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The role of serum cystatin C level in detection of early onset kidney injury after coronary artery bypass surgery

Koroner arter baypas cerrahisi sonrası erken dönemde gelişen böbrek hasarının saptanmasında serum sistatin C düzeyinin rolü

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Abstract

Aim: Acute kidney injury (AKI) is an important condition after coronary artery bypass graft (CABG) surgery. Precautions can be taken to prevent AKI by recognizing the risky patients in the preoperative period. In this study, we investigated the relationship between the serum cystatin C (CyC) levels and AKI after CABG surgery.

Methods: A total of 42 patients (mean age 59.33 (6.66) and 69% male) who underwent isolated on-pump CABG between June 2018 and January 2019 were included in this prospective cohort study. Creatinine and CyC levels were evaluated at the preoperative period, postoperative 2nd and 24th hours. Patients were assessed for the development of AKI according to the Acute Kidney Injury Network criteria and divided into two groups as those with and without AKI in the postoperative period.

Results: Based on the creatinine level at the postoperative 24th hour, 9 (21.4%) patients developed AKI. Compared to patients who did not develop AKI, it was found that CyC level was significantly higher at the postoperative 2nd hour in patients who developed AKI (1.06 (0.26) vs 0.87 (0.19), P=0.023). In patients who developed AKI, the duration of cross-clamp was significantly longer (P=0.038), and erythrocyte suspension (P<0.001) and the number of fresh frozen plasma infusions (P<0.001) were significantly higher.

Conclusion: Increased CyC levels were associated with the development of AKI in the early postoperative period. CyC measurements performed in the initial period after CABG can be used in the diagnosis of cardiac surgery related AKI.

Keywords: Coronary artery bypass graft surgery, Serum cystatin C, Acute kidney injury

Öz

Amaç: Akut böbrek hasarı (AKI), koroner arter baypas greft (KABG) ameliyatından sonra gelişebilen önemli bir klinik durumdur. Preoperatif dönemde riskli hastaları tanıyarak AKI'nın önlenmesi için önlemler alınabilir. Bu nedenle, AKI için risk faktörlerini belirlemek çok önemlidir. Bu çalışmada, serum sistatin C (CyC) düzeyleri ile CABG cerrahisi sonrası gelişen AKI arasındaki ilişkiyi araştırdık.

Yöntemler: Haziran 2018-Ocak 2019 tarihleri arasında kardiyopulmoner bypass eşliğinde yapılan KABG cerrahisi yapılan toplam 42 hasta (ortalama yaş 59,33 (6,66) ve %69 erkek) bu prospektif kohort çalışmasına dahil edildi. Acut Kidney İnjury Network (AKİN) kriterlerine göre AKI gelişimi değerlendirildi. Hastalar postoperatif dönemde AKI olan ve olmayanlar olmak üzere iki gruba ayrıldı.

Bulgular: Postoperatif 24. saatte kreatinin düzeyine göre 9 (%21,4) hastada AKI gelişti. AKI gelişmeyen hastalarla karşılaştırıldığında, AKI gelişen hastalarda postoperatif 2. saatte CyC düzeyinin kreatinin düzeyine göre anlamlı derecede yüksek olduğu bulundu (1,06 (0,26) vs 0,87 (0,19), P=0,023). AKI gelişen hastalarda krosklemp süresi anlamlı olarak daha uzun (P=0,038), eritrosit süspansiyonu (P<0,001) ve taze donmuş plazma (P<0,001) kullanımı AKI gelişmeyen hastalardan anlamlı olarak daha yüksekti.

Sonuç: Artmış CyC düzeyleri, postoperatif erken dönemde AKI gelişimi ile ilişkili bulunmuştur. CABG sonrası erken dönemde yapılan CyC ölçümleri, kalp cerrahisi ile ilişkili AKI tanısında kullanılabilir.

Anahtar kelimeler: Koroner arter baypas greft cerrahisi, Serum sistatin C, Akut böbrek hasarı

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Introduction

Development of kidney failure after coronary artery bypass graft (CABG) surgery is one of the significant causes of morbidity and mortality [1]. Cardiac surgery-associated acute kidney injury (CSA-AKI) affects approximately 30% of the cases who undergo cardiac surgery. CSA-AKI development is related with lengthened hospital stays and increased mortality rates [2-4]. Various inflammatory parameters have been extensively studied in the diagnosis and prediction of the prognosis of cardiovascular diseases [5,6]. One of them, cystatin C (CyC) is a 13kD endogenous cysteine proteinase inhibitor that plays an important role in the intracellular catabolism of proteins and peptides. Some studies have shown that, in comparison to creatinine, CyC is a better marker in terms of the detection of kidney injury [7,8]. In patients who had cardiac surgery, it was shown that CyC measurement made within the first 24 hours following the operation could detect AKI development earlier [9]. In bypass surgeries, preoperative CyC levels were associated with postoperative kidney injury development [10]. To prevent CSA-AKI formation, studies are carried out on modifiable risk factors. Operation time and cross-clamp duration have special significance [1]. The relationship between an increase in early-term CyC levels and AKI development has not been reported yet. This study investigated the relationship between the postoperative change of blood CyC levels in patients receiving CABG surgery and early-developing CSA-AKI, and the effect of cross-clamp duration.

Materials and methods

Patient selection

After approval of the ethics committee from Harran University (2018 74059997-050.04.04), the trial was registered on ANZCTR with Id of ACTRN12619000061134. Written consent was obtained from the patients. This prospective cohort study included forty-two consecutive patients between the ages of 18-80 years who underwent CABG surgery between June 2018 and January 2019. Patients were divided into two groups as those with and without AKI. Renal failure after the operation was determined according to the Acute Kidney Injury Network (AKIN) criteria, as shown below [2]:

Stage 1: Increase in serum creatinine ≥1.5 × baseline or ≥0.3 mg/dL, or decrease in glomerular filtration rate (GFR) ≥25%

Stage 2: Increase in serum creatinine ≥2.0 × baseline or decrease in GFR ≥50%

Stage 3: Increase in serum creatinine ≥3.0 × baseline or ≥4.0 mg/dL (354 μmol/L), or decrease in GFR ≥75%, or initiation of renal replacement therapy

Patients with kidney disease (preoperative creatinine level >2 mg/dl), hemodialysis patients, those who were planned to undergo cardiac valve surgery with CABG surgery, pregnant patients, those to receive revision surgery, patients in whom normotension could not be achieved with inotropic support after development of hypotensive attack, and patients who had emergency surgery (those taken into surgery within 24 hours following coronary angiography application) were excluded. The demographic data (age, gender, height, weight) of the patients and their preoperative left ventricular ejection fraction (LVEF) were recorded. Written informed consent was obtained from all patients.

Blood sampling

Preoperatively and at the 2nd and 24th postoperative hours, blood samples were collected for BUN, creatinine and CyC. For CyC measurements, 5-ml serum separator tubes were used, and the obtained blood samples were centrifuged and kept at -80°C until analyzed. The serum CyC analyses were carried out by the "immunonephelometric method" in a Siemens BN ProSpec analyzer by using the Siemens N Latex Cystatin C commercial kits (Dade-Behring, Germany) (reference range: 0.62-1.11 mg/L).

Statistical analysis

The data were analyzed with SPSS 20.0 software (SPSS Inc. an IBM Company, Chicago, USA). Kolmogorov-Smirnov test was used to check the normality of distribution of the variables. The normally distributed continuous variables were compared with student's t-test and represented as mean ± standard deviation. The non-normally distributed continuous variables were compared by Mann Whitney-U test and represented as median (25-75th quartiles). The categorical variables were represented as frequency (percentage) and compared with chi-square or Fisher's exact tests. Pearson's or Spearman's correlation coefficient was used for correlation analysis. *P*-values<0.05 were considered statistically significant.

Results

The preoperative basal characteristics of 42 patients who were included in the study are shown in Table 1. The mean age of the patients was 59.33 (6.66) years, and 69% (29) of the patients were male. Seventeen patients (40.5%) had a history of hypertension, while 16 (38.1%) had a history of diabetes mellitus. The mean LVEF was 53.7% (5.4).

The postoperative basal characteristics of the patients are presented in Table 2. While the median cross-clamp duration was 95 (80-120) minutes, the median bypass duration was 127 (100-146) minutes. The mean extubation time after the operation was 5.83 (0.96) hours. Inotropic agent support was used in 17 patients. Considering the creatinine level at the 24th postoperative hour, acute kidney injury (AKI) developed in 9 (21.4%) patients.

Table 1: Preoperative basal characteristics of patients

Variables	(n=42)
Age, years, mean(sd)	59.33 (6.66)
Male gender (%)	29 (69.0)
Hypertension (%)	17 (40.5)
Diabetes mellitus (%)	16 (38.1)
Smoking (%)	14 (33.3)
Ejection Fraction (%),mean(sd)	53.7 (5.4)
Preoperative urea, mg/dL, mean(sd)	33.41 (12.85)
Preoperative creatinine, mg/dL, mean(sd)	0.75 (0.18)
Preoperative Cystatin C, mean(sd)	0.87 (0.20)

Table 2: Postoperative basal characteristics of patients

Variables	(n=42)
Cross-clamp duration, min.	95 (80-120)
Cardiopulmonary Bypass duration, min.	127 (100-146)
Number of grafts	3.17 (0.76)
Extubation hour	5.83 (0.96)
Mediastinal drainage amount, ml	300 (237-400)
Thorax drainage amount, ml	300 (200-400)
Number of erythrocyte suspensions given	2 (1-3)
Number of fresh frozen plasma given	2 (2-3)
Inotropic support (%)	17 (40.5)
Acute kidney injury development (%)	9 (21.4)

min: minutes, ml: milliliters

Table 3 shows the comparison of the preoperative characteristics of the patients who developed AKI and those who did not. There was no statistically significant difference between the groups in terms of preoperative characteristics. Table 4 shows the comparison of postoperative characteristics of these patients. In comparison to the patients who did not develop AKI, those who did had longer cross-clamp durations (P=0.038) and higher amounts of erythrocyte suspension (P<0.001) and fresh frozen plasma infused (P<0.001). These differences were all statistically significant. The patients who developed AKI had significantly higher cystatin levels at the 2nd postoperative hour (1.06 (0.26) vs 0.87 (0.19), P=0.023). Furthermore, as expected, the 24th-hour creatinine levels in the patients who developed AKI were significantly higher than those who did not (0.99 (0.30) vs 0.71 (0.21), P=0.003). However, there was no statistically significant difference between the groups in terms of the 2nd-hour creatinine levels (P=0.167).

Creatinine level in 3 patients, and cystatin levels in 9 patients increased significantly at the 2nd postoperative hour compared to basal levels. Table 5 shows the comparison of the patients who did and did not develop AKI in terms of significant creatinine and cystatin increase at the 2nd postoperative hour. Among 9 patients who developed AKI, only 2 had significant creatinine and 8 had significant CyC increase at the 2nd postoperative hour. There was no significant difference between the groups in terms of creatinine increase (P=0.111), however, CyC increase was significantly higher in the AKI- developing group (88.9% vs 33.3%, P=0.006). The correlation analysis revealed that cross-clamp duration was positively correlated with the postoperative 2nd hour cystatin (r=0.406, P=0.008), postoperative 2nd hour creatinine (r=0.400, P=0.009) and postoperative 24th hour creatinine (r=0.385, P=0.012) levels. Additionally, postoperative 2nd hour CyC level was positively corelated with the postoperative 2nd hour creatinine (r=0.425, P=0.005) and postoperative 24th hour creatinine (r=0.531, P<0.001) levels (Figure 1).

Table 3: Comparison of the preoperative characteristics of patients who developed AKI and those who did not

	AKI [-] (n=33)	AKI [+] (n=9)	*P*-value
Age, years	58.36 (6.48)	62.89 (6.41)	0.084
Male gender (%)	22 (66.7)	7 (77.8)	0.695
Hypertension (%)	16 (48.5)	1 (11.1)	0.060
Diabetes mellitus (%)	13 (39.4)	3 (33.3)	1.000
Smoking (%)	9 (27.3)	5 (55.6)	0.133
Ejection Fraction (%)	54.24 (5.46)	51.67 (5.00)	0.201
Preoperative urea, mg/dl	33.18 (12.29)	34.29 (15.54)	0.821
Preoperative creatinine, mg/dl	0.77 (0.16)	0.66 (0.19)	0.070
Preoperative Cystatin C	0.86 (0.20)	0.87 (0.20)	0.909

AKI: Acute kidney injury, mg: milligrams, dl: deciliters

Table 4: Comparison of the postoperative characteristics of patients who did and did not develop AKI

	AKI [-] (n=33)	AKI [+] (n=9)	*P*-value
Cross-clamp duration, min.	88 (71-114)	113 (96-124)	0.038
Cardiopulmonary Bypass duration, min.	117 (95-143)	143 (120-159)	0.052
Number of grafts	3.15 (0.83)	3.22 (0.44)	0.809
Extubation hour	5.73 (1.01)	6.22 (0.67)	0.174
Mediastinal drainage amount, ml	300 (225-400)	300 (250-375)	0.857
Thorax drainage amount, ml	300 (250-400)	200 (125-350)	0.056
Number of erythrocyte suspensions given	1.79 (0.65)	3.78 (0.67)	< 0.001
Number of fresh frozen plasma given	2.24 (0.50)	3.33 (0.87)	< 0.001
Inotropic support (%)	11 (33.3)	6 (66.7)	0.124
Postoperative 2nd hour urea, mg/dl	35.92 (9.15)	41.96 (15.11)	0.139
Postoperative 2nd hour Creatine, mg/dl	0.75 (0.20)	0.85 (0.23)	0.167
Postoperative 2nd hour Cystatin C	0.87 (0.19)	1.06 (0.26)	0.023
Postoperative 24th hour urea, mg/dl	36.08 (12.38)	45.22 (18.55)	0.281
Postoperative 24th hour Creatinine, mg/dl	0.71 (0.21)	0.99 (0.30)	0.003
Postoperative 24th hour Cystatin c	0.93 (0.20)	1.09 (0.28)	0.143

AKI: Acute kidney injury, mg: milligrams, dl: deciliters, ml: milliliters

Table 5: Comparison of the patients who did and did not develop AKI based on postoperative 2nd hour significant creatine and cystatin increase

	AKI [-] (n=33)	AKI [+] (n=9)	*P*-value
2nd hour significant creatinine increase n(%)	1 (3)	2 (22.2)	0.111
2nd hour significant cystatin increase n(%)	11 (33.3)	8 (88.9)	0.006

AKI: Acute kidney injury, Significant creatinine increase: Any stage of the Acute Kidney Injury Network criteria, Significant cystatin increase: At least 15% increase compared to basal value

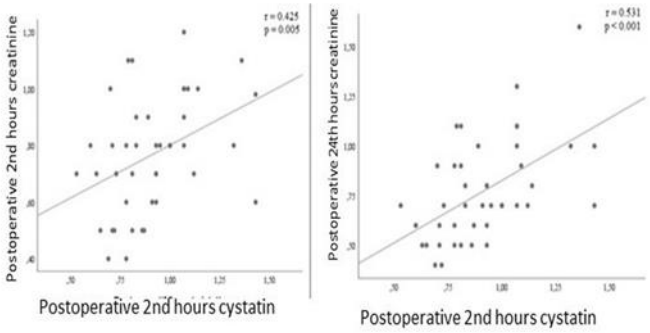

Figure 1: Comparison of Cystatin C and Creatinine values

Discussion

The main finding obtained in this study is that a relationship was determined between early postoperative period CyC levels and AKI. CyC is a protein with a low molecular weight. Although the serum concentrations of many proteins with low molecular weights increase in inflammatory, immunological, and neoplastic disorders, CyC concentrations remain unaffected. Many studies have shown that its disposal from the body occurs only by glomerular filtration, it does not vary based on age, gender, or body muscle mass, and it is better than creatinine as a glomerular filtration rate (GFR) indicator. CyC is not bound by any protein and is freely filtered from the glomerulus. Differing from creatinine, it does not undergo tubular secretion, and its half-life (90-120 min – 4 h) is shorter [8]. The production rate of CyC is highly stable, and its plasma concentration may be used as a reliable measurement of the glomerular filtration rate. In comparison to other biomarkers, it was reported that measurement of blood CyC levels provided the best results in determining AKI development in postoperative care patients in the intensive care unit after cardiac surgery [11]. In a study they conducted with 1246 patients, Wasen et al. showed that increases in CyC and creatinine levels are highly associated with AKI development [12]. In our study, we examined CyC levels in the postoperative early period and observed an increase, which was related to AKI development. This suggests that CyC measurement may be useful in predicting a kidney injury that starts during an operation.

One important finding of our study is the positive correlation between cross-clamp duration and AKI, where more AKI development was observed in cases with prolonged cross-clamp duration. In physiological conditions, until the average blood pressure drops under 80 mmHg, the glomerular filtration rate (GFR) is preserved by autoregulation. During cardiac surgery, the average blood pressure progresses under the critical limit. It was shown that there is a noticeable decrease (25-70%) in kidney blood flow, as well as a reduction in glomerular filtration rate in patients undergoing cardiac surgery. Patients' exposure to angiotensin-converting enzyme, angiotensin receptor blockers, non-steroid anti-inflammatory drugs and nephrotoxic drugs such as radiocontrast agents increases their risk of kidney failure. During CPB, low perfusion pressure and non-pulsatile

flow reduce kidney blood flow and increase renin secretion and angiotensin-II production. During CPB, patients are exposed to strong systemic inflammatory response. Inflammation is a major risk factor for ischemic kidney injury [2]. A retrospective study which investigated 669 patients between the ages of 18-40 years who underwent cardiac surgery due to congenital heart disease reported that a mean cross-clamp duration of 52 minutes was associated with increased AKI [13]. Another study conducted in 145 pediatric cardiac surgery cases reported that CPB and long aortic cross-clamp duration were effective in development of AKI [14]. A study on 45 patients who received off-pump CABG reported that AKI developed in 24%, and CPB and aortic cross-clamp durations were significantly longer in patients who developed AKI in comparison to those who did not [15]. In our study, cross-clamp durations were noticeably longer in 21.4% of the patients that developed AKI, which suggests that increased cross-clamp duration in CABG patients plays a role in AKI development.

The mechanisms where perioperative anemia and RBC transfusions could lead to AKI in cardiac surgery have not been clarified. The latest proteomic studies suggest that all patients who experience cardiac surgery with CPB developed the early stages of ischemia-reperfusion kidney damage, but whether or not they developed AKI was dependent on not only the revelation of other renal effects but also the following inflammatory response and the severity of hypoxia and oxidative stress. Anemia and RBC transfusion may lead to AKI by directly harming the kidney or increasing the susceptibility of patients to simultaneous kidney damage [16]. During storage, RBCs experience various changes that may harm the kidney after transfusion. These changes include reduction in 2,3-Diphosphoglycerate, adenosine triphosphate and S-nitroso-hemoglobinase and increased concentrations of lactate, potassium, cytokines, iron, and free hemoglobin in the supernatant [17-21]. Red blood cells may also be even more deformed in a time-dependent manner during storage and become more fragile. This leads to accumulation of hemoglobin-loaded microvesicles in the supernatant, while causing approximately 25% of RBCs to become susceptible to early hemolysis within the hour following transfusion [22-24]. Cumulatively, these changes may lead to a disruption in the transmission of oxygen to the tissue after transfusion, increased severity of inflammatory response and oxidative stress, and thus, kidney damage. Based on this hypothesis, some retrospective studies have found a relationship between the age of blood and negative outcomes.

There are different views on the indication of blood transfusion. Some authors transfused blood when the Hb level was 9 gr/dl, while some others waited until it decreased to 7.5 gr/dl. However, the meta-analysis carried out by Mazer et al. [25] that was published recently reported that transfusion made based on the Hb level in cardiac surgery patients carrying a moderate-high risk of mortality did not affect morbidity, and there was no difference between the restrictive and liberal approaches in terms of mortality, myocardial infarction, stroke or newly-onset kidney failure requiring dialysis. A liberal strategy was followed in our study, and the Hb levels were aimed to be kept at 8.5 gr/dL or higher. It was observed that more AKI developed in patients who received blood transfusion than those who did not; however, none of these patients developed kidney failure. In order to understand better the extent to which blood transfusion affects AKI in these patients, it may be necessary to conduct broader-scale studies. In the meta-analysis by Chen et al. [26] on patients who underwent cardiac surgery, it was reported that the restrictive transfusion strategy did not have lower rates of 30-day mortality, pulmonary morbidity, postoperative infection, cerebrovascular event, AKI or acute myocardial infarction in comparison to the liberal strategy.

A retrospective study including 1444 cardiac surgery patients investigated the relationship between preoperative, intraoperative anemia and erythrocyte suspension transfusion and AKI. The researchers reported that one or more of these risk factors were found in more than a third of the patients, AKI developed in 16% of the patients, and there was an increase of 2.6 times in the risk of AKI development in these patients in comparison to individuals who did not have any of the risk factors [3]. Stover et al. [27] suggested that the frequency of blood transfusion in patients who receive CABG surgery is between 27% and 92%, but this variability cannot be explained solely by the preoperative characteristics of patients, CPB time or perioperative bleeding amounts. It was argued that this difference may be dependent on the clinic, and excessive blood transfusion is made at some clinics in proportion to perioperative blood loss. A study by Koch et al. [28] on approximately 12000 patients who received CABG surgery showed that erythrocyte suspension transfusion is a risk factor for postoperative cardiac complications, severe infections, kidney failure, neurological complications, total morbidity, prolonged ventilator support and in-hospital mortality depending on the number of units. A retrospective study carried out by Güven et al. [29] on 407 patients who had CABG surgery demonstrated that blood and blood product transfusion in patients having CABG surgery increased postoperative complications and mortality in relation to the number of units. In that study, it was reported that fresh frozen plasma transfusion noticeably increased mortality in patients who received CABG surgery. The effects of erythrocyte suspension and fresh frozen plasma transfusion on morbidity are not completely known. The finding in our study that more AKI developed in the patients who received blood transfusion may lead one to think that transfusion causes kidney damage. However, it would be appropriate to investigate the issue of whether this damage is caused by transfusion or the clinical situation that required the transfusion with further studies with larger number of patients.

Limitations

Its single-center design and the fact that operations were conducted by multiple surgical teams are some of the limitations of our study. Also, our number of patients was relatively low. Further studies involving larger populations are needed to confirm these findings.

Conclusion

We observed that increased serum CyC levels in the early postoperative period was associated with AKI development. As AKI can be diagnosed and treated early, we believe that CyC measurements in initial period after CABG may

be helpful for early diagnosis of CSA-AKI. Further studies involving larger populations are needed to confirm this finding.

References

1. Özçelik Z, Askar FZ. Frequency and factors affecting the development of acute kidney injury following open heart surgery. J Surg Med. 2020;4(5):340-5.
2. Rosner MH, Okusa MD. Acute kidney injury associated with cardiac surgery. Clin J Am Soc Nephrol. 2006 Jan 1;(1):19-32.
3. Karkouti K, Wijeysundera DN, Beattie WS. Reducing Bleeding in Cardiac Surgery (RBC) Investigators. Risk associated with preoperative anemia in cardiac surgery: a multicenter cohort study. Circulation. 2008;117:478-84.
4. Machado MN, Nakazone MA, Maia LN. Prognostic value of acute kidney injury after cardiac surgery according to kidney disease: Improving global outcomes definition and staging (KDIGO) criteria. PLoS One. 2014;9:e98028.
5. Erdolu B, Engin M. Can C-reactive protein to albumin ratio be used as a predictor of amputation development in acute lower extremity ischemia? J Surg Med. 2020;4(6):501-4.
6. Çayır MÇ, Til A. The utility of mean platelet volume as a predictor of postoperative atrial fibrillation following coronary artery bypass grafting. J Surg Med. 2020;4(6):438-42.
7. Dharnidharka VR, Kwon C, Stevens G. Serum cystatin C is superior to serum creatinine as a marker of kidney function: A meta-analysis. Am J Kidney Dis. 2002 Aug;40(2):221-6.
8. Odutayo A, Cherney D. Cystatin C and acute changes in glomerular filtration rate. Clin Nephrol. 2012 Jul;78(1):64-75.
9. Arun O, Celik G, Oc B, Unlu A, Celik JB, Oc M, et al. Renal effects of coronary artery bypass graft surgery in diabetic and non-diabetic patients: a study with urinary neutrophil gelatinase-associated lipocalin and serum cystatin C. Kidney Blood Press Res. 2015;40(2):141-52.
10. Dardashti A, Nozohoor S, Algotsson L, Ederoth P, Bjursten H. The predictive value of s-cystatin C for mortality after coronary artery bypass surgery. J Thorac Cardiovasc Surg. 2016 Jul;152(1):139-46.
11. Klein SJ, Brandtner AK, Lehner GF, Ulmer H, Bagshaw SM, et al. Biomarkers for prediction of renal replacement therapy in acute kidney injury: a systematic review and meta-analysis. Intensive Care Med. 2018;44:323-36.
12. Wasén E, Isoaho R, Mattila K, Vahlberg T, Kivelä SL, Irjala K. Estimation of glomerular filtration rate in the elderly: a comparison of creatinine-based formulae with serum Cystatin C. J Intern Med. 2004;256(1):70-8.
13. Fuhrman DY, Nguyen LG, Sanchez-de-Toledo J, Priyanka P, Kellum JA. Postoperative Acute Kidney Injury in Young Adults with Congenital Heart Disease. Ann Thorac Surg. 2019 May;107(5):1416-20.
14. Ueno K, Seki S, Shiokawa N, Matsuba T, Miyazono A, Hazeki D, et al. Validation of acute kidney injury according to the modified KDIGO criteria in infant safter cardiac surgery for congenital heart disease. Nephrology (Carlton). 2019 Mar;24(3):294-300.
15. Chew STH, Hwang NC. Acute Kidney Injury After Cardiac Surgery: A Narrative Review of the Literature. J Cardiothorac Vasc Anesth. 2019 Apr;33(4):1122-38.
16. Ho J, Lucy M, Krokhin O, Hayglass K, Pascoe E, Darroch G, et al. Mass spectrometry-based proteomic analysis of urine in acute kidney injury following cardiopulmonary bypass: a nested case-control study. Am J Kidney Dis. 2009;53:584-95.
17. Almac E, Ince C. The impact of storage on red cell function in blood transfusion. Best Pract Res Clin Anaesthesiol. 2007; 21:195-208.
18. Comporti M, Signorini C, Buonocore G, Ciccoli L. Iron release, oxidative stress and erythrocyte ageing. Free Radic Biol Med. 2002;32:568-76.
19. Hogman CF, Meryman HT. Storage parameters affecting red blood cell survival and function after transfusion. Transfus Med Rev. 1999;13:275-96.
20. Donadee C, Raat NJ, Kanias T, Tejero J, Lee JS, Kelley EE, et al. Nitric oxide scavenging by red blood cell microparticles and cell-free hemoglobin as a mechanism for the red cell storage lesion. Circulation. 2011;124:465-76.
21. Bennett-Guerrero E, Veldman TH, Doctor A, Telen MJ, Ortel TL, Reid TS, et al. Evolution of adverse changes in stored RBCs. Proc Natl Acad Sci. 2007;104:17063-8.
22. Bosman GJ, Werre JM, Willekens FL, Novotny VM. Erythrocyte ageing in vivo and in vitro: structural aspects and implications for transfusion. Transfus Med. 2008;18:335-47.
23. Bosman GJ, Lasonder E, Groenen-Dopp YA, Willekens FL, Werre JM, Novotny VM. Comparative proteomics of erythrocyte aging in vivo and in vitro. J Proteomics. 2010;73:396-402.
24. Luten M, Roerdinkholder-Stoelwinder B, Schaap NP, de Grip WJ, Bos HJ, Bosman GJ. Survival of red blood cells after transfusion: a comparison between red cells concentrates of different storage periods. Transfusion. 2008;48:1478-85.
25. Mazer CD, Whitlock RP, Fergusson DA, Hall J, Belley-Cote E, Connolly K, et al. Restrictive or Liberal Red-Cell Transfusion for Cardiac Surgery. N Engl J Med. 2017;377:2133-44.
26. Chen QH, Wang HL, Liu L, Shao J, Yu J, Zheng RQ. Effects of restrictive red blood cell transfusion on the prognoses of adult patients undergoing cardiac surgery: a meta-analysis of randomized controlled trials. Crit Care. 2018 May 31;22(1):142.
27. Stover EP, Siegel LC, Parks R, Levin J, Body SC, Maddi R, et al. Variability in transfusion practice for coronary artery bypass surgery persists despite national consensus guidelines: a 24-institution study. Institutions of the Multicenter Study of Perioperative Ischemia Research Group. Anesthesiology. 1998 Feb;88(2):327-33.
28. Koch CG, Li L, Duncan AI, Mihaljevic T, Cosgrove DM, Loop FD, et al. Morbidity and mortality risk associated with red blood cell and blood-component transfusion in isolated coronary artery bypass grafting. Crit Care Med. 2006;34:1608-16.
29. Güven CY, Aksun M, Karahan N, Girgin S, Kuru V, Golboyu BE, et al. Koroner Arter Baypas Greftleme (KABG) Cerrahisi Geçiren Hastalarda Kan ve Kan Ürünü Transfüzyonunun Postoperatif Komplikasyonlar Üzerine Olan Etkileri. GKDA Derg. 2015;21(2):101-10.

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