Check for updates

ORIGINAL ARTICLE

Mean arterial pressure difference before and during cardiopulmonary bypass: what should be the ideal mean perfusion pressure?

Diferencia de la presión arterial media antes y durante un bypass cardiopulmonar: ¿cuál debe ser la presión de perfusión media ideal?

Bişar Amaç[1], Murat Ersoy[2], Murat Z. Bağiş[3], and Mahmut Padak[4]*

[1]Department of Perfusion, Faculty of Health Sciences, Harran University; [2]Department of Cardiovascular Surgery, University of Health Sciences, Sanliurfa Mehmet Akif Inan, Training and Research Hospital; [3]Department of Cardiovascular Surgery, Faculty of Medicine, Harran University; [4]Department of Perfusion, Faculty of Health Sciences, Harran University. Sanliurfa, Turkey

Abstract

Objectives: *The difference between mean arterial pressure (MAP) before cardiopulmonary bypass (CPB) and mean perfusion pressure (MPP) during CPB is thought to be a strong predictor of acute kidney injury (AKI). In this study, we aimed to evaluate whether the difference between MAP and MPP is a good index to predict the development of AKI and what the ideal MPP should be during CPB.* **Methods:** *A total of 296 consecutive patients were included in this retrospective study. MAP-MPP differences of patients who developed AKI and those who did not develop AKI according to standard guidelines and their relation with adverse outcomes were evaluated.* **Results:** *MAP values of patients who did not develop AKI and patients who developed AKI were higher in the group with AKI, 67.60 mmHg versus 64.84 mmHg (p = 0.001). The MAP-MPP difference was 5.07 in the group without AKI and 9.44 in the group with AKI (p = 0.000).* **Conclusion:** *We found that the difference between MAP and MPP is a good index for predicting the development of CPB-related AKI and poor outcomes. We also suggest that patients' preoperative arterial blood pressure should be taken into account for an ideal MPP.*

Keywords: *Cardiopulmonary bypass. Mean arterial pressure. Mean perfusion pressure. Acute kidney injury. Mean arterial pressure-mean perfusion pressure difference.*

Resumen

Objetivo: *La diferencia de la presión arterial media (PAM) antes del bypass cardiopulmonar y la presión de perfusión media (PPM) durante el bypass cardiopulmonar se considera un factor predictivo importante de insuficiencia renal aguda (IRA). En este estudio nos propusimos evaluar si la diferencia entre la PAM y la PPM es un buen índice para predecir el desarrollo de IRA y cuál debe ser la PPM ideal durante el bypass cardiopulmonar.* **Métodos:** *Estudio retrospectivo de 296 pacientes. Se evaluaron las diferencias entre la PAM y la PPM de los pacientes que desarrollaron IRA y los que no la desarrollaron según las directrices estándar y su relación con los resultados adversos.* **Resultados:** *Los valores de PAM de los pacientes que no desarrollaron IRA y de los pacientes que desarrollaron IRA fueron superiores en el grupo con IRA: 67,60 mmHg frente a 64,84 mmHg (p = 0,001). La diferencia PAM-PPM fue de 5.07 en el grupo sin IRA y de 9.44 en el grupo con IRA (p = 0.000).*

***Correspondence:**
Bişar Amaç
E-mail: amacbisar@gmail.com

Date of reception: 03-06-2024
Date of acceptance: 12-01-2025
DOI: 10.24875/CIRUE.M25000869

Cir Cir (Eng). 2025;93(4):419-426
Contents available at PubMed
www.cirugiaycirujanos.com

2444-0507/© 2025 Academia Mexicana de Cirugía. Published by Permanyer. This is an open access article under the terms of the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

Conclusiones: *Encontramos que la diferencia entre la PAM y la PPM es un buen índice para predecir el desarrollo de IRA relacionada con bypass cardiopulmonar y malos resultados. También sugerimos que debe tenerse en cuenta la presión arterial preoperatoria de los pacientes para obtener una PPM ideal.*

Palabras clave: *Bypass cardiopulmonar. Presión arterial media. Presión de perfusión media. Lesión renal aguda. Diferencia PAM-PPM.*

Introduction

A bloodless and immobilized environment is needed in cardiac surgical applications performed with cardiopulmonary bypass (CPB), so a perfusion device (heart–lung machine) is used, which temporarily performs the pump of the heart and the respiratory properties of the lungs. In this process, the patient's heart and lung functions are disabled and perfusion is performed for a certain period of time with the heart–lung machine. Depending on this perfusion process, various changes may occur in metabolism and organs during or after CPB[1-3]. One of these is acute kidney injury (AKI) associated with cardiac surgery[4]. Post-operative renal dysfunction, one of the most common complications of cardiac surgery performed with CPB, is associated with cardiac surgery[5]. AKI is associated with increased morbidity and mortality in the short term. Modifiable and non-modifiable factors may contribute to the development and progression of AKI during cardiac surgery. It is thought that the difference between preoperative mean arterial pressure (MAP) and MAP (mean perfusion pressure [MPP]) during CPB may strongly predict AKI[5-8]. It has also been reported that it may be predictive in many morbidities and mortalities and low MPP is associated with unfavorable outcomes[6,9].

In this study, we aimed to answer two questions. First, we aimed to evaluate whether the difference between MAP and MPP is a good index for predicting the development of AKI. Second, we aimed to find the answer to the question of what should be the ideal MAP during CPB, that is, the ideal perfusion pressure.

Methods

Type of research

This study is a retrospective clinical study.

Ethical dimension of the research

In this study, approval was obtained from the institution and the local ethics committee (Harran University Clinical Research Ethics Committee) (Date: March 18, 2024-Approval no: HRÜ/February 24, 2025). Since the study was retrospective, consent was not required from the participants. The study was conducted in accordance with the principles of the Helsinki Declaration.

Study population

In this retrospective study, patient data of the last 1 year before ethics committee approval were included (March 1, 2023-March 1, 2024). The study included data of 296 consecutive patients who underwent CPB-guided cardiac surgery (coronary artery bypass graft [CABG], aortic or mitral valve replacement) in the Cardiovascular Surgery Clinic of Mehmet Akif Inan Training and Research Hospital after applying the exclusion criteria.

Exclusion and inclusion criteria

Patients with chronic hypertension or hypotension, patients undergoing emergency bypass, patients scheduled for additional cardiac surgery such as aortic aneurysm or dissection, reoperations, chronic renal disease, chronic diabetes, chronic autoimmune disease, systemic inflammatory disease, chronic liver disease, hematological disease, and history of atrial fibrillation were excluded. After applying the exclusion criteria, adult patients aged between 20 and 85 years who underwent CPB-guided cardiac surgery in the last consecutive year were included in the study.

Formation of groups

In this study, patients were grouped and compared in two different ways to analyze the results. First, patients were divided into two groups as those who developed AKI and those who did not develop AKI to evaluate the relationship between the MAP-MPP difference and AKI. Second, the MAP-MPP difference was compared with the presence or absence of other post-operative adverse events and variables.

Data collection method

Data of the patients were obtained from computer, operating theater records, perfusion follow- up records, intensive care unit follow-up cards, and file records.

Procedures and variables used in the research

The data of the patients obtained in this study were recorded and entered into the computer. Descriptive data of the patients (age, gender, height, weight, body surface area [BSA], flow, ejection fraction percentage [EF%], aortic cross clamp time, total perfusion time, and type of surgery performed [CABG numbers, aortic valve, mitral valve, etc.]); MAP value (last arterial pressure measured just before induction of anesthesia) and MPP value (MPP recorded every 20 min while connected to the heart-lung machine), post-operative adverse outcomes; and acute liver failure (ALF), major bleeding, need for ultrafiltration during CPB, need for pacemaker, need for intra-aortic balloon pump (IABP), need for CPB weaning defibrillation, need for CPB weaning inotropes, intensive care unit (ICU) inotrope requirement, intubation time (hours), ICU length of stay (days), hospital stay (days), neurological complications (paralysis or delirium), and mortality rate data were recorded.

CPB (perfusion) method

Standard coronary and valvular heart surgery techniques were performed in all patients. After midline sternotomy in coronary heart surgery patients, arterial cannulation was performed from the ascending aorta and venous cannulation was performed from the right atrium with a single venous cannula (two-stage venous conduit). Left mammary artery graft was used in all cases. Saphenous vein graft was applied to other coronary grafts. Complete revascularization was performed in all patients. In valvular heart surgery patients, in addition to standard surgical techniques, in mitral valve replacements after midline sternotomy, arterial cannulation was performed from the ascending aorta and venous cannulation was performed with two venous cannulae from the vena cava superior and vena cava inferior (bicaval cannulation). In aortic valve replacements, arterial cannulation was performed from the ascending aorta and venous cannulation was performed from the right atrium with a single venous cannula (two-stage cannulation).

Blood flow rates (Flow) of the patients included in the study during extracorporeal circulation were determined non-pulsatile according to their BSAs (2.4 L/min/m^2). Oxygenators and tubing sets suitable for the patient's weight and cannula diameters suitable for BSAs were used. Membrane oxygenator/tubing sets with integrated arterial filter were used. Tubing set venous line diameter was 1/2 and arterial line diameter was 3/8. All patients were subjected to 32°C hypothermia during extracorporeal circulation. Preoperative MAP was adjusted to prevent severe hypotension > 50 mmHg. The overall target MAP was 60 mmHg. Arterial line pressures were maintained between 150 and 180 mmHg on average during CPB. MPP was kept around 60 mmHg. Active clotting time was kept at 480 s and above by providing adequate anticoagulation. As prime solution, 1,200 mL of balanced solution (isolate), 150 mL of 20% mannitol, 5 thousand units of heparin, and 2 g of cefazolin were used. Blood cardioplegia solution was used in all patients. In patients in whom isothermic blood cardioplegia solution (32°C) was used, the initial amount of cardioplegia solution was administered as kg × 15 mL (full dose) and the maintenance dose was administered as half dose (1/2) every 20 min.

AKI Identification

AKI was defined using RIFLE criteria in which three damage layers were defined[10]:

1. Risk-serum creatinine increase × 1.5 or glomerular filtration rate (GFR) > 25%; basal or urine output < 0.5 mL/kg/h × 6 h[10],
2. Damage-serum creatinine increase × 2.0 or GFR > 50% or urine output < 0.5 mL/kg/h × 12 h and[10]
3. Insufficiency-serum creatinine × 3.0, GFR > 75% or serum creatinine level ≥ 4 mg/dL; or urine output < 0.3 mL/kg/h × 24 h or anuria for 12 h[10].

The first 24 h after cardiac surgery was considered in the assessment of AKI. The rationale for this "early" definition was to capture AKI that was most likely attributable to intraoperative factors, such as CPB, rather than factors in the post-operative period. Other adverse outcome events were defined according to standardized guidelines.

Statistical analyses

Statistical analyses were performed using the Statistical Package for the Social Sciences (SPSS)® 17.0 computer program (version 17.0, SPSS, Chicago, IL,

Table 1. Demographic and operative characteristics of the study population

Variables	No AKI (mean ± SD or n,%) (n = 206) (%)	AKI (mean ± SD or n,%) (n = 90) (%)	p
Age (year) (mean ± SD)	62.83 ± 9.23	63.98 ± 9.41	0.292
Gender, n (%)			
Male	124, 60.2	55, 61.1	0.882
Female	82, 39.8	35, 38.9	
Surgical type, n (%)			
CABGX1	11, 5.3	4, 4.4	0.207
CABGX2	30, 14.6	16, 4.4	
CABGX3	43, 20.9	22, 24.4	
CABGX4	48, 23.3	22, 24.4	
CABGX5	39, 18.9	18, 20	
MVR	19, 9.2	4, 4.4	
AVR	16, 7.8	4, 4.4	
Height (cm) (mean ± SD)	163.11 ± 9.93	164.48 ± 8.11	0.368
Weight (kg) (mean ± SD)	73.50 ± 15.59	75.20 ± 10.41	0.666
BSA m^2 (mean ± SD)	1.81 ± 0.20	1.84 ± 0.14	0.534
Flow (L) (mean ± SD)	4.33 ± 0.51	4.42 ± 0.34	0.539
Pre-operative EF % (mean ± SD)	46.48 ± 11.67	45.50 ± 10.87	0.902
Cross clamp time (minutes) (mean ± SD)	76.41 ± 36.85	71.93 ± 19.57	0.634
Total perfusion time (minutes) (mean ± SD)	110.46 ± 44.06	107.90 ± 31.07	0.806
Intubation time (hours) (mean ± SD)	7.17 ± 4.82	6.68 ± 2.06	0.200
ICU duration (days) (mean ± SD)	1.98 ± 1.48	2.22 ± 0.95	0.000
Duration of hospital stay (days) (mean ± SD)	5.32 ± 2.99	8.57 ± 3.47	0.000

AKI: acute kidney injury; Mean ± SD: mean ± standard deviation; N: frequency; %: percent; CABG: coronary artery bypass graft; MVR: mitral heart valve; AVR: aortic heart valve; BSA: body surface area; EF: ejection fraction; ICU: intensive care unit.

USA). Means and standard deviations were calculated for continuous and ordinal data. Kolmogorov-Smirnov test and Shapiro-Wilk test were used to assess normality distribution. Compera Means (Independent-Samples T Test [Student T Test]) and Nonparametric Test (2 Independent Samples [Mann-Whitney U]) tests were used to evaluate normal and non-normally distributed data, respectively. Receiver-operating characteristic (ROC) curve analysis was performed to test the ability of MAP and MAP-MPP difference to predict the association with AKI outcomes. The areas under the ROC curves (area under the curve) were expressed using the mean 95% confidence interval. Frequency and percentage analyses were performed for nominal data. A $p < 0.05$ was considered statistically significant.

Results

In this retrospective study, data from 296 patients fulfilling the criteria were included. AKI developed in 90 (30.4%) of these patients in the first 24 h postoperatively. As shown in table 1, demographic data including age, gender, surgical procedure, height, weight, BSA, flow, pre-operative EF%, aortic cross clamp time, and total perfusion time were similar in the patient groups who did not develop AKI and those who developed AKI (p = 0.292; p = 0.882; p = 0.207; p = 0.368; p = 0.666; p = 0.534; p = 0.539; p = 0.902; p = 0.634; p = 0.806, respectively).

While the extubation times of patients who did not develop AKI and those who developed AKI were similar with a mean of 7.17 h versus 6.68 h (p = 0.200), the ICU length of stay was higher in the group who developed AKI with a mean of 1.98 days versus 2.22 days (p = 0.000). In addition, the duration of hospital stay was also higher in the group that developed AKI with 8.57 days versus 5.32 days (p = 0.000) (Table 1).

MAP values of patients who did not develop AKI and patients who developed AKI were higher in the group with AKI, 67.60 mmHg versus 64.84 mmHg (p = 0.001). However, MPP values were similar in both groups (p = 0.104). The MAP-MPP difference was 5.07 in the group without AKI and 9.44 in the group with AKI (p = 0.000) (Table 2).

ROC curve analysis was performed to predict AKI outcomes in patients undergoing CPB- guided cardiac surgery. According to these results, the test power of MAP-MPP difference was determined to be 72.8%. At the same time, Roc analysis related to MAP revealed that the test power was 61.6%. In the analysis, the cut-off value for MAP-MPP difference was found to be

2.50 (87.8% sensitivity and 73.8% specificity) (p < 0.001). The cut-off value for MAP was 47 (98.9% sensitivity and 99.0% specificity) (p = 0.002) (Table 3 and Fig. 1).

The MAP-MPP difference values of patients who did not develop ALF were 6.28, while those who developed ALF were 8.85 and the difference was higher (p = 0.047). While the MAP-MPP difference was 6.27 in patients who did not need ultrafiltration during CPB, it was 9.23 in patients who needed ultrafiltration and the difference was higher (p = 0.027). While the MAP-MPP difference was 6.26 in patients who did not need pacemaker, it was 9.46 in those who needed pacemaker and the difference was higher (p = 0.031). While the MAP-MPP difference was 6.15 in patients who did not need CPB weaning defibrillation, it was 7.84 in patients who needed CPB weaning defibrillation and the difference was higher (p = 0.045). While the MAP-MPP difference was 4.87 in patients who did not need CPB weaning inotropes, it was 6.65 in those who needed CPB weaning inotropes and the difference was higher (p = 0.026). While the MAP-MPP difference was 5.06 in patients without ICU inotrope requirement, it was 6.76 in patients with ICU Inoptop Requirement, and the difference was higher (p = 0.030). There was no significant difference between the rates of major bleeding, need for IABP, neurological complications (stroke or delirium), and mortality and the MAP-MPP difference (p = 0.959; p = 0.822; p = 0.577; p = 0.467, respectively) (Table 4).

Discussion

In CPB-guided cardiac surgery, prediction of adverse post-operative outcomes and predetermination of standards during CPB are of great importance. In this study, we determined that the MAP-MPP difference is a strong predictive marker for the development of AKI after CPB and that MPP during CPB indexed to BSA should be evaluated together with pre-operative MAP. We found that indexing MPP only to BSA was associated with unfavorable results. With the data we obtained, we found that it is not sufficient to consider only the BSA in the calculation of the ideal MPP, and the pre-operative MAP of the patient should also be taken into consideration. We also found that high MAP-MPP difference was associated with ALF, need for ultrafiltration during CPB, need for pacemaker, need for CPB weaning defibrillation, need for CPB weaning inotropes, and need for ICU inoptop. These findings are among the advantages of this study.

Table 2. Comparison of MAP, MPP, and MAP-MPP differences of the groups and relationship with AKI

Variables	No AKI (Mean ± SD) (n = 206)	AKI (Mean ± SD) (n = 90)	p
MAP (mmHg) (mean ± SD)	64.84 ± 6.05	67.60 ± 5.88	0.001
MPP (mmHg) (mean ± SD)	60.09 ± 5.95	59.48 ± 4.61	0.104
MAP-MPP difference	5.07 ± 3.36	9.44 ± 5.89	0.000

AKI: acute kidney injury; Mean ± SD: mean ± standard deviation; MAP: mean arterial pressure; MPP: mean perfusion pressure; MAP-MPP difference: difference between mean arterial pressure and mean perfusion pressure.

Table 3. Receiver-operating characteristic curve analysis

Risk factors	AUC (95)	Cut off	p	Sensitivity	Specificity
MAP-MPP difference	0.728 (0.660-0.797)	2.50	0.000	87.8	73.8
MAP	0.616 (0.545-0.686)	47.00	0.002	98.9	99.0

AUC: area under the curve; MAP-MPP difference: difference between mean arterial pressure and mean perfusion pressure; MAP: mean arterial pressure.

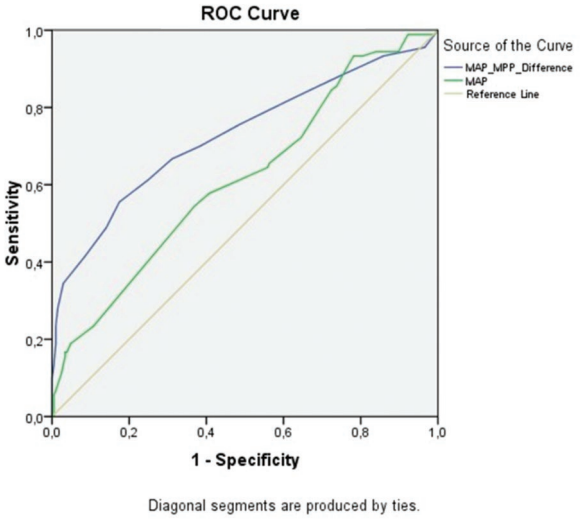

Figure 1. *Receiver-operating characteristic curve analysis of mean arterial pressure (MAP), mean arterial pressure, and mean perfusion pressure difference (MAP-mean perfusion pressure difference) in predicting the outcome of acute kidney injury.*

Some studies have also reported that the difference between arterial pressure before CPB and perfusion pressure during CPB is a strong determinant of AKI[7,9]. Kanji et al. performed a prospective observational study on 157 consecutive high-risk patients who underwent cardiac surgery with CPB. In their study, they reported that the difference between MAP and

Table 4. The relationship between MAP-MPP difference and other post-operative adverse events

Variables	Negative situation existence	n, %	MAP-MPP difference (mean ± SD)	p
ALF	No	282, 95.3	6.28 ± 4.67	0.047
	Yes	14, 4.7	8.85 ± 5.34	
Major hemorrhage	No	280, 94.6	6.41 ± 4.75	0.959
	Yes	16, 5.4	6.18 ± 4.43	
Ultrafiltration requirement during CPB	No	283, 95.6	6.27 ± 4.68	0.027
	Yes	13, 4.4	9.23 ± 5.05	
Need for pacemaker	No	283, 95.6	6.26 ± 4.63	0.031
	Yes	13, 4.4	9.46 ± 5.83	
Need for IABP	No	291, 98.3	6.40 ± 4.69	0.822
	Yes	5, 1.7	6.20 ± 7.29	
CPB weaning the defibrillation requirement	No	252, 85.1	6.15 ± 4.56	0.045
	Yes	44, 14.9	7.84 ± 5.40	
CPB weaning inotrope requirement	No	41, 13.9	4.87 ± 4.03	0.026
	Yes	255, 86.1	6.65 ± 4.79	
ICU inoptop requirement	No	63, 21.3	5.06 ± 3.37	0.030
	Yes	233, 78.7	6.76 ± 4.97	
Neurological complications	No	294, 99.3	6.40 ± 4.74	0.577
	Yes	2, 0.7	7.00 ± 1.41	
Mortality	No	291, 98.3	6.41 ± 4.70	0.467
	Yes	5, 1.7	6.12 ± 6.15	

Mean ± SD: mean ± standard deviation; N: frequency; %: percent; MAP-MPP difference: difference between mean arterial pressure and mean perfusion pressure; ALF: acute liver failure; CPB: cardiopulmonary bypass; IABP: intra-aortic balloon pump; ICU: intensive care unit.

MPP was independently associated with early post-operative AKI in high-risk patients. They also stated that these factors were potentially identifiable and modifiable[7]. Rajagopalan et al. also reported that low MPP indexed to BSA is a strong predictor of poor outcomes after heart transplantation in patients with high pre-transplant venous pressure. They retrospectively studied 250 heart transplant recipients who underwent isolated heart transplantation in a single center between October 2012 and March 2020. They stated that in patients with high right atrial pressure, the acceptable blood pressure during vasodilator therapy should be higher, especially in patients with high BSA[9]. The results of our study are compatible with the literature and the results of this study support our study. Dhanyee et al. investigated the relationship between pre-operative and CPB MAP difference and AKI in cardiac surgery patients undergoing valve surgery. They included 112 patients who underwent valve and valve plus CABG with CPB. In their study, they reported that MAP and CPB flows were not associated with early post-operative AKI. However, they reported that the pressure difference in the early post-operative period independently predicted the development of AKI[11]. In our study, we found that MAP alone predicted AKI. Although other results were similar, we think that this difference may be due to the patient population.

Molina-Andujar et al. investigated the association of the MAP-MPP difference with a high incidence of AKI in cardiac surgery patients in a randomized controlled trial. At the end of their study, they reported that individualized hemodynamic management did not reduce the incidence of AKI compared with standard treatment. However, they also stated that personalized perfusion pressure management was safe. They also stated that there was no difference between the groups in terms of extrarenal complications. They also reported that there

was no difference in terms of mean ICU length of stay and post-operative hospital stay, transfusion requirement, cardiovascular complications, or mortality[12]. In our study, we found that the MAP-MPP difference was related to AKI. We think that the fact that we evaluated AKI in the first 24 h after surgery in our study and they evaluated AKI in the 1st week after cardiac surgery may have an effect on the emergence of different results from the study of Molina-Andujar et al.

It has been reported that higher perfusion pressure and pump flow during CPB are also beneficial for renal function[13]. However, in our study, we think that MPP alone does not mean anything and should be evaluated together with MAP. We think that this difference may be due to the fact that pre-operative MAP was not evaluated in the related study. In a meta-analysis study, it was reported that high blood pressure or low blood pressure target during CPB may cause little or no difference in patient outcomes, including AKI and mortality[14]. In another study in the literature, it was reported that they could not detect systematic differences in terms of pump flow or MPP between patients who developed AKI after CPB and those who did not. They stated that they obtained little information from their observational studies regarding the effect of changes in pump flow and MPP on the risk of AKI. However, they stated that a clinical study to evaluate the effects of more target pump flow and MPP on the risk of AKI is needed[15]. Although these data in the literature emphasize the justification of the results of our study, they suggest that MPP during CPB should be evaluated in a patient-based manner and pre-operative MAP should also be evaluated. In addition, when our study results are compared with the data in the literature, we think that the MAP-MPP difference may be a predictor for the detection of CPB-related AKI and may also suggest a solution for ideal perfusion pressure.

De la Hoz et al. reported that intraoperative hypotension during cardiac surgery was associated with increased risk of AKI, mortality, or stroke[6]. In contrast to this study, Turner et al. reported that low perfusion pressure and low perfusion flow during CPB were not predictors of post-operative AKI, stroke, or death[16]. In our study, we found that lower perfusion pressure compared to pre-operative blood pressure, i.e., MAP-MPP difference, was associated with AKI but not with neurological complications (stroke or delirium) and mortality, and we think that these differences may be due to the patient population and other different surgical dynamics.

In the literature, it is reported that CPB may cause well-defined hemostatic activation and acquired coagulopathy, which may be complicated by life-threatening bleeding. It has been reported that major bleeding may occur in 10% of patients in cardiac surgery, and major bleeding may occur in 20-40% of patients, especially in reoperations or complex surgeries and may require blood transfusion[17]. In our study, we think that the MAP-MPP difference, i.e., perfusion pressures between pre-operative and during CPB, is not related with major bleeding or has no significant effect on major bleeding.

It has been reported that the use of ultrafiltration is beneficial and safe in CPB-related AKI[18]. However, it has also been reported that excessive ultrafiltration volume contributes to the risk of development of AKI[19]. Considering this benefit-harm debate, the presence of the need for ultrafiltration during CPB, which we found to be associated with the MAP-MPP Difference, emphasizes the importance of the MAP-MPP difference and supports our opinion that patient-based perfusion pressure assessment is required.

According to flow rate clinical guidelines, the target blood flow during CPB depends on BSA and temperature and is usually 2.2-2.8 L/min/m^2 under conditions of shallow hypothermia[20]. However, there has always been controversy regarding the optimal setting of flow rates and perfusion pressures. However, in our study, we think that pre-operative blood pressure should be taken into consideration in addition to this approach. There is also a correlation between oxygen delivery during CPB and AKI. Since oxygen delivery can be adjusted with the pump flow rate, it is a modifiable factor. In this case, the targeted perfusion method comes to the fore. Oxygen delivery provided with a higher pump flow rate has also been reported to contribute to a lower incidence of AKI[21]. In this case, individualized blood pressure management should be introduced to ensure a higher flow rate. It has also been reported that blood pressure management may be associated with end-organ dysfunction after cardiac surgery[22]. Based on this, the ideal perfusion pressure comes to the forefront once again. At this point, the importance of individualized perfusion pressure emerges. Although these data are promising, specialized and skilled perfusionists will always be needed for the management of extracorporeal circulation equipment.

Limitations of the study

The limitations of this study include the retrospective and single-center nature of the study. Although the results of the study are at a generalizable

statistical level, we think that multicenter and more patient populations will give more comprehensive results.

Conclusion

The MPP during CPB is managed as standard BSA × 2.4 L. However, in our study, we found that the patient's pre-operative arterial blood pressure should also be taken into account because we found that the difference between MAP and MPP is a good index for predicting the development of CPB-related AKI. Therefore, we think that it is important to prioritize patient-based physiology for ideal MPP. In conclusion, MPP indexed only to BSA, excluding pre-operative arterial pressure, is a strong predictor of poor outcomes after cardiac surgery.

Funding

The authors declare that they have not received funding.

Conflicts of interest

The authors declare no conflicts of interest.

Ethical considerations

Protection of humans and animals. The authors declare that the procedures followed complied with the ethical standards of the responsible human experimentation committee and adhered to the World Medical Association and the Declaration of Helsinki.

Confidentiality, informed consent, and ethical approval. The authors have followed their institution's confidentiality protocols, obtained informed consent from patients, and received approval from the Ethics Committee. The authors have obtained approval from the Ethics Committee for the analysis of routinely obtained and anonymized clinical data, so informed consent was not necessary. In this study, approval was obtained from the institution and the local ethics committee (Harran University Clinical Research Ethics Committee) (Date: March 18, 2024-Approval no: HRÜ/February 24, 25).

Declaration on the use of artificial intelligence. The authors declare that no generative artificial intelligence was used in the writing of this manuscript.

References

1. Passaroni AC, Silva MA, Yoshida WB. Cardiopulmonary bypass: development of John Gibbon's heart-lung machine. Rev Bras Cir Cardiovasc. 2015;30:235-45.
2. Tan A, Newey C, Falter F. Pulsatile perfusion during cardiopulmonary bypass: a literature review. J Extra Corpor Technol. 2022;54:50-60.
3. Gerstein NS, Panikkath PV, Mirrakhimov AE, Lewis AE, Ram H. Cardiopulmonary bypass emergencies and intraoperative issues. J Cardiothorac Vasc Anesth. 2022;36:4505-22.
4. Massoth C, Zarbock A, Meersch M. Acute kidney injury in cardiac surgery. Crit Care Clin. 2021;37:267-78.
5. Milne B, Gilbey T, De Somer F, Kunst G. Adverse renal effects associated with cardiopulmonary bypass. Perfusion. 2024;39:452-68.
6. De La Hoz MA, Rangasamy V, Bastos AB, Xu X, Novack V, Saugel B, et al. Intraoperative hypotension and acute kidney injury, stroke, and mortality during and outside cardiopulmonary bypass: a retrospective observational cohort study. Anesthesiology. 2022;136:927-39.
7. Kanji HD, Schulze CJ, Hervas-Malo M, Wang P, Ross DB, Zibdawi M, et al. Difference between pre-operative and cardiopulmonary bypass mean arterial pressure is independently associated with early cardiac surgery-associated acute kidney injury. J Cardiothorac Surg. 2010;5:71.
8. Slogoff S, Reul GJ, Keats AS, Curry GR, Crum ME, Elmquist BA, et al. Role of perfusion pressure and flow in major organ dysfunction after cardiopulmonary bypass. Ann Thorac Surg. 1990;50:911-8.
9. Rajagopalan G, Balakrishnan KR, Suresh Rao KG, Ravi Kumar R, Kumar RK. Low mean perfusion pressure indexed to body surface area is a powerful predictor of poor outcomes after heart transplantation in patients with high pre-transplant venous pressure: a clinical study with physiological insights from mathematical modelling of biventricular heart failure. Heart Lung Circ. 2024;33:292-303.
10. Bellomo R, Ronco C, Kellum JA, Mehta RL, Palevsky P, Acute Dialysis Quality Initiative workgroup. Acute renal failure - definition, outcome measures, animal models, fluid therapy and information technology needs: the second international consensus conference of the acute dialysis quality initiative (ADQI) group. Crit Care. 2004;8:R204-12.
11. Dhanyee AS, Parida S, Thangaswamy CR, Jha AK, Rajappa M, Munuswamy H, et al. Relationship between difference of preoperative and cardiopulmonary bypass mean arterial pressure, and acute kidney injury in cardiac surgical patients undergoing valve surgery. Perfusion. 2024;40:173.
12. Molina-Andujar A, Rios J, Piñeiro GJ, Sandoval E, Ibañez C, Quintana E, et al. Assessment of individualized mean perfusion pressure targets for the prevention of cardiac surgery-associated acute kidney injury-the prevhemaki randomized controlled trial. J Clin Med. 2023;12:7746.
13. Udzik J, Pacholewicz J, Biskupski A, Safranow K, Wojciechowska-Koszko I, Kwiatkowski P, et al. Higher perfusion pressure and pump flow during cardiopulmonary bypass are beneficial for kidney function-a single-centre prospective study. Front Physiol. 2024;15:1257631.
14. Kotani Y, Kataoka Y, Izawa J, Fujioka S, Yoshida T, Kumasawa J, et al. High versus low blood pressure targets for cardiac surgery while on cardiopulmonary bypass. Cochrane Database Syst Rev. 2022;11:CD013494.
15. Noe KM, Don A, Cochrane AD, Zhu MZ, Ngo JP, Smith JA, et al. Intraoperative hemodynamics and risk of cardiac surgery-associated acute kidney injury: an observation study and a feasibility clinical trial. Clin Exp Pharmacol Physiol. 2023;50:878-92.
16. Turner L, Hardikar A, Jose MD, Bhattarai K, Fenton C, Sharma R, et al. Acute kidney injury, stroke and death after cardiopulmonary bypass surgery: the role of perfusion flow and pressure. Perfusion. 2021;36:78-86.
17. Erdoes G, Faraoni D, Koster A, Steiner ME, Ghadimi K, Levy JH. Perioperative considerations in management of the severely bleeding coagulopathic patient. Anesthesiology. 2023;138:535-60.
18. Kandil OA, Motawea KR, Darling E, Riley JB, Shah J, Elashhat MA, et al. Ultrafiltration and cardiopulmonary bypass associated acute kidney injury: a systematic review and meta-analysis. Clin Cardiol. 2021;44:1700-8.
19. Manning MW, Li YJ, Linder D, Haney JC, Wu YH, Podgoreanu MV, et al. Conventional ultrafiltration during elective cardiac surgery and postoperative acute kidney injury. J Cardiothorac Vasc Anesth. 2021;35:1310-8.
20. Authors/Task Force Members, Kunst G, Milojevic M, Boer C, De Somer FM, Gudbjartsson T, et al. 2019 EACTS/EACTA/EBCP guidelines on cardiopulmonary bypass in adult cardiac surgery. Br J Anaesth. 2019;123:713-57.
21. Yang X, Zhu L, Pan H, Yang Y. Cardiopulmonary bypass associated acute kidney injury: better understanding and better prevention. Ren Fail. 2024;46:2331062.
22. Mohr NL, Krannich A, Jung H, Hulde N, Von Dossow V. Intraoperative blood pressure management and its effects on postoperative delirium after cardiac surgery: a single-center retrospective cohort study. J Cardiothorac Vasc Anesth. 2024;38:1127-34.