Renal Resistive Index Measurement by Transesophageal Echocardiography: Comparison With Translumbar Ultrasonography and Relation to Acute Kidney Injury

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Objectives: **The aim of this study was to evaluate the relationship between transesophageal ultrasonography-derived renal resistive index values (RRI_{TEE}) and a standard translumbar renal ultrasound-derived RRI (RRI_{TLUSG}). The effectiveness of each method to predict acute kidney injury (AKI) after cardiac surgery also was compared.**

Design: **A prospective observational study.**

Setting: **A teaching university hospital.**

Participants: **Sixty patients undergoing cardiac surgery.**

Interventions: **First, RRI was measured with both methods after anesthesia induction. Second, another measurement was performed with TEE after cardiopulmonary bypass and immediately following the surgery with translumbar ultrasound. To test the correlation between the 2 methods and to plot a Bland-Altman graph, preoperative RRI values measured by both techniques were used. Receiver operating characteristic curves also were plotted to compare the diagnostic values of RRI measured intraoperatively by TEE after cardiopulmonary bypass and by RRI_{TLUSG} after surgery.**

Measurements and Main Results: **There was a statistically significant correlation between the 2 RRI measurement approaches ($r = 0.86$, $p < 0.0001$). The Bland-Altman plot indicated good agreement between the methods. The area under the curve (AUC) of RRI_{TEE} in predicting AKI was 0.82 (95% confidence interval [CI] = 0.64-0.9, $p = 0.001$), and the AUC of RRI_{TLUSG} after surgery was 0.85 (95% CI = 0.7-0.98, $p < 0.0001$). In predicting AKI, an uncertainty zone for RRI_{TEE} values between 0.68 and 0.71 was computed by the gray-zone approach.**

Conclusions: **RRI_{TEE} showed clinically acceptable agreement with RRI_{TLUSG}. Indeed, RRI measured intraoperatively with TEE was comparable to RRI_{TLUSG} in terms of detecting postoperative AKI.**

KEY WORDS: transesophageal echocardiography, Doppler, renal resistive index, acute kidney injury, cardiac surgery

DESPITE IMPROVEMENTS in monitoring technology and therapeutic strategies, cardiac surgery-associated acute kidney injury (AKI) remains a common and serious postoperative complication. After cardiac surgery, the incidence of AKI has been reported to be 3% to 30%, depending on its definition.[1–4] Even in patients who do not require dialysis, AKI is associated with increased morbidity and mortality.[2] In clinical practice, the diagnosis of AKI is based on serum creatinine and urinary output. The relationship between a minimal increase in creatinine and 30-day mortality has been well documented in previous studies.[2,5] However, both serum creatinine and urinary output are relatively insensitive and unreliable markers in detecting AKI because serum creatinine levels can vary widely with age, sex, muscle mass, muscle metabolism, medications, and hydration status, and serum creatinine does not depict accurately kidney function until steady-state equilibrium has been achieved during acute changes in glomerular filtration.[6,7] Moreover, they can be altered by several factors during the perioperative period.[8] Park et al[9] proposed that the failure of prior interventional trials is, in part, attributable to delays in the diagnosis of AKI on the basis of early changes in serum creatinine. However, optimal preventative and therapeutic interventions require expeditious diagnosis of AKI, as for any other disease state.

Several biologic and physiologic early AKI markers have been investigated.[10] However, most of these novel biomarkers are impractical for use at the bedside and intraoperatively because of their cost, predictability, and delayed results.[10,11]

Renal blood flow is decreased at an early stage during acute tubular necrosis as a consequence of protracted intrarenal vasoconstriction.[12] The Doppler-based renal resistive index (RRI = [peak systolic velocity – end-diastolic velocity]/peak systolic velocity), measured with ultrasonography, is a noninvasive, practical, and inexpensive method of predicting AKI in the early phase.[13–15] Renal resistive index values (RRI) usually is obtained by transabdominal or translumbar renal Doppler ultrasonography (RRI_{TLUSG}), but these approaches are impractical during cardiac surgery. Transesophageal echocardiography (TEE) also can be used to measure renal arterial blood flow Doppler velocities and RRI (RRI_{TEE}) in patients undergoing cardiac surgery.[16,17] However, data regarding the utility of TEE in monitoring RRI, the concordance between RRI_{TEE} and RRI_{TLUSG}, and the prognostic value of RRI_{TEE} in predicting AKI are insufficient.

In this prospective study, it was hypothesized that there would be a good correlation and agreement between RRI_{TEE} and RRI_{TLUSG} in patients undergoing cardiac surgery. The effectiveness of the 2 methods in predicting AKI also was compared.

METHODS

After obtaining institutional ethics committee approval and informed consent, 60 patients scheduled for elective cardiovascular surgery with cardiopulmonary bypass (CPB) were examined in this prospective, observational study. The exclusion criteria were any renal or renal artery disease, nonsinus cardiac

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rhythm, use of an intraaortic balloon pump, severe aortic insufficiency, and any contraindication to the use of TEE, such as esophageal stricture, esophageal diverticulum, esophageal tumor, recent esophageal/gastric surgery, or radiation to the chest.

Standard monitoring was used, and the same induction and maintenance methods for anesthesia were used in all patients. After systemic heparinization, aortic and venous cannulations were performed, and nonpulsatile CPB was initiated. The flow rate was maintained at 2.2 to 2.4 L/min/m^2, mean arterial pressure (MAP) at 50 to 80 mmHg, and temperature at 28°C to 30°C. Intermittent antegrade cold blood cardioplegia was used for myocardial protection. During weaning from CPB an inotrope or vasopressor agent was selected, as necessary, according to echocardiographic and hemodynamic findings.

After anesthesia induction, an anesthesiologist experienced in measuring RRI performed translumbar RRI measurements with a 3C5s convex probe and a Mindray M5 sonogram (Mindray Medical International Limited, Shenzhen, China). First, the left kidney was localized, renal vasculature was identified using color Doppler, and then the arterial waveforms were obtained by Doppler in the interlobar renal artery. The Doppler spectrum was considered optimal when at least 4 similar consecutive waveforms were visualized (Fig 1). Then, Doppler blood flow velocities (peak systolic velocity and end-diastolic velocity) were recorded. Subsequently, the RRI was calculated: (RRI = [peak systolic velocity – end-diastolic velocity] / peak systolic velocity). RRI_{TLUSG} was measured after the induction of anesthesia (T_0) and immediately after completion of the surgical procedure (T_1).

Using an HD11 XE echocardiograph and TEE probe (Philips, Bothell, WA), a TEE examination also was performed after the induction of anesthesia. Another experienced anesthesiologist-echocardiographer, blinded to the RRI_{TLUSG} values, manipulated the probe to obtain images of the renal parenchyma and measured the Doppler velocities of the interlobar artery using the technique described by Bandyopadhyay et al.[18] The TEE probe was advanced to obtain a midpapillary transgastric short-axis view. The probe was turned counterclockwise to visualize the descending aorta. The origin of the left renal artery was then located, and the probe was turned to the right to visualize the left kidney. In patients in whom the origin of the left renal artery could not be located, the probe was turned blindly through 90° right and advanced 5 to 10 cm beyond the transgastric short-axis view to locate the left kidney. To optimize the two-dimensional renal image, the imaging plane, depth, frequency, and gain settings were adjusted as appropriate. Color-flow Doppler (Nyquist limit 15-20 cm/sec) was used to visualize the renal vasculature. Probe position and gain were adjusted to locate the renal interlobar artery. The Doppler cursor then was moved into the center of the interlobar artery. After blood flow spectral waveforms were obtained by a pulsed-wave Doppler technique, peak systolic and end-diastolic velocities were measured in the interlobar artery (Fig 1). To optimize the pulsed-wave Doppler waveform, the lowest wall filter (50 Hz) was selected, a gate length of 2 mm was used, and the Doppler transmit gain was adjusted as appropriate. The same measurement methodology as with translumbar USG was used to calculate RRI. RRI_{TEE} was measured at the same time as the RRI_{TLUSG} measurement (T_0), and after the aortic and venous cannulae were removed after weaning from CPB (T_1).

Blood samples were collected for blood gas analyses, including lactate and hematocrit, before surgery and on CPB at 30-minute intervals. Serum creatinine was measured prospectively before surgery and daily until postoperative day 7. Surgery type, duration of surgery, aortic cross-clamp and CPB, need for transfusion, mean arterial pressure, heart rate, arterial carbon dioxide pressure, right atrial pressure, lowest hematocrit values on CPB, and doses of vasopressor or inotrope also were recorded.

AKI was defined according to Kidney Disease: Improving Global Outcomes (increase in creatinine by ≥ 0.3 mg/dL within 48 hours, or increase in creatinine to ≥ 1.5-fold the baseline value, which is known or presumed to have occurred within the prior 7 days, or urine volume <0.5 mL/kg/hour for 6 hours).[19] Urine output was measured until the Foley catheter was removed. Subsequently, only daily serum creatinine values were used. Renal replacement therapy was started in patients with AKI according to the authors' center's protocol (intractable metabolic acidosis with a pH below 7.20, serum potassium values of >6.5 mmol/L, the presence of severe refractory volume overload, a blood urea level of >100 mg/dL, and serum sodium levels of <115 or >160 mmol/L).

Sample size estimation was based on detecting a correlation between translumbar- and TEE- derived RRI values. With a

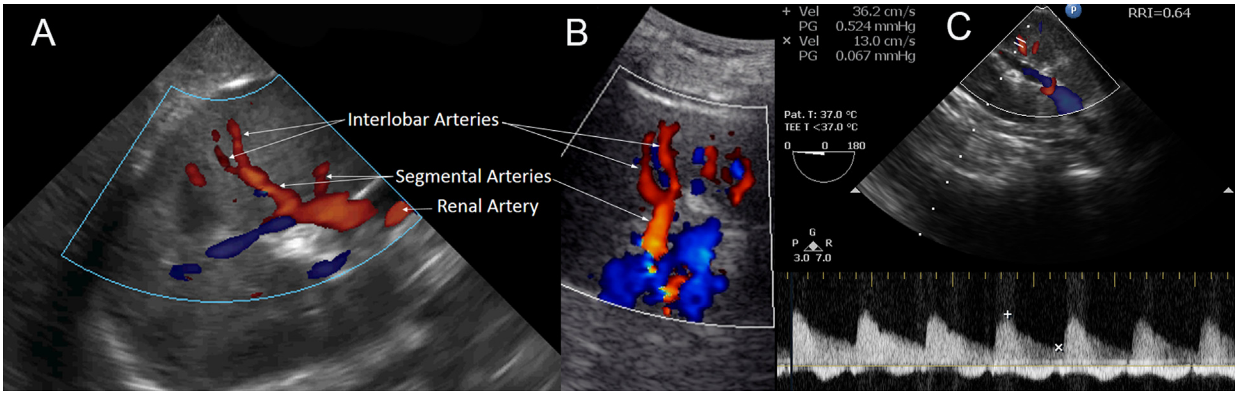

Fig 1. Examples of color-flow Doppler imaging of transesophageal (A) and translumbar USG (B) and pulsed-wave Doppler imaging (C) obtained by transesophageal echocardiography.