protocols established at the Heart Center, Department of Cardiac Surgery (Kaunas University of Medicine), serum potassium levels are kept at ≥ 4.5 mmol/L, and potassium supplements are infused when serum potassium levels decline. The role of potassium in maintaining cardiac rhythm is well established. Hypokalemia causes cellular hyperpolarity, increases resting potential, hastens depolarization, and increases automaticity and excitability (14). Perioperative hypokalemia was associated with atrial arrhythmias with an odds ratio of 1:7 (even after adjusting for confounding factors) in a multicenter trial, where more than 2400 patients were followed up after cardiac surgery (15). Thus, electrolyte imbalances and hypokalemia may contribute to the etiology of postoperative AF. The results of our study confirm the effectiveness of the method. According to the results of our study, serum sodium and ionized calcium levels also did not differ significantly.

Though there are publications showing a high incidence of hypophosphatemia after cardiac surgery, our study did not confirm such findings. Anyway, Cohen et al. (16) in their study found out that severe hypophosphatemia (<0.48 mmol/L) developed in patients who required more blood products and received more cardioactive drugs at the time of admission to the ICU. Thus, catecholamines, which are often required during such procedures and were used intraoperatively in 80% of the patients, might cause an intracellular shift of phosphate via beta-adrenergic receptor mediated stimulation of phosphate uptake, which

appears to be dose dependent. The authors conclude that intraoperative course was more traumatic in the patients who developed severe hypophosphatemia, and the levels of phosphate should be measured more frequently (16).

Urinary electrolyte excretion depends on various factors, as well as on fluid and electrolyte balance. Increased excretion of electrolytes can be caused by the increase of their serum concentration and the expansion of intravascular space. Potassium and calcium excretion is directly related with the sodium intake (orally or intravenously). Calcium excretion depends on serum phosphate level. Magnesium excretion is related with serum magnesium and calcium concentration, extracellular fluid volume, magnesium and phosphate intake. An intensive fluid administration during cardiac surgery may influence urinary electrolyte excretion because of extracellular space expansion by solutions on the base of saline. In addition, detected serum electrolyte deficit is corrected intravenously. On the other hand, a quick correction of serum electrolytes even within physiologic ranges causes a higher excretion of these electrolytes.

A significantly higher magnesium excretion in the group 1 during the surgery and after the surgery was not unexpected. It correlates with the increased serum magnesium concentration before CPB, immediately after the surgery, and 15–18 hours after the surgery. However, during the first day after the surgery, magnesium excretion in the group 2 exceeded normal ranges. It means that magnesium excretion was enhanced not only due to magnesium sulphate infusion (enhances excretion by 2.5 times), but also due to expansion of extracellular space (enhances excretion by 1.5 times).

Calcium excretion remained within normal ranges during the study, though significantly higher in the group 1 compared to the group 2 due to higher serum magnesium. Calcium and magnesium balance is clo-

sely related, so when serum magnesium increases, urinary calcium excretion increases as well. It is supposed that higher magnesium concentration in the peritubular interstitium depresses transcellular calcium absorption in the kidney. Additionally, hypermagnesemia depresses PTH secretion and reabsorption in the kidney (13, 17).

The data of our study confirm that anesthesia and CPB methods for myocardial revascularization in the Clinic of Cardiac Surgery, Hospital of Kaunas University of Medicine, do not disturb electrolyte balance in patients who have no risk factors for electrolyte balance disorders and postoperative atrial fibrillation.

Postoperative AF remains a challenging problem that has not been resolved. The etiology and pathophysiology of AF after heart surgery is incompletely understood. There is still no explanation for the fact that some patients develop postoperative AF whereas others, having the same surgical intervention, remain in sinus rhythm.

Conclusions

1. More than one-quarter (27.4%) of patients had atrial fibrillation on the first three postoperative days after myocardial revascularization surgery with cardiopulmonary bypass. In the most cases atrial fibrillation was tachyarrhythmic and did not disturb hemodynamics.

2. Serum K^+ , Na^+ , Ca^{2+} , Cl^- , P^- concentrations was within normal ranges and serum Mg^{2+} concentration was increased in patients without risk factors for postoperative atrial fibrillation after myocardial revascularization with cardiopulmonary bypass.

3. Magnesium sulphate, infused during myocardial revascularization with cardiopulmonary bypass, did not decrease the rate of postoperative atrial fibrillation in normomagnesemic patients during the first three postoperative days.

Prieširdžių virpėjimas, kraujo serumo ir šlapimo elektrolitų pokyčiai po aortos vainikinių arterijų jungčių suformavimo operacijų

Milda Švagždienė, Edmundas Širvinskas, Rimantas Benetis¹, Laima Ralienė, Violeta Šimatonienė²

Kauno medicinos universiteto Biomedicininio tyrimų institutas,

¹Širdies centras, ²Fizikos, matematikos ir biofizikos katedra

Raktažodžiai: prieširdžių virpėjimas, aortos vainikinių jungčių suformavimo operacija, elektrolitų pusiausvyra serume, magnio papildai, hipomagnezemia.

Santrauka. *Tyrimo tikslas.* Nustatyti prieširdžių virpėjimo dažnį, serumo elektrolitų koncentracijos bei pasiūalinimo su šlapimu pokyčius po miokardo revaskulizacijos operacijų.

Tyrimo medžiaga ir metodai. Gavus Kauno regiono biomedicininį tyrimų Etikos komiteto leidimą bei raštišką ligonių sutikimą, į tyrimą įtraukti 165 ligoniai, kuriems 2004–2005 m. Kauno medicinos universiteto klinikų Kardiochirurgijos klinikoje atliktos miokardo revaskulizacijos operacijos. Tirta K^+ , Na^+ , Mg^{2+} , Ca^{2+} , Cl^- ir P^- koncentracija serume prieš dirbtinę kraujo apytaką (DKA), po operacijos paguldžius į intensyviosios terapijos skyrių, 15–18 val. po operacijos. Taip pat nustatytas K^+ , Na^+ , Mg^{2+} , Ca^{2+} , Cl^- ir P^- pasišalinimas su šlapimu parą iki operacijos, operacijos metu ir parą po operacijos. Širdies veikla buvo stebėta viso tyrimo metu, o atsiradus ritmo sutrikimų, dokumentuota. Visi ligoniai atsitiktinės atrankos būdu suskirstyti į dvi grupes. I grupės ($n=55$) ligoniams skirta magnio sulfato infuzija, II grupės ($n=110$) ligoniams magnio sulfato neskirta.

Rezultatai. Prieširdžių virpėjimo dažnis buvo 27,4 proc. I grupės ligoniams nustatyta reikšmingai didesnė magnio koncentracija serume prieš DKA ir reikšmingai didesnė chloridų koncentracija po operacijos. Magnio ir kalcio pasišalinimas su šlapimu taip pat buvo didesnis I grupės ligoniams operacijos metu ir parą po operacijos. Parą prieš operaciją ir parą po operacijos I grupės ligoniams nustatyta reikšmingai didesnis fosfatų pasišalinimas su šlapimu.

Išvados. Prieširdžių virpėjimas po aortos vainikinių jungčių suformavimo operacijų yra dažnas (27,4 proc.). Elektrolitų koncentracija serume aortos vainikinių jungčių suformavimo operacijų metu ir po jų svyruoja normos ribose. Magnio sulfato infuzija nesumažino prieširdžių virpėjimo dažnio ankstyvuoju pooperaciniu laikotarpiu.

Adresas susirašinėti: E. Širvinskas, KМУ Biomedicininį tyrimų institutas, Eivenių 4, 50009 Kaunas
El. paštas: sirdiskr@kmu.lt

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