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Association Between Repeated Pringle Clamping Cycles and Postoperative Acute Kidney Injury After Liver Resection A retrospective single-centre cohort study

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Abstract

Background

Acute kidney injury is a frequent complication after liver resection. Previous studies have examined whether a Pringle maneuver was used or have focused on cumulative ischemia time, but the number of separate clamp and reperfusion cycles has rarely been evaluated. We examined whether repeated clamping cycles were associated with postoperative acute kidney injury.

Methods

This retrospective single-centre cohort included 429 adults undergoing elective liver resection from 2016 to 2025. Pringle exposure was classified as no maneuver, one cycle, or at least two cycles. Acute kidney injury was defined by Kidney Disease: Improving Global Outcomes serum creatinine criteria during postoperative days 0 to 7. Multivariable logistic regression, Firth regression, propensity-score matching, a separate analysis of total ischemia duration, and a post hoc complete-case sensitivity analysis were performed.

Results

Acute kidney injury occurred in 107 patients (24.9%). Compared with no Pringle maneuver, at least two cycles were associated with acute kidney injury after adjustment (odds ratio 1.87, 95% confidence interval 1.07 to 3.30; p = 0.029); one cycle was not clearly associated (odds ratio 1.58, 0.67 to 3.75; p = 0.295). A separate total ischemia duration model showed no clear evidence of an association (odds ratio 1.01 per minute, 0.99 to 1.02; p = 0.082). Estimates were directionally similar in Firth regression (odds ratio 2.11, 95% confidence interval 1.12 to 3.13; p = 0.028), propensity-score matching (106 pairs; odds ratio 1.88, 1.01 to 3.50; p = 0.046), and a post hoc complete-case model with fluid administration and recorded central venous pressure (381 patients; odds ratio 1.84, 1.01 to 3.35; p = 0.046).

Conclusions

Repeated Pringle clamping cycles were associated with postoperative acute kidney injury in this observational cohort. Evidence for an association with cumulative ischemia duration was inconclusive; prolonged durations were rare. These exploratory findings support prospective evaluation and do not establish causality.

Background

Acute kidney injury (AKI) is a common complication after liver resection and has been associated with prolonged hospitalization, major postoperative complications, post-hepatectomy liver failure (PHLF), and

mortality [1–3]. Its reported incidence varies with the population, extent of resection, and AKI definition. Contemporary cohorts have reported AKI in approximately 9% after mixed hepatectomy procedures and in 21% to 26% after extended or major hepatectomy [1–6].

The renal insult after hepatectomy is multifactorial. Reported risk factors include older age, arterial hypertension, diabetes, chronic kidney disease, open or extensive surgery, blood loss and transfusion, prolonged surgery, and intraoperative hypotension [1–8]. Low central venous pressure (CVP) techniques may reduce venous bleeding during parenchymal transection, while inadequate circulating volume or sustained hypotension can compromise renal perfusion [2, 8–10]. Postoperative creatinine changes may reflect baseline susceptibility, operative complexity, hemodynamics, fluid and vasopressor management, inflammation, and liver dysfunction [1, 2, 9, 10].

The Pringle maneuver temporarily occludes the portal triad to reduce bleeding during transection. Intermittent clamping allows reperfusion between occlusions. In a randomized comparison with continuous clamping, Belghiti and colleagues reported better postoperative hepatic parenchymal tolerance of intermittent clamping, particularly in patients with abnormal liver parenchyma [11]. Subsequent studies examined Pringle use as a binary exposure, cumulative ischemia time, or different methods of hepatic inflow control [3, 6, 12–16]. The association of the number of clamping cycles with renal injury remains less well characterized.

Patients with similar cumulative clamping times can undergo different numbers of ischemia and reperfusion transitions. Experimental hepatic ischemia and reperfusion has produced renal injury, and a prospective liver transplant cohort linked hepatic reperfusion injury markers to AKI [17, 18]. These studies provide biological context for the hypothesis that repeated clamping may be relevant after liver resection; neither directly evaluated cycle number in this setting. Our primary objective was to examine the association between the number of Pringle clamping cycles and postoperative AKI. We evaluated cumulative ischemia duration in a separate analysis. We hypothesized that repeated clamping cycles would be associated with postoperative AKI after adjustment for measured clinical and operative factors.

Methods

Study design and participants

We conducted a retrospective single center cohort study of consecutive adults undergoing elective liver resection for benign or malignant hepatic lesions at Klinikum Dortmund between 2016 and 2025. The report follows the Strengthening the Reporting of Observational Studies in Epidemiology statement [19]. Clinical trial number is not applicable. Of 462 patients screened, 429 were included. Exclusion criteria were liver resection combined with another major procedure (n = 9), missing serum creatinine measurements through postoperative day 7 (n = 15), age younger than 18 years (n = 3), and missing Pringle maneuver data (n = 6).

The Ethics Committee of Witten/Herdecke University approved the study (S-152/2025, 12 June 2025) and waived individual informed consent because of its retrospective design. Data were analyzed in accordance with institutional data protection requirements.

Surgical exposure and perioperative variables

Open, laparoscopic, and robotic resections were performed according to institutional practice and surgeon judgment. When used, the Pringle maneuver followed an intermittent protocol of 20 minutes of portal triad occlusion followed by 5 minutes of reperfusion. The primary exposure was categorized as no Pringle maneuver, one clamping cycle, or at least two cycles. Cumulative ischemia duration in minutes was examined separately. A binary comparison of any maneuver versus none was retained as a descriptive analysis because it does not address the primary question regarding cycle number.

Major hepatectomy was defined as resection of at least three Couinaud segments. Pre-existing chronic kidney disease was identified from a documented diagnosis in the preoperative medical record. Mean arterial pressure (MAP) was continuously measured through an invasive arterial catheter and the recorded minimum MAP was extracted. Recorded central venous pressure (CVP) during resection and at the end of surgery, administered intraoperative fluid volume, and administered red blood cell, fresh frozen plasma, and albumin amounts were available for an exploratory complete-case analysis. Fluid losses and urine output were insufficiently recorded to calculate an accurate net fluid balance; duration below MAP thresholds and time-resolved vasopressor exposure were not consistently available. CVP was analysed as a recorded pressure, not as a direct measure of circulating volume [20].

Outcomes

The primary outcome was AKI defined by Kidney Disease: Improving Global Outcomes serum creatinine criteria: an increase of at least 0.3 mg/dL within 48 hours or to at least 1.5 times baseline within the previous 7 days [21]. AKI was ascertained from surgery through postoperative day 7, following the accepted window for postoperative AKI [10]. Baseline creatinine was the most recent preoperative value within 30 days. Urine output was not consistently recorded and was not used for staging. AKI stages 1, 2, and 3 were reported descriptively; their respective event counts did not support reliable comparisons of associations by severity.

Renal replacement therapy (RRT) was recorded throughout the entire index hospitalization, whereas AKI stage was fixed by the 7 day creatinine ascertainment window. Consequently, RRT initiated after postoperative day 7 could occur in patients classified as no AKI or stage 1 during the prespecified window. No patient who met AKI criteria during the 7 day window was clinically classified as having hepatorenal syndrome. Secondary outcomes were PHLF according to International Study Group of Liver Surgery criteria [22], length of stay, in hospital mortality, and RRT.

Statistical analysis

Continuous variables were summarized as median with interquartile range or mean with standard deviation as appropriate and compared with parametric or nonparametric tests according to distribution. Categorical variables were summarized as number and percentage and compared with the chi-square or Fisher exact test. The three-level clamping exposure was retained for the primary analysis. The descriptive three-group comparison and binary comparison answer different questions and are therefore reported together rather than treated as interchangeable tests. Crude absolute risks and risk differences were calculated to aid clinical interpretation. Because exposure was not randomized, these descriptive measures should not be interpreted causally.

Multivariable logistic regression assessed any postoperative AKI. Covariates were clamping category, age, arterial hypertension, chronic kidney disease, major hepatectomy, operative duration, transfusion, surgical approach, and minimum MAP. The model was based on clinical relevance and known perioperative risk factors. Total ischemia duration was entered in a separate adjusted model, not in the cycle model. Firth bias-reduced regression with the same covariates as the primary model was used as a sensitivity analysis [23]. The primary analysis included all 429 patients; no imputation was performed. A post hoc complete-case sensitivity model added administered fluid volume, red blood cell units, fresh frozen plasma units, albumin, CVP during resection, and CVP at the end of surgery to the original covariates. The binary transfusion indicator was omitted from this additional model to avoid duplicating red blood cell exposure. This model included 381 patients, of whom 103 had AKI; 48 patients lacked at least one required variable, including four with AKI. The complete-case analysis did not replace the primary model or propensity-score matching.

To address measured confounding by indication, patients with at least two cycles were matched 1:1 to patients without a Pringle maneuver; the 45 patients with one cycle were excluded from this analysis. The propensity score included age, sex, body mass index, arterial hypertension, diabetes, chronic kidney disease, approach, major hepatectomy, operative duration, transfusion, and minimum MAP. Nearest-neighbour matching without replacement used a caliper of 0.2 standard deviations of the logit of the propensity score [24]. Balance was assessed with absolute standardized mean differences, with values below 0.10 considered desirable. Conditional logistic regression was used in the matched cohort. An E-value was used as a sensitivity measure for unmeasured confounding [25]. Because AKI was a common outcome, the odds ratio was first converted approximately to the risk-ratio scale by taking its square root [25, 26]; for a risk ratio R above 1, E-value = R + sqrt[R × (R − 1)]. The same procedure was used for the confidence limit closest to the null. Two-sided p values below 0.05 were considered statistically significant. Analyses were performed using jamovi version 2.7.23 and MedCalc version 23.5.5.

Use of generative artificial intelligence

During manuscript preparation, the authors used ChatGPT (OpenAI) and Claude (Anthropic) to assist with language editing, organization, formatting, and consistency checking. These tools did not collect

data, define outcomes, or perform the reported statistical analyses. The authors reviewed and verified the final text and accept full responsibility for its content.

Results

Cohort and acute kidney injury incidence

Among 429 included patients, median age was 65 years (interquartile range 57 to 73) and 262 (61.1%) were male. AKI occurred in 107 patients (24.9%): stage 1 in 61 (14.2%), stage 2 in 31 (7.2%), and stage 3 in 15 (3.5%). The no AKI, stage 1, and stage 2 to 3 groups differed descriptively in age, body mass index, hypertension, chronic kidney disease, diabetes, approach, resection extent, transfusion, and minimum MAP (Table 1). Minimum CVP did not differ across AKI strata ($p = 0.755$).

Table 1
Baseline demographic clinical intraoperative and postoperative characteristics according to postoperative acute kidney injury severity

Variable	No AKI (n = 322)	AKI Stage 1 (n = 61)	AKI Stage 2–3 (n = 46)	P value
Demographics	Demographics	Demographics	Demographics	Demographics
Age, years*	63.0 (55–72)	69.0 (62–75)	70.5 (64–76)	< 0.001
Male sex	191 (59.3%)	37 (60.7%)	34 (73.9%)	0.164
BMI, kg/m²*	25.6 (23–28)	29.0 (26–32)	27.4 (25–33)	< 0.001
Comorbidities	Comorbidities	Comorbidities	Comorbidities	Comorbidities
Arterial hypertension	149 (46.3%)	47 (77.0%)	30 (65.2%)	< 0.001
Chronic kidney disease	22 (6.8%)	11 (18.0%)	10 (21.7%)	< 0.001
Diabetes mellitus	66 (20.5%)	22 (36.1%)	18 (39.1%)	0.002
Surgical characteristics	Surgical characteristics	Surgical characteristics	Surgical characteristics	Surgical characteristics
Open surgery	196 (60.9%)	54 (88.5%)	45 (97.8%)	< 0.001
Major hepatectomy†	195 (60.6%)	36 (59.0%)	37 (80.4%)	0.028
Operative time, min*	191.5 (153–247)	215 (155–245)	207 (173–275)	0.184
Blood transfusion	52 (16.1%)	16 (26.2%)	13 (28.3%)	0.042
Pringle maneuver	Pringle maneuver	Pringle maneuver	Pringle maneuver	0.162
No Pringle maneuver	125 (38.8%)	16 (26.2%)	13 (28.3%)	
One Pringle cycle	33 (10.2%)	5 (8.2%)	7 (15.2%)	
≥2 Pringle cycles	164 (50.9%)	40 (65.6%)	26 (56.5%)	

Values are median (interquartile range) or number (percentage), unless otherwise indicated. Minimum CVP is mean ± standard deviation. The p values are descriptive and not adjusted for multiple testing. RRT was captured for the entire index hospitalization, whereas AKI stage was assigned from serum creatinine during postoperative days 0 to 7. *Continuous values are medians (interquartile range) and were compared using Kruskal–Wallis tests; categorical values were compared using chi-square tests. †Major hepatectomy means at least three Couinaud segments. ‡CVP is mean ± standard deviation; its p value is from a Kruskal–Wallis test; CVP is reported in mmHg. §§Length of stay was available for 321 of 322 No-AKI patients.

Variable	No AKI (n = 322)	AKI Stage 1 (n = 61)	AKI Stage 2–3 (n = 46)	P value
Intraoperative hemodynamics	Intraoperative hemodynamics	Intraoperative hemodynamics	Intraoperative hemodynamics	Intraoperative hemodynamics
Minimum MAP, mmHg*	59.0 (53–63)	55.0 (51–62)	55.5 (50–63)	0.039
Minimum CVP, mmHg‡	2.62 ± 3.49	2.67 ± 3.12	2.13 ± 2.88	0.755
Postoperative outcomes	Postoperative outcomes	Postoperative outcomes	Postoperative outcomes	Postoperative outcomes
Post-hepatectomy liver failure (PHLF)	8 (2.5%)	7 (11.5%)	16 (34.8%)	< 0.001
Renal replacement therapy (RRT)	3 (0.9%)	4 (6.6%)	13 (28.3%)	< 0.001
Length of hospital stay, days*§§	9.0 (6–15)	16.0 (9–26)	19.0 (13–26)	< 0.001
In-hospital mortality	7 (2.2%)	8 (13.1%)	18 (39.1%)	< 0.001

Values are median (interquartile range) or number (percentage), unless otherwise indicated. Minimum CVP is mean ± standard deviation. The p values are descriptive and not adjusted for multiple testing. RRT was captured for the entire index hospitalization, whereas AKI stage was assigned from serum creatinine during postoperative days 0 to 7. *Continuous values are medians (interquartile range) and were compared using Kruskal–Wallis tests; categorical values were compared using chi-square tests. †Major hepatectomy means at least three Couinaud segments. ‡CVP is mean ± standard deviation; its p value is from a Kruskal–Wallis test; CVP is reported in mmHg. §§Length of stay was available for 321 of 322 No-AKI patients.

Table 2
Multivariable logistic regression analysis of postoperative acute kidney injury

Variable	Odds Ratio (OR)	95% Confidence Interval	P value
Pringle maneuver	Pringle maneuver	Pringle maneuver	Pringle maneuver
1 cycle vs. no Pringle maneuver	1.58	0.67–3.75	0.295
≥ 2 cycles vs. no Pringle maneuver	1.87	1.07–3.30	0.029
Open surgery	8.43	3.62–19.65	< 0.001
Arterial hypertension	2.49	1.45–4.27	< 0.001
Minimum MAP (per mmHg)	0.97	0.94–1.00	0.044
Age (per year)	1.02	1.00–1.05	0.070
Chronic kidney disease	1.85	0.87–3.90	0.108
Major hepatectomy†	1.21	0.67–2.20	0.525
Operative time (per minute)	1.00	0.995–1.003	0.597
Blood transfusion	0.98	0.53–1.79	0.954

The primary model included 429 patients. Major hepatectomy was defined as resection of at least three Couinaud segments.

Pringle exposure and primary analysis

A Pringle maneuver was used in 275 patients (64.1%): 45 had one cycle and 230 had at least two cycles. Of these 275 patients, 24 (8.7%) had at least 60 minutes of cumulative ischemia, 13 (4.7%) exceeded 60 minutes, and three (1.1%) exceeded 70 minutes; the maximum reported duration was 101 minutes. AKI occurred in 29 of 154 patients without a maneuver (18.8%), 12 of 45 with one cycle (26.7%), and 66 of 230 with at least two cycles (28.7%). The crude risk difference for at least two cycles versus no maneuver was 9.9 percentage points (Supplementary Table S8, Additional file 1). In the binary comparison, AKI occurred in 28.4% with any maneuver and 18.8% without a maneuver (p = 0.038). Across the no-AKI, stage 1, and stage 2–3 strata, the distribution of the three Pringle categories did not differ clearly (p = 0.162; Table 1). These tests use different exposure categories and do not replace the adjusted primary analysis.

In the primary multivariable model, at least two cycles were associated with AKI compared with no maneuver (odds ratio [OR] 1.87, 95% confidence interval [CI] 1.07 to 3.30; p = 0.029). The estimate for one cycle was OR 1.58 (95% CI 0.67 to 3.75; p = 0.295); its confidence interval does not establish that a single cycle is safe. Open surgery was associated with AKI (OR 8.43, 95% CI 3.62 to 19.65; p < 0.001), as

was arterial hypertension (OR 2.49, 95% CI 1.45 to 4.27; p < 0.001). A higher minimum MAP was associated with lower odds of AKI (OR 0.97 per mmHg, 95% CI 0.94 to 1.00; p = 0.044).

For the primary adjusted odds ratio (1.87, lower 95% confidence limit 1.07), the E-values were 2.08 and 1.22, respectively, using the square-root approximation for a common outcome.

Sensitivity and secondary analyses

In a separate adjusted model, cumulative ischemia duration was not statistically significantly associated with AKI over the observed time range (OR 1.01 per minute, 95% CI 0.99 to 1.02; p = 0.082). Firth regression produced a directionally similar estimate for at least two cycles (OR 2.11, 95% CI 1.12 to 3.13; p = 0.028; Supplementary Table S2, Additional file 1).

Propensity matching generated 106 pairs. Balance improved substantially, and all post-matching absolute standardized mean differences were below 0.10 (Supplementary Table S1 and Supplementary Figure S1, Additional file 1). In the matched cohort, at least two cycles were associated with AKI (OR 1.88, 95% CI 1.01 to 3.50; p = 0.046). These analyses use overlapping patients and do not establish causality.

In the post hoc complete-case sensitivity model (381 patients; 103 with AKI) additionally accounting for administered fluid volume, blood products, albumin, and recorded CVP, the estimate for at least two cycles versus no maneuver was OR 1.84 (95% CI 1.01 to 3.35; p = 0.046). Fluid volume and the CVP measures showed no clear associations in this model; the minimum MAP association was not statistically significant within this smaller, differently adjusted model (p = 0.117). The in-sample area under the receiver operating characteristic curve was 0.784. Full coefficients and the complete-case denominator appear in Supplementary Table S9 (Additional file 1). The model does not measure net fluid balance or determine volume status.

Clinical outcomes

PHLF occurred in 31 patients (7.2%) and increased across AKI severity. Because only 31 PHLF events occurred and no patient in the one-cycle group developed PHLF, the exploratory PHLF model used binary Pringle exposure and only three predictors. Pringle use was not independently associated with PHLF (OR 0.85, 95% CI 0.38 to 1.87; p = 0.678); estimates for open surgery and major resection were large but imprecise, consistent with sparse data. These analyses are secondary and should not be used to infer a protective or harmful PHLF effect of clamping (Supplementary Tables S3 and S6, Additional file 1).

RRT was required by 20 patients during the index hospitalization: 3 of 322 classified as no AKI during days 0 to 7, 4 of 61 with stage 1 AKI, and 13 of 46 with stages 2 to 3. The seven patients in the first two strata began dialysis after the 7 day AKI observation window, explaining the apparent discrepancy between early AKI stage and later RRT. Median length of stay was 9 days without AKI, 16 days with stage 1 AKI, and 19 days with stages 2 to 3. In hospital mortality was 2.2%, 13.1%, and 39.1%, respectively. Overall in-hospital mortality was 33 of 429 (7.7%; Supplementary Tables S4, S5, and S7, Additional file 1).

These outcome associations describe prognosis after AKI and do not demonstrate that AKI itself was the sole cause.

Discussion

At least two Pringle clamping cycles were associated with postoperative AKI in the adjusted primary model. The association was directionally similar in the Firth, propensity-score-matched, and complete-case analyses. Cumulative ischemia duration, examined in a separate adjusted model, was not statistically significantly associated with AKI over the observed time range. Because cycle number and duration were examined separately, these analyses cannot establish whether the association with cycle number is independent of duration.

The principal contribution is the direct clinical evaluation of clamping cycle number in relation to AKI after liver resection, alongside a separate analysis of cumulative ischemia duration. Earlier studies focused on hepatic outcomes of continuous versus intermittent clamping or on prolonged inflow occlusion [11, 13–16], while observational AKI studies often recorded Pringle use as a binary exposure [2, 3, 6]. Swartling and colleagues reported an association between AKI and PHLF after major hepatectomy but did not evaluate AKI by the number of clamping cycles [1].

The separate cumulative-duration model showed no statistically significant association with AKI within the ischemia times observed here (OR 1.01 per minute, 95% CI 0.99 to 1.02; p = 0.082). Only 24 of 275 Pringle recipients had at least 60 minutes of cumulative ischemia and three exceeded 70 minutes; the cohort therefore offers little information about longer exposure. In a separate hepatectomy cohort, Zdujic and colleagues found no increase in overall postoperative morbidity or mortality with intermittent clamping beyond 60 minutes, but did not establish a renal safety threshold [27]. The association with cycle number raises the hypothesis that repeated clamp-and-release transitions may contribute to renal injury. Experimental hepatic ischemia-reperfusion caused AKI in mice [17], and markers of hepatic reperfusion injury were associated with AKI in a prospective liver transplantation cohort [18]. Neither study examined the number of Pringle cycles after resection; in our cohort, repeated cycles could also reflect more complex surgery, bleeding, or unmeasured hemodynamic changes.

Arterial hypertension was associated with AKI, consistent with previous hepatectomy cohorts [2, 5]. Open surgery had a strong association with AKI in our model; other studies have also reported associations between open approach and postoperative renal injury [6, 7]. Operative approach may reflect case complexity and selection, rather than a causal effect. A single lowest MAP value does not capture the duration of hypotension: another hepatectomy cohort reported an association between sustained hypotension and AKI [8]. The minimum MAP estimate in our complete-case model came from a smaller sample and different covariates. A single CVP measurement cannot establish circulating volume or fluid responsiveness [20]; similar CVP values across AKI groups therefore cannot rule out a role for volume management.

Hepatorenal syndrome has a distinct diagnostic context [28]; none of the 107 patients classified with AKI in the seven-day window was clinically classified with this syndrome. PHLF became more frequent across AKI strata, but binary Pringle use was not associated with PHLF in our sparse exploratory model. Intermittent clamping was associated with better hepatic parenchymal tolerance than continuous clamping in a randomized study [11], and a retrospective study reported lower postoperative bilirubin with intermittent Pringle use [29]. These hepatic findings neither predict nor establish an effect on ISGLS-defined PHLF in our cohort. The higher rates of subsequent RRT, longer length of stay, and mortality among patients with AKI are consistent with previous hepatectomy cohorts [1–4].

The study included consecutive patients and explicitly recorded clamping cycle number. The primary model accounted for measured clinical and operative factors; Firth regression, propensity matching, and a post hoc complete-case analysis examined the association under additional modelling choices. These analyses used overlapping patients and remain susceptible to residual confounding.

This retrospective single-centre study cannot establish causality; some intraoperative adjustment variables may also be affected by the surgical course, so the adjusted estimates are not estimates of a total causal effect; surgeon-selected clamping and differences in operative complexity may have confounded the association. Because of missing covariates, the post hoc fluid/CVP sensitivity analysis included 381 rather than 429 patients (103 rather than 107 with AKI), and its complete cases may differ from excluded patients. Intraoperative fluid input was documented, but incomplete urine output and other losses prevented calculation of an accurate net fluid balance. A recorded CVP value cannot establish volume status [20]. Few patients had long cumulative clamping durations; duration of hypotension and mechanistic biomarkers were unavailable. The creatinine-based seven-day outcome did not capture urine-output-only or later AKI. Sepsis, infection, PHLF, and other early postoperative events may also have contributed to AKI within the observation window.

The findings do not support avoiding a clinically necessary Pringle maneuver. When effective hemostasis is achievable, the possible role of repeated clamp-and-release transitions warrants prospective assessment. Such a study could prespecify cycle number and duration, record blood loss, fluid input and output, MAP exposure over time, vasopressors, liver function, and postoperative creatinine and urine output. It could better distinguish effects of clamping pattern from operative complexity and other perioperative factors.

Conclusions

In this retrospective cohort, at least two Pringle clamping cycles were associated with postoperative AKI after liver resection. Cumulative ischemia duration was not statistically significantly associated with AKI in a separate adjusted model over the observed time range. These findings are hypothesis-generating and support prospective evaluation of clamping pattern with detailed hemodynamic and fluid data.

Abbreviations

AKI
acute kidney injury
CI
confidence interval
CKD
chronic kidney disease
CVP
central venous pressure
KDIGO
Kidney Disease: Improving Global Outcomes
MAP
mean arterial pressure
OR
odds ratio
PHLF
post-hepatectomy liver failure
PSM
propensity-score matching
RRT
renal replacement therapy
SMD
standardized mean difference.

Declarations

Ethics approval and consent to participate

The Ethics Committee of Witten/Herdecke University approved the study (S-152/2025, 12 June 2025) and waived informed consent because of the retrospective design.

Consent for publication

Not applicable.

Availability of data and materials

The data contain patient level clinical information and are subject to institutional data protection requirements. Deidentified data may be made available by the corresponding author upon reasonable request and subject to institutional approval.

Competing interests

The authors declare that they have no competing interests.

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Authors contributions

NF: conceptualization, methodology, formal analysis, investigation, project administration, supervision, visualization, original draft, and review and editing. UG: investigation, data curation, validation, visualization, original draft, and review and editing. NB: investigation, data curation, validation, and review and editing. MS: methodology, resources, clinical interpretation, and review and editing. SH: supervision, methodology, clinical interpretation, and review and editing. RKE: supervision, methodology, clinical interpretation, and review and editing. NF is the corresponding author. All authors critically revised the manuscript, approved the submitted version, and agree to be accountable for the work.

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Figures

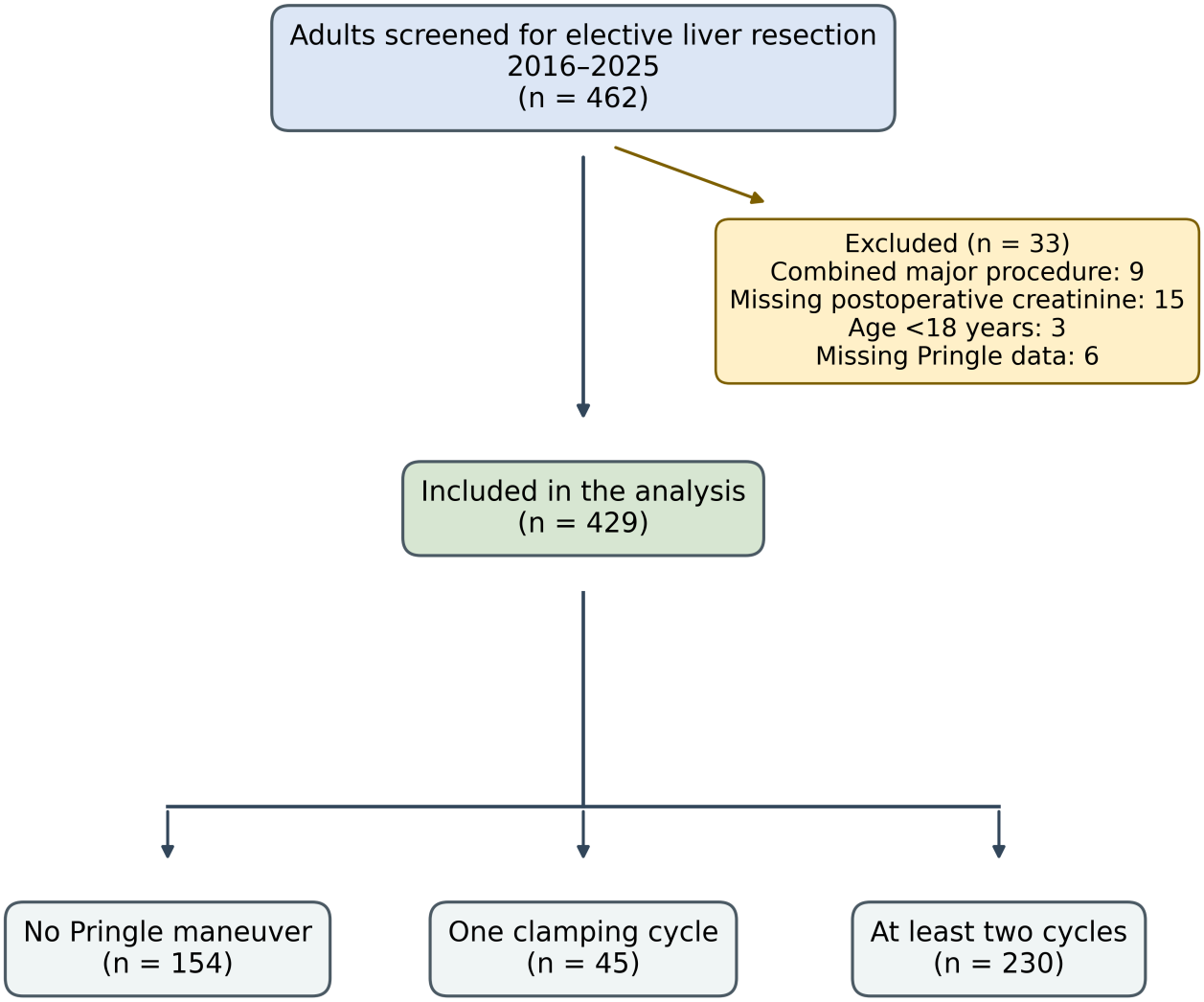
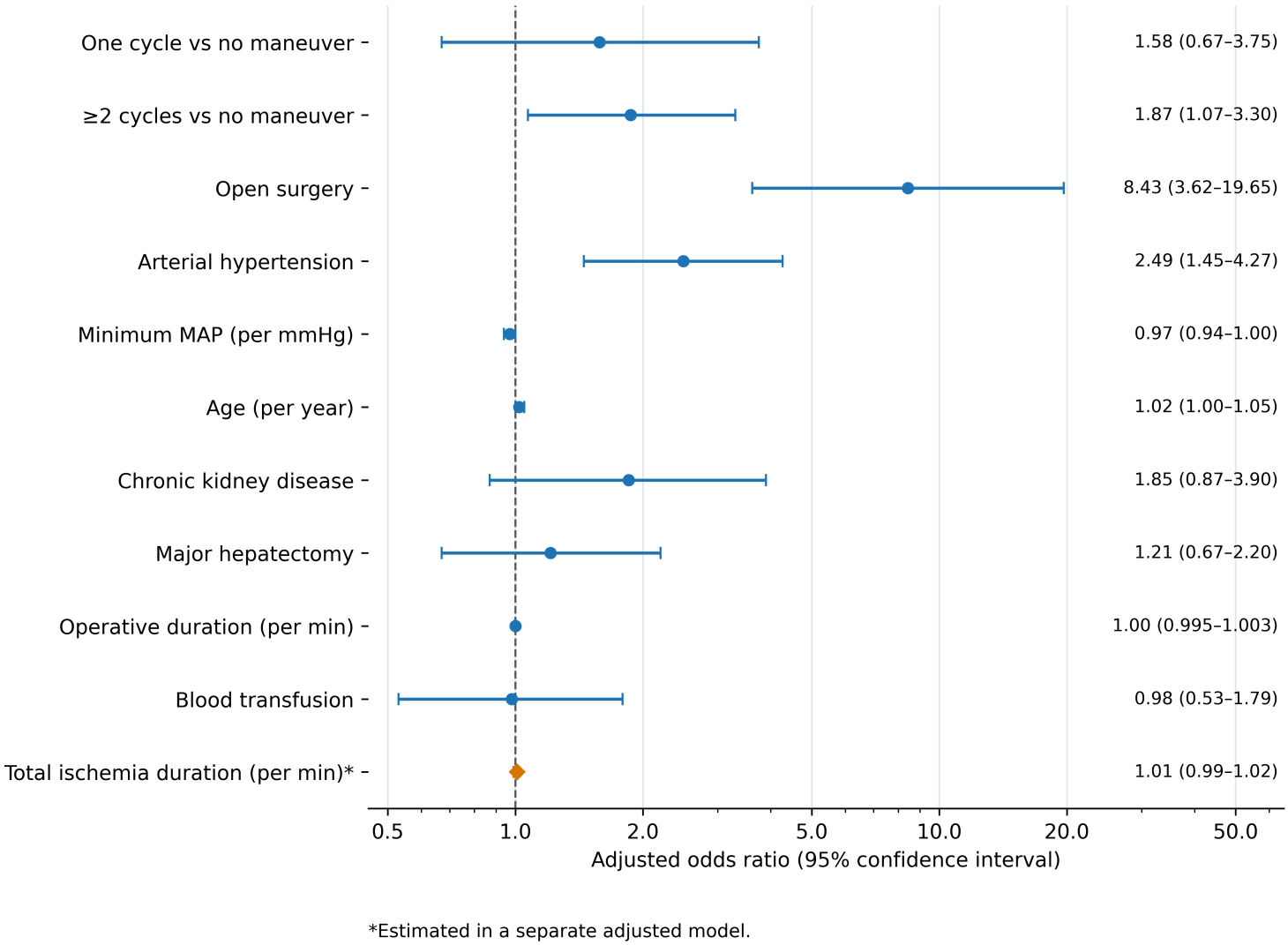


Figure 1

Study flow diagram. Of 462 screened patients, 429 were included after exclusion of combined major procedures, missing postoperative creatinine, age younger than 18 years, or missing Pringle maneuver data.



*Estimated in a separate adjusted model.

Figure 2

Adjusted odds ratios for postoperative acute kidney injury. Blue circles show the primary multivariable model; the orange diamond shows total ischemia duration from a separate adjusted model. Odds ratios are displayed on a logarithmic scale with 95% confidence intervals and a reference line at 1.0.

Supplementary Files

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- FigureS1LovePlot.png