〈Regular Article〉

Analysis of water balance for perioperative management in coronary artery bypass grafting

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ABSTRACT For patients who undergo heart surgery, it is well known that good perioperative body fluid management is important because it can affect the postoperative course, particularly the development of complications. The purpose of this study was to clarify the perioperative water balance in coronary artery bypass grafting (CABG) patients and to determine if certain prognostic predictive markers could be adapted for CABG perioperative care. Additionally, fluid balance was examined in CABG surgeries with and without a cardiopulmonary bypass (CPB). Eighteen patients who underwent CABG at Kawasaki Medical Hospital from March 2018 to February 2021 had their perioperative body water levels tracked. An InBody S10 body water analysis machine was used for measurements and the results were retrospectively analyzed. Correlations were found between the preoperative edema index (EI), which is the ratio of extracellular water to TBW, and various predictive markers including preoperative hemoglobin (R^2: 0.4422, p = 0.0026), albumin (R^2: 0.436, p = 0.00286), eGFR (R^2: 0.305, p = 0.0173), and body mass index (BMI) (R^2: 0.2426, p = 0.0378). There was also a correlation between the maximum postoperative value of EI and the length of intensive care unit stay (R^2: 0.3562, p = 0.01466). A sub-analysis was performed of CABG surgeries performed with and without a CPB. Non-CPB surgeries had a larger change in TBW, while CPB surgeries experienced a significantly larger change in EI. The EI can be a predictor of prognosis in CABG surgeries, and fluctuations in the EI were found to vary significantly depending on whether CPB was used or not.

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Key words：Coronary artery bypass graft, Bioelectrical impedance analysis, Edema index; Perioperative water balance

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INTRODUCTION

Generally, the perioperative management of a patient's body fluid can greatly affect the postoperative course. Especially for heart surgery patients, the balance of body fluid can significantly affect the chance of developing postoperative complications[1, 2]. Proper care requires coordination and cooperation between surgeons, anesthesiologists and the intensive care unit (ICU) staff. Currently, the published body of evidence on perioperative body fluid balance is insufficient. In the relatively few available studies that evaluate perioperative body fluid balance during cardiac surgery, an increase of perioperative water levels has been correlated with an extended time of hospital stay, re-admission to the ICU, the need for a blood transfusion, and a higher 90-day mortality rate[3, 4, 5].

One method of assessing perioperative body water balance is bioelectrical impedance analysis (BIA). BIA can non-invasively measure body composition such as water, muscle and fat. Being non-invasive, BIA muscle measurement is widely used to diagnose sarcopenia[6-10].

Edema index (EI), which is the ratio of extracellular water (ECW) to total body water (TBW), is reported to be a predictive indicator of the drainage amount in acute heart failure patients. Also reported in the critical care field, mortal patients in the ICU had higher EI[11]. A previous report of ours analyzed perioperative water changes in valvular heart disease patients using BIA and showed that the EI can be a postoperative prognostic indicator[12]. Also, there are reports that the phase angle, which is a measurement value of BIA, has a correlation to the nutritional status index and can be a predictive indicator for the amount of blood transfusion required during cardiac surgery[12-15].

The chance of pleural effusion in coronary artery bypass grafting (CABG) cases is high and we often have a difficulty to manage water balance in the clinical setting. The postoperative course must be different from that of valvular disease surgeries[12].

The purpose of this study was to clarify perioperative water changes in CABG patients and to assess if the EI that we reported on in our previous study was similarly applicable to CABG patients as a prognostic predictive marker[12]. Also, water changes when using a cardiopulmonary bypass (CPB) or not during CABG were retrospectively analyzed and evaluated.

METHODS

Patients

Body water changes in 18 patients who underwent a CABG at Kawasaki Medical Center from March 2018 to February 2021 were measured and retrospectively analyzed. Cases requiring urgent surgery, patients with an implanted pacemaker and cases that could not otherwise be measured were excluded from this study. Patient background data is shown in Table 1. Males were the vast majority of cases with 16 (88.9%), and the average age was 67.8 ± 10.75 years old. There were 9 cases (50.0%) with a history of diabetes, 16 cases (88.9%) had a smoking history and 17 cases (94.4%) had hypertension. Patients were managed according to the discharge criteria from ICU after surgery.

Measurements

An InBody S10 water analysis machine was used for the measurements (InBody Japan, Tokyo, Japan). Eight-polar BIA technology calculates the electric impedance from a weak flow of electric current through eight contacts in the hands and feet, which can be used to measure various body components. By measuring at multiple frequencies, intracellular water (ICW) and extracellular water can be accurately and separately estimated[12].

Eight-polar BIA values were measured at 6 different frequency settings (1, 5, 50, 250, 500 and 1,000 kHz). Measurements taken were the levels of extracellular water, ICW, TBW, the EI, which is the

Table 1. Baseline characteristics of all patients

Factor	
Patients	Mean [SD]
Age	67.77 [10.57]
LVEF (%)	55.14 [9.97]
Phase angle (degree)	6.11[2.17]
BMI (kg/m^2)	24.08 [4.82]
Albumin (g/dL)	3.91 [0.57]
Hemoglobin (g/dL)	13.34 [2.40]
BNP (pg/dL)	172.86 [232.30]
eGFR (ml/min/1.73m^2)	56.98 [21.89]
Na (mEq/l)	139.78 [2.82]
K (mEq/l)	4.31 [0.63]
Cl (mEq/l)	104.44 [3.31]
Operative Characteristics	
Duration of surgery (min)	413.83 [51.70]
Water balance during surgery (ml)	2545.06 [986.69]
Perioperative BIA data	
Preoperative BIA data	
Intracellular water [ICW preoperative] (kg)	22.33 [4.71]
Extracellular water [ECW preoperative] (kg)	14.13 [2.76]
Total body water [TBW preoperative] (kg)	37.34 [9.11]
Edema index [EI preoperative]	0.39 [0.012]
Peak BIA data	
ICW peak (kg)	24.07 [4.76]
ECW peak (kg)	16.07 [2.87]
TBW peak (kg)	40.02 [7.53]
EI peak	0.41 [0.0085]
Differences between pre and peak data	
TBW peak-preoperative (kg)	2.68 [4.19]
EI peak-preoperative	0.018 [0.0069]

Values are expressed as the mean and SD in branckets for continuous factors.
LVEF, left ventricle ejection fraction; BMI, body mass index; BNP, brain natriuretic peptide; eGFR, estimated glomerular filtration rate; BIA, bioelectrical impedance analysis; ICW, intracellular water; ECW, extracellular water; TBW, total body water; EI, edema index; ICU, Intensive Care Unit

ratio of ECW to TBW, and the phase angle, which is the arctangent value of the directly measured ratio of reactance to resistance. The phase angle does not depend on conventional body composition regression equations and has been reported as a predictive marker of both frailty and severity of chronic heart failure[15, 16]. The first EI measurement taken was designated as the "preoperative EI" and the maximum measured EI as the "peak EI".

In addition to the BIA water balance measurements, other clinical data collected during the perioperative period was the occurrence of atrial fibrillation and pleural fluid, ventilation duration and the length of ICU stay.

Ethics

This study was conducted with the approval of the ethics committee of Kawasaki Medical School, and informed consent was given by all patients. This study was approved by the institutional ethics board of Kawasaki Medical School (No. 3651-01).

Statistical analysis

Linear regression analysis was used to identify correlations between the preoperative EI and postoperative peak EI data for each patient, using the BIA data (ECW, ICW, TBW), and the more conventional blood analysis and water management data (hemoglobin, creatinine, BNP; brain natriuretic peptide, albumin, eGFR; estimated glomerular filtration rate, age, body mass index (BMI), change in body weight, duration of surgery, ventilation time and ICU stay). Simple linear regression analysis was employed to find possible correlations between the BIA data and all of the other parameters, including outcomes. Additionally, surgeries with a CPB and those without a CPB were compared using a t-test. A two-tailed p value less than 0.05 was considered significant. Statistical analysis was performed with R 3.6.0 software (The R Foundation, Vienna, Austria).

RESULTS

Preoperative data

The preoperative blood data for all 18 cases are shown in Table 1: hemoglobin, 13.3 ± 2.3 g/dL; hematocrit, 40.1 ± 6.5%; creatinine, 1.4 ± 1.5 mg/dL; BNP, 172.8 ± 232.3 ng/dL; eGFR, 57.0 ± 21.9 mL/min/1.7m^2; and albumin, 3.9 ± 0.6 g/dL. The surgical factors were a surgical duration of 413.8

± 51.7 min; 7.0 ± 10.5 hours of ventilation and an ICU stay of 4.5 ± 1.3 days.

Correlation with preoperative EI

The following factors showed a correlation with the preoperative EI: preoperative hemoglobin (R^2: 0.4422, p = 0.0026) (Fig. 1), albumin (R^2: 0.436, p = 0.00286) (Fig. 2), eGFR (R^2: 0.305, p = 0.0173) (Fig. 3), BMI (R^2: 0.2426, p = 0.0378) (Fig. 4). There was also a correlation between the postoperative peak EI and the length of ICU stay (R^2: 0.3562, p = 0.01466) (Fig. 5). There was no correlation found between preoperative EI and ventilation time (R^2: 0.001046, p = 0.0617), nor between preoperative EI and the length of hospital stay (R^2: 0.02313, p = 0.574). There was also no correlation between peak EI and ventilation time (R^2: 0.005224, p = 0.7902) or the length of hospital stay (R^2: 0.0004462, p = 0.9381). The preoperative EI and the length of ICU stay (R^2: 0.210, p = 0.0555) (Fig. 6) showed a tendency that was below the threshold of significance.

Difference of baseline characteristics

Table 2 shows the patient background, surgical factors and perioperative BIA water values divided for the sub-analysis of CPB and non-CPB cases. There was no significant difference

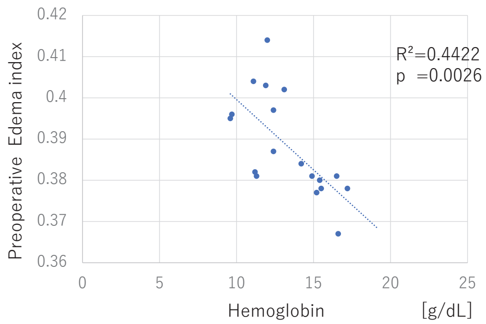

Fig. 1. Relationship between the preoperative edema index (EI) and preoperative hemoglobin. There was a negative correlation between the preoperative EI and preoperative hemoglobin (R = 0.664, p = 0.0026).

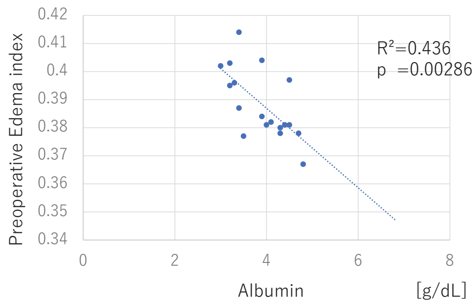

Fig. 2. Relationship between the preoperative edema index (EI) and preoperative albumin. There was a negative correlation between the preoperative EI and preoperative albumin (R = 0.660, p = 0.0028).

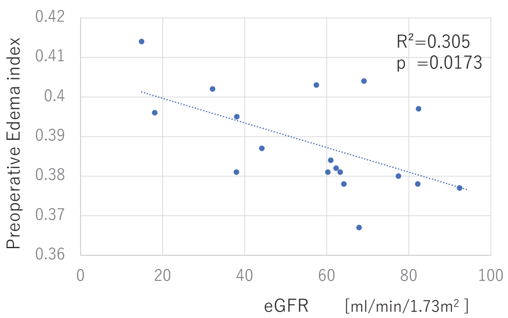

Fig. 3. Relationship between the preoperative edema index (EI) and preoperative eGFR.
There was a negative correlation between the preoperative EI and preoperative eGFR (R = 0.552, p = 0.017).

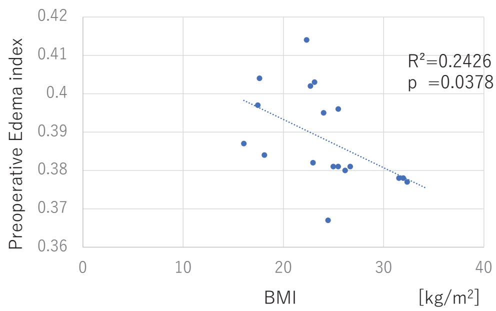

Fig.4. Relationship between the preoperative edema index (EI) and preoperative BMI.
There was a negative correlation between the preoperative EI and preoperative BMI (R = 0.492, p = 0.037).

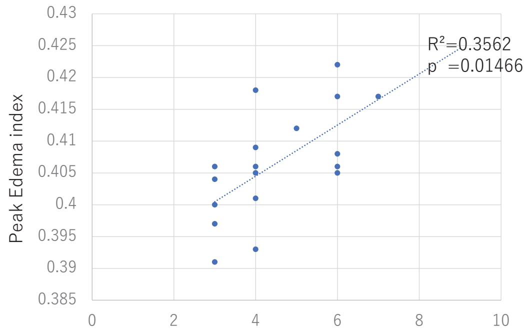

Fig. 5. Relationship between the postoperative peak edema index (EI) and the duration of the intensive care unit (ICU) stay. There was a positive correlation between the postoperative peak EI and the duration of the ICU stay. (R = 0.596, p = 0.0378).

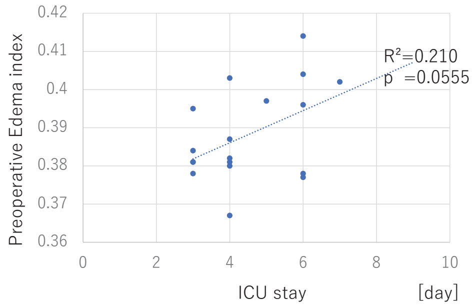

Fig.6. Relationship between the preoperative edema index (EI) and the duration of the intensive care unit (ICU) stay. There was a tendency of positive correlation between the preoperative EI and the duration of the ICU stay, but it was not significant (R = 0.458, p = 0.055).

Table 2. Difference of baseline characteristics between off pump and on pump coronary artery bypass grafting.

Factor	Mean [SD]		
Patients	Off pump	On pump	P value
Age	70.56[11.97]	65 [8.77]	0.28
LVEF (%)	54.4 [10.60]	55.89 [9.89]	0.76
Phase angle (degree)	4.97 [1.03]	7.26[2.45]	0.02
BMI (kg/m^2)	22.46 [4.82]	25.70 [4.49]	0.16
Albumin (g/dL)	3.63 [0.51]	4.19 [0.52]	0.035
Hemoglobin (g/dL)	12.34 [1.75]	14.34 [2.63]	0.076
BNP (pg/dL)	199.89 [207.07]	145.83 [264.86]	0.64
eGFR (ml/min/1.73m^2)	48.58 [20.70]	65.38 [20.76]	0.1
Na (mEq/l)	140.44 [3.36]	139.11 [2.15]	0.33
K (mEq/l)	4.14 [0.52]	4.47 [0.71]	0.29
Cl (mEq/l)	105 [4.18]	103.89 [2.26]	0.49
Operative Characteristics			
Duration of surgery (min)	403.78 [39.67]	423.89 [62.28]	0.43
Water balance during surgery (ml)	2552.78 [1107.10]	2537.33 [918.14]	0.97
Perioperative BIA data			
preoperative BIA data			
Intracellular water [ICW preoperative] (kg)	20.62 [4.70]	24.04 [4.31]	0.13
Extracellular water [ECW preoperative] (kg)	13.38 [2.84]	14.88 [2.63]	0.26
Total body water [TBW preoperative] (kg)	34.02 [7.53]	40.67 [9.74]	0.12
Edema index [EI preoperative]	0.39 [0.012]	0.38 [0.0093]	0.032
Peak BIA data			
ICW peak (kg)	23.11 [5.33]	25.03 [4.21]	0.41
ECW peak (kg)	15.57 [3.13]	16.58 [2.67]	0.47
TBW peak (kg)	38.58 [8.37]	41.47 [6.75]	0.43
EI peak	0.41 [0.010]	0.40 [0.0054]	0.22
Differences between pre and peak data			
TBW peak-preoperative (kg)	4.56 [1.58]	0.8 [5.17]	0.054
EI peak-preoperative	0.015 [0.0049]	0.022 [0.0070]	0.023

Values are expressed as the mean and SD in branckets for continuous factors.

between the CPB and non-CPB groups in terms of age, preoperative ejection fraction, BMI, hemoglobin, BNP or eGFR. The CPB group had significantly higher phase angle and albumin values. No significant difference was found in terms of operation duration or intraoperative water balance. Preoperative and postoperative ICW, ECW, and TBW had no significant differences, and only preoperative EI was significantly lower in the CPB group. However, the non-CPB group had a tendency to have higher changes in TBW, and the change of EI was significantly more in the CPB group.

DISCUSSION

Preoperative EI showed a significant correlation to preoperative hemoglobin, albumin, eGFR and BMI. Our prior study on EI in valvular disease surgeries also showed that preoperative EI has a correlation to preoperative hemoglobin, albumin, eGFR and BMI. These factors define the water balance in the body regardless of whether a patient has valvular or ischemic heart disease[12].

Preoperative EI in this study showed a tendency, but not a significant correlation, with the length of ICU stay. Thus, further research should be carried out to determine if the tendency might be significant when a greater number of cases are examined and whether preoperative EI could be used as an indicator of the length of ICU stay. On the other hand, there was a significant correlation between the postoperative peak EI and ICU stay, so maintaining a proper postoperative water balance may be a possible way to improve patient prognosis. The length of hospital stay is often affected by cultural factors, and no correlation was found in this study. The occurrence of delirium was not examined in this study, but is reported to greatly affect the length of hospital admission[16−20].

The retrospective sub-analysis of CPB and non-CPB cases showed a significant difference in preoperative albumin and phase angle, but no significant difference in cardiac function, heart failure or other surgical factors. The two surgery types had no significant difference in the absolute values of the BIA water balance measurements, but the TBW in the non-CPB group had a greater increase. On the contrary, the change in EI was significantly more in the CPB group.

The two groups had no difference in preoperative water balance nor in intraoperative water input/output, so the surgery type itself could be an influential factor. The EI in the CPB group changed greatly, and the intracellular and extracellular water levels were more off balance due to the extracorporeal circulation. The CPB cases also showed a significantly higher preoperative albumin and the phase angle, but those higher values usually indicate a better nutritious status and body fluid would be less likely to lose balance. Yet the results showed that the EI increased in the CPB cases, which could mean that using a CPB has a greater effect than a patient's background does.

In examining the 18 cases, the EI showed a correlation to the length of ICU stay, which matched our previous examination of valvular disease cases, and EI could therefore be a prognostic indicator of ICU stay. The higher the preoperative EI, the more possible it is to suppress the change in EI. By choosing a non-CPB surgery and suppressing the maximum postoperative EI, an improvement in prognosis may be possible. Also, the preoperative EI value could be a reference when choosing to use a CPB or not. The adjustment of preoperative physical conditions and the strict management of perioperative water balance are certainly a matter of great importance.

This study indicated the possibility for the EI to be a predictive indicator of prognosis in CABG patients. EI can be one of the factors considered when choosing the appropriate surgical treatment, and a non-CPB CABG can minimize the perioperative change in EI, which may lead to better short term outcomes. Also, the present study has some limitations in terms of case number or study design such as a retrospective analysis

CONCLUSIONS

EI is applicable as a predictive indicator of prognosis in coronary artery bypass grafting and can be a useful factor in deciding to perform a CPB or not.

CONFLICTS OF INTEREST

The authors have no conflicts of interest to disclose.

REFERENCES

1) Toraman F, Evrenkaya S, Yuce M, Turek O, Aksoy N, Karabulut H, Demirhisar O, Alhan C: Highly positive intraoperative fluid balance during cardiac surgery is associated with adverse outcome. Perfusion 2004; 19: 85-91. doi: 10.1191/0267659104pf723oa.

2) Li C, Wang H, Liu N, Jia M, Zhang H, Xi X, Hou X; Beijing Acute Kidney Injury Trial (BAKIT) Workgroup: Early negative fluid balance is associated with lower mortality after cardiovascular surgery. Perfusion 2018; 33: 630-637. doi: 10.1177/0267659118780103.

3) Varelmann D, Shook D, Buric D, *et al.*: Enhanced recovery after cardiac surgery: fluid balance and incidence of acute kidney injury. J Cardiothorac Vasc Anesth 2019; 33: S141-142. DOI: https://doi.org/10.1053/j.jvca.2019.07.015.

4) Elham SD, Houshang S, Hooman B, Mostafa S, Seyed MA: Fluid balance has effects on the length of hospital stay after coronary artery bypass grafting surgery. Iran J Kidney Dis 2020; 14: 36-43.

5) Rosner MH, Okusa MD: Acute kidney injury associated with cardiac surgery. Clin J Am Soc Nephrol 2006; 1: 19-32. doi: 10.2215/CJN.00240605.

6) Kyle UG, Bosaeus I, De Lorenzo AD, *et al.*: Bioelectrical impedance analysis--part I: review of principles and methods. Clin Nutr 2004; 23: 1226-1243. doi: 10.1016/j.clnu.2004.06.004.

7) Gonzalez MC, Heymsfield SB: Bioelectrical impedance analysis for diagnosing sarcopenia and cachexia: what are we really estimating? J Cachexia Sarcopenia Muscle 2017; 8: 187-189. doi: 10.1002/jcsm.12159.

8) Chen LK, Liu LK, Woo J, *et al.*: Sarcopenia in Asia: consensus report of the Asian Working Group for Sarcopenia. J Am Med Dir Assoc 2014; 15: 95-101. doi: 10.1016/j.jamda.2013.11.025.

9) Cruz-Jentoft AJ, Baeyens JP, Bauer JM, *et al.*: Sarcopenia: European consensus on definition and diagnosis: Report of the European Working Group on Sarcopenia in Older People. Age Ageing 2010; 39: 412-423. doi: 10.1093/ageing/afq034.

10) Fearon K, Strasser F, Anker SD, *et al.*: Definition and classification of cancer cachexia: an international consensus. Lancet Oncol 2011; 12: 489-495. doi: 10.1016/S1470-2045(10)70218-7.

11) Sung Hoon Kim, Jae Gil Lee, Hyoung Won Cho, *et al.*: The Clinical Application of Bioelectrical Impedance Analysis in Patients with Critical Illness. Surg Metab Nutr 2010; 1: 30-35.

12) Watanabe T, Ishida N, Takaoka M, *et al.*: Bioelectrical impedance analysis for perioperative water management in adult cardiovascular valve disease surgery. Surg Today. (Epub: 2020.12.1), doi: 10.1007/s00595-020-02184-3 (e-pub on ahead).

13) Barbosa Silva MC, Barros AJ, Post CL, Waitzberg DL, Heymsfield SB: Can bioelectrical impedance analysis identify malnutrition in preoperative nutrition assessment? Nutrition 2003; 19: 422-6. doi: 10.1016/s0899-9007(02)00932-2.

14) Ringaitiene D, Gineityte D, Vicka V, Zvirblis T, Norkiene I, Sipylaite J, Irnius A, Ivaskevicius J: Malnutrition assessed by phase angle determines outcomes in low-risk cardiac surgery patients. Clin Nutr 2016; 35: 1328-1332. doi: 10.1016/j.clnu.2016.02.010. Epub 2016 Feb 18.

15) Ringaitiene D, Gineityte D, Vicka V, Sabestinaite A, Klimasauskas A, Gaveliene E, Rucinskas K, Ivaska J, Sipylaite J: Concordance of the new ESPEN criteria with low phase angle in defining early stages of malnutrition in cardiac surgery. Clin Nutr 2018; 37: 1596-1601. doi: 10.1016/j.clnu.2017.08.007. Epub 2017 Aug 12.

16) Uemura K, Doi T, Tsutsumimoto K, Nakakubo S, Kim MJ, Kurita S, Ishii H, Shimada H: Predictivity of bioimpedance phase angle for incident disability in older adults. J Cachexia Sarcopenia Muscle 2020; 11: 46-54. doi: 10.1002/jcsm.12492. Epub 2019 Aug 22.

17) Tanya Mailhot RN, Sylvie Cossette RN, Jean Lambert,

et al.: Delirium After Cardiac Surgery and Cumulative Fluid Balance: A Case-Control Cohort Study. J Cardiothorac Vasc Anesth 2019; 33: 93-101. doi: 10.1053/j.jvca.2018.07.012. Epub 2018 Aug 17.

18) Rudolph JL, Jones RN, Levkoff SE, *et al.*: Derivation and validation of a preoperative prediction rule for delirium after cardiac surgery. Circulation 2009; 119: 229-236. doi: 10.1161/CIRCULATIONAHA.108.795260. Epub 2008 Dec 31.

19) Saczynski JS, Marcantonio ER, Quach L, Fong TG, Gross A, Inouye SK, Jones RN: Cognitive trajectories after postoperative delirium. N Engl J Med 2012; 367: 30-39. doi: 10.1056/NEJMoa1112923.

20) Inouye SK, Westendorp RG, Saczynski JS: Delirium in elderly people. Lancet 2014; 911-912. doi: 10.1016/S0140-6736(13)60688-1.