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**Original Article**

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# Acute kidney injury after radical gastrectomy: incidence, risk factors, and impact on prognosis

Benlong Zhang[1], Li Li[1], Yunhe Gao[1], Zijian Wang[1], Yixun Lu[1], Lin Chen [1] and Kecheng Zhang[1,*]

[1]Department of General Surgery, The First Medical Center of Chinese PLA General Hospital, Beijing, P. R. China

*Corresponding author. Department of General Surgery, First Medical Center, Chinese PLA General Hospital, Beijing 100853, P. R. China. Tel: +86-10-66938328; Email: zhangkecheng@301hospital.com.cn

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## Abstract

**Background:** Acute kidney injury (AKI) is a serious adverse event often overlooked following major abdominal surgery. While radical gastrectomy stands as the primary curative method for treating gastric cancer patients, little information exists regarding AKI post-surgery. Hence, this study aimed to ascertain the incidence rate, risk factors, and consequences of AKI among patients undergoing radical gastrectomy.

**Methods:** This was a population-based, retrospective cohort study. The incidence of AKI was calculated. Multivariate logistic regression was used to identify independent predictors of AKI. Survival curves were plotted by using the Kaplan–Meier method and differences in survival rates between groups were analyzed by using the log-rank test.

**Results:** Of the 2,875 patients enrolled in this study, 61 (2.1%) developed postoperative AKI, with AKI Network 1, 2, and 3 in 50 (82.0%), 6 (9.8%), and 5 (8.2%), respectively. Of these, 49 patients had fully recovered by discharge. Risk factors for AKI after radical gastrectomy were preoperative hypertension (odds ratio [OR], 1.877; 95% CI, 1.064–3.311; $P = 0.030$), intraoperative blood loss (OR, 1.001; 95% CI, 1.000–1.002; $P = 0.023$), operation time (OR, 1.303; 95% CI, 1.030–1.649; $P = 0.027$), and postoperative intensive care unit (ICU) admission (OR, 4.303; 95% CI, 2.301–8.045; $P < 0.001$). The probability of postoperative complications, mortality during hospitalization, and length of stay in patients with AKI after surgery were significantly higher than those in patients without AKI. There was no statistical difference in overall survival (OS) rates between patients with AKI and without AKI (1-year, 3-year, 5-year overall survival rates of patients with AKI and without AKI were 93.3% vs 92.0%, 70.9% vs 73.6%, and 57.1% vs 67.1%, respectively, $P = 0.137$).

**Conclusions:** AKI following radical gastrectomy is relatively rare and typically self-limited. AKI is linked with preoperative hypertension, intraoperative blood loss, operation time, and postoperative ICU admission. While AKI raises the likelihood of postoperative complications, it does not affect OS.

**Keywords:** gastric cancer; surgery; complication; acute kidney injury; AKIN criteria

## Introduction

Gastric cancer, with an incidence rate of approximately 17 cases per 10,000 individuals, ranks as the fifth most prevalent cancer globally and the fourth most fatal, contributing to 7.7% of all cancer-related mortalities and presenting a significant public health concern [1]. Notably, China bears a substantial burden, accounting for 42.5% of new gastric cancer diagnoses and 45.0% of associated deaths annually, making it the epicenter of gastric cancer prevalence worldwide [2]. Advancements in early screening modalities, neoadjuvant therapies, and multimodal treatment approaches, alongside the progressive evolution of medical technologies, have notably enhanced the prognostic landscape for patients afflicted with gastric cancer [3]. Presently, radical gastrectomy stands as the cornerstone of treatment for this malignancy [4, 5]. However, irrespective of the surgical approach adopted, the incidence of postoperative complications remains notably high, ranging from 17.4% to 24.5% across laparoscopic, robotic, and open surgical interventions. Contemporary clinical investigations concerning postoperative complications in gastric cancer predominantly concentrate on intra-abdominal infections, pancreatic fistulas, anastomotic leaks, and abdominal abscesses, with limited exploration into renal complications, notably acute kidney injury (AKI) [6, 7].

AKI, often asymptomatic until substantial renal impairment ensues, poses a challenge for clinical detection. Despite its significance, large-scale randomized controlled trials focusing on post-gastrectomy outcomes lack comprehensive data on AKI [8–10]. Findings from a nationwide survey in China underscore the alarming trend of AKI nonrecognition, with rates reaching up to 74.2% [11]. Delayed identification of AKI emerges as an independent predictor of in-hospital mortality, emphasizing the critical need for heightened awareness and surveillance of this postoperative complication [12].

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While AKI following cardiac surgery has been extensively documented, there remains a dearth of data concerning AKI subsequent to major abdominal procedures, particularly gastrectomy. Hence, this study aimed to compile clinicopathological data from patients undergoing radical gastric cancer surgery at a prominent tertiary referral center to elucidate the incidence of postoperative AKI. AKI diagnosis was predicated on pre- and post-operative creatinine levels. Additionally, we endeavored to identify the risk factors contributing to postoperative AKI and evaluate its impact on both short- and long-term patient outcomes.

# Patients and methods

## Patient selection and data collection

This study retrospectively analyzed the data of patients who underwent elective radical surgery for gastric malignant tumor under general anesthesia between January 2010 and December 2018 at the First Medical Center of the PLA General Hospital (Beijing, China). Patients were aged 18 to 90 years, of either sex, with American Society of Anesthesiologists (ASA) classification lower than grade IV. Exclusion criteria were as follows: (1) emergency surgery; (2) other concurrent malignancies; (3) history of other malignancies within 5 years of diagnosis, except cured basal cell carcinoma of the skin and carcinoma *in situ* of the cervix; (4) other serious medical illnesses or conditions; or (5) incomplete clinical information or absence of follow-up. This study was approved by the Ethics Committee of the PLA General Hospital (ethics approval number: S2023-092–01). Intraoperative patient information was exported in its entirety through the center's surgical information query system. Patient information was collected using a predesigned case information form.

## Data and variables

Variables collected in this study included basic patient information: sex, age, height, weight, history of smoking, history of alcohol consumption, combined underlying diseases (hypertension, diabetes), and ASA classification. Treatment information included history of neoadjuvant chemotherapy, surgical route, total intraoperative fluid infusion, crystalloid infusion, colloid infusion, intraoperative bleeding, intraoperative urine volume, intraoperative hypotension, whether returned to intensive care unit (ICU) after surgery, duration of surgery, type of gastrectomy, and mode of lymph node dissection (D1+, D2). Pathology information included tumor location, maximum tumor diameter, depth of infiltration, lymph node metastasis, and TNM stage. The information listed above was organized and archived by relevant personnel upon discharge of the patient.

AKI was defined as a rise of serum creatinine of >26.5 mmol/L (0.3 mg/dL), or a relative percentage increase of 50% from baseline, within 48 h of surgery, according to the AKI Network (AKIN) criteria [13]. Stage I was defined as a rise of serum creatinine of >26.5 mmol/L (0.3 mg/dL), or a relative percentage increase of 50% (1.5 × baseline value) from baseline, within 48 h of surgery; stage II was defined as a 100% increase (2.0 × baseline value); stage III represented an increase of ≥354 mmol/L (4.0 mg/dL) or more than 200% (3.0 × baseline value). We defined renal recovery at discharge as full recovery with serum creatinine decreased to below threshold, or to baseline. We defined partial recovery as serum creatinine decreased by 25% or more from peak concentration but remaining higher than the threshold or baseline. We defined failure to recover as the state that the patient was still dependent on dialysis, or that serum creatinine decreased by less than 25% from peak concentration [11]. The preoperative and postoperative creatinine values of the patients were obtained from the testing database during our study.

Patients' preoperative creatinine values (baseline values) were compared with the highest creatinine values at 48 h postoperatively to determine the presence of postoperative AKI. Urine volume was not included in the diagnostic criteria in this study because of the use of diuretics. Intraoperative hypotension was defined as an intraoperative mean arterial pressure ≤65 mmHg or a systolic pressure ≤90 mmHg according to previous studies [14]. The Clavien–Dindo grading scale was used to record postoperative complications, which included anastomotic leakage, pancreatic fistula, intra-abdominal abscess, intra-abdominal bleeding, intraluminal bleeding, ileus, cholecystitis, anastomotic stenosis, and wound infection [15]. We mainly focused on the postoperative complications with Clavien–Dindo classification ≥3. Radical gastrectomy with D1+/D2 lymphadenectomy was performed according to the Japanese gastric cancer treatment guidelines [16]. Postoperative patients were routinely returned to the general ward. Patients who were older, had poorer underlying physical condition, or were unstable intraoperatively were returned to the ICU at the joint discretion of the anesthesiologist and surgeon.

## Follow-up

To obtain long-term follow-up results, this study adhered to a standardized follow-up strategy after gastric cancer surgery [17]. Postoperative patients were monitored through outpatient review registration, telephone, short message system, and other methods. The follow-up endpoint was overall survival (OS), defined as the period from the time of surgery to the time of death from any cause or the last follow-up.

## Statistical analysis

Data analysis was performed using IBM SPSS Statistics for Windows (Statistical Package for the Social Sciences, version 19.0, IBM Corp., Armonk, NY, USA). The drawings were produced using GraphPad Prism, version 9 for Windows (GraphPad Software, San Diego, CA, USA). If the continuous variables conformed to a normal distribution, descriptive data are presented as mean ± SD; if not, descriptive data are presented as median (interquartile range, IQR). Categorical variables are expressed as numbers (%). Univariable comparisons between groups were performed using the Student's $t$ test or Mann–Whitney $U$-test for continuous variables and $\chi^2$ test, Fisher's exact test, and Mann–Whitney $U$-test for categorical variables. Survival analysis was performed using the Kaplan–Meier method, and differences in survival rates between groups were compared using the log-rank test. Variables with statistically significant differences in the single factor analysis were included in the multifactor analysis by using logistic regression or Cox proportional hazards regression models, which ensured that only those variables with the highest simple correlation with the outcome were included, thereby improving the model's estimate of risk. $P < 0.05$ indicated that the difference was statistically significant. All statistical calculations in this study were performed using two-sided tests.

# Results

## Population characteristics

After implementing strict inclusion and exclusion criteria, we included clinicopathological information for 2,875 patients who underwent radical gastric cancer surgery (Table 1). The median age was 60 (IQR, 52–67) years. There were 2,173 (75.6%) male and 702 (24.4%) female patients. A total of 177 (6.2%) patients were

**Table 1.** Clinicopathologic characteristics of entire study population and a comparison between AKI and non-AKI cohorts

| Characteristic | All patients ($n = 2,875$) | No AKI ($n = 2,814$) | AKI ($n = 61$) | P value |
|---|---|---|---|---|
| Clinical characteristic | | | | |
| Age, years, median (IQR) | 60 (52, 67) | 60 (52, 67) | 65 (55, 72) | **0.003** |
| Gender, *n* (%) | | | | 0.140 |
| Male | 2,173 (75.6) | 2,122 (75.4) | 51 (83.6) | |
| Female | 702 (24.4) | 692 (24.6) | 10 (16.4) | |
| BMI, kg/m$^2$, median (IQR) | 23.8 (21.5, 26.0) | 23.8 (21.5, 26.0) | 24.8 (22.4, 27.4) | **0.006** |
| Smoking, *n* (%) | | | | 0.268 |
| Yes | 1,140 (39.7) | 1,120 (39.8) | 20 (32.8) | |
| No | 1,735 (60.3) | 1,694 (60.2) | 41 (67.2) | |
| Drinking, *n* (%) | | | | 0.622 |
| Yes | 1,220 (42.4) | 1,196 (42.5) | 24 (39.3) | |
| No | 1,655 (57.6) | 1,618 (57.5) | 37 (60.7) | |
| Hypertension, *n* (%) | | | | **<0.001** |
| Yes | 613 (21.3) | 588 (20.9) | 25 (41.0) | |
| No | 2,262 (78.7) | 2,226 (79.1) | 36 (59.0) | |
| Diabetes, *n* (%) | | | | **0.040** |
| Yes | 328 (11.4) | 316 (11.2) | 12 (19.7) | |
| No | 2,547 (88.6) | 2,498 (88.8) | 49 (80.3) | |
| ASA grade, *n* (%) | | | | **0.001** |
| Grade I–II | 2,562 (89.1) | 2,516 (89.4) | 46 (75.4) | |
| Grade III–IV | 313 (10.9) | 298 (10.6) | 15 (24.6) | |
| Treatment characteristic | | | | |
| Neoadjuvant chemotherapy, *n* (%) | | | | 0.499 |
| Yes | 177 (6.2) | 175 (6.2) | 2 (3.3) | |
| No | 2,698 (93.8) | 2,639 (93.8) | 59 (96.7) | |
| Surgical approach, *n* (%) | | | | 0.114 |
| Open | 1,752 (60.9) | 1,707 (60.7) | 45 (73.8) | |
| Laparoscopic | 934 (32.5) | 921 (32.8) | 13 (21.3) | |
| Robotic | 189 (6.6) | 186 (6.5) | 3 (4.9) | |
| Intraoperative urine volume, mL, median (IQR) | 1.3 (0.7, 2.3) | 1.3 (0.7, 2.3) | 1.4 (0.8, 1.9) | 0.542 |
| Blood loss, mL, median (IQR) | 200 (100, 200) | 200 (100, 200) | 300 (200, 400) | **<0.001** |
| crystalloid, mL, median (IQR) | 2,100 (1,600, 2,500) | 2,100 (1,600, 2,500) | 2,100 (1,600, 2,275) | 0.571 |
| colloid, mL, median (IQR) | 1,000 (500, 1,000) | 1,000 (500, 1,000) | 1,000 (500, 1,000) | **0.009** |
| Intraoperative hypotension, *n* (%) | | | | 0.067 |
| Yes | 2,218 (77.1) | 2,165 (76.9) | 53 (86.9) | |
| No | 657 (22.9) | 649 (23.1) | 8 (13.1) | |
| Return to ICU after operation, *n* (%) | | | | **<0.001** |
| Yes | 215 (7.5) | 194 (6.9) | 21 (34.4) | |
| No | 2,660 (92.5) | 2,620 (93.1) | 40 (65.6) | |
| Operation time, min, median (IQR) | 205 (170, 245) | 205 (170, 245) | 222 (190, 287.5) | **0.002** |
| Type of gastrectomy, *n* (%) | | | | 0.089 |
| Proximal gastrectomy | 835 (29.0) | 811 (28.8) | 24 (39.4) | |
| Distal gastrectomy | 1,373 (47.8) | 1,352 (47.1) | 21 (34.4) | |
| Total gastrectomy | 667 (23.2) | 651 23.1) | 16 (26.2) | |
| Scope of lymph node dissection, *n* (%) | | | | 0.574 |
| D1+ | 1,886 (65.6) | 1,844 (65.5) | 42 (68.9) | |
| D2 | 989 (34.4) | 970 (34.5) | 19 (31.1) | |
| Pathologic characteristic | | | | |
| Tumor location, *n* (%) | | | | 0.120 |
| Upper third | 1,086 (37.8) | 1,055 (37.5) | 31 (50.8) | |
| Middle third | 410 (14.3) | 406 (14.4) | 4 (6.6) | |
| Lower third | 1,312 (45.6) | 1,287 (45.7) | 25 (41.0) | |
| Entire | 67 (2.3) | 66 (2.4) | 1 (1.6) | |
| Tumor size, cm, median (IQR) | 4 (2.5, 6.0) | 4 (2.5, 6) | 4 (3, 6.25) | 0.075 |
| T stage, *n* (%) | | | | 0.321 |
| T1 | 678 (23.6) | 668 (23.7) | 10 (16.4) | |
| T2 | 458 (15.9) | 447 (15.9) | 11 (18.0) | |
| T3 | 662 (23.0) | 647 (23.0) | 15 (24.6) | |
| T4 | 1,077 (37.5) | 1,052 (37.4) | 25 (41.0) | |
| N stage, *n* (%) | | | | 0.790 |
| N0 | 1,278 (44.5) | 1,252 (44.5) | 26 (42.6) | |
| N1 | 464 (16.1) | 453 (16.1) | 11 (18.0) | |
| N2 | 481 (16.7) | 472 (16.8) | 9 (14.8) | |
| N3 | 652 (22.7) | 637 (22.6) | 15 (24.6) | |
| TNM stage, *n* (%) | | | | 0.501 |
| I | 897 (31.2) | 879 (31.2) | 18 (29.5) | |
| II | 763 (26.5) | 749 (26.6) | 14 (23.0) | |
| III | 1,215 (42.3) | 1,186 (42.2) | 29 (29.5) | |

AKI = acute kidney injury, ASA = American Society of Anesthesiologists, BMI = body mass index, ICU = intensive care unit, IQR = inter-quartile range. The *P* values in bold indicate statistically significant.

treated with neoadjuvant chemotherapy prior to surgery; 1,752 (60.9%), 934 (32.5%), and 189 (6.6%) patients underwent open, laparoscopic, and robotic surgery, respectively. In the cohort, 835 (29.0%), 1,373 (47.8%), and 667 (23.2%) patients underwent proximal, distal, and total gastrectomy, respectively. Finally, 897 (31.2%), 763 (26.5%), and 1,215 (42.3%) patients were stage I, stage II, and stage III, respectively.

## AKI incidence and risk factors

Of the 2,875 patients studied, 61 (2.1%) patients developed postoperative AKI. These patients were classified as AKIN 1 ($n=50$, 82.0%), AKIN 2 ($n=6$, 9.8%), and AKIN 3 ($n=5$, 8.2%). By discharge, 49 patients with AKI had fully recovered, including 46 patients with AKIN 1, two patients with AKIN 2, and one patient with AKIN 3. Three patients with AKI had partially recovered: one patient with AKIN 2, and two patients with AKIN 3. Nine patients with AKI failed to recover: four patients with AKIN 1, three patients with AKIN 2, and two patients with AKIN 3. Compared with non-AKI patients, AKI patients were older ($P=0.003$), had a higher body mass index (BMI) ($P=0.006$), a higher percentage of comorbidities with a history of diabetes ($P=0.040$) and hypertension ($P<0.001$), and a higher percentage of ASA scores of III–IV ($P=0.001$). Patients with AKI had greater intraoperative blood loss ($P<0.001$), colloid transfusion ($P=0.009$), and a higher percentage of postoperative ICU admission ($P=0.002$) than non-AKI patients. However, the difference between AKI and non-AKI patients was not statistically significant in terms of the composition of each pathological parameter (tumor location, size, T stage, N stage, and TNM stage).

We included variables with statistically significant differences in multivariate conditional logistic regression analysis, and four risk factors for AKI after gastrectomy were identified (Table 2): preoperative hypertension (OR, 1.877; 95% CI, 1.064–3.311; $P=0.030$), intraoperative blood loss (OR, 1.001; 95% CI, 1.000–1.002; $P=0.023$), operation time (OR, 1.303; 95% CI, 1.030–1.649; $P=0.027$), and postoperative ICU admission (OR, 4.303; 95% CI, 2.301–8.045; $P<0.001$).

## Operative complications, length of postoperative hospital stay, and in-hospital mortality comparisons between AKI and non-AKI patients

As shown in Table 3, 54 of 2,875 (1.9%) patients had postoperative complications of Clavien–Dindo classification ≥3, including 6 (9.8%) patients with AKI and 48 (1.7%) patients without AKI. Patients with AKI were significantly more likely to have postoperative complications of Clavien–Dindo classification ≥3 than those without AKI.

**Table 2.** Multivariable logistic regression analysis of risk factors for postoperative AKI among patients after radical gastrectomy

| Risk factor | OR | 95% CI | P value |
|---|---|---|---|
| Age | 1.017 | 0.989–1.046 | 0.247 |
| BMI | 1.052 | 0.985–1.124 | 0.128 |
| Hypertension | 1.877 | 1.064–3.311 | **0.030** |
| Diabetes | 1.292 | 0.651–2.566 | 0.464 |
| ASA grade | 1.337 | 0.677–2.643 | 0.403 |
| Blood loss | 1.001 | 1.000–1.002 | **0.023** |
| Colloid | 1.000 | 0.999–1.001 | 0.655 |
| Operation time | 1.303 | 1.030–1.649 | **0.027** |
| Postoperative ICU admission | 4.303 | 2.301–8.045 | **<0.001** |

AKI = acute kidney injury, ASA = American Society of Anesthesiologists, BMI = body mass index, CI = confidential interval; ICU = intensive care unit, OR = odd ratio. The P values in bold indicate statistically significant.

**Table 3.** Postoperative outcomes in patients with AKI

| Characteristic | All patients ($n=2,875$) | No AKI ($n=2,814$) | AKI ($n=61$) | P value |
|---|---|---|---|---|
| Clavien–Dindo classification ≥ 3, n (%) | 54 (1.9) | 48 (1.7) | 6 (9.8) | **<0.001** |
| Clavien-Dindo classification, n (%) | | | | **<0.001** |
| No complication | 2,586 (89.9) | 2,545 (90.4) | 41 (67.2) | |
| Grade I | 109 (3.8) | 102 (3.6) | 7 (11.5) | |
| Grade II | 126 (4.4) | 119 (4.2) | 7 (11.5) | |
| Grade III | 26 (0.9) | 23 (0.8) | 3 (4.9) | |
| Grade IV | 16 (0.6) | 15 (0.5) | 1 (1.6) | |
| Grade V | 12 (0.4) | 10 (0.4) | 2 (3.3) | |
| Postoperative hospitalization, days, median (IQR) | 11 (9, 14) | 11 (9, 13) | 13 (11, 20) | **<0.001** |
| In-hospital mortality, n (%) | 14 (0.5) | 12 (0.4) | 2 (3.3) | **0.034** |

AKI = acute kidney injury, IQR = inter-quartile range. The P values in bold indicate statistically significant.

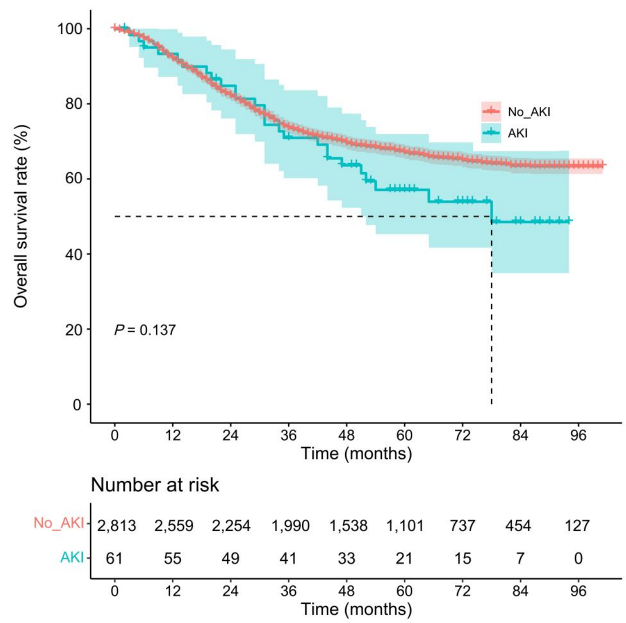


**Figure 1.** Kaplan-Meier curve comparing overall survival in those with and without acute kidney injury (AKI). 3-year survival: No-AKI group, 73.6%; AKI group, 70.9%.

The median postoperative hospitalization was 11 (IQR, 9–13) days and 13 (IQR, 11–20) days in patients without and with AKI, respectively. The postoperative hospital stay was significantly longer in patients with AKI than in those without ($P<0.001$). Death during hospitalization occurred in 14 (0.5%) patients, including 12 (0.4%) patients without AKI and 2 (3.3%) patients with AKI. The probability of death during hospitalization was significantly higher in patients without AKI than in patients without AKI.

## AKI and OS

There was no statistical difference in OS between patients with and without AKI (1-year overall survival, 3-year overall survival, and 5-year overall survival: 93.3% vs 92.0%, 70.9% vs 73.6%, and 57.1% vs 67.1%, respectively; log-rank test $P=0.137$, Breslow test $P=0.339$), as shown in Figure 1. There were also no statistical differences in OS among patients with AKIN 1, AKIN2, and AKIN3 as shown in Supplementary Figure S1 (log-rank test $P=0.464$, Breslow test $P=0.543$).

**Table 4.** Univariate and multivariate analysis of factors associated with survival outcome in entire study population

| Variable | Univariate analysis | | *P* value | Multivariate analysis | | *P* value |
|---|---|---|---|---|---|---|
| | HR | 95% CI | | HR | 95% CI | |
| Clinical characteristic | | | | | | |
| Age | 1.034 | 1.027–1.040 | **<0.001** | 1.028 | 1.021–1.035 | **<0.001** |
| BMI, kg/m$^2$ | 0.957 | 0.939–0.975 | **<0.001** | 0.970 | 0.952–0.989 | **0.002** |
| Gender, Female vs Male | 0.960 | 0.825–1.117 | 0.597 | | | |
| Smoking, Yes vs No | 1.194 | 1.045–1.364 | **0.009** | 1.118 | 0.942–1.327 | 0.202 |
| Drinking, Yes vs No | 1.196 | 1.048–1.364 | **0.008** | 1.043 | 0.881–1.236 | 0.642 |
| Hypertension, Yes vs No | 0.967 | 0.826–1.132 | 0.677 | | | |
| Diabetes, Yes vs No | 1.086 | 0.893–1.321 | 0.410 | | | |
| ASA grade, III–IV vs I–II | 1.637 | 1.370–1.957 | **<0.001** | 1.153 | 0.955–1.393 | 0.139 |
| Treatment characteristic | | | | | | |
| Neoadjuvant chemotherapy, Yes vs No | 0.964 | 0.725–1.282 | 0.802 | | | |
| Operative Approach | | | **0.026** | | | 0.367 |
| Laparoscopic vs Open | 1.169 | 1.038–1.316 | 0.010 | 0.931 | 0.807–1.074 | 0.328 |
| Robotic vs Open | 1.009 | 0.887–1.147 | 0.890 | 0.832 | 0.611–1.134 | 0.244 |
| Type of gastrectomy | | | **<0.001** | | | **0.039** |
| Distal gastrectomy vs Proximal gastrectomy | 0.719 | 0.616–0.840 | **<0.001** | 0.827 | 0.626–1.093 | 0.183 |
| Total gastrectomy vs Proximal gastrectomy | 1.513 | 1.286–1.780 | **<0.001** | 1.081 | 0.878–1.331 | 0.463 |
| Clavien-Dindo classification ≥ 3, Yes vs No | 2.358 | 1.682–3.305 | **<0.001** | 1.986 | 1.410–2.797 | **<0.001** |
| Postoperative AKI, Yes vs No | 1.342 | 0.908–1.981 | 0.140 | | | |
| Pathologic characteristic | | | | | | |
| Tumor size | 1.187 | 1.165–1.208 | **<0.001** | 1.062 | 1.035–1.090 | **<0.001** |
| Tumor location | | | **<0.001** | | | 0.423 |
| Middle third vs Upper third | 0.921 | 0.758–1.121 | 0.413 | 1.166 | 0.910–1.494 | 0.224 |
| Lower third vs Upper third | 0.742 | 0.643–0.855 | **<0.001** | 1.163 | 0.902–1.498 | 0.244 |
| Entire vs Upper third | 2.457 | 1.787–3.378 | **<0.001** | 1.315 | 0.906–1.911 | 0.150 |
| T stage, T3–T4 vs T1–T2 | 4.124 | 3.476–4.892 | **<0.001** | 1.902 | 1.561–2.318 | **<0.001** |
| N stage, N1–N3 vs N0 | 4.951 | 4.183–5.860 | **<0.001** | 3.156 | 2.625–3.795 | **<0.001** |
| TNM stage | | | **<0.001** | | | |
| Stage II vs Stage I | 2.696 | 2.080–3.496 | **<0.001** | | | |
| Stage III vs Stage I | 8.661 | 6.908–10.858 | **<0.001** | | | |

AKI = acute kidney injury, ASA = American Society of Anesthesiologists, BMI = body mass index, HR = hazard ratio.
Age, BMI, and Tumor size are continuous variables. The *P* values in bold indicate statistically significant.

The univariate results revealed that age, BMI, smoking, drinking, ASA grade, operative approach, type of gastrectomy, Clavien–Dindo classification ≥3, tumor size, tumor location, T stage, N stage, and TNM stage were risk factors affecting the survival of patients with gastric cancer (Table 4). Because tumor stage was derived from the combined assessment of two indicators, T stage and N stage, variables with statistically significant differences other than stage were included in the univariate analysis in a Cox regression model for multifactorial analysis, and the results showed that age, type of gastrectomy, Clavien–Dindo classification ≥3, tumor size, T stage, N stage were independent risk factors affecting the OS of patients with gastric cancer.

## Discussion

AKI represents a rare yet notably serious complication following surgical procedures. Despite its clinical significance, there exists a paucity of large-scale clinical investigations examining the incidence and ramifications of postoperative AKI in patients undergoing radical gastrectomy for gastric cancer. To the best of our knowledge, this study represents the inaugural endeavor in China to explore the incidence, associated risk factors, and prognostic implications of postoperative AKI in individuals undergoing radical surgery for gastric cancer. The findings from this study carry profound implications for enhancing clinicians' comprehension of this entity and informing clinical decision-making.

Despite numerous investigations into postoperative AKI, there remains a dearth of understanding regarding its incidence following radical surgery for gastric cancer. In our study, utilizing the AKIN criteria, we observed an AKI incidence of 2.1% subsequent to radical gastrectomy. Multivariate analysis revealed four predictors of postoperative AKI: preoperative hypertension, intraoperative blood loss, duration of surgery, and postoperative admission to the intensive care unit. Existing literature presents a wide array of findings. Kim *et al.* [18], in a study involving 4,718 individuals, reported a postoperative AKI incidence of 14.4% based on the Kidney Disease Improving Global Outcomes (KDIGO) guidelines. They noted significant associations between AKI and male gender, hypertension, chronic obstructive pulmonary disease, hypoalbuminemia, diuretic and vasopressor use, contrast agent administration, and packed red blood cell transfusions. Conversely, Zhang *et al.* [19], defining AKI as a ≥50% rise in serum creatinine within the initial three postoperative days, reported a lower incidence of 6.9% among 536 patients, with age, BMI, hypertension, hyperlipidemia, and preoperative cystatin C levels identified as associated factors. Similarly, Li *et al.* [20], utilizing KDIGO criteria in a cohort of 2,453 Chinese patients, reported a postoperative AKI incidence of 13.9% among gastric cancer patients. However, this study did not specifically analyze AKI risk factors in the gastric cancer subgroup. Our findings align closely with those of a population-based cohort study in China, which reported an overall AKI incidence of 4.7% in gastric cancer patients, encompassing both community- and hospital-acquired cases [21]. The observed disparities in AKI incidence can be attributed in part to variations in AKI criteria employed across studies. Furthermore, differences in surgical techniques, perioperative care protocols, patient demographics, and tumor characteristics may contribute to the heterogeneous reported incidences of AKI.

AKI represents a clinical syndrome characterized by a rapid decline in renal function resulting from various etiologies and stands as a significant adverse event in postoperative patients [22]. The incidence of postoperative AKI among hospitalized individuals ranges from 2% to 13% [23–25]. Predominantly, AKI manifests as a substantial reduction in glomerular filtration rate, concomitant with elevations in serum creatinine and other metabolic derangements. In severe instances, AKI may progress to uremia, often leading to prolonged hospitalizations, heightened severity of illness, and increased in-hospital mortality rates [26]. Notably, AKI necessitating dialysis substantially escalates healthcare expenditures, imposing considerable emotional and financial burdens on patients. Consequently, early identification of modifiable risk factors holds pivotal clinical significance for AKI patients. In noncardiac surgical settings, postoperative AKI exhibits associations with male sex, elevated BMI, anemia, hypoalbuminemia, diabetes mellitus, as well as preoperative hypertension or chronic kidney disease [27, 28].

The pathogenesis of AKI encompasses intricate pathophysiological mechanisms, principally categorized into prerenal, renal, and postrenal factors. Perturbations such as significant perioperative hemorrhage, shock, and excessive vasodilation disrupt hemodynamics, resulting in a hypotensive and hypovolemic state. This leads to diminished renal blood flow, precipitating renal ischemia and hypoxia, thereby provoking kidney damage. Additionally, certain comorbid chronic conditions, notably hypertension and diabetes, heighten the propensity for AKI. Chronic hypertension exacerbates glomerulosclerosis and glomerular stenosis, impairing the kidney's intrinsic regulatory function and augmenting the risk of postoperative AKI [29]. Furthermore, patients administered or previously prescribed antihypertensive medications, such as angiotensin-converting enzyme inhibitors or angiotensin II receptor blockers, may face an elevated risk of postoperative AKI [30].

Intraoperative hypotension stands as a significant factor associated with postoperative AKI [31–33]. Several large retrospective cohort studies have demonstrated that intraoperative mean arterial pressure ≤60–65 mmHg or a decrease ≤20% from baseline correlates with subsequent AKI and myocardial injury [16, 34–36]. The severity of impairment positively correlates with both the magnitude and duration of the blood pressure decline. However, our study did not validate the association between intraoperative hypotension and postoperative AKI, potentially due to the predominant use of noninvasive cuff blood pressure measurements during gastric surgeries at our institution. These intermittent measurements, typically obtained every 3–5 min, might have missed instances of hypotension between readings, leading to biased results. Moreover, due to data constraints, our analysis focused solely on the presence of renal injury without stratifying to investigate the impact of varying durations of intraoperative hypotension on postoperative AKI, suggesting that brief episodes of intraoperative hypotension might not incite renal injury. Intraoperative fluid management remains an area of considerable interest and controversy. The impact of intraoperative colloid infusion on postoperative complications, particularly AKI, remains uncertain. Studies comparing intraoperative fluid therapy utilizing 0.9% saline versus hydroxyethyl starch among patients undergoing major abdominal surgery reveal no statistically significant differences in mortality or surgical complication rates at 14 days postoperatively [37]. However, evidence suggests a potential association between intraoperative hydroxyethyl starch usage and increased incidence of postoperative AKI [38].

A key discovery of this study is the relatively infrequent and seldom severe occurrence of AKI following radical gastric cancer surgery, with most cases manifesting as AKIN 1 and exhibiting self-limiting characteristics, often leading to full recovery by discharge—an observation not previously documented in literature. While it is widely acknowledged that postoperative AKI impacts the immediate complications in hospitalized patients, its effect on long-term patient prognosis remains contentious, with varying study outcomes. For instance, a comprehensive clinical review of 1,135 postoperative esophageal cancer patients, including 208 with AKI, demonstrated that while AKI correlated with increased postoperative complications, prolonged ICU stays, post-discharge dialysis, and in-hospital mortality, it did not significantly influence postoperative disease-free survival, disease-specific survival, or OS [39]. Similarly, a study analyzing 6,580 colorectal cancer surgery patients in Denmark, with 1,337 developing postoperative AKI, revealed elevated mortality rates on 8–30 days and 31–90 days post-surgery compared with those without AKI, yet found no significant difference in mortality on 91–365 days post-surgery [40]. Conversely, contrasting results have been reported. A large-scale study in Scotland involving 6,220 orthopedic surgery patients, 672 of whom developed postoperative AKI, indicated worse survival outcomes in AKI patients, particularly in the short term [41]. Additionally, a study by Zakkar *et al.* [42] examining 398 patients undergoing repeat coronary artery bypass surgery, with 70 developing postoperative AKI, demonstrated increased 30-day mortality, major complications, and decreased long-term survival associated with AKI. In our investigation, patients with postoperative AKI exhibited prolonged hospital stays, increased in-hospital mortality, and increased postoperative complications—particularly severe complications according to the Clavien–Dindo classification ≥3—compared with those without AKI. Consequently, more attention to postoperative AKI in clinical settings is warranted to emphasize the significance of early prevention and treatment to enhance patient early prognoses. Furthermore, our study established a link between AKI and OS following gastric cancer surgery. Despite increasing in-hospital mortality, AKI did not significantly impact patient OS, nor did it influence OS among patients with varying AKI grades. Multifactorial regression analysis, considering potential confounding factors, confirmed that AKI did not affect patient OS. Notably, postoperative complications with a Clavien–Dindo classification ≥3 emerged as independent risk factors for OS in patients undergoing radical gastrectomy, underscoring the potential to improve long-term prognosis through the prevention and treatment of severe postoperative complications.

Several limitations must be acknowledged in our study. First, its single-center design renders our findings susceptible to selective bias. Second, the absence of urine output criteria in defining AKI may have underestimated the incidence of postoperative AKI. The utility of urine output as a diagnostic criterion for kidney injury is a contentious issue. While the KDIGO guidelines highlight the poor correlation between brief periods of oliguria and minor fluctuations in serum creatinine levels, some studies posit that urine output is influenced by diuretics and that oliguria primarily reflects volume depletion, rather than renal impairment. Consequently, intraoperative urine output may decrease significantly independent of renal function [43, 44].

While the incidence of postoperative AKI is relatively low, numerous clinical studies have consistently demonstrated its detrimental impact on patient prognosis. The majority of AKI cases are asymptomatic. Identifying the risk factors associated with AKI is essential for early detection and diagnosis among high-risk patients, facilitating timely clinical intervention to mitigate irreversible kidney damage and reduce AKI incidence rates. Apart from clinical and pathological characteristics, the development of highly sensitive biomarkers capable of detecting AKI is imperative [45]. Therefore, ongoing basic research endeavors are warranted to identify specific AKI biomarkers in the future.

## Conclusions

AKI after radical gastrectomy was a relatively rare postoperative complication, occurring in 2.1% of patients in this study, and it was self-limiting in most patients. AKI is linked with preoperative hypertension, intraoperative blood loss, operation time, and postoperative ICU admission. While AKI can affect the short-term prognosis of patients, including postoperative complications, length of hospital stay, and in-hospital mortality, it has little impact on long-term OS.

## Supplementary Data

Supplementary data is available at *Gastroenterology Report* online.

## Authors' Contributions

Z.B., L.L., and G.Y. reviewed the literature, collected data, analyzed data, and drafted the manuscript. Z.K. and C.L. conceived and designed the study and finalized manuscript. W.Z. and L.Y. Revised the manuscript. All authors read and approved the final manuscript.

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## Conflicts of Interest

No potential conflict of interest relevant to this article was reported.

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