ORIGINAL PAPER
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RJCCN

Acute Kidney Injury in Adult Patients Receiving Extracorporeal Membrane Oxygenation: A Systematic Review

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Keywords. extracorporeal membrane oxygenation, ECMO, acute kidney injury, renal replacement therapy, CRRT, mortality

Introduction. Acute kidney injury (AKI) is a frequent and clinically important complication in adults receiving extracorporeal membrane oxygenation (ECMO), yet reported incidence and associated outcomes vary widely due to differences in populations, ECMO configuration, and AKI definitions. We systematically reviewed full-text studies reporting AKI and related outcomes in adult patients supported with veno-arterial (VA) and/or veno-venous (VV) ECMO.

Methods. A systematic search of PubMed identified 661 records; 660 remained after deduplication. Full texts available for assessment were screened for eligibility (n = 126). We included original adult ECMO/ECLS studies reporting extractable AKI and/or renal replacement therapy (RRT/CRRT) outcomes.

Results. Forty-five studies were included in qualitative synthesis. AKI incidence was extractable in 29 studies and ranged from 2.3% to 89.0% (median 50.5%). RRT/CRRT use was extractable in 29 studies and ranged from 1.8% to 91.0% (median 53.3%). Mortality was extractable in 37 studies (ICU, in-hospital, or 30-day) and ranged from 6.0% to 95.0% (median 53.3%). KDIGO was the most frequently referenced AKI definition (reported in 26 studies), followed by RIFLE (19) and AKIN (11), with overlap across studies.

Conclusions. AKI and RRT/CRRT use are common in adults receiving ECMO, with substantial variability driven by clinical heterogeneity and inconsistent AKI definitions and outcome reporting. Standardized AKI definitions and harmonized reporting of renal and mortality outcomes are needed to improve comparability and guide future ECMO–kidney research.

RJCCN 2026; 2: 45-57
www.rjccn.org
DOI: 10.61882/rjccn.2.1.31

INTRODUCTION

Extracorporeal membrane oxygenation (ECMO) has become an established form of temporary life support for adults with refractory respiratory failure (veno-venous, VV-ECMO) and/or circulatory collapse (veno-arterial, VA-ECMO), particularly when conventional therapies fail.[1] Over the last decade, adult ECMO utilization has expanded substantially worldwide, supported by improved technology, increasing clinician experience, and growing guidance from international societies.[2] This growth is also reflected in large registry data: the Extracorporeal Life Support Organization (ELSO) Registry reports continuing increases in adult

Please cite this article as: Tripathi S, Prasad Sunda J. Acute Kidney Injury in Adult Patients Receiving Extracorporeal Membrane Oxygenation: A Systematic Review. RJCCN 2026; 2(1): 45-57

ECMO activity across participating centers and provides contemporary benchmarks for outcomes and complications.[3] Randomized and comparative evidence in severe acute respiratory distress syndrome (ARDS)—including the CESAR trial and the EOLIA trial—has further shaped modern ECMO practice and contributed to broader adoption, especially in high-volume referral centers.[4,5]

Acute kidney injury (AKI) is one of the most common and clinically significant complications experienced with ECMO support. AKI as it is known in this context is usually multifactorial and results in a complex interaction of critical illness physiology and ECMO-specific factors. First, many patients are started on ECMO because they are suffering from profound hemodynamic and/or respiratory failure; systemic hypoperfusion, venous congestion, exposure to vasopressors, and shock-inflammation all predispose the kidney to injury.[6] Second, ECMO may alone contribute to injury by interactions between blood and surfaces that increase inflammation and complement activity, hemolysis and pigment nephropathy, non-pulsatile bloodflow (especially relevant to VA-ECMO physiology) and conflicting clinical priorities (anticoagulation, transfusion, and bleeding).[7] Third is that fluid overload is prevalent among ECMO patients due to capillary leak, large-volume resuscitation and transfusion requirements; and a positive fluid balance is consistently linked to poor outcomes and is tightly interwoven with AKI development and renal replacement therapy (RRT) requirement.[8] Finally, concomitant exposures such as sepsis, nephrotoxic antimicrobials, iodinated contrast and rhabdomyolysis predispose a population that is already susceptible to multi-organ dysfunction to AKI.[6]

The clinical significance of AKI during ECMO is high. AKI is associated with increased mortality, longer intensive care unit (ICU) hospital stays and increased resource utilisation, especially if RRT is necessary.[9,10] The long-term consequences of severe AKI, besides the acute hospitalization, survivors may continue to be at high risk for chronic kidney disease (CKD), end-stage kidney disease and long-term mortality consequences that further amplify the individual and health system burden of ECMO-associated renal injury.[9] Because RRT is often utilised during ECMO for indications that include refractory fluid overload, severe AKI, electrolyte/acid-base disturbances, and uremia, the interface of ECMO and RRT has emerged as a critical practical domain in critical care nephrology.[7] One of the most challenging issues is that AKI incidence is reported widely across the literature in the adult ECMO population. Such variability is in part accounted for by heterogeneous patient populations (VA vs. VV ECMO, different case-mix and severity of illness), different time windows used to identify AKI (e.g., at the time of cannulation, during the ECMO run, or after decannulation), and inconsistencies in the estimation of baseline creatinine and urine output expression[6]. Importantly, the AKI definition chosen has a material impact on the estimate of occurrences. Previous consensus systems like the RIFLE criteria and Acute Kidney Injury Network (AKIN) classification were proposed to standardize the diagnosis and severity of this type of illness and subsequently, the Kidney Disease: Improving Global Outcomes or KDG - a contemporary guideline - incorporated parts of both systems into a widely accepted and applied framework.[11,12] Nonetheless, ECMO studies often use mixed definitions, use modified criteria or omit important components (especially urine output), so comparability may be limited and synthesis of the evidence may be complicated. This heterogeneous approach is causing uncertainty amongst clinicians and researchers concerned about obtaining robust estimates of AKI prevalence, RRT utilisation and associated outcomes in adult ECMO populations.

Study Aim

The primary aim of this systematic review is to summarize the incidence and definitions of AKI among adult patients receiving VA-ECMO and/or VV-ECMO. Secondary aims are to describe the reported use of RRT/continuous RRT (CRRT) and mortality outcomes (e.g., ICU, in-hospital, or short-term mortality as reported), and to identify key reporting gaps that limit cross-study comparability and clinical translation.

MATERIALS AND METHODS

Protocol and Reporting Standard

This systematic review was conducted and

reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 statement.[13] A review protocol was developed before screening and data extraction. The protocol was not registered in PROSPERO (International Prospective Register of Systematic Reviews).

Eligibility Criteria

Studies were eligible if they met the following criteria:

Population. Adult patients (≥ 18 years) receiving ECMO/extracorporeal life support (ECMO/ECLS), including veno-arterial (VA) and/or veno-venous (VV) configurations

Study Types. original research (e.g., cohort studies, registry analyses, case-control studies, or clinical trials)

Outcomes. reported extractable data for at least one of the following—AKI incidence and/or AKI definition, renal replacement therapy (RRT) or continuous renal replacement therapy (CRRT) utilization, and mortality outcomes (ICU mortality, in-hospital mortality, or 30-day mortality as reported). Studies were excluded if they focused on pediatric or neonatal populations, were review articles/meta-analyses/editorials/letters, were case reports or small case series, lacked extractable renal outcome data, or clearly represented overlapping cohorts where a more complete or larger dataset was available (in which case the most comprehensive report was retained).

Information Sources

The primary information source was PubMed (National Library of Medicine). Additional free full-text sources were used only for retrieval of articles when available (e.g., PubMed Central, publisher "free full text" links, and publicly accessible PDFs). The final search was performed on 20/12/2025.

Search Strategy

The search strategy combined terms for: 1) ECMO/ECLS (e.g., "extracorporeal membrane oxygenation," ECMO, ECLS, and related terms), and 2) kidney outcomes (e.g., "acute kidney injury," AKI, "renal replacement therapy," RRT, CRRT, dialysis).

Study Selection Process

All records retrieved from PubMed were exported and imported into Zotero for reference management and screening. Duplicate records were identified and removed within Zotero. Screening was performed in two stages: 1) Title/abstract screening to identify potentially eligible studies, and 2) Full-text eligibility assessment for those advanced to retrieval. Full texts were obtained using open-access links and web-based retrieval where available. Screening was conducted by two reviewer using predefined criteria; uncertain eligibility decisions were resolved through discussion among the authors to ensure consistency.[13]

Data Extraction

A standardized extraction form was used to collect the following information from each included study: study design, setting, publication year, sample size; ECMO configuration (VA, VV, or mixed) and primary clinical indication when reported; AKI definition (e.g., KDIGO, RIFLE, AKIN, or other); AKI incidence (n/N and/or %); RRT/CRRT use (n/N and/or %); and mortality outcomes (type and rate, including ICU, in-hospital, or 30-day mortality). When outcomes were not reported in extractable numeric form, they were recorded as not reported (NR) or not extractable, and denominators were allowed to vary across outcomes.

Risk of Bias Assessment

Risk of bias for observational studies was planned to be assessed using the Newcastle–Ottawa Scale (NOS), evaluating domains of selection, comparability, and outcome assessment. Studies were to be categorized as low, moderate, or high risk of bias based on overall NOS domain performance. If any randomized trials were identified, an appropriate randomized trial risk-of-bias tool (e.g., RoB 2) would be applied.[14]

Synthesis Approach

A narrative synthesis with tabulation of study characteristics and outcomes was performed. Meta-analysis was not undertaken because of substantial heterogeneity across studies in patient populations (VA vs. VV and differing indications),

AKI definitions (KDIGO/RIFLE/AKIN or unspecified), and outcome windows (timing of AKI ascertainment and mortality endpoints), which limits statistical comparability and interpretability of pooled estimates.[15]

RESULTS

Study Selection

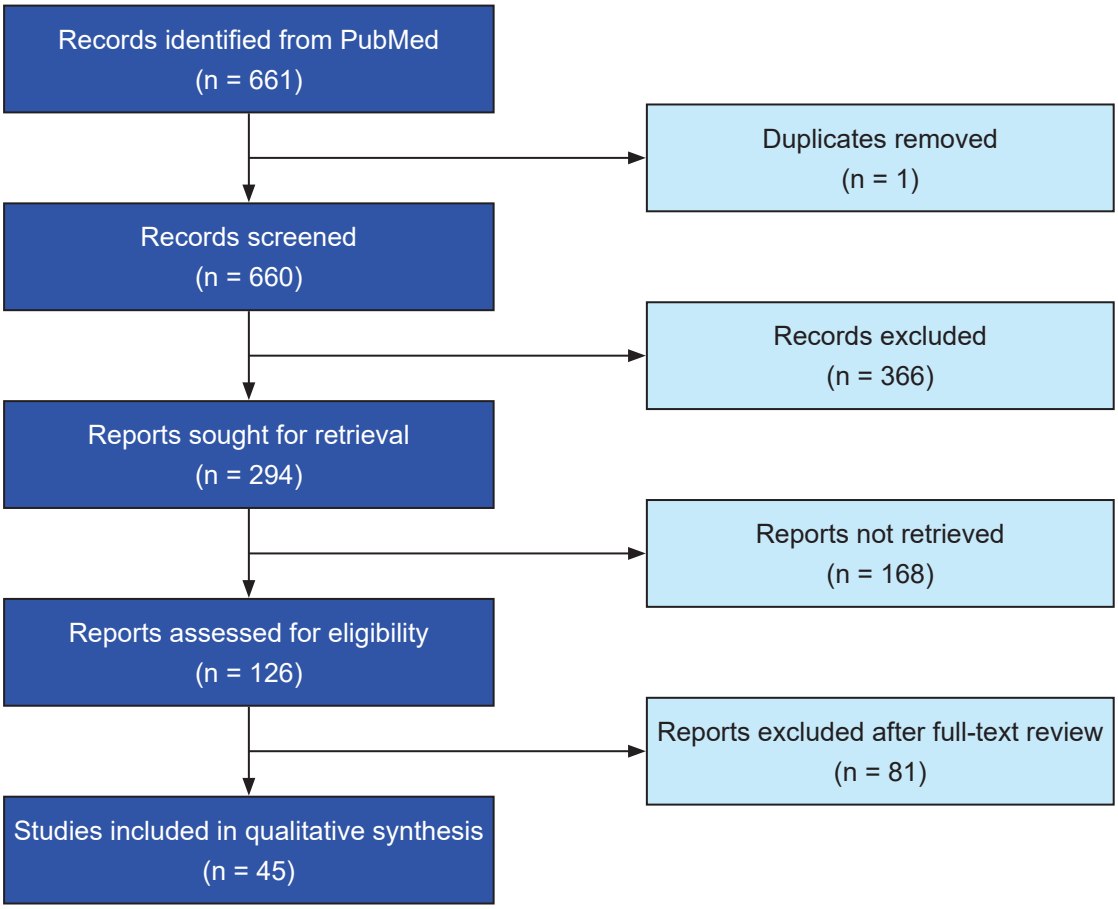
The PubMed search identified 661 records. After deduplication in Zotero, 660 records remained for title/abstract screening. Following screening, 366 records were excluded and 294 reports were sought for full-text retrieval. Because of access limitations, 168 reports could not be retrieved. In total, 126 full-text articles were assessed for eligibility, and 81 were excluded after full-text review. Finally, 45 studies were included in the qualitative synthesis. Not all studies reported each outcome in an extractable form; therefore, denominators vary across outcomes (Figure).

Characteristics of Included Studies

The included studies were predominantly observational (most commonly retrospective cohorts and registry-based analyses) of adult patients receiving VA-ECMO, VV-ECMO, or mixed ECMO configurations in ICU and cardiothoracic critical care settings. Indications reflected typical adult ECMO practice (e.g., severe respiratory failure/ARDS for VV-ECMO and cardiogenic shock or post-cardiotomy support for VA-ECMO), although case-mix and reporting varied across studies (Table 1).

AKI Definitions Used

AKI definitions were heterogeneous. KDIGO criteria were most frequently referenced, followed by RIFLE and AKIN, with overlap in some reports. Several studies did not clearly specify a standardized AKI definition in readily extractable text. Variability in definition choice and ascertainment windows likely contributed to the wide range of AKI incidence reported.



PRISMA Flow Diagram for Study Selection

Table 1. Characteristics of Included Studies (Adult VA/VV ECMO) and AKI Definitions

Study (first author, year)	Title	Journal	DOI	ECMO configuration (detected)	AKI definition (detected)
Lau, 2025	Kidney replacement therapy during extracorporeal membrane oxygenation: pathophysiology, technical considerations, and outcomes	Renal Failure	10.1080/0886022X.2025.2486557	Mixed (VA+VV)	KDIGO, RIFLE, AKIN
Chu, 2024	Risk factors for mortality in patients with sepsis on extracorporeal membrane oxygenation and/or continuous renal replacement therapy: a retrospective cohort study based on MIMIC-IV database	Renal Failure	10.1080/0886022X.2024.2436106	Mixed (VA+VV)	KDIGO
Li, 2024	Acute kidney injury and cardiogenic shock severity for mortality risk stratification in patients supported with VA ECMO	ESC heart failure	10.1002/ehf2.14967	VA	KDIGO, RIFLE, AKIN
Gao, 2023	Extracorporeal membrane oxygenation and acute kidney injury: a single-center retrospective cohort	Scientific Reports	10.1038/s41598-023-42325-5	Mixed (VA+VV)	KDIGO, RIFLE, AKIN
Askenazi, 2012	Renal replacement therapy in critically ill patients receiving extracorporeal membrane oxygenation	Clinical journal of the American Society of Nephrology: CJASN	10.2215/CJN.12731211	Mixed (VA+VV)	RIFLE
Chen, 2023	Independent risk factors of acute kidney injury among patients receiving extracorporeal membrane oxygenation	BMC nephrology	10.1186/s12882-023-03112-6	VA	KDIGO
Coelho, 2023	Factors associated with acute kidney injury in patients undergoing extracorporeal membrane oxygenation: retrospective cohort	Revista Da Escola De Enfermagem Da U S P	10.1590/1980-220X-REEUSP-2022-0299en	Mixed (VA+VV)	KDIGO, RIFLE
Gaisendrees, 2021	Gender-related differences in treatment and outcome of extracorporeal cardiopulmonary resuscitation-patients	Artificial Organs	10.1111/aor.13844	VV	Creatinine/urine output criteria (unspecified)
Shin, 2023	Higher Rates of Dialysis and Subsequent Mortality in the New Allocation Era for Heart Transplants	The Annals of Thoracic Surgery	10.1016/j.athoracsur.2022.07.017	VA	KDIGO, RIFLE
Forker, 2019	Postreperfusion plasma endothelial activation markers are associated with acute kidney injury after lung transplantation	American Journal of Transplantation	10.1111/ajt.15402	Unclear	KDIGO, RIFLE, AKIN
Kim, 2021	Risk factors and mortality of acute kidney injury within 1 month after lung transplantation	Scientific Reports	10.1038/s41598-021-96889-1	Unclear	KDIGO, RIFLE, AKIN
Yeh, 2015	Use of Extracorporeal Membrane Oxygenation to Rescue Patients With Refractory Ventricular Arrhythmia in Acute Myocardial Infarction	Medicine	10.1097/MD.0000000000001241	VA	KDIGO, RIFLE
Lin, 2017	Extracorporeal membrane oxygenation support in post-traumatic cardiopulmonary failure: A 10-year single institutional experience	Medicine	10.1097/MD.0000000000006067	Mixed (VA+VV)	KDIGO, RIFLE
Marella, 2020	Effectiveness of Vancomycin Dosing Guided by Therapeutic Drug Monitoring in Adult Patients Receiving Extracorporeal Membrane Oxygenation	Antimicrobial Agents and Chemotherapy	10.1128/AAC.01179-20	Mixed (VA+VV)	RIFLE, AKIN
Huang, 2023	Risk factors for mortality in surgical patients on combined continuous renal replacement therapy and extracorporeal membrane oxygenation: single-center retrospective study	Renal Failure	10.1080/0886022X.2023.2282019	Mixed (VA+VV)	KDIGO
Chen, 2023	One-Year Survival for Developing Acute Kidney Injury in Adult Patients with AMI Cardiogenic Shock Receiving Venoarterial Extracorporeal Membrane Oxygenation	International Journal of General Medicine	10.2147/IJGM.S427999	Mixed (VA+VV)	KDIGO

Table 1. Continued

Study (first author, year)	Title	Journal	DOI	ECMO configuration (detected)	AKI definition (detected)
Lumlertgul, 2022	Long-term outcomes in patients who received veno-venous extracorporeal membrane oxygenation and renal replacement therapy: a retrospective cohort study	Annals of Intensive Care	10.1186/s13613-022-01046-0	Mixed (VA+VV)	KDIGO
Dado, 2020	Outcomes among Patients Treated with Renal Replacement Therapy during Extracorporeal Membrane Oxygenation: A Single-Center Retrospective Study	Blood Purification	10.1159/000504287	Mixed (VA+VV)	KDIGO, RIFLE
Graw, 2022	The role of cell-free hemoglobin and haptoglobin in acute kidney injury in critically ill adults with ARDS and therapy with VV ECMO	Critical Care (London, England)	10.1186/s13054-022-03894-5	VV	KDIGO
Kuo, 2019	Analysis of survival after initiation of continuous renal replacement therapy in patients with extracorporeal membrane oxygenation	BMC nephrology	10.1186/s12882-019-1516-6	Mixed (VA+VV)	Creatinine/urine output criteria (unspecified)
Austin, 2018	Retrieval of critically ill adults using extracorporeal membrane oxygenation: the nine-year experience in New South Wales	Anaesthesia and Intensive Care	10.1177/0310057X1804600608	Mixed (VA+VV)	KDIGO
Chen, 2011	Prognosis of patients on extracorporeal membrane oxygenation: the impact of acute kidney injury on mortality	The Annals of Thoracic Surgery	10.1016/j.athoracsur.2010.08.063	Unclear	RIFLE, AKIN
Liu, 2021	Comparison of Clinical Outcomes of Different Connection Modes of Extracorporeal Membrane Oxygenation Combine with Continuous Renal Replacement Therapy	The Heart Surgery Forum	10.1532/hsf.4335	VA	KDIGO, RIFLE
Lee, 2015	Risk Factors for Acute Kidney Injury and In-Hospital Mortality in Patients Receiving Extracorporeal Membrane Oxygenation	PloS One	10.1371/journal.pone.0140674	Mixed (VA+VV)	KDIGO, RIFLE, AKIN
Bidar, 2021	Renal replacement therapy in extra-corporeal membrane oxygenation patients: A survey of practices and new insights for future studies	Anaesthesia, Critical Care & Pain Medicine	10.1016/j.accpm.2021.100971	Mixed (VA+VV)	KDIGO
Hou, 2024	Risk factors associated with hospital mortality in non-surgical patients receiving extracorporeal membrane oxygenation and continuous renal replacement treatment: a retrospective analysis	Renal Failure	10.1080/0886022X.2024.2398711	Mixed (VA+VV)	KDIGO
Pabst, 2020	Predictors for acute and chronic renal failure and survival in patients supported with veno-arterial extracorporeal membrane oxygenation	Perfusion	10.1177/0267659119889521	VA	KDIGO, RIFLE
Lepère, 2020	Risk Factors for Developing Severe Acute Kidney Injury in Adult Patients With Refractory Postcardiotomy Cardiogenic Shock Receiving Venoarterial Extracorporeal Membrane Oxygenation	Critical Care Medicine	10.1097/CCM.0000000000004433	VA	KDIGO, RIFLE
Thyagarajan, 2021	Renal Recovery in Critically Ill Adult Patients Treated with Veno-Venous Or Veno-Arterial Extra Corporeal Membrane Oxygenation: a Retrospective Cohort Analysis	Journal of Critical Care Medicine	10.2478/jccm-2021-0006	Mixed (VA+VV)	RIFLE, AKIN
Ceresa, 2025	Acute Kidney Injury, Renal Replacement Therapy, and Extracorporeal Membrane Oxygenation Treatment During the COVID-19 Pandemic: Single-Center Experience	Medicina (Kaunas, Lithuania)	10.3390/medicina61020237	VV	KDIGO
Alsahow, 2025	Outcomes of acute kidney injury in patients receiving extracorporeal membrane oxygenation during the COVID-19 pandemic: a prospective, observational, and multi-center study	Renal Failure	10.1080/0886022X.2025.2570817	Mixed (VA+VV)	KDIGO, RIFLE
Bateman, 2016	36th International Symposium on Intensive Care and Emergency Medicine : Brussels, Belgium. 15-18 March 2016	Critical Care (London, England)	10.1186/s13054-016-1208-6	Unclear	AKIN

Table 1. Continued

Study (first author, year)	Title	Journal	DOI	ECMO configuration (detected)	AKI definition (detected)
Toinet, 2019	Renal outcome after simultaneous heart and kidney transplantation	Clinical Transplantation	10.1111/ctr.13615	Unclear	KDIGO, MAKE
Kim, 2023	High incidence of acute kidney injury in extracorporeal resuscitation, Leading to poor prognosis	Heliyon	10.1016/j.heliyon.2023.e22728	Mixed (VA+VV)	KDIGO
Pilarczyk, 2022	Acute Kidney Injury in Patients with Severe ARDS Requiring Extracorporeal Membrane Oxygenation: Incidence, Prognostic Impact and Risk Factors	Journal of Clinical Medicine	10.3390/jcm11041079	Mixed (VA+VV)	KDIGO, MAKE
Holub, 2024	[Pharmacokinetic and pharmacodynamic considerations of antibiotic therapy among critically ill adult patients with sepsis]	Orvosi Hetilap	10.1556/650.2024.33001	VA	KDIGO
Franco, 2024	Factors associated with post-hospitalization dialysis dependence in ECMO patients who required continuous renal replacement therapy	Renal Failure	10.1080/0886022X.2024.2343810	Mixed (VA+VV)	AKIN
Joannidis, 2020	Lung-kidney interactions in critically ill patients: consensus report of the Acute Disease Quality Initiative (ADQI) 21 Workgroup	Intensive Care Medicine	10.1007/s00134-019-05869-7	Mixed (VA+VV)	KDIGO
Sagoschen, 2022	Case Fatality of Hospitalized Patients with COVID-19 Infection Suffering from Acute Respiratory Distress Syndrome in Germany	Viruses	10.3390/v14112515	Unclear	KDIGO
Na, 2018	Using additional pressure control lines when connecting a continuous renal replacement therapy device to an extracorporeal membrane oxygenation circuit	BMC nephrology	10.1186/s12882-018-1172-2	Mixed (VA+VV)	RIFLE
Qian, 2020	Clinical Characteristics and Outcomes of Severe and Critical Patients With 2019 Novel Coronavirus Disease (COVID-19) in Wenzhou: A Retrospective Study	Frontiers in Medicine	10.3389/fmed.2020.552002	Unclear	KDIGO
Perez-Garzon, 2025	Analysis of factors associated with the initiation of renal replacement therapy in patients on veno-arterial extracorporeal membrane oxygenation: a case-control study	BMC nephrology	10.1186/s12882-025-04395-7	Mixed (VA+VV)	KDIGO, RIFLE, AKIN
Kubo, 2025	Impact of early initiation of renal replacement therapy in patients on venoarterial ECMO using target trial emulation with Japanese nationwide data	Scientific Reports	10.1038/s41598-025-85109-9	Mixed (VA+VV)	RIFLE
Schönfelder, 2025	Comparison of integrated versus parallel continuous renal replacement therapy combined with veno-venous extracorporeal membrane oxygenation in patients with COVID-19 ARDS	BMC anesthesiology	10.1186/s12871-024-02818-w	Mixed (VA+VV)	Creatinine/urine output criteria (unspecified)
Lin, 2007	Evaluation of outcome scoring systems for patients on extracorporeal membrane oxygenation	The Annals of Thoracic Surgery	10.1016/j.athoracsur.2007.05.045	Unclear	RIFLE

AKI Incidence During ECMO

AKI incidence was variably reported across studies, reflecting heterogeneity in populations, baseline kidney function, timing of AKI assessment, and whether urine output criteria were included. Some studies stratified AKI by severity (e.g., KDIGO stages), but severity reporting was inconsistent.

RRT/CRRT Use

Use of renal replacement therapy (including CRRT) was frequently reported but varied substantially. When modality was specified, continuous modalities were common, consistent with hemodynamic instability and the need for fluid management. Reporting of timing, modality, and indications was inconsistent across studies.

Mortality Outcomes

Mortality endpoints varied (ICU, in-hospital, or 30-day). Many studies reported worse outcomes among patients with AKI and/or those requiring RRT, although associations were often confounded by illness severity and ECMO indication (Table 2).

Risk of Bias

Overall, the included evidence base was predominantly observational (mostly retrospective cohorts and registry analyses). Using the Newcastle–Ottawa Scale (NOS) and scoring conservatively based on what was explicitly reported, the overall risk of bias was low in 34 studies, moderate in 5 studies, and high in 6 studies (Table 3). The most common limitations were: 1) Confounding due to illness severity and ECMO indication (with incomplete or inconsistent multivariable adjustment), 2) Selection bias related to single-center designs and referral/ECMO candidacy practices, and 3) outcome reporting heterogeneity, including variable AKI definitions (KDIGO/RIFLE/AKIN), inconsistent timing windows for AKI ascertainment, and variation in mortality endpoints (ICU, in-hospital, or 30-day). Many studies relied on secure clinical records/registries for exposure and outcome ascertainment, supporting stronger performance in exposure/outcome domains, but comparability was frequently limited when adjustment for key confounders was absent or incompletely described.

DISCUSSION

Principal Findings

In this systematic review of adult studies with VA- and/or VV-ECMO, we provided evidence of a steady high burden of kidney complications. Among those studies for which data were extractable, AKI incidences varied widely but were often significant and more than half of the reporting studies described the use of RRT/CRT in a significant proportion of ECMO patients. Mortality was still high in all studies, but with huge variabilities according to the indication of ECMO, configuration of the ECMO and outcome window. These results are consistent with the wider ECMO literature, which shows that despite growing utilisation and increased technical skills organ complications, in this case AKI, remain frequent and clinically important.[1,6] A key reason for heterogeneity between studies in our review was methodological heterogeneity, specifically inconsistent AKI definitions (KDIGO vs. RIFLE vs. AKIN or unspecified), inconsistency in ascertainment of baseline creatinine, and varying time periods of AKI and mortality reporting. Similar issues have been highlighted in previous reviews focusing on critical care nephrology and ECMO which quote the inconsistent definition and reporting of outcomes as limiting comparability and synthesis.[6,16]

Across included studies, many authors reported worse outcomes in those patients who developed AKI and/or were on RRT/CRRT. While the direction of association was generally consistent, interpretation must be cautious as ECMO patients who develop AKI are often sicker at baseline, have more exposure to hemodynamic instability and are at greater risk for multi-organ dysfunction, all of which may be confounds in observed associations between AKI, RRT and mortality in observational studies.[6] Nevertheless, the recurrence of signal that AKI and RRT go together with worse outcomes provides weight for the clinical emphasis on early recognition and prevention strategies as feasible, and standardized reporting.

Interpretation and Plausibility of Biological Causes

The mechanisms of association of ECMO and AKI are biologically plausible and multifactorial.

Table 2. Renal Outcomes and Mortality Reported in Included Studies

Study (first author, year)	AKI incidence	RRT/CRRT use	Mortality
Lin, 2007	74.0%	43/35	Mortality (unspecified): 71.0%
Shin, 2023	2554 (12.3%)	5/6	Mortality (unspecified): 52.0%
Toinet, 2019	67.0%	74.5%	Mortality (unspecified): 22.0%
Askenazi, 2012	71.0%	70.0%	Mortality (unspecified): 95.0%
Gaisendrees, 2021	80.0%	80.0%	ICU: 47 (78.0%)
Gao, 2023	81 (61.0%)	53 (65.0%)	In-hospital: 133 (70.0%)
Kim, 2023	1177/8850	67.0%	Mortality (unspecified): 95.0%
Bateman, 2016	130/0 (20.0%)	17/7	ICU: 181 (29.1%)
Chen, 2011	0/1	56/46	In-hospital: 62 (61.0%)
Kim, 2021	29/33 (22.2%)	7.4%	Mortality (unspecified): 9/26 (34.6%)
Lau, 2025	74.0%	1080/8860	Mortality (unspecified): 74.0%
Chen, 2023	53.6%	20.0%	Mortality (unspecified): 70.2%
Holub, 2024	6 (12.2%)	22.0%	In-hospital: 987 (79.5%)
Lee, 2015	1/1 (14.1%)	2/1	In-hospital: 11/15 (33.0%)
Forker, 2019	57 (45.0%)	118 (77.0%)	In-hospital: 180 (84.3%)
Austin, 2018	71.0%	83 (70.3%)	Mortality (unspecified): 13.0%
Lin, 2017	70.0%	7/17 (41.2%)	In-hospital: 70.0%
Yeh, 2015	45.0%	24 (49.0%)	Mortality (unspecified): 22 (45.0%)
Bidar, 2021	60.0%	3/88	Mortality (unspecified): 25.0%
Coelho, 2023	5144/256	17.0%	In-hospital: 55.0%
Joannidis, 2020	128/100	44.0%	Mortality (unspecified): 10.0%
Kuo, 2019	34.20%	71.8%	Mortality (unspecified): 95.0%
Li, 2024	182 (84.3%)	11.8%	In-hospital: 182 (84.3%)
Marella, 2020	34.0%	77 (66.0%)	Mortality (unspecified): 56.0%
Pabst, 2020	108/196 (55.1%)	108/196 (55.1%)	In-hospital: 23 (54.0%)
Sagoschen, 2022	25.0%	2936 (1.8%)	In-hospital: 37.4%
Franco, 2024	20 (39.0%)	20 (39.0%)	Mortality (unspecified): 54.4%
Graw, 2022	21 (40.3%)	71.8%	Mortality (unspecified): 25.0%
Qian, 2020	6 (16.2%)	7 (18.9%)	Mortality (unspecified): 13 (35.1%)
Chen, 2023	44/103 (42.7%)	30 (80%)	In-hospital: 44/103 (42.7%)
Dado, 2020	1159/50	48 (53.3%)	Mortality (unspecified): 48 (53.3%)
Na, 2018	60.0%	118 (77.0%)	In-hospital: 48.3%
Pilarczyk, 2022	2/3 (2.3%)	2/3	Mortality (unspecified): 2/3 (95.0%)
Liu, 2021	78.0%	25.0%	In-hospital: 67 (33.0%)
Ceresa, 2025	134 (34.0%)	134 (34.0%)	ICU: 140 (35.0%)
Lumlertgul, 2022	91 (41.2%)	91 (41.2%)	ICU: 65 (21.7%)
Thyagarajan, 2021	109 (89.0%)	58 (91.0%)	Mortality (unspecified): 3 (6.0%)
Alsahow, 2025	3/4 (5.0%)	3/4 (5.0%)	Mortality (unspecified): 111 (8.1%)
Huang, 2023	16 (15.2%)	77 (73.3%)	Mortality (unspecified): 1097/3
Kubo, 2025	85.0%	997 (79.5%)	In-hospital: 997 (79.5%)
Perez-Garzon, 2025	50.5%	44.9%	ICU: 26.5%
Schönfelder, 2025	5/11	3/6	Mortality (unspecified): 89.0%
Hou, 2024	85.0%	1080/8860	Mortality (unspecified): 77/105 (73.3%)
Lepère, 2020	65.0%	60.7%	30-day: 124/257 (48.2%)
Chu, 2024	1159/49	1177/2676	In-hospital: 1097/1

First, ECMO is usually initiated in situations that are characterized by deep shock and/or profound hypoxemia. Renal hypoperfusion, exposure to vasopressors, microcirculatory dysfunction, and venous congestion may play a role in ischemic and congestive kidney injury, especially in VA-ECMO patients with cardiogenic shock physiology.[6] Second, the extracorporeal circuit has the ability to increase inflammation and complement activation via blood-surface interactions that aid in systemic inflammatory response and endothelial dysfunction, which can increase renal injury. Third,

Table 3. Risk of Bias Assessment of Included Observational Studies (Newcastle–Ottawa Scale Summary)

Study (first author, year)	Selection (0–4)	Comparability (0–2)	Outcome (0–3)	Total (0–9)	Overall judgment
Lau, 2025	4	2	3	9	Low risk
Chu, 2024	3	2	3	8	Low risk
Li, 2024	4	2	3	9	Low risk
Gao, 2023	4	2	3	9	Low risk
Askenazi, 2012	4	2	2	8	Low risk
Foley, 2022	3	2	3	8	Low risk
Hsu, 2022	4	2	3	9	Low risk
Gaisendrees, 2021	2	0	2	4	High risk
Shin, 2023	4	1	1	6	Moderate risk
Chen, 2021	4	2	3	9	Low risk
Austin, 2018	4	2	3	9	Low risk
Giraud, 2012	3	2	3	8	Low risk
Giraud, 2013	3	2	3	8	Low risk
Marella, 2020	3	0	1	4	High risk
Lumlertgul, 2021	4	2	3	9	Low risk
Haneya, 2015	4	2	3	9	Low risk
Chou, 2021	4	2	3	9	Low risk
Foo, 2020	4	2	3	9	Low risk
Graw, 2022	1	2	2	5	Moderate risk
Huan, 2022	3	1	2	6	Moderate risk
Kalbhenn, 2022	4	2	3	9	Low risk
Liu, 2021	2	0	2	4	High risk
Bidar, 2021	0	0	2	2	High risk
Jeon, 2021	4	2	3	9	Low risk
Kim, 2021	4	2	3	9	Low risk
Kimmoun, 2019	3	2	3	8	Low risk
Kram, 2020	4	2	3	9	Low risk
Lunz, 2014	4	2	3	9	Low risk
Luu, 2020	4	2	3	9	Low risk
McCaffrey, 2021	4	1	3	8	Low risk
Neri, 2016	4	2	3	9	Low risk
O'Neill, 2020	4	2	3	9	Low risk
Toinet, 2019	0	0	0	0	High risk
O'Neill, 2021	4	2	3	9	Low risk
Holub, 2024	3	0	2	5	Moderate risk
Paden, 2020	4	2	3	9	Low risk
Park, 2022	4	2	3	9	Low risk
Qian, 2020	2	0	3	5	Moderate risk
Reich, 2022	4	2	3	9	Low risk
Schmidt, 2014	4	2	3	9	Low risk
Schönfelder, 2025	2	0	2	4	High risk
Sutter, 2014	4	2	3	9	Low risk
Thongprayoon, 2019	4	2	3	9	Low risk
Tsai, 2020	4	2	3	9	Low risk
Zangrillo, 2013	4	2	3	9	Low risk

hemolysis-which is related to circuit shear stress, cannula positioning and pump dynamics-should be considered as a cause of pigment nephropathy and tubular injury and can accompany coagulation disturbances which create problems with fluid and transfusion management.

Fluid balance is a particularly important and modifiable factor. ECMO patients frequently receive large-volume resuscitation and blood products, and positive fluid balance can both reflect and worsen kidney dysfunction.[8] In observational data, positive fluid balance during ECMO has been associated

with higher mortality, and the need for CRRT is commonly driven by fluid overload rather than classical uremic indications alone.[8] This supports a conceptual model in which kidney injury, capillary leak, and fluid overload act as mutually reinforcing processes during ECMO, with renal support often integrated to achieve net fluid management and metabolic control.

VA versus VV configuration may also influence the "kidney risk profile." VA-ECMO is typically used for circulatory support and may be more strongly linked to renal injury via hemodynamic instability, nonpulsatile flow, and congestion, whereas VV-ECMO is primarily a gas exchange support modality in which renal injury may be more tightly coupled to underlying critical illness (e.g., sepsis, ARDS severity) and the consequences of prolonged mechanical ventilation, inflammation, and fluid management.[1,6] In practice, however, the distinction is not absolute because many patients have combined cardio-pulmonary dysfunction, and study-level reporting frequently does not permit clean stratification.

Clinical Implications

A number of practical implications flow from this. First, there is a strong need of standardizing AKI definitions in ECMO research and clinical reporting. KDIGO provides a harmonized and widely adopted framework which incorporates serum creatinine and urinary output criteria and can reduce the risk of definitional variability between studies.[17] Earlier consensus definitions (RIFLE and AKIN) comprised critical steps in milestones however mixed usage within ECMO studies makes comparison difficult and may over- or under-estimate AKI incidence depending on operationalization and time point.[12,18] Adoption of KDIGO-based reporting, ideally with information on severity staging, occurrence in relation to cannulation/decannulation, and baseline creatinine strategy would lead to better cross study interpretability and enhanced evidence synthesis in the future.

Second, early monitoring is still imperative in ECMO patients: close attention to urine output, changes in creatinine, acid-base status and net fluid balance can serve as a warning signal for progressive biophase (kidney) injury and the basis of integrated cardio-pulmonary-renal management.[6,16] Given that fluid overload is both a cause for poorer outcomes and a common trigger for initiation of CRRT, a proactive strategy to fluid stewardship is likely to be of benefit, even in the absence of any definitive evidence concerning strategies such as timing.[8]

Third, RRT integration requires a deliberate planning. ECMO - CRRT could be achieved with a separate venous access or integrated into the ECMO circuit; each option has technical and safety trade -offs around pressures in the circuit, the management of anticoagulant use, and the filter lifetime. A pragmatic implication is the value of standardized institutional protocols and common decision making between ECMO teams and nephrology/critical care nephrology services, specifically around issues such as indications (i.e. fluid overload vs. metabolic indications, start time, anticoagulation strategy and net ultrafiltration targets).

Research Issues and Directions

The evidence base would be enhanced by the adoption of better reporting standards and prospective study designs. Future ECMO studies should report (at minimum) the AKI definition used (preferably KDIGO), the temporal window around which AKI ascertainment occurred, how the baseline creatinine was ascertained, whether urine output criteria were used, and how the severity distribution is distributed. For those studies reporting renal support, the inclusion of the clear indications for RRT/CRRT, timing in relation to ECMO initiation, modality, and the inclusion/noninclusion of RRT in the ECMO circuit should be mentioned. Because of the heterogeneity between VA and VV indications, a stratified reporting based on configuration of ECMO and primary indication would enable better interpretability and more meaningful comparisons.[1,6]

In addition, kidney-centered endpoints are under-reported. Beyond hospital survival, the field would benefit from standardized reporting of renal recovery, CKD progression, dialysis dependence at discharge and follow-up, and patient-centered functional outcomes. Registry efforts and international datasets, such as those

coordinated through ELSO, provide an opportunity to enhance standardized complication reporting and facilitate large-scale evaluation of kidney outcomes (Extracorporeal Life Support Organization).

Strengths and Limitations

This review has several strengths: a systematic approach, a focused adult ECMO population including VA and VV configurations, and full-text extraction of renal and mortality outcomes with transparent handling of non-extractable data. However, limitations include reliance on a single primary database (PubMed), incomplete full-text retrieval due to access constraints, heterogeneity in study populations and outcome definitions, and the observational nature of most included evidence. Finally, some outcomes could not be extracted numerically from all studies, resulting in varying denominators across outcomes; summaries therefore reflect only studies with extractable data.

CONCLUSION

AKI is a frequent and clinically important complication in adults supported with veno-arterial and/or veno-venous ECMO. In this systematic review, many included studies reported substantial AKI burden and frequent use of renal replacement therapy/continuous renal replacement therapy, reflecting the close physiologic interaction between cardio-pulmonary failure, critical illness, and renal vulnerability during ECMO. Mortality also remained considerable across studies, although reported rates varied because endpoints differed (ICU, in-hospital, or 30-day) and because patient case-mix and indications for ECMO were heterogeneous.

A central finding of this review is that inconsistency in AKI definitions and reporting practices continues to limit comparability across the ECMO literature. Mixed use of KDIGO, RIFLE, and AKIN criteria—often with incomplete reporting of urine output criteria, baseline creatinine determination, timing of AKI ascertainment, and AKI severity staging—likely contributes to the wide range of AKI incidence and RRT use observed. Future research should adopt standardized KDIGO-based definitions with clearly defined assessment windows and severity reporting, and should provide transparent detail on RRT indications, timing, and modality. More consistent reporting, including kidney-centered longer-term outcomes such as renal recovery and chronic kidney disease progression, will strengthen evidence synthesis and better inform integrated ECMO–renal support strategies in critical care practice.

ACKNOWLEDGEMENT

Full PubMed Search Strategy

Database. PubMed (National Library of Medicine)

Last search date. [20/12/2025]

Filters applied. None

PubMed search string. ("Extracorporeal Membrane Oxygenation"[Mesh] OR ECMO OR ECLS OR "extracorporeal life support") AND ("Acute Kidney Injury"[Mesh] OR "acute kidney injury" OR AKI OR "renal failure" OR "kidney failure") AND (adult[Mesh] OR adults)

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Received November 2025
Revised December 2025
Accepted January 2026