BJA

British Journal Of Anaesthesia, 117 (5): 623–34 (2016)

doi: 10.1093/bja/aew307
Paediatrics

PAEDIATRICS

Non-invasive measurement of renal perfusion and oxygen metabolism to predict postoperative acute kidney injury in neonates and infants after cardiopulmonary bypass surgery

F. Neunhoeffer[1]*, M. Wiest[1], K. Sandner[1], H. Renk [1], E. Heimberg[1], C. Haller[2], M. Kumpf[1], C. Schlensak[2] and M. Hofbeck[1]

[1]Department of Paediatric Cardiology, Pulmology and Paediatric Intensive Care Medicine, University Children's Hospital, Hoppe-Seyler-Straße 1, Tübingen 72076, Germany and [2]Department of Thoracic and Cardiovascular Surgery, University Hospital, Hoppe-Seyler-Straße 1, Tübingen 72076, Germany

*Corresponding author. E-mail: felix.neunhoeffer@med.uni-tuebingen.de

Abstract

Background: The pathophysiology of acute kidney injury (AKI) after cardiopulmonary bypass surgery for congenital heart disease is not completely understood. The aim of this study was to carry out a prospective analysis of the diagnostic value of non-invasive monitoring of renal oxygenation and microcirculation by combining laser Doppler flowmetry and tissue spectrometry.

Methods: In 50 neonates and infants who underwent repair ($n = 31$) or neonatal palliation ($n = 19$) of congenital heart disease with cardiopulmonary bypass, renal oxygenation, and microcirculatory flow, the approximate renal metabolic rate of oxygen and Doppler-based renal resistive index were determined after surgery. Correlations between these parameters and the occurrence of AKI according to the Pediatric Risk, Injury, Failure, Loss, End Stage Renal Disease criteria were investigated.

Results: Acute kidney injury occurred in 45% of patients after repair and in 32% after palliation. Renal oxygenation was significantly lower and the approximate renal metabolic rate of oxygen significantly higher in patients with AKI ($P < 0.05$). The microcirculatory flow was significantly higher in patients with AKI after neonatal palliation ($P < 0.05$), whereas renal resistive index was significantly higher in patients with AKI after repair ($P < 0.05$). The sensitivity of renal oxygenation, metabolic rate of oxygen, microcirculation, and resistive index in predicting AKI was 78–80, 73–78, 64–83, and 71–74%, respectively, with a specificity of 63–65, 54–75, 64–78, and 46–74% (area under the curve: 0.73–0.75, 0.68–0.83, 0.52–0.68, and 0.60–0.75), respectively.

Conclusions: Monitoring of renal oxygen metabolism allows early prediction of AKI in infants after cardiac surgery. In contrast, renal resistive index does not allow prediction of AKI after neonatal palliation with aortopulmonary shunt establishment.

Key words: acute kidney injury; cardiopulmonary bypass; heart defect, congenital; infant; neonate; renal blood flow, effective; renal circulation; thoracic surgery

Accepted: June 23, 2016

Editor's key points

- Acute kidney injury (AKI) is a common complication of cardiac surgery and is associated with adverse outcome.
- Early prediction or detection of AKI may assist with management and improve outcome.
- The authors studied 50 neonates with congenital heart disease who underwent corrective or palliative procedures.
- They investigated correlations between postoperative renal metabolism, oxygenation, and flow parameters and AKI development.

Neonates and infants undergoing cardiopulmonary bypass (CPB) surgery for congenital heart disease are at risk of acute kidney injury (AKI) in the immediate postoperative period.[1,2] The clinical manifestation of AKI varies from little increase in serum creatinine to complete anuria. The reported incidence ranges from 5 to 52% in patients after paediatric CPB surgery.[1,3–7] The pathogenetic factors involved in the development of AKI after CPB are multifactorial and include renal ischaemia and reperfusion injury, oxidative stress, and systemic inflammatory response, aggravated by reduced postoperative cardiac output and nephrotoxin exposure.[8] Early detection of AKI is important to improve strategies to preserve and optimize renal function, because AKI is related to poor outcomes, such as a longer length of paediatric intensive care unit (PICU) stay and higher rate of mortality.[7,9–12] The severity of AKI is stated according to the RIFLE (risk, injury, failure, loss, end-stage renal disease) criteria, which have been modified for children (pRIFLE).[13,14] The pRIFLE criteria rely on measurements of renal dysfunction, such as creatinine clearance and oliguria, which are rather late markers of renal injury. Several novel biomarkers have been studied in humans, indicating renal structural damage at an earlier stage. Urine neutrophil gelatinase-associated lipocalin (NGAL) indicates the damaging force of CPB, and serum cystatin C is a valuable predictive biomarker for detecting AKI.[15] The renal resistive index (RRI), determined by Doppler ultrasonography, directly reveals and quantifies renal vascular resistance. Measurement of RRI predicts the risk for AKI in critically ill patients or after cardiac surgery in adults.[16,17] Bossard and colleagues[18] and Guinot and colleagues[19] found the RRI after cardiac surgery with CPB to be a parameter predictive of AKI. Although Doppler examinations of renal perfusion have been performed in infants and children with AKI after CPB,[20] no systematic data are available describing the value of RRI in the prediction of AKI among these high-risk patients.

Recent studies have suggested that renal near-infrared spectroscopy (NIRS) monitoring might be a non-invasive tool for early detection of AKI in infants undergoing cardiac surgery with CPB.[21–24] Near-infrared spectroscopy uses an infrared light source to measure regional oxyhaemoglobin saturation (rS_{O_2}) non-invasively. Low NIRS saturations, obtained from the flank probes, appear to be associated with AKI, worse clinical status, and increased length of mechanical ventilation in neonates and infants after repair of congenital heart disease.[21–24] A novel device called oxygen to see (O2C; LEA Medizintechnik, Giessen, Germany) provides not only the possibility of non-invasive monitoring of regional oxygenation but also of quantification of the microcirculation based on combined laser Doppler flowmetry and tissue spectrometry. The device has already been used for examination of the tissue microcirculation and oxygenation in various settings, including the gastrointestinal tract,[25,26] myocardium,[27] palmar microcirculation after radial artery transplantation surgery,[28] and monitoring of cortical microcirculation during neurosurgery.[29,30] To the best of our knowledge, this technique has not yet been used for evaluation of renal perfusion in neonates and infants.

The purpose of this prospective single-centre study was to establish the diagnostic value of renal O2C measurements and Doppler-based determination of RRI in the assessment of renal perfusion and early prediction of AKI after CPB surgery in neonates and infants.

Methods

From January, 2013 to January, 2014, 52 neonates and infants undergoing repair or neonatal palliation of congenital heart disease were enrolled in our prospective study. Inclusion criteria were age <1 yr, cardiac surgery performed with the aid of CPB, and written parental informed consent for all patients. Two children were excluded owing to a postoperative requirement for extracorporeal membrane oxygenation, because the external oxygenator would affect O2C and RRI data. Therefore, 50 patients were included. The study was approved by the local ethics committee (575/2012BO1).

Patient characteristic data comprised the age at operation, preoperative weight and height, sex, cardiac diagnosis, surgical procedure, RACHS-1 (Risk Adjustment for Congenital Heart Surgery) classification,[31] and duration of CPB. Haemodynamic status was estimated by calculation of a daily maximal vasoactive inotropic score (VIS) for the first 5 days after CPB.[32] RACHS-1 is a consensus-based method of risk adjustment for in-hospital mortality among children younger than 18 yr after surgery for congenital heart disease. It was created to judge relative institutional performance, either by evaluating within-risk-category differences or by comparisons of observed and expected mortality rates.[31] The inotrope score was initially described to quantify the amount of cardiovascular support received by neonates undergoing cardiac surgery with CPB. The VIS is a tool to measure illness severity. Maximal VIS in the first 24 h after PICU admission is strongly associated with morbidity and mortality and predicts poor clinical outcome in infants undergoing cardiac surgery.[32] For each patient, serum creatinine and urea concentrations, hourly urine output, the use of renal replacement therapy, arterial saturation (Sa_{O_2}), and haemoglobin (Hb) were recorded daily for up to 5 days. The baseline estimated creatinine clearance was calculated by means of a serum creatinine concentration measured <48 h before surgery using the Schwartz AKI equation.[33] The pRIFLE criteria were applied, and the patients were assigned to the appropriate pRIFLE stage (risk, injury, failure, loss or end-stage) if they met either estimated creatinine clearance, calculated using the Schwartz equation, or urine output criteria, or both. We limited the postoperative time period to 72 h because AKI is clinically manifested during this time period. After 5 days of observation, patients were classified into the maximal pRIFLE stage (Fig. 1). The primary end point was the occurrence of AKI within 5 days after the end of CPB.

For further analysis, we split the study population into four groups depending on the type of surgery and development of AKI. Patients with biventricular hearts, who underwent surgical repair with separation of both circulations, were summarized in the category 'surgical repair', whereas procedures in children with biventricular or functional univentricular hearts without separation of both circulations were subsumed to the category