Preoperative Renal Resistive Index Predicts Risk of Acute Kidney Injury in Patients Undergoing Cardiac Surgery

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Objective: **To investigate whether an elevated preoperative renal resistive index (RRI) predicts acute kidney injury (AKI) in patients undergoing cardiac surgery.**

Design: **Prospective cohort study.**

Setting: **University hospital.**

Participants: **Cohort of 96 adult cardiac surgical patients.**

Interventions: **Resistive index was measurement the day before surgery.**

Measurements and Main Results: **Renal Doppler was used to measure the resistive index in renal cortical or arcuate arteries the day before surgery. An elevated RRI was defined as $\geq$0.7. AKI was defined as an absolute increase in postoperative compared with preoperative serum creatinine levels by $\geq$26 μmol/L or a relative increase by $\geq$50% or a postoperative urine output $<$0.5 mL/kg for 6 hours or longer. The relative risk of AKI in patients with an elevated RRI compared with those without an elevated RRI was analyzed using logistic regression. Among patients with an RRI $<$0.7, 6 (16%) developed AKI compared with 21 (36%) with an RRI $\geq$0.7. The mean increases in postoperative serum creatinine levels were 12 μmol/L in those with an RRI $<$0.7 and 30 μmol/L in those with an RRI $\geq$0.7. The crude odds ratio for AKI in patients with an RRI $\geq$0.7 was 3.03 (1.09-8.42) compared with those with an RRI $<$0.7. After multivariable adjustment, the odds ratio was 2.95 (0.97-9.00).**

Conclusions: **Patients with an elevated preoperative RRI have an increased risk of developing AKI after cardiac surgery. In combination with other markers, the RRI might be a tool for identifying patients with an increased risk of developing AKI.**

KEY WORDS: renal resistive index, acute kidney injury, cardiac surgery, preoperative risk factors

ACUTE KIDNEY INJURY (AKI) after cardiac surgery is a common complication and is associated with an increased risk of end-stage renal disease, myocardial infarction, heart failure, and death.[1–3] The causes of AKI are likely multifactorial, and several risk factors for developing AKI have been identified. These risk factors include hemodynamic alterations from heart failure, metabolic disorders, such as diabetes mellitus and increased body mass index, and kidney disease.[4,5] Besides a low glomerular filtration rate, there might be alterations in kidney physiology that may increase the susceptibility for AKI after cardiac surgery.

The resistive index is a measure derived from ultrasonography with a Doppler of arterial blood vessels.[6] The resistive index can be measured on renal interlobar or arcuate arteries within the renal cortex. This method is mostly known as the renal resistive index (RRI) and is $<$0.7 in a healthy population.[7] This method is easy to learn and is reproducible.[8] Recent studies have shown that the RRI might be a useful predictor of AKI in critically ill patients, in patients with sepsis, and after surgery.[9–11] However, few studies have investigated the association between preoperative RRI and risk of postoperative AKI. Therefore, this study aimed to investigate whether an elevated preoperative RRI predicted development of AKI in patients undergoing cardiac surgery.

METHODS

Study Design

The authors performed a prospective cohort study. Inclusion criteria were patients aged $\geq$18 years undergoing elective coronary artery bypass grafting, heart valve surgery, or aortic surgery from September 21, 2014 to April 22, 2015 at the Karolinska University Hospital, Stockholm, Sweden. Patients undergoing minimally invasive cardiac surgery were not included. Patients were excluded if the examiner was unable to obtain a satisfactory pulsed-wave Doppler reading (n = 6), if they had a kidney transplant (n = 0), if they had dialysis-dependent kidney disease (n = 0), or if they had cancelled surgery (n = 2). The study complied with the Declaration of Helsinki and was approved by the regional ethics committee in Stockholm, Sweden. Written informed consent was obtained before inclusion and data collection.

Ultrasound Measurements

All ultrasound examinations were performed by the author, S.L.C., who was trained by the author, K.L., who is a specialist in clinical physiology. The examinations were performed the day before surgery. The resistive index was calculated as the difference between the highest systolic blood velocity and lowest diastolic blood velocity divided by the highest systolic blood velocity ($[vmax_{systole} - vmin_{diastole}]/vmax_{systole}$). The quotient can thus be a number between 0 and 1. The velocities were measured using pulsed Doppler. The preoperative RRI was obtained with an ACUSON Sequoia 512 ultrasound machine (Siemens, Mountain View, CA) with a curvilinear probe. The examination was conducted at the preoperative ward with the patients lying on their side, if they were able,

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with the kidney visualized from the flank or back as appropriate. Three coronal windows were obtained from each kidney; 1 from the most rostral third, 1 from the middle third, and 1 from the caudal third. From each window, 1 interlobar or arcuate artery was analyzed with pulsed-wave Doppler at 3 MHz. A reading was considered satisfactory once 3 consecutive similar-looking waveforms were obtained. At this point, the minimum and maximum Doppler shifts, as well as the resistive index as calculated by the ultrasound machine, were recorded. A mean RRI was calculated from all measurements. This method previously has been described in detail elsewhere.[7] The examiner was only informed about the planned surgical procedure and was blinded to the patients' characteristics, except for visual characteristics, when performing the examination.

Patients' Characteristics

The patients' characteristics, as well as preoperative and postoperative serum creatinine levels, were retrieved from medical records. The authors used the preoperative serum creatinine value that was analyzed at the closest time before surgery, generally within 24 hours, and the postoperative serum creatinine value was the highest value within 48 hours after surgery. Postoperative urine production was obtained from the hourly measurements during the cardiac surgery intensive care unit stay or the first 24 hours in patients with a longer cardiac surgery intensive care unit stay. Left ventricular ejection fraction was extracted from echocardiographic examination protocols and was dichotomized into 2 categories ($\geq$50%, $<$50%).

Definitions

An elevated RRI was defined as $\geq$0.7. AKI was defined according to the Acute Kidney Injury Network criteria stage 1 or worse as an absolute increase in postoperative compared with preoperative serum creatinine levels by $\geq$26 μmol/L or a relative increase by $\geq$50% or a postoperative urine output $<$0.5 mL/kg for 6 hours or longer.[12,13] The preoperative glomerular filtration rate was estimated using the Chronic Kidney Disease Epidemiology Collaboration formula.[14] Diabetes, chronic obstructive pulmonary disease, peripheral vascular disease, previous stroke, and myocardial infarction were defined as a registered diagnosis in the medical records. Atrial fibrillation was defined as a registered diagnosis of persistent or paroxysmal atrial fibrillation, or atrial fibrillation during an ultrasound examination.

Statistical Analysis

The association between the RRI and AKI was analyzed using logistic regression. Odds ratios for developing AKI in patients with an RRI $\geq$0.7 compared with the reference group with an RRI $<$0.7 were calculated using logistic regression and reported with 95% confidence intervals. A cutoff of $\geq$0.7 has been used previously.[15] The authors also performed adjusted

Table 1. Patients' Characteristics

	All patients	RRI $<$0.7	RRI $\geq$0.7	p Value
Number of patients	96	38	58	
Age at surgery (years), median (Q1, Q3)	69 (61, 73)	64 (59, 71)	70 (66, 76)	0.002
Female, n (%)	26 (27)	9 (24)	17 (29)	0.64
eGFR (mL/min/1.73 m^2), median (Q1, Q3)	81 (70, 91)	85 (68, 93)	81 (73, 90)	0.33
Preoperative serum creatinine (μmol/L), median (Q1, Q3)	81 (72, 93)	83 (72, 93)	79 (71, 91)	0.64
Heart rate (beats/min), median (Q1, Q3)	64 (60, 72)	64 (60, 72)	64 (60, 72)	0.80
Systolic blood pressure (mmHg), median (Q1, Q3)	130 (119, 145)	123 (110, 135)	130 (120, 150)	0.021
Diastolic blood pressure (mmHg), median (Q1, Q3)	78 (70, 80)	80 (70, 85)	73 (65, 80)	0.002
Pulse pressure (mmHg), median (Q1, Q3)	50 (40, 68)	43 (40, 50)	60 (50, 70)	$<$0.001
Left ventricular ejection fraction				0.15
Ejection fraction $>$50%, n (%)	71 (75)	31 (84)	40 (69)	
Ejection fraction $<$50%, n (%)	24 (25)	6 (16)	18 (31)	
Diabetes, n (%)	20 (21)	5 (13)	15 (26)	0.20
Body mass index (kg/m^2), median (Q1, Q3)	26 (24, 29)	26 (24, 28)	26 (25, 30)	0.68
Atrial fibrillation diagnosis, n (%)	10 (10)	3 (8)	7 (12)	0.74
Previous myocardial infarction, n (%)	20 (21)	6 (16)	14 (24)	0.44
Previous heart surgery, n (%)	5 (5)	1 (3)	4 (7)	0.65
COPD, n (%)	4 (4)	0 (0)	4 (7)	0.15
Previous stroke, n (%)	5 (5)	3 (8)	2 (3)	0.38
Peripheral vascular disease, n (%)	2 (2)	0 (0)	2 (3)	0.52
Type of procedure; isolated CABG, n (%)	36 (38)	15 (39)	21 (36)	0.83
Type of procedure; isolated heart valve surgery, n (%)	40 (42)	16 (42)	24 (41)	1.00
Type of procedure; isolated aortic surgery, n (%)	6 (6)	2 (5)	4 (7)	1.00
Type of procedure; CABG + valve and/or aortic surgery n (%)	7 (7)	2 (5)	5 (9)	0.70
Type of procedure; valve + aortic surgery, n (%)	7 (7)	3 (8)	4 (7)	1.00
Use of ECC	96 (100%)	38 (100%)	58 (100%)	—
ECC time, median (Q1, Q3)	91 (67, 142)	93 (66, 138)	90 (68, 142)	0.97
Cross-clamp time, median (Q1, Q3)	61 (48, 100)	68 (47, 90)	60 (51, 102)	0.65

Abbreviations: RRI, renal resistive index; Q1, first quartile; Q3, third quartile; eGFR, estimated glomerular filtration rate; COPD, chronic obstructive pulmonary disease; CABG, coronary artery bypass grafting.