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Review Article

Incidence and Associations of Acute Kidney Injury After Lung Resection Surgery: A Systematic Review and Meta-analysis

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The incidence and clinical implications of acute kidney injury (AKI) following thoracic lung resection surgery remain insufficiently characterized. The authors conducted a systematic review to determine the incidence of AKI, identify risk factors for AKI, evaluate preventive interventions for AKI, and assess the associations of AKI with key postoperative outcomes. A systematic search of PubMed, Embase, and the Cochrane Library was conducted through June 25, 2025. The authors included observational and interventional studies that reported the incidence of AKI following lung resection, defined according to Risk, Injury, Failure, Loss, End-stage (RIFLE), Acute Kidney Injury Network (AKIN), or Kidney Disease: Improving Global Outcomes (KDIGO) consensus-based criteria. The study protocol was prospectively registered in the International Prospective Register of Systematic Reviews (CRD420251142075). Twenty studies involving 19,918 patients were included. The pooled incidence of AKI was 5.31% (95% confidence interval [CI], 3.61%–6.70%), with mild AKI and moderate to severe AKI occurring in 5.51% and 0.96% of patients, respectively. AKI was significantly associated with prolonged hospital stay (mean difference, 0.92 days; 95% CI, 0.52–1.30 days) and increased short-term mortality (risk ratio, 5.60; 95% CI, 1.66–18.83). Goal-directed fluid therapy did not significantly reduce the risk of AKI (risk ratio, 0.64; 95% CI, 0.32–1.27). AKI is a common complication following thoracic lung resection surgery and is strongly associated with a broad spectrum of severe adverse postoperative outcomes. In patients undergoing lung resection, AKI should be considered as a highly significant prognostic indicator that requires early risk stratification and proactive preventive strategies.

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Key Words: acute kidney injury; lung resection; length of hospital stay; mortality; goal-directed fluid therapy

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ACUTE KIDNEY INJURY (AKI) is one of the most common perioperative complications in noncardiac thoracic surgery and is associated with increased mortality, prolonged hospitalization, and progression to chronic kidney disease.¹ Thoracic surgery involving lung resection represents a period of severe physiological perturbation, typically involving intraoperative hemodynamic instability, vasopressor use, ventilation-to-perfusion mismatches, higher shear stresses on alveolar tissue, a variety of consequent systemic inflammatory

responses, and perhaps longer duration of anesthesia exposure.² AKI is increasingly recognized as a clinically significant complication after thoracic surgery, with reported incidences ranging from 2.2% to 35.3%.^{3–5} The implications for hospital costs, resource utilization, longer intensive care unit or hospital stays, 30-day readmission, and discharge to a nursing facility or rehabilitation center are profound.

Prior meta-analyses have investigated AKI across heterogeneous thoracic surgical populations, often combining esophagectomy and mediastinal procedures, but have not specifically focused on lung resection.^{6,7} In lung resection (lobectomy, segmentectomy, wedge resection, and pneumonectomy), avoidance of fluid overload has been routinely advocated to minimize lung injury,⁸ yet perioperative fluid restriction may in turn precipitate AKI through hypovolemia.⁹ Lung resection also entails unique challenges, such as hypoxemia and hypercarbia induced by one-lung ventilation, potentially leading to right heart dysfunction, which can reduce renal perfusion and thus increase the risk of AKI.¹⁰ Given the rising global burden of lung cancer and the growing number of high-risk patients undergoing thoracic surgery, the absence of precise incidence estimates and robust risk factor characterization in this setting constitutes a critical knowledge gap.

Accordingly, the authors conducted a meta-analysis to determine the pooled incidence of AKI following lung resection based on consensus definitions and different classification systems. Secondary objectives were to identify independent risk factors, examine the impact of perioperative fluid management strategies, and assess the prognostic significance of postoperative AKI.

Methods

This meta-analysis was conducted in adherence to the Preferred Reporting Items for Systematic Reviews and Meta-analyses guidelines (checklist in [Supplementary Table 1](#)).¹¹ The protocol for this study was prospectively registered in the International Prospective Register of Systematic Reviews (CRD420251142075).

Study Selection

Studies were eligible if they met the following criteria: (1) observational or interventional studies that reported the incidence of AKI in adult patients (≥ 18 years) undergoing thoracic lung resection surgery and (2) studies in which AKI was defined according to consensus-based criteria, including either Risk, Injury, Failure, Loss, End-stage (RIFLE), Acute Kidney Injury Network (AKIN), or Kidney Disease: Improving Global Outcomes (KDIGO) criteria. Exclusion criteria were (1) studies focused on cardiovascular surgery or solid organ transplantation, (2) studies including mixed surgical types without extractable data specific to lung resection, and (3) case reports or small case series enrolling < 50 eligible patients.

Search Strategy

A comprehensive search of PubMed, Embase, and the Cochrane Library was performed to identify peer-reviewed

original articles. The database-specific search strategies are detailed in [Supplementary Table 2](#), with the final search update conducted on June 25, 2025. To ensure completeness, the authors manually reviewed the reference lists of all included studies, as well as those of relevant reviews and meta-analyses. The search was not limited by any restrictions on language. Two reviewers (J.Y., Y.-q.W.) independently screened all retrieved records for eligibility in a sequential manner. Discrepancies were resolved through discussion, and when consensus could not be reached, a third reviewer (Y.Z.) adjudicated the decision.

Data Extraction and Quality Assessment

Data from each eligible study were extracted using a standardized collection form, which included the following variables: article title, publication date, study country, study design, patient baseline characteristics, surgical details, duration of postoperative follow-up, diagnostic criteria for AKI, identified risk factors for AKI, incidence and severity of AKI, length of hospital stay, and mortality outcomes. The methodological quality of the included studies was independently evaluated by 2 reviewers (X.-s.S., X.-Y.L.) using the Newcastle-Ottawa Scale.¹² Any discrepancies arising during the quality assessment process were initially resolved through discussion between the 2 reviewers to achieve consensus. If consensus could not be reached, a third reviewer (H.L.) was consulted for adjudication.

Statistical Analysis

Considering the anticipated clinical and methodological heterogeneity across studies, a random-effects meta-analysis of proportions was conducted to estimate the pooled incidence of AKI following lung resection surgery. Subgroup analyses were performed according to AKI severity, defined as mild (RIFLE stage R, AKIN stage 1, and KDIGO stage 1) versus moderate to severe (RIFLE stage I/F, AKIN stages 2–3, and KDIGO stages 2–3), as well as by diagnostic criteria for AKI and surgical type (sublobar resection, lobectomy, and bilobectomy or pneumonectomy). Sensitivity analyses were conducted based on diagnostic time frame. To explore independent risk factors for postoperative AKI, the authors synthesized evidence from studies using multivariable regression analyses. They also evaluated the potential protective effect of goal-directed fluid therapy (GDFT), a strategy commonly applied in lung resection, on AKI incidence. To assess the reliability and sufficiency of the evidence, they performed trial sequential analysis (TSA) using TSA viewer software (version 0.9.5.5 beta; Copenhagen Trial Unit, Copenhagen, Denmark).¹³ In the TSA diagram, crossing the monitoring boundary or futility boundary indicates that the cumulative evidence is sufficient to draw a conclusion, and further studies are unlikely to change the inference; otherwise, the evidence remains inconclusive. For dichotomous outcomes, the authors specified a type I error of 5%, a power of 80%, and two-sided tests based on a prior meta-analysis.¹⁴ Variance-based O'Brien–Fleming heterogeneity correction and α – β spending functions were used throughout. Finally, postoperative

outcomes were compared between patients with and without AKI to assess its clinical impact.

For dichotomous outcomes, pooled relative risks (RRs) with 95% confidence intervals (CIs) were estimated, whereas for continuous outcomes, pooled weighted mean differences with 95% CIs were calculated. Statistical heterogeneity across studies was assessed using two complementary approaches: the Cochran Q test, with $p < 0.05$ indicating significant heterogeneity, and the I^2 statistic, which quantifies the magnitude of heterogeneity. Predefined thresholds were applied to interpret I^2 values, classifying heterogeneity as low (25%-49%), moderate (50%-74%), or high ($\geq 75\%$).¹⁵ Publication bias was examined using a funnel plot and the Egger test.¹⁵ All statistical analyses were performed using Stata (version 18.0; StataCorp, College Station, TX).

Results

Study Characteristics

As depicted in the study flow diagram (Fig 1), a total of 5,714 studies were initially reviewed. Following title and abstract screening, 5,601 records were excluded because they did not meet the predefined eligibility criteria. Ultimately, 20 studies involving 19,918 patients who underwent lung resection surgery were included in the meta-analysis.^{2,4,7,9,16–31} The clinical characteristics of these studies are summarized in Table 1. Of these studies, 13 were retrospective observational studies and 7 used prospective designs. The RIFLE, AKIN, and KDIGO criteria were used in 3 studies,^{2,16,18} 9 studies,^{9,17,19,20,23–25,28,30} and 8 studies,^{4,7,21,22,26,27,29,31} respectively.

Quality Assessment

The quality assessment of the included studies is summarized in Supplementary Table 3. Most studies demonstrated high quality in the selection of the non-exposed cohort, ascertainment of AKI, and comparability, with 18 studies adequately adjusting for key confounders.^{2,4,7,9,16–22,25–31} There were variations in outcome assessment across studies, with 7 studies lacking a detailed description of AKI confirmation processes, although all used standardized diagnostic criteria.^{17,20,21,23,26,28,31} Six studies had an insufficient follow-up that may not fully capture all postoperative AKI events.^{20,23,24,28–30} To account for these methodological variations, corresponding subgroup analyses and sensitivity analyses were performed in subsequent analyses.

Incidence of AKI Among Patients After Lung Resection Surgery

From the meta-analysis, the pooled estimated incidence of AKI across the 20 included studies (19,918 patients) was 5.31% (95% CI, 3.61%-6.70%; $I^2 = 94.08\%$) (Table 2, Supplementary Fig 1). No evidence of publication bias was detected ($p = 0.806$, Egger test) (Fig 2, A). In a subgroup analysis, among the 8 studies that reported AKI severity,^{2,9,16,19,20,22,25,29} the pooled incidences were 5.51% (95% CI, 4.17%-6.85%) for mild AKI and 0.96% (95% CI, 0.61%-1.31%) for moderate to severe AKI, with an overall pooled estimate of 3.15% (95% CI, 2.18%-4.12%) (Table 2, Supplementary Fig 2). According to diagnostic criteria, the pooled incidence of AKI was 5.57% (95% CI, 3.93%-7.20%) when defined by RIFLE, 6.33% (95% CI, 4.04%-8.62%) when

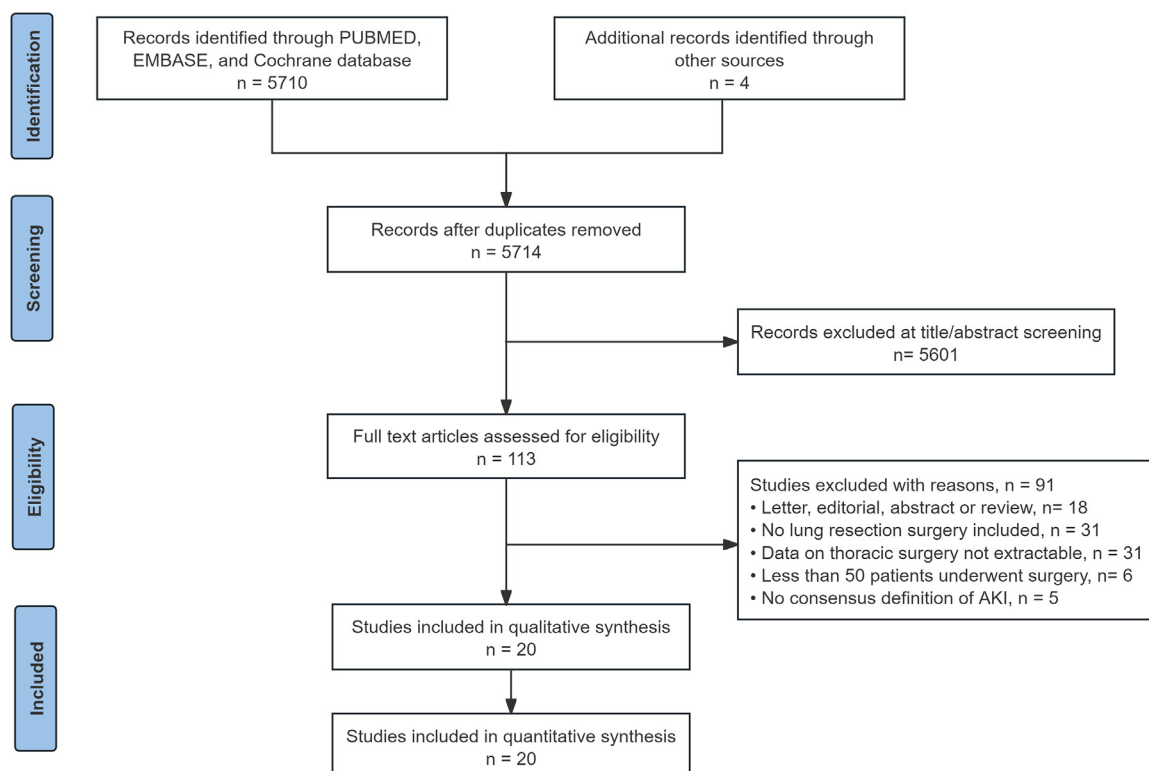


Fig 1. Flow diagram illustrating article screening and selection process. AKI, acute kidney injury.

Table 1
Main Characteristics of Included Studies

Number	Study	Country	Design	Type of Surgery	Patient Selection	Age, y	Comorbidity: HTN, DM, CKD, %	Baseline Renal Function*	AKI Criteria	Total	AKI	Time Frame for AKI Diagnosis, d
1	Licker et al., ² 2011	Switzerland	R, O	Lung resection	Consecutive, excluding ESRD	63	35, 10, 15	eGFR: 83 mL/min/1.73 m ²	RIFLE	1,345	91	3
2	Ishikawa et al., ¹⁶ 2012	Canada	R, O	Lung resection	Consecutive, excluding ESRD	61	41, 10, 28	eGFR: 73 mL/min/1.73 m ²	RIFLE, AKIN	1,129	67	3
3	Imperatori et al., ¹⁸ 2012	Italy	R, O	Lobectomy	Consecutive	65	40, 13, NA	SCr: 1.0 mg/dL	RIFLE	454	17	7
4	Assaad et al., ¹⁷ 2015	United States	P, O	Lung resection	Consecutive	67	NA	SCr: 1.0 mg/dL	AKIN	40	3	3
5	Moon et al., ¹⁹ 2016	Germany	R, O	Lung resection	Consecutive	66	47, 11, NA	SCr: 0.9 mg/dL	AKIN	1,207	98	2
6	Kaufmann et al., ⁹ 2016	Germany	P, I	Lung resection	Consecutive	65	49, 11, 13	SCr: 0.8 mg/dL	AKIN	96	3	2
7	Cardinale et al., ²⁰ 2018	Italy	P, O	Lung resection	Consecutive, excluding ESRD and AKI	63	43, 8, 6	eGFR: 100 mL/min/1.73 m ²	AKIN	2,179	222	2
8	Sahutoglu et al., ²¹ 2018	Turkey	R, O	Lobectomy	Consecutive, excluding ESRD	61	NA	SCr: 0.8 mg/dL	KDIGO [†]	85	3	7
9	Oh et al., ²² 2019	Republic of Korea	R, O	Lung resection	Consecutive, excluding ESRD	65	36, 16, 8	NA	KDIGO	1,477	77	3
10	Matesanz et al., ²³ 2019	Spain	P, O	Lung resection	Consecutive	66	45, NA, NA	NA	AKIN	174	12	2
11	Garutti et al., ²⁴ 2019	Spain	R, O	Lung resection	Consecutive	NA	NA	NA	AKIN	174	12	2
12	Kim et al., ²⁵ 2020	Republic of Korea	R, O	Lung resection	Consecutive	64	40, 17, 0.6	NA	AKIN	1,031	63	3
13	Meng and Mu, ²⁷ 2020	China	R, O	Lung resection	Consecutive, excluding ESRD	59	39, 18, NA	NA	KDIGO	1,393	31	7
14	Li and Peng, ²⁰ 2021	China	P, I	Lobectomy	Consecutive, excluding ESRD	63	14.4, 12.7, 3.4	NA	KDIGO	124	1	7
15	Wu et al., ⁴ 2021	China	R, O	Lobectomy	Consecutive, excluding ESRD	63	NA, 8.8, NA	NA	KDIGO	548	12	7
16	Naruka et al., ⁷ 2022	United Kingdom	R, O	Lung resection	Consecutive, excluding ESRD	NA	NA	NA	KDIGO	6,432	568	7
17	Yang et al., ²⁸ 2022	China	R, O	Lobectomy	Consecutive, excluding ESRD	63.2	NA, 8.5, NA	NA	AKIN	563	13	2
18	Bohn et al., ²⁹ 2023	Canada	R, O	Lung resection	Consecutive, excluding ESRD	NA	48.3, 32.6, NA	NA	KDIGO	1,045	57	2
19	Ma et al., ³⁰ 2023	China	P, I	Lung resection	Consecutive, excluding CKD	66.5	40.9, 22.8, NA	NA	AKIN	276	17	2
20	Habicher et al., ³¹ 2025	Germany	P, I	Lung resection	Consecutive, excluding ESRD	65	55.5, 16.4, 5.5	NA	KDIGO	146	8	7

Abbreviations: AKI, acute kidney injury; AKIN, Acute Kidney Injury Network; CKD, chronic kidney disease; DM, diabetes mellitus; eGFR, estimated glomerular filtration rate; ESRD, end-stage renal disease; HTN, hypertension; KDIGO, Kidney Disease: Improving Global Outcomes; NA, not available; I, interventional; O, observational; P, prospective; R, retrospective; RIFLE, Risk, Injury, Failure, Loss, End-stage; SCr, serum creatinine.

* SCr is presented in milligrams per deciliter (multiply by 88.4 to convert to micromoles per liter).

† AKI was diagnosed based on SCr.

Table 2
AKI After Lung Resection Surgery: Pooled Incidence, Severity, and Subgroup Analysis

	No. of Studies	No. of Patients	AKI Incidence (95% CI), %	Heterogeneity (I^2), %
Overall	20	19,918	5.31 (3.91-6.70)	94.08
AKI severity				
Mild	8	9,509	5.51 (4.17-6.85)	87.51
Moderate to severe	8	9,509	0.96 (0.61-1.31)	67.65
AKI definition				
RIFLE	3	2,928	5.57 (3.93-7.20)	72.73
AKIN	9	5,740	6.33 (4.04-8.62)	90.53
KDIGO	8	11,762	4.42 (1.81-6.63)	96.75
Surgical type				
Sublobar resection	4	2,069	3.77 (1.44-6.11)	88.32
Lobectomy	9	4,024	4.87 (2.70-7.03)	91.56
Bilobectomy or pneumonectomy	6	722	11.94 (7.00-16.88)	66.85
Time frame for AKI diagnosis				
≤ 2 Postoperative days	8	5,714	6.18 (3.81-8.54)	91.86
≤ 7 Postoperative days	12	104,204	4.74 (2.93-6.54)	95.15

Abbreviations: AKI, acute kidney injury; AKIN, Acute Kidney Injury Network; KDIGO, Kidney Disease: Improving Global Outcomes; RIFLE, Risk, Injury, Failure, Loss, End-stage.

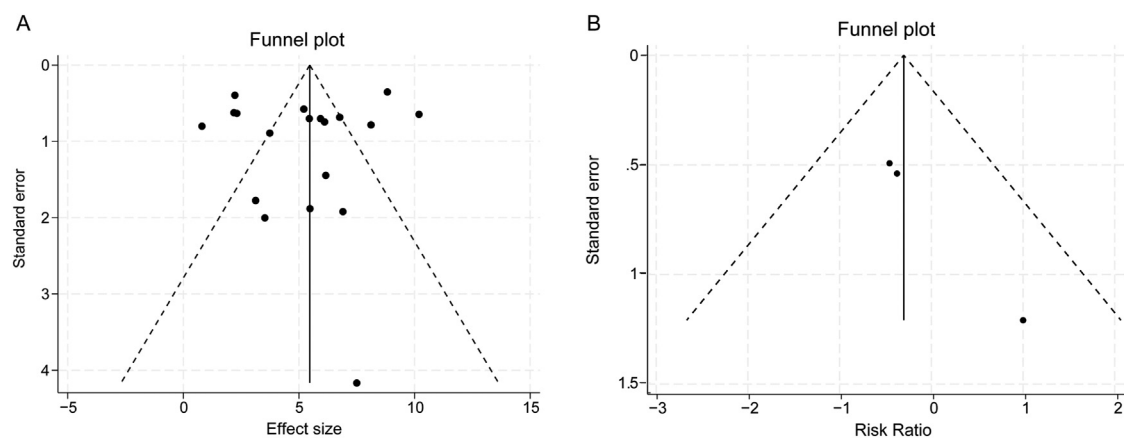


Fig 2. Funnel plots assessing publication bias in studies reporting incidence of acute kidney injury after lung resection surgery (A) and in studies evaluating impact of goal-directed fluid therapy on acute kidney injury incidence (B). Dots indicate individual studies, solid vertical line indicates the pooled effect size, dashed lines indicate the 95% CI; CI, confidence interval.

defined by AKIN, and 4.42% (95% CI, 1.81%-6.63%) when defined by KDIGO. Although the pooled incidences across these diagnostic criteria were generally consistent, substantial heterogeneity was observed among studies (Table 2, Supplementary Fig 3). When stratified by surgical type, the incidence of AKI differed significantly ($p = 0.01$). AKI occurred in 3.77% of patients (95% CI, 1.44%-6.11%) after sublobar resection, 4.87% (95% CI, 2.70%-7.03%) after lobectomy, and 11.94% (95% CI, 7.00%-16.88%) after bilobectomy or pneumonectomy (Table 2, Supplementary Fig 4), indicating substantial variation across surgical procedures. Although all included studies reported the use of general anesthesia, perioperative analgesic management was described with considerable heterogeneity across studies. Regarding the regional analgesic technique performed, there was no significant difference in the incidence of AKI observed among the subgroups ($p = 0.72$). The pooled incidence of AKI was 5.87% (95% CI, 5.23%-6.52%) in patients receiving thoracic epidural

analgesia, 4.97% (95% CI, 1.23%-8.72%) in those undergoing paravertebral block, and 4.82% (95% CI, 1.86%-7.77%) in those managed with other analgesic modalities (Supplementary Table 4, Supplementary Fig 5).

In the sensitivity analysis, the incidence of AKI was 6.18% (95% CI, 3.81%-8.54%) when the diagnosis was established within the first 2 days postoperatively and 4.74% (95% CI, 2.93%-6.54%) when the diagnosis was established within 7 days postoperatively. These findings suggest that the timing of AKI diagnosis did not significantly influence the observed incidence ($p = 0.43$, $I^2 = 94.08\%$) (Table 2, Supplementary Fig 6).

Goal-Directed Fluid Therapy and AKI

The risk of postoperative AKI between patients who received GDFT and those who received conventional fluid therapy was evaluated across three randomized controlled trials, two of which

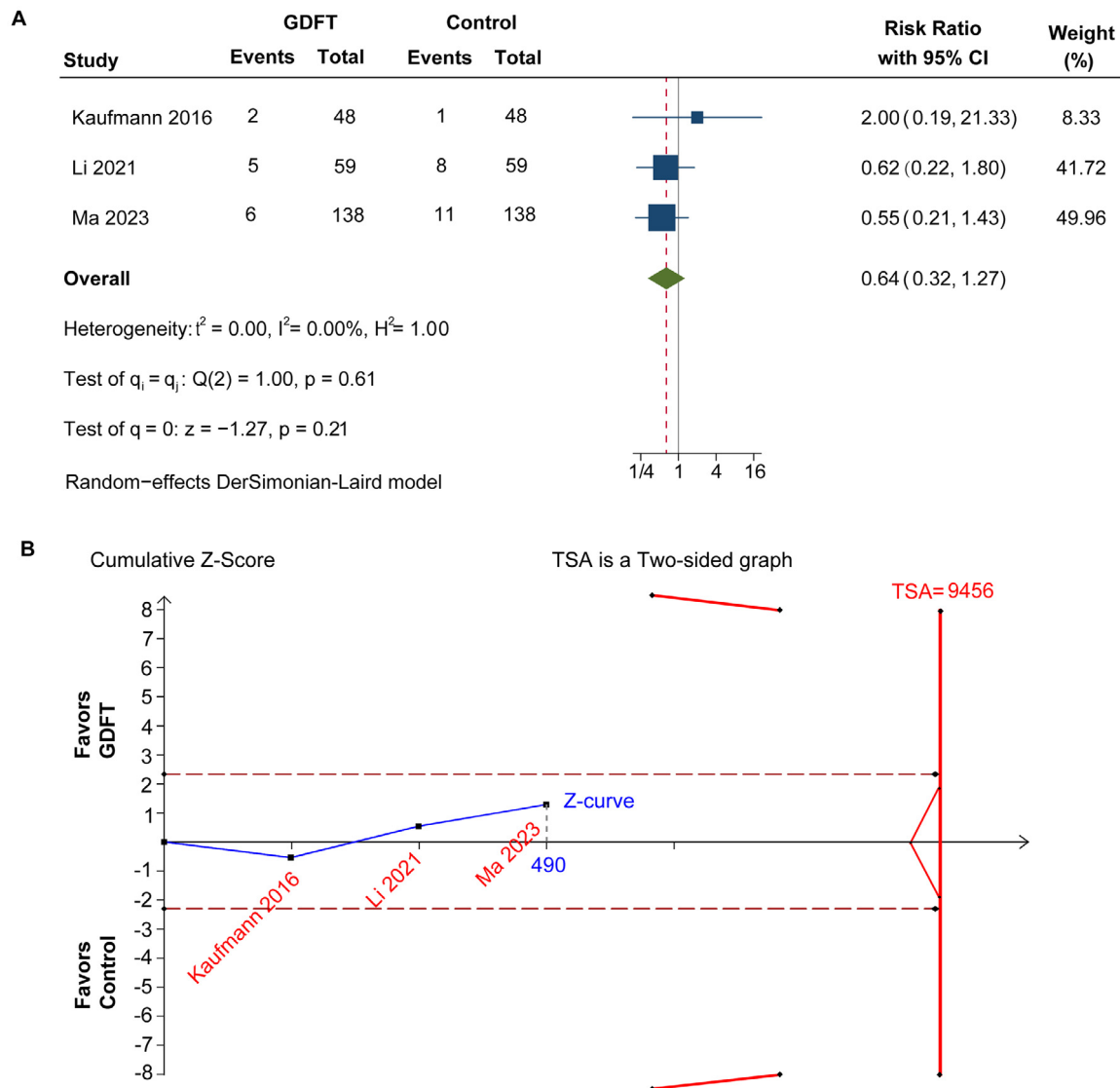


Fig 3. Pooled results of the effect of goal-directed fluid therapy (GDFT) on the incidence of AKI. (A) Forest plot. For each study, the risk ratio for each study is represented by the center of the *blue square*. The *horizontal blue line* shows the 95% confidence interval (CI). The overall risk ratio is represented by the *green diamond*, with the width of the diamond representing the 95% CI. The dashed red line passing through the center of the green diamond indicates the pooled risk ratio estimate. The gray line is the demarcation line for a risk ratio of 1. (B) Trial sequential analysis (TSA) diagram. TSA is based on a relative risk reduction of 20%. The *inward-sloping red lines* indicate the trial sequential monitoring boundary; *outward-sloping red lines*, futility boundary; *brown dashed lines*, conventional benefit boundary; and *blue line*, Z curve.

used stroke volume variation—guided protocols^{26,30} and one of which used an esophageal Doppler monitoring—based algorithm.⁹ The pooled analysis revealed no significant difference in AKI incidence between the two groups (RR, 0.64; 95% CI, 0.32–1.27; $p = 0.21$) (Fig 3, A). There was no evidence of publication bias ($p = 0.259$, Egger test) (Fig 2, B). In the TSA, with the assumption of a 20% RR reduction in the incidence of AKI, the Z curve crossed neither the conventional benefit boundary nor the trial sequential monitoring boundary (Fig 3, B). The required sample size for AKI was estimated to be 9,456, while the accrued sample size in this analysis was 490. The results of the TSA suggested that there was insufficient evidence from existing meta-analyses to make a definitive conclusion.

Risk Factors for Postoperative AKI

Several studies have examined potential risk factors for postoperative AKI, with details summarized in [Supplementary Table 5](#). Factors independently associated with an increased risk of postoperative AKI in multivariable analyses included American Society of Anesthesiologists physical status classification (III or IV), advanced age, male sex, smoking history, higher body mass index, comorbidities (hypertension, diabetes mellitus, peripheral vascular disease, chronic kidney disease), lower forced expiratory volume in 1 second, thoracotomy (vs minimally invasive approaches), synthetic colloids, elevated preoperative N-terminal pro-B-type natriuretic peptide levels, increased intraoperative blood loss,

long-term use of angiotensin-converting enzyme inhibitors or angiotensin II receptor blockers, perioperative vasopressor use, and low preoperative hemoglobin levels.

Associations of AKI With Postoperative Outcomes

Four studies, involving 4,827 patients, reported the hospital length of stay in relation to postoperative AKI.^{2,16,20,23} Patients who developed AKI had a significantly prolonged hospital length of stay compared with those without AKI (mean difference, 0.92 days; 95% CI, 0.52–1.30 days) (Fig 4, A). No evidence of publication bias was found ($p = 0.967$, Egger test) (Supplementary Fig 7, A). However, the pooled estimate was not considered robust because of considerable heterogeneity across studies ($I^2 = 90.14\%$).

A total of 5 studies reported short-term mortality (30 days) in relation to postoperative AKI.^{2,16,20,23,29} The pooled mortality rate was 1.24% among patients without AKI (57 deaths out of 4,593 patients) compared with 4.72% among those with any stage of AKI (22 deaths out of 466 patients). Patients who

developed AKI had a significantly higher unadjusted risk of short-term mortality relative to those without AKI (RR, 5.60; 95% CI, 1.66–18.83) (Fig 4, B). Considerable statistical heterogeneity was present among the 5 included studies ($I^2 = 64.54\%$). Two studies reported a markedly increased mortality risk in patients with AKI (RR ranging from 13.78 to 27.00),^{2,23} whereas three studies did not demonstrate a significant association.^{16,20,29} There was no indication of publication bias ($p = 0.586$, Egger test) (Supplementary Fig 7, B). One study specifically evaluated long-term outcomes and consistently demonstrated a significant association between postoperative AKI and increased long-term mortality.²³

Discussion

In this meta-analysis, the authors investigated the incidence and clinical associations of AKI following lung resection surgery. This is the first meta-analysis that includes only patients undergoing lung resection surgery. Twenty studies encompassing 19,918 patients were included. The pooled analysis

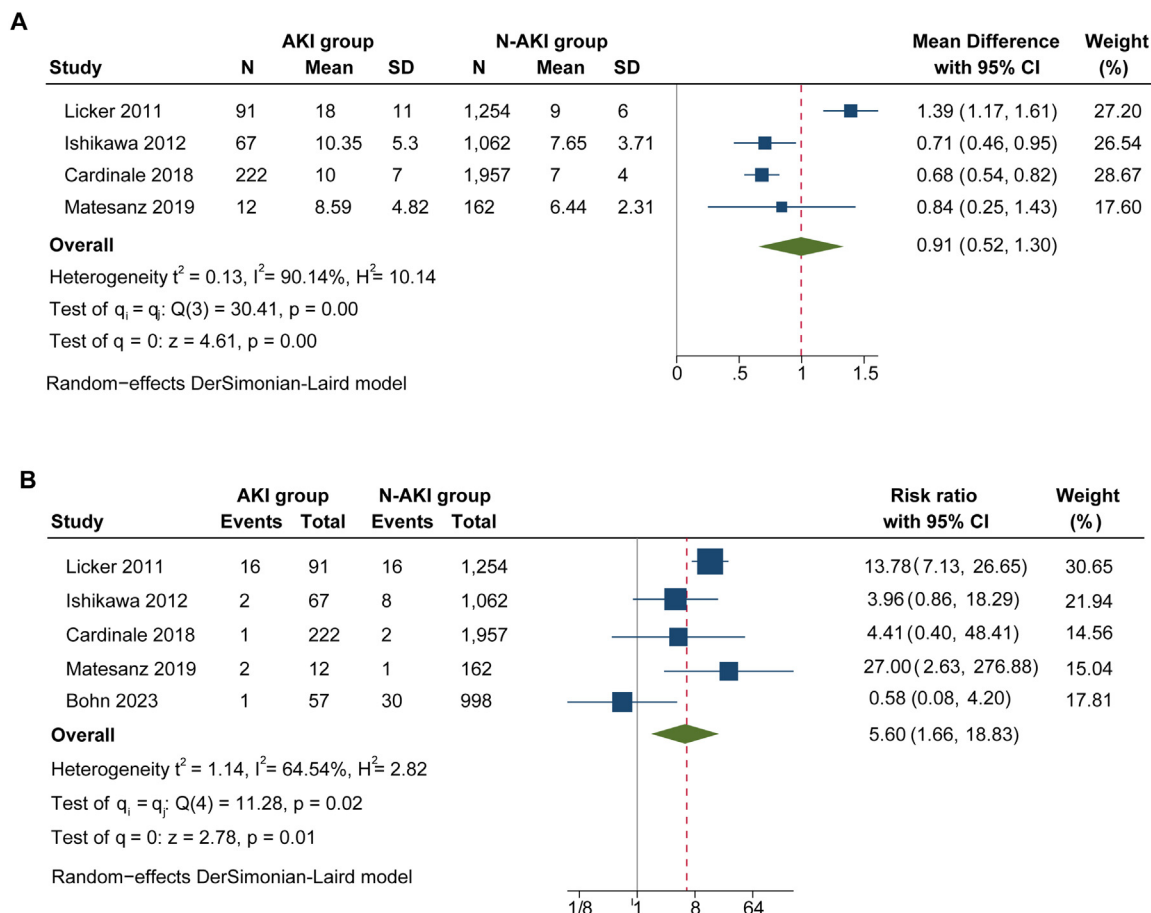


Fig 4. A) Forest plots showing associations of acute kidney injury (AKI) after lung resection surgery with length of hospital stay. For each study, the effect estimate is represented by the center of the blue square. The horizontal blue line shows the 95% confidence interval (CI). The pooled estimate is represented by the green diamond, with the width of the diamond representing the 95% CI. The black line is the demarcation line for a mean difference of 1. The dashed red line passing through the center of the green diamond indicates the pooled mean difference estimate. (B) Forest plots showing associations of AKI after lung resection surgery with postoperative short-term mortality. The pooled estimate is represented by the green diamond, with the width of the diamond representing the 95% CI. The gray line is the demarcation line for a risk ratio of 1. The dashed red line passing through the center of the green diamond indicates the pooled risk ratio estimate. SD, standard deviation; N-AKI, no acute kidney injury.

indicated that AKI is a common complication after lung resection, with an overall incidence of 5.31%. Ishikawa et al.¹⁶ previously reported an incidence of 5.9% within 72 hours using AKIN criteria; Bohn et al.,²⁹ an incidence of 5.5% within 48 hours using KDIGO criteria; and Cardinale et al.,²⁰ an incidence of 10% within 7 days using AKIN criteria. Patients who developed postoperative AKI had significantly prolonged hospital stays and higher short-term mortality compared with those without AKI. Notably, GDFT was not associated with a significant reduction in AKI incidence.

AKI is an abrupt decline in kidney function over hours to days, characterized by a rapid rise in serum creatinine (SCr), reduced urine output, or both.³² The pooled incidence is lower than the rates reported in other thoracic procedures, such as esophagectomy and mixed thoracic surgeries (approximately 8%),^{6,33} as well as those after cardiac, major abdominal, or other noncardiac surgeries.^{34–36} This difference may be attributable to variations in surgical complexity and physiological stress. For example, esophagectomy frequently involves extensive dissection, substantial alterations in intrathoracic pressure, and pronounced third-space fluid shifts, whereas lung resection generally does not entail such extensive retroperitoneal or mediastinal manipulation.^{37,38} Furthermore, 4 randomized clinical trials included in this analysis evaluated GDFT or hypotension prediction index–guided hemodynamic management. These advanced hemodynamic optimization strategies may contribute to a lower incidence of postoperative AKI by reducing episodes of intraoperative hypoperfusion. This study demonstrated that AKI incidence increased with surgical complexity, with the highest rates observed in bilobectomy and pneumonectomy. Nevertheless, considerable heterogeneity in the incidence of AKI was identified across studies and even within subgroup analyses restricted to specific surgical types. This variability is likely attributable to differences in patient characteristics, surgical complexity, and perioperative management strategies.

Fluid management remains a critical perioperative challenge given that maintaining the delicate balance between hypovolemia and fluid overload directly influences postoperative outcomes, particularly the risk of organ dysfunction.³⁹ In lung surgery, restrictive fluid regimens have been associated with reduced postoperative complications,⁴⁰ yet overly restrictive regimens may paradoxically precipitate renal hypoperfusion.¹⁶ To balance these risks, the Enhanced Recovery After Surgery Society and the European Society of Thoracic Surgeons have recommended a strategy targeting euvoolemia, aimed at optimizing tissue perfusion.⁴¹ The concept of GDFT in thoracic surgical patients appears attractive because it helps the clinician better understand the elusive concept of “euvoolemia.” However, the current pooled analysis of 5 prospective randomized controlled studies (1,198 patients) indicated GDFT was not associated with a significantly reduced incidence of AKI (RR, 0.71), with minimal heterogeneity across studies.^{9,21,25,26,28–30} These findings align with recent evidence questioning the efficacy of GDFT in major surgery, particularly in low- to moderate-risk patients.^{42,43} These results suggest that fluid optimization alone may not be sufficient to prevent AKI in this context, in which renal injury is likely driven by multifactorial mechanisms.

Accordingly, the KDIGO guidelines advocate for the implementation of a bundle of supportive measures to prevent AKI, including optimization of volume status and hemodynamics, glycemic control, avoidance of nephrotoxic agents, and monitoring of novel AKI biomarkers.⁴⁴ Early risk stratification would allow such strategies to be targeted toward high-risk individuals rather than being diluted among low-risk populations.

In this study, several risk factors for AKI after lung resection were identified, spanning patient demographic characteristics, comorbidities, surgical factors, and perioperative characteristics. Many of these variables are already incorporated into established AKI prediction models for mixed or specific categories of noncardiac surgery.^{45,46} Notably, preoperative N-terminal pro-B-type natriuretic peptide in combination with baseline SCr has shown promise for predicting AKI risk in lung resection.²⁰ Such a simplified model may provide a practical tool for preoperative identification of patients at high risk of AKI.

Mechanisms underlying AKI after lung resection are multifactorial. One-lung ventilation may induce hypoxemia and hypercapnia, both of which compromise renal blood flow and may precipitate renal ischemia and subsequent injury.⁴⁷ In addition, acute intrathoracic pressure changes and right ventricular dysfunction following lung tissue removal can elevate renal venous pressure, thereby reducing glomerular filtration.⁴⁸ In the present study, most postoperative AKI cases were mild, with severe AKI occurring in <1% of patients in the majority of studies.^{2,9,16,19,20,22,25,29} Nevertheless, even mild AKI was associated with prolonged hospital stays and increased short-term mortality, despite being considered reversible.⁴⁹ These findings are consistent with prior evidence demonstrating that even slight increases in SCr were linked to a significantly elevated risk of mortality.⁵⁰ Because of variations in assessment methods across studies, the authors did not further stratify short-term mortality by AKI severity or pool long-term outcomes.

Several limitations of this meta-analysis should be acknowledged. First, significant heterogeneity persisted across the meta-analysis and subgroup analyses, which could not be fully explained, therefore limiting the external validity of the current findings. Second, the limited number of randomized controlled trials on GDFT and their small sample sizes restricted the statistical power to draw definitive conclusions regarding its efficacy. Third, inconsistent reporting of perioperative risk factors precluded meta-regression analyses to identify potentially modifiable predictors of AKI. Fourth, the subgroup analyses were constrained by a relatively small sample size, reducing the statistical power to detect meaningful differences across strata. Finally, the studies included in this meta-analysis categorized procedures primarily by surgical type, without detailed consideration of surgical indications or operative approach. Future well-designed prospective studies focusing on AKI after thoracic lung resection may help to better account for these potential confounding factors.

In conclusion, this is the first meta-analysis to demonstrate that AKI is a common complication following lung resection surgery, with considerable heterogeneity observed across surgical centers. Postoperative AKI remains strongly associated

with prolonged hospitalization and increased short-term mortality. The variability in reported AKI rates underscores the need for the preoperative identification of high-risk patients and the immediate implementation of KDIGO-recommended bundled protective measures to mitigate the risk of AKI.

Data sharing statement

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declaration of competing interest

Given his role as editor of the *Journal of Cardiothoracic and Vascular Anesthesia*, H. Liu had no involvement in the peer-review process for this article and had no access to information regarding its peer review. Full responsibility for the editorial process for this article was delegated to another journal editor. All the other authors have no competing interests.

CRedit authorship contribution statement

Xi-sheng Shan: Writing – review & editing, Methodology. **Jing Yan:** Writing – original draft, Investigation. **Yi-qing Wang:** Formal analysis, Data curation. **Yang Zhang:** Project administration, Methodology, Investigation. **Xin-Yu Li:** Validation, Software, Resources. **Christos Koutentis:** Methodology, Investigation. **Wanda M. Popescu:** Visualization, Resources, Project administration, Investigation. **Fu-hai Ji:** Funding acquisition, Data curation, Conceptualization. **Hong Liu:** Writing – review & editing, Supervision, Data curation, Conceptualization.

Supplementary materials

Supplementary material associated with this article can be found in the online version at doi:10.1053/j.jvca.2026.04.035.

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