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Acute Kidney Injury in Patients Undergoing On-Pump Cardiac Surgery: A Single Center Experience

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1. Abstract

1.1. Background: Cardiopulmonary bypass (CPB) was one of the risk factors for acute kidney injury (AKI) in patients undergoing cardiac surgery. Previous studies indicated that the incidence of AKI in on-pump surgery varied from 1% to 64%, according to different criteria of AKI and types of surgery. Fuwai Hospital is a prominent center for cardiac surgery in China. The incidence of AKI in patients undergoing cardiac surgery with CPB in our center remained unknown. Therefore, we wanted to summarize the incidence of acute kidney injury (AKI) in patients undergoing on-pump cardiac surgery at Fuwai Hospital and analyze the risk factors and preventive and therapeutic measures for AKI.

1.2. Methods: Relevant articles were searched from China National Knowledge Infrastructure (CNKI), VIP Data, WANFANG Data, Sino-Med, PubMed, Ovid, and Embase, using the search terms: ("Fuwai" OR "fuwai") AND ("acute kidney injury" OR "renal dysfunction" OR" renal failure" OR "renal replacement therapy" OR" dialysis" OR "blood urea nitrogen" OR "creatinine") AND ("cardiopulmonary bypass" OR " extracorporeal circulation").

1.3. Results: Seventeen studies were included in this analysis. The incidence of on-pump cardiac surgery-induced AKI ranged from 25.6% to 77.6%. Risk factors for AKI in adults included increased age, prolonged cardiopulmonary bypass (CPB) duration, elevated body mass, male sex, history of hypertension, total red blood cell infusion, aortic dissection, and total arch replacement combined with frozen elephant trunk implantation. In pediatric patients, the risk factors for AKI were preoperative cardiac dysfunction, early fluid overload, higher preoperative estimated creatinine clearance, higher postoperative day neutrophil-to-lymphocyte ratio, postoperative day renal hypoperfusion pressure, and a previous bidirectional Glenn procedure. In addition, urine neutrophil gelatinase-associated lipocalin was a highly predictive early biomarker of AKI. Levosimendan reduced the incidence of postoperative AKI in critically ill patients undergoing on-pump coronary artery bypass grafting. The aortic balloon occlusion technique decreased the incidence of postoperative AKI. A lower threshold of hypothermic-indexed oxygen delivery was negatively associated with AKI. A longer duration from diagnosis to surgical repair and a higher preoperative albumin level helped lower the risk of AKI in pediatric patients with left coronary reimplantation.

1.4. Conclusions: The incidence of AKI varied from 25.6% to 77.6% among patients undergoing cardiac surgery with CPB at the Fuwai Hospital. Risk factors for AKI persisted throughout the perioperative period. Preoperative, intraoperative, and postoperative preventive and therapeutic measures were helpful in reducing the incidence of AKI.

2. Introduction

Acute kidney injury (AKI) occurring after on-pump cardiac surgery was common and extended the length of stay in intensive care unit and hospital, as well as increased the risk of mortality [1-3]. At present, the diagnostic criteria for AKI in adults were Kidney Disease, Improving Global Outcomes (KDIGO), risk, injury, failure, loss, end-stage (RIFLE), and acute kidney injury network (AKIN) in most studies [4]. In pediatric patients, the criteria for AKI were p-RIFLE, KDIGO, and AKIN [5]. It was reported that cardiopulmonary bypass (CPB) was one of the significant risk factors for AKI after cardiac surgery [6]. Previous studies indicated that the incidence of AKI in on-pump surgery varied from 1% to 64%, according to different definitions of AKI and types of surgery [7-14]. A study reported that acute renal failure in patients undergoing cardiac surgery occurred in up to 30%, and 1% of the patients required dialysis [15].

The Fuwai Hospital is a prominent center for cardiac surgery in China. The incidence of AKI in patients undergoing cardiac surgery with CPB at our center remains unknown. Therefore, we aimed to summarize the incidence of AKI in patients undergoing on-pump cardiac surgery at Fuwai Hospital and analyze the risk factors and preventive and therapeutic measures for AKI.

3. Method

3.1. Research Strategy

Relevant articles were identified through computerized searches of the China National Knowledge Infrastructure (CNKI), VIP Data, WANFANG Data, Chinese Bio-Medical Literature& Retrieval System (Sino-Med), PubMed, Ovid, and Embase, from database establishment to September 1, 2022, using the search terms: ("Fuwai" OR "fuwai") AND ("acute kidney injury" OR "renal dysfunction" OR" renal failure" OR "renal replacement therapy" OR" dialysis" OR "blood urea nitrogen" OR "creatinine") AND ("cardiopulmonary bypass" OR" extracorporeal circulation"). Titles and abstracts of candidate studies for eligibility were independently reviewed by two authors (Q. C. and Y. T. Y.), and those that seemed obviously ineligible were excluded. Eligibility for the final inclusion of the remaining literature was subsequently determined by examining the full text.

3.2. Inclusion and Exclusion Criteria

The inclusion criteria were as follows: (1) Research conducted at the Fuwai Hospital. (2) Clinical studies. (3) The incidence and diagnostic criteria for AKI have been described. The exclusion criteria were: (1) Reviews, guidelines, meta-analyses, case reports, and conference abstracts. (2) Studies lacking information on the outcomes of interest. (3) Animal studies. (4) Duplicate articles.

3.3. Literature Screening and Data Extraction

Two authors (Q.C. and Y.T.Y.) independently screened the literature and extracted data strictly according to the inclusion and exclusion criteria. Each author independently extracted the following data from the included studies: (1) The author, research time, and publication year of the included articles. (2) Types of surgical procedure used in this study. (3) AKI incidence. (4) Diagnostic criteria for AKI. (5) Risk factors for AKI. (6) Preventive and Therapeutic Measures for AKI. Disagreements were resolved through discussions between the two authors during the data abstraction process.

4. Results

4.1. Literature Search

As depicted in the flowchart (Figure 1), the initial search retrieved 453 studies through a database search. There were 28 potentially qualified articles were included by reading the titles or abstracts. After examining the complete text, 17 literatures were confirmed to be eligible and included [16-32]. A descriptive analysis of included literatures was presented in Table 1. Among them, 15 were retrospective studies, and 2 were randomized controlled trials. The publication dates of these articles ranged from 2014 to 2022 (Figure 2). Nine studies focused on adult patients undergoing cardiac surgery with CPB, and the remaining eight studied pediatric patients (Figure 3). These studies included 6,827 patients (4,064 adults and 2,763 pediatric patients). Of these patients, 46.3% (n = 3,163) underwent aortic surgery, 13.2% (n=901) underwent on-pump coronary artery bypass grafting (CABG), and the remaining 2,763 pediatric patients underwent congenital heart disease (CHD) surgery.

Table 1: Characteristics of included studies

Study	Research time	Study type	Patients(n)	Surgery	Group	AKI diagnosis criteria	AKI (%)
Wang et al[16]	2013 to 2016	Retrospective	553	TAR+FET	Single cohort	KDIGO	77.6
Sun et al[17]	2017 to 2019	Retrospective	188	TAR+FET	(MHCA/ACP)/ABO	RIFLE	74.5
Sun et al[18]	2010 to 2018	Retrospective	1,305	TAR+FET	Balloon occlusion/Conventional	RIFLE	31.7
Liu et al[19]	2016 to 2017	RCT	65	CHD surgery	AC/ACA	AKIN	36.9
Wang et al[20]	2010 to 2017	Retrospective	89	ALCAPA Repair	Single cohort	p-RIFLE	67.4
Wang et al[21]	2010 to 2017	Retrospective	88	ALCAPA Repair	Single cohort	p-RIFLE	71.6
Wang et al[22]	2013 to 2016	Retrospective	627	TAR+FET	MHCA/DHCA	KDIGO	75.4

Sun et al[23]	2017 to 2019	Retrospective	360	TAR+FET	Aortic balloon occlusion/ Conventional	KDIGO	31.1
Duan et al[24]	2017 to 2018	Retrospective	1,440	CHD surgery	CM/non-CM	KDIGO	29.5
Liu et al[25]	2012 to 2018	Retrospective	126	ASO	Single cohort	KDIGO	46.8
Liu et al[26]	2020 to 2021	Retrospective	314	CHD surgery	Non-ID/ Absolute ID/ Functional ID	Creatinine increase >50%	39.8
Liu et al[27]	2008 to 2020	Retrospective	377	TCPC	Single cohort	p-RIFLE	32.6
Wang et al[28]	2012 to 2013	Retrospective	130	TAR	AKI/non-AKI	RIFLE	51.5
Li et al[29]	Not reported	Retrospective	43	CABG	AKI/non-AKI	KDIGO	25.6
Zheng et al[30]	2013 to 2015	RCT	79	CABG	Levosimendan /Control group	KDIGO	27.8
Yang et al[31]	2011 to 2013	Retrospective	779	CABG	AKI/non-AKI	KDIGO	74.1
Liu et al[32]	2012 to 2021	Retrospective	264	CHD surgery	PMV/non-PMV	KDIGO	32.6

Abbreviations: ABO = aortic balloon occlusion, AC = artificial colloid, ACA = artificial colloid combined albumin, ACP = antegrade cerebral perfusion, ALCAPA = anomalous origin of the left coronary artery from the pulmonary artery, AKI = acute kidney injury, AKIN = acute kidney injury network, ASO = arterial switch operation, CABG = coronary artery bypass grafting, CHD = congenital heart disease, CM = contrast exposure, ID = iron deficiency, KDIGO = Kidney Disease, Improving Global Outcomes, MHCA/DHCA = moderate/deep hypothermic circulatory arrest, PMV = prolonged mechanical ventilation, p-RIFLE = pediatric-(risk, injury, failure, loss, end-stage), RCT = randomized controlled trial, RIFLE = risk, injury, failure, loss, end-stage renal disease, TAR = total aortic arch replacement, TAR+FET = total aortic arch replacement combined with frozen elephant trunk implantation, TCPC = total cavopulmonary connection.

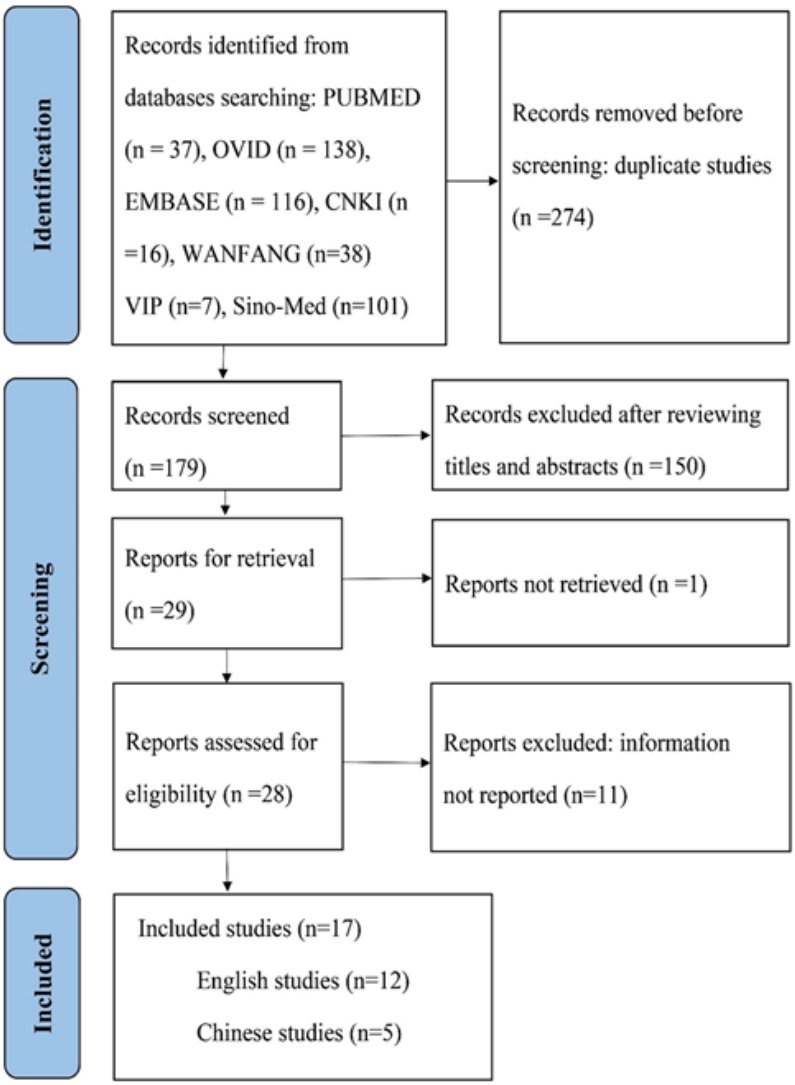

Figure 1: Flow diagram of study selection process.

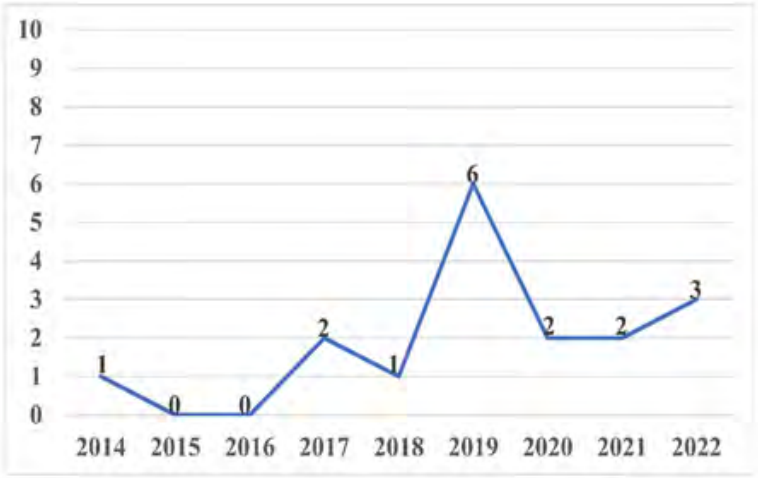

Figure 2: Acute kidney injury study publication number per year.

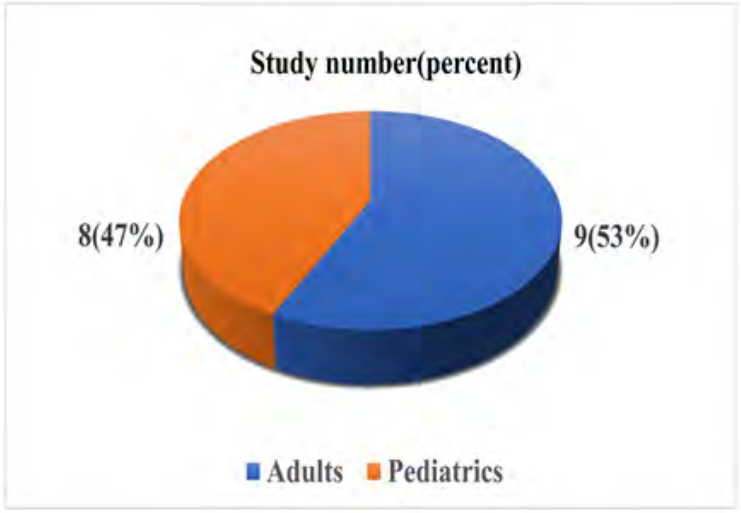

Figure 3: Acute kidney injury studies involving adults and pediatrics.

4.2. Diagnostic Criteria

AKI was identified and classified by KDIGO in nine studies, RIFLE or p-RIFLE in six studies, and AKIN in one study. One study defined AKI as an increase in creatinine level > 50%.

4.3. Incidence of AKI

The incidence of AKI varied from 25.6% to 77.6%, based on different AKI diagnostic criteria and different types of surgery (Table 1). The incidence of AKI ranged from 25.6% to 77.6% in adults undergoing on-pump cardiac surgery. In pediatric patients undergoing CHD surgery with CPB, the incidence of AKI ranged from 29.5% to 71.6%.

4.4. Risk Factors

As shown in Table 2, risk factors for AKI in patients undergoing total aortic arch replacement (TAR) under deep hypothermic circulatory arrest (DHCA) included increased age, aortic dissection, and total red blood cells infusion [28]. Advanced age was one of the independent risk factors for postoperative AKI in patients undergoing CABG with CPB [31]. Elevated body mass, older age, prolonged CPB duration, and male sex were confirmed as independent risk factors for postoperative AKI in patients undergoing TAR combined with frozen elephant trunk (FET) implantation [16]. Compared with other aortic surgeries, TAR combined with FET implantation might have more harmful effects on postoperative AKI [16]. Increased age, high body mass index, prolonged CPB duration, and hypertension were independent risk factors for AKI in patients undergoing TAR with FET procedures [22]. In pediatrics, preoperative cardiac dysfunction (left ventricular ejection fraction < 35%) [20] and early fluid overload [21] were strongly associated with AKI in patients undergoing repair for anomalous origin of the left coronary artery from the pulmonary artery (ALCAPA). Higher postoperative day neutrophil-to-lymphocyte ratio (NLR), and postoperative hypotension were associated with AKI after total cavopulmonary connection (TCPC) [27]. Previous bidirectional Glenn procedure was significantly associated with the severity of postoperative AKI [27].

Table 2: Potential acute kidney injury risk factors.

Study	Surgery	Adults/Pediatrics	Risk factors
Wang et al28	TAR	Adults	1) Increased age (OR = 1.055, 95% CI = 1.003-1.110, *P* = 0.039)
			2) Diagnosis of aortic dissection (OR = 21.770, 95% CI = 1.888-251.050, *P* = 0.014)
			3) Total red blood cell infusion (OR = 1.108, 95% CI = 1.002-1.225, *P* = 0.046)
Yang et al31	CABG	Adults	Advanced age (OR = 1.02, 95 % Cl = 1.00-1.04, *P* = 0.040)
Wang et al16	TAR+FET	Adults	1) Male sex (OR = 1.94, 95% CI = 1.22-3.18, *P* = 0.005)
			2) Older age (OR = 1.37, 95% CI = 1.14-1.67, *P* = 0.001)
			3) Elevated body mass (OR = 1.41, 95% CI = 1.08-1.87, *P* = 0.01)
			4) Prolonged cardiopulmonary bypass duration (OR = 1.17, 95% CI = 1.01-1.37, *P* = 0.03)
			5) TAR combined with FET implantation
Wang et al22	TAR+FET	Adults	1) Increased Age (OR = 1.02, 95% CI = 1.00-1.04, *P* = 0.022)
			2) High body mass index (OR = 1.06, 95% CI = 1.01-1.12, *P* = 0.016)
			3) Prolonged cardiopulmonary bypass duration (OR = 1.01, 95% CI = 1.00-1.01, *P* = 0.003)
			4) Hypertension history (OR = 1.76, 95% CI = 1.14-2.70, *P* = 0.010)
Wang et al20	ALCAPA Repair	Pediatrics	Preoperative cardiac dysfunction (left ventricular ejection fraction < 35%), (OR = 5.55, 95% CI = 1.39-22.13, P = 0.015)
Wang et al21	ALCAPA Repair	Pediatrics	Early fluid overload in pediatric patients undergoing repair for ALCAPA (OR = 5.09, 95% CI = 1.36-19.07, P = 0.016)
Liu et al27	TCPC	Pediatrics	1) Higher preoperative estimated creatinine clearance (OR = 1.039, 95% CI =1.024-1.055, *P* < 0.001)
			2) Higher postoperative day neutrophil-to-lymphocyte ratio (OR =1.208, 95% CI = 1.128-1.294, P < 0.001)
			3) Postoperative day renal hypoperfusion pressure (OR = 0.962, 95% CI = 0.938-0.986, P = 0.002)
			4) Previous bidirectional Glenn procedure (OR = 0.253, 95% CI = 0.088-0.731, *P* = 0.011)

Abbreviations: ALCAPA = anomalous origin of the left coronary artery from the pulmonary artery, CABG = coronary artery bypass grafting, TAR = total aortic arch replacement, TAR+FET = total aortic arch replacement combined with frozen elephant trunk implantation, TCPC = total cavopulmonary connection.

4.5. Preventive and Therapeutic Measures

Preventive and therapeutic measures were presented in Table 3. The concentration of urine neutrophil gelatinase-associated lipocalin (NGAL) was a highly predictive early biomarker for AKI in patients undergoing CABG with CPB29. Levosimendan reduced the incidence of AKI in critically patients undergoing CABG with CPB30. The aortic balloon occlusion (ABO) technique helped to raise the lowest nasopharyngeal temperature to 28°C and reduce the circulatory arrest time, which can help reduce the incidence of AKI [17, 18, 23]. In pediatric patients, the lower threshold of hypothermic indexed oxygen delivery (DO2i) was negatively associated with AKI in newborns undergoing arterial switch operations. DO2i > 269 ml min−1 m−2 might help reduce the incidence of postoperative AKI in neonates [25]. A longer duration from diagnosis to surgical repair and a higher preoperative albumin level helped lower the risk of AKI in pediatrics with left coronary reimplantation [20].

4.6. Postoperative Serum Creatinine Level

As shown in Figure 4, the two studies included postoperative serum creatinine (Scr) levels. A total of 1665 subjects were included, with no heterogeneity between the two studies (I2 = 0%, P= 0.95). The meta-analysis results showed that the ABO technique helped reduce the postoperative Scr level in patients undergoing TAR combined with FET implantation, and the difference was statistically significant (WMD = −23.29, 95% CI: −33.51- −13.06, P<0.00001).

4.7. Incidence of Postoperative AKI

Two studies included indicators of the incidence of postoperative AKI. A total of 1665 subjects were included, with no heterogeneity between the two studies (I2 = 35%, P= 0.21). The meta-analysis results showed that the ABO technique helped to reduce the incidence of postoperative AKI in patients undergoing TAR combined with FET implantation, and the difference was statistically significant (WMD =0.44, 95% CI: 0.27-0.72, P=0.001) (Figure 5).

Table 3: Preventive and therapeutic measures for acute kidney injury

Study	Surgery	Adults/Pediatrics	Preventive and therapeutic measures
Li et al29	CABG	Adults	Urine NGAL represented a highly predictive early biomarker for AKI
Zheng et al30	CABG	Adults	Levosimendan reduced the incidence of AKI in critical patients (OR = 0.680, 95%CI = 0.420-0.870, P = 0.032)
Sun et al17	TAR+FET	Adults	ABO technique was a protective factor for AKI (OR = 0.432, 95% CI = 0.204-0.915, *P* = 0.028)
Sun et al18	TAR+FET	Adults	The ABO technique decreased postoperative AKI
Sun et al23	TAR+FET	Adults	ABO technique reduced the incidence of AKI
Liu et al25	ASO	Pediatrics	The lower threshold of hypothermic DO_2i was negatively associated with AKI (OR = 0.991, 95% CI = 0.983-0.998, P = 0.018)
Wang et al20	ALCAPA Repair	Pediatrics	A longer duration from diagnosis to surgical repair (OR = 0.97, 95% CI = 0.95-1.00, *P* =0.049) and a higher preoperative albumin level (OR = 0.83, 95% CI = 0.70-0.99, *P* = 0.041) helped lower the risk of AKI

Abbreviations: ABO = aortic balloon occlusion, ALCAPA = anomalous origin of the left coronary artery from the pulmonary artery, AKI = acute kidney injury, ASO = arterial switch operation, CABG = Coronary artery bypass grafting, DO2i = indexed oxygen delivery, NGAL = neutrophil gelatinase-associated lipocalin, TAR = total aortic arch replacement, TAR+FET = total arch replacement combined with frozen elephant trunk implantation.

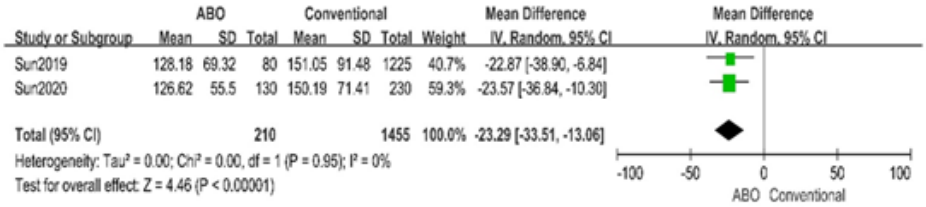

Figure 4: Forest plot of effects of the ABO technique in postoperative Scr level in patients undergoing TAR combined with FET implantation. CI = confidence interval, df = degrees of freedom, SD = standard deviation.

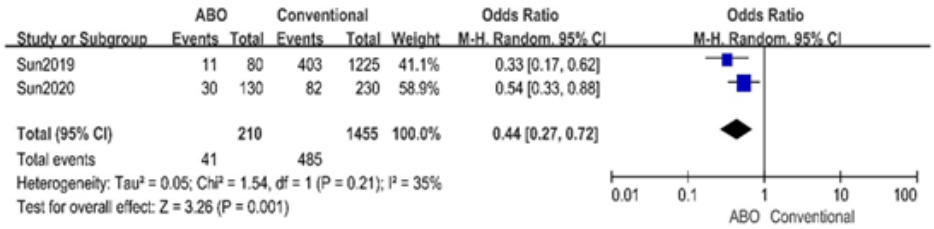

Figure 5: Forest plot of effects of the ABO technique in the incidence of postoperative AKI in patients undergoing TAR combined with FET implantation. CI = confidence interval, df = degrees of freedom, SD = standard deviation.

5. Discussion

Acute kidney injury (AKI) was reported as a common complication of cardiac surgery. In this study, we aimed to determine the incidence of AKI in adult and pediatric patients undergoing cardiac surgery with CPB at the Fuwai Hospital. The total incidence of AKI varied from 25.6% to 77.6% in patients undergoing on-pump cardiac surgery. The incidence of AKI in patients undergoing CABG with CPB varied from 25.6% to 74.1% according to the KDIGO criteria. The incidence of AKI in patients undergoing aortic surgery ranged from 31.7% to 77.6% and the diagnostic criteria used were KDIGO and RIFLE. In pediatric patients who underwent CHD surgery with CPB, the incidence of AKI ranged from 29.5% to 71.6%, owing to the different types of surgery and diagnostic criteria. A meta-analysis indicated that the incidence of AKI in patients undergoing on-pump cardiac surgery varied from 1% to 53%, based on different definitions of AKI and types of surgery [10]. Two studies showed that the incidence of AKI varied from 18% to 55% after thoracic aortic surgery, depending on the criterion of AKI and aortic pathology [9, 12]. Among pediatric patients who underwent CHD with CPB, the incidence of AKI ranged from 28% to 51% [13, 14]; in neonates, the incidence was up to 64% [11].

There were multi-definitions of CSA-AKI based on different diagnostic methodologies [33]. Currently, most of the researchers used KDIGO, AKIN, and RIFLE criteria to define AKI [34]. In our study, 52.9% of studies used KDIGO as the diagnostic criteria for AKI, and the RIFLE and AKIN percentages were 35.3% and 5.9%. Compared with the RIFLE and AKIN criteria, KDIGO

may be more suitable for defining CSA-AKI. One study showed that the KDIGO criteria were more sensitive in detecting AKI and predicting AKI-associated in-hospital mortality [35]. Without correcting for serum creatinine changes due to fluid balance, AKI was underdiagnosed when applying AKIN and RIFLE standards following cardiac surgery [36].

The risk factors for AKI in adults were increased age, older age, prolonged CPB duration, elevated body mass, male sex, history of hypertension, total red blood cell infusion, aortic dissection, and TAR combined with FET implantation. In pediatric patients, the risk factors for AKI were preoperative cardiac dysfunction (left ventricular ejection fraction < 35%), early fluid overload undergoing repair for ALCAPA, higher preoperative estimated creatinine clearance, higher postoperative day NLR, postoperative day renal hypoperfusion pressure, and a previous bidirectional Glenn procedure. Most of these risk factors were consistent with those reported in other studies of AKI. Other risk factors were not included in our study because of the limited number of studies. Other risk factors associated with AKI included female sex, the existence of various comorbidities (diabetes mellitus, congestive heart failure, hypercholesterolemia, chronic obstructive pulmonary disease, previous cardiac surgery, and pre-existing chronic kidney disease) [37], undergoing nighttime surgery [38], lower preoperative platelet count, lower preoperative hemoglobin concentration, and prolonged DHCA duration [39]. Except for TAR combined with FET implantation, complex surgery (combined valve and coronary surgery) was also increased the incidence of postoperative AKI [40].

A study in Fuwai Hospital showed that male sex was an independent risk factor for AKI in patients who underwent TAR combined with FET implantation, which contradicted the generally held consensus that female sex was an independent risk factor for the development of postoperative AKI [41-43]. However, we found that this finding was consistent with some studies, including the results of an epidemiologic study of a large number of discharges(more than 5 million) [44], a study of prognostic factors for preoperative AKI in patients with type A acute aortic dissection procedures [45], and a meta-analysis of sex and the risk of AKI following cardiac surgery [46].

CPB is one of the risk factors for AKI in patients undergoing cardiac surgery, and CPB duration is a modifiable predictor among the risk factors of AKI [16]. The pathogenesis of AKI after CPB is multifactorial, and is primarily due to hypoperfusion34. reperfusion injury [47], and activation of the systemic inflammatory response [48]. All patients who underwent on-pump cardiac surgery experienced some degree of ischemia reperfusion injury (IRI), and severe IRI-induced AKI occurred in approximately 1-2% of patients undergoing cardiac surgery with CPB6. Renal hypoxia, particularly in the medulla, played a role in on-pump cardiac surgery-associated (CSA) AKI [49]. CPB might initiate systemic inflammatory responses by releasing mitochondrial DNA (mt DNA) signaling toll-like receptor 9 (TLR9) and interleukin 6 (IL-6) [50].

Several techniques, biomarkers, and drugs can help predict or reduce the occurrence of AKI in patients undergoing cardiac surgery with CPB, such as urine NGAL concentration, which was a sensitive predictive early biomarker for AKI in patients undergoing CABG with CPB. Levosimendan reduced the incidence of AKI in critically ill patients undergoing CABG with CPB. Moderate hypothermic circulatory arrest rather than deep hypothermic circulatory arrest might help reduce the incidence of AKI. The ABO technique helped raise the lowest nasopharyngeal temperature to 28 °C and reduce the circulatory arrest time, which helped reduce the incidence of AKI. In pediatric patients, a lower threshold of hypothermic DO2i was negatively associated with AKI in newborns undergoing arterial switch operations. A longer duration from diagnosis to surgical repair and a higher preoperative albumin level helped lower the risk of AKI in pediatric patients with left coronary reimplantation. Except for these measurements, increased preoperative NT-pro BNP concentration was associated with postoperative AKI in patients undergoing cardiac surgery [51], preoperative statin exposure was associated with decreases in the incidence of all stages of postoperative CSA-AKI and stage 3 CSA-AKI [52]. Remote ischemic preconditioning prevented postoperative AKI after open TAR53. Dexmedetomidine pretreatment attenuated ischemia reperfusion injury-induced AKI [47].

We should acknowledge the limitations of this study. First, our study only summarized the incidence of AKI in patients undergoing cardiac surgery with CPB at the Fuwai Hospital. Second, most of the included articles were retrospective. Third, our study did not include the incidence of AKI for all surgical types in Fuwai Hospital.

6. Conclusions

Our study demonstrated that the incidence of postoperative AKI varied from 25.6% to 77.6% among patients undergoing on-pump cardiac surgery at the Fuwai Hospital. Risk factors for AKI, including CPB, persisted throughout the perioperative period. Preoperative, intraoperative, and postoperative preventive and therapeutic measures were helpful in reducing the incidence of AKI.

7. Ethical Approval

This study was a meta-analysis of previously published studies, ethical approval was not necessary under the Ethical Committee of Hunan Aerospace Hospital.

8. Author Contributions

Qiang Chen: conceptualization, software, data collection, data analysis/interpretation, and writing of the original draft.

Jia-li Shao: data collection, data analysis/interpretation, and revision of the article.

Yun-tai Yao: conceptualization, formal analysis, methodology, supervision, critical revision of the article, writing of the original draft and approval of the article.

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