ORIGINAL ARTICLE

The Effect of Perioperative Fluid Therapy on Postoperative Renal Functions in Patients Receiving Liver Transplantation from Living Donors: A Retrospective Observational Study

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Abstract

Background: Perioperative fluid management (PFM) is critical in liver transplantation, especially regarding its impact on postoperative renal function. Acute kidney injury (AKI) is a common complication in liver transplant recipients, often influenced by the type and volume of fluids administered during the perioperative period. This study investigates the effects of different fluid management strategies on renal outcomes following liver transplantation from living donors.

Patients and methods: This retrospective observational study included 91 liver transplant recipients who were categorized into three groups based on their PFM strategy: restrictive ($n = 1$), moderate ($n = 34$), and liberal ($n = 56$). Data were collected from patient medical records, focusing on fluid types, peak serum creatinine levels, urine output, and length of hospital stay. Statistical analyses, including ANOVA and logistic regression, were conducted to assess renal outcomes among the groups.

Results: The moderate fluid management group demonstrated the best renal outcomes, with the lowest peak serum creatinine (1.02 ± 0.25 mg/dL) and shorter ICU stays (2.47 ± 0.62 days) compared to the liberal fluid strategy group (1.40 ± 0.92 mg/dL and 2.88 ± 0.83 days, respectively). Moreover, liberal fluid strategies were associated with fluid overload and increased peak serum creatinine levels. Intraoperative fluid administration showed a greater protective effect on renal function compared to postoperative fluid administration.

Conclusions: Moderate PFM, particularly with careful intraoperative fluid administration, is optimal for minimizing the risk of AKI and improving renal outcomes in liver transplant patients. These findings emphasize the importance of individualized fluid therapy in reducing renal complications after liver transplantation.

Keywords: Acute kidney injury, Colloids, Fluid management, Liver transplantation, Perioperative care, Renal outcomes.

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Highlight

This study evaluates the impact of perioperative fluid therapy strategies on renal outcomes in liver transplant recipients. It identifies moderate fluid management and intraoperative fluid administration as optimal approaches to minimize acute kidney injury (AKI) risk, improve serum creatinine levels, and stabilize postoperative fluid balance for better patient outcomes.

Introduction

Perioperative fluid management (PFM) is critical in liver transplantation, addressing challenges such as end-stage liver disease, significant blood loss, and the need to maintain cardiovascular and renal function.[1–4] Renal dysfunction, a common complication in liver transplant recipients, significantly increases morbidity and mortality.[5] Fluid management strategies range from restrictive regimens, which minimize hemodynamic instability, to liberal regimens that maintain perfusion but risk fluid overload and related complications.[6–10]

Goal-directed therapy (GDT) offers an individualized approach to reduce postoperative complications, though its impact on perioperative mortality and AKI remains uncertain.[11] Balanced crystalloids are considered safer than synthetic colloids, and isotonic saline is often preferred to preserve renal function in surgeries, including liver transplantation.[12,13] Preventive measures, such as hemodynamic optimization and structured fluid therapy protocols, further emphasize the importance of precise fluid management in mitigating AKI risks.[14,15]

Despite advancements, the evidence on PFM remains inconsistent, with limited randomized controlled trials and funding for large multicenter studies.[16] Research highlights gaps such as insufficient consensus on outcomes, heterogeneity in methodologies, and the lack of unified guidelines for perioperative fluid strategies.[17,18] Zhang et al. identified cumulative fluid balance as an AKI risk factor in liver transplantation but did not account for other confounders, underscoring the complexity of fluid therapy.[19,20]

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Table 1: Summary of key dependent variables (e.g., peak SCr, urine output, fluid balance) across different fluid management strategies in liver transplant recipients

Parameter	*Restrictive (n = 1)*	*Moderate (n = 34)*	*Liberal (n = 56)*	*Total (n = 91)*
Peak SCr (mg/dL)	0.89	1.02 ± 0.25	1.40 ± 0.92	1.25 ± 0.76
Urine output (mL)	4,630	4,447 ± 1,151	5,066 ± 1,683	4,830 ± 1,519
24-hour fluid balance (mL)	840	–464 ± 649	428 ± 1,112	100 ± 1,050
LOS ICU (days)	3.00	2.47 ± 0.62	2.88 ± 0.83	2.73 ± 0.78
LOS hospital (days)	8.00	7.38 ± 0.74	8.30 ± 1.82	7.96 ± 1.56

LOS, length of stay

This study aims to address these gaps by evaluating the impact of restrictive, moderate, and liberal fluid regimens, along with the use of colloids and blood products, on postoperative renal outcomes in liver transplant recipients.

Methodology

Study Design

This retrospective observational study evaluated the impact of PFM on postoperative renal outcomes in 91 liver transplant recipients.

Study Population

Data from 91 liver transplant patients were analyzed, excluding those with missing data or pre-existing renal failure.

Data Collection

Medical records were reviewed to extract information on fluid types (e.g., crystalloids, colloids, albumin, blood products) and renal outcomes, including AKI incidence, serum creatinine, urine output, and hospital stay length. Data were organized in Excel for accuracy.

Statistical Analysis

Data were analyzed using SPSS version 20. Descriptive statistics summarized demographics and clinical variables. Renal outcomes across fluid management groups were compared using one-way ANOVA, and logistic regression estimated AKI risk by fluid strategy.

Baseline Characteristics

Baseline factors were evaluated for comparability among fluid strategy groups, including:

- **Demographics:** Age, sex.
- **Clinical markers:** MELD, Child-Pugh scores.
- **ESLD etiology:** Hepatitis B, HCC, alcoholic cirrhosis, etc.
- **Fluid volumes:** Crystalloids, colloids, albumin, RBC transfusions, FFP, platelets.
- **Surgical variables:** Cross-clamp duration, surgical time, vasopressor use.
- **Medications:** Perioperative antibiotics, including nephrotoxic agents.

Confounding Factor Control

To reduce bias, the study implemented:

- **Complete data:** Patients with missing key data were excluded.
- **Statistical adjustments:** Multivariate analyses controlled for confounders (e.g., fluid type, surgical duration).

Inclusion Criteria

Only patients with complete datasets were included.

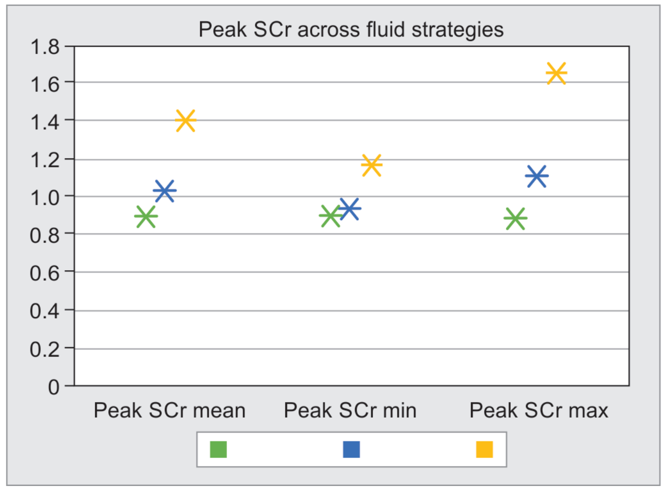

Fig. 1: Comparison of peak serum creatinine (SCr) levels across restrictive, moderate, and liberal fluid replacement strategies

Reproducibility

The study provided detailed data collection and statistical methodologies to ensure reproducibility and transparency, facilitating future research replication.

Results

Overview of Study Groups

The study included 91 liver transplant recipients categorized into three fluid management strategies: restrictive, moderate, and liberal.[21–23] Baseline characteristics and primary renal outcomes by group are shown in Table 1.

Renal Function (SCr)

The moderate group (Fig. 1) exhibited the least variance in renal outcomes, with a mean peak SCr of 1.02 ± 0.25, compared to 1.40 ± 0.92 mg/dL in the liberal group, indicating higher renal dysfunction risk in the latter.

Urine Output

Despite liberal strategies increasing urine output (5,066 ± 1,683 mL), this did not correlate with improved renal protection based on SCr values.

Fluid Balance

Figure 2 highlights that the moderate strategy resulted in a negative fluid balance at 24 hours (–464 ± 649 mL), a key determinant of renal outcomes. In contrast, the liberal strategy showed a positive balance (428 ± 1,112 mL), increasing the risk of fluid overload.

Length of Stay (LOS)

The moderate group had shorter ICU stays (2.47 ± 0.62 days) and hospital stays (7.38 ± 0.74 days) compared to the liberal group (2.88 ± 0.83 and 8.30 ± 1.82 days, respectively).

Comparison of Patient Groups

Baseline characteristics (Table 2) indicate no significant differences in demographic or clinical markers (e.g., age, MELD scores) between groups. The liberal group received higher fluid volumes, consistent with its protocol. These differences underscore the impact of fluid strategies on renal outcomes rather than confounding factors.

Main Effects (Time and Fluid Strategy)

Repeated measures analysis showed significant time effects on fluid balance ($F(1.01, 24.36) = 12.45$, $p < 0.001$, $\eta^2 = 0.32$) and fluid strategy effects ($F(2, 24) = 3.45$, $p = 0.045$, $\eta^2 = 0.15$). Table 1 illustrates that the moderate group achieved the best fluid balance at 24 hours (–0.464 ± 0.649) compared to the liberal group (0.428 ± 1.112).

Figure 3 aligns with trends where fluid retention decreases postoperatively, with liberal strategies linked to positive fluid balances and elevated SCr, signaling renal stress.

Interaction Effect (Time × Fluid Strategy)

Significant interaction effects [$F(2.02, 48.72) = 6.23$, $p = 0.007$, $\eta^2 = 0.20$] indicate that fluid balance trends over time depended on the fluid strategy (Table 3). Figure 4 shows the moderate group maintained negative fluid balances across all time points (–720.00 mL at 24 hours, improving to –395.00 mL at 72 hours). Liberal strategies resulted in consistently positive balances, peaking at 48 h (+1232.14 mL).

A bar chart of the means for FB24, FB48, and FB72 by fluid strategy has been included in Figure 4. These findings demonstrate that moderate strategies reduce fluid overload risks. The restrictive group also showed favorable results but requires further data validation. These differences are depicted by descriptive statistics in Table 3 at the three time points (24, 48, and 72 hours).

Between-Subjects Effects of Fluid Strategy on Renal Outcomes

Between-subjects analysis (Fig. 5) confirmed significant differences in renal outcomes based on fluid strategy. One-way ANOVA (Table 4) results showed fluid strategy significantly affected fluid balance

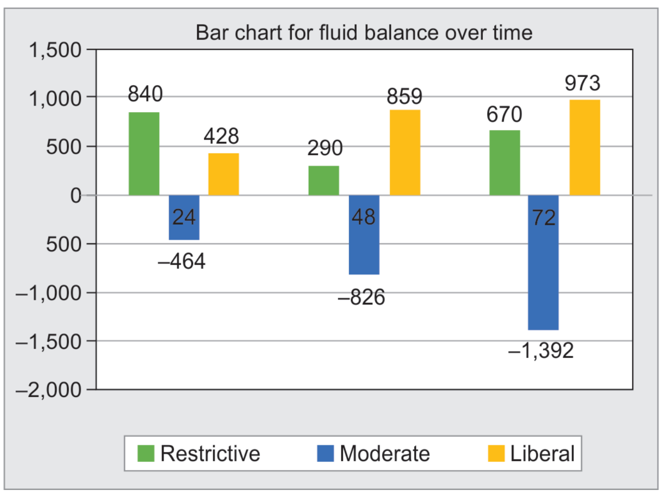

Fig. 2: Fluid balance trends at 24, 48, and 72 hours for restrictive, moderate, and liberal fluid strategies

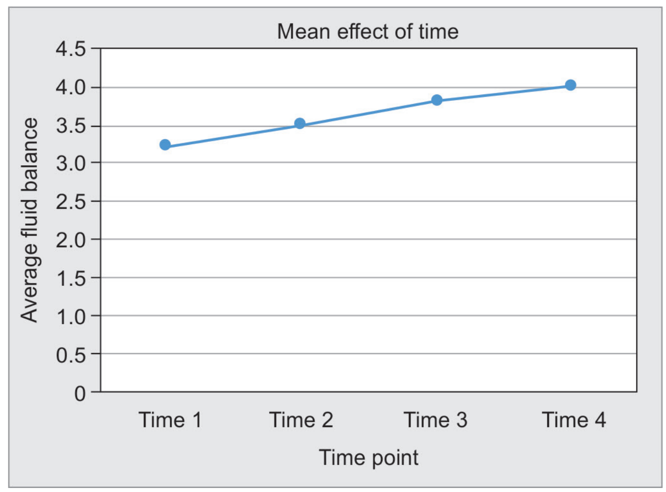

Fig. 3: Average fluid balance (mL) over the postoperative period, irrespective of fluid strategy

Table 3: Repeated measures ANOVA results

Effect	*F*	*df*	*p-value*	*Effect size* (η^2\eta^2η^2)
Time	12.45	1.01, 24.36	<0.001	0.32
Time × fluid strategy	6.23	2.02, 48.72	0.007	0.20
Fluid strategy (between)	3.45	2, 24	0.045	0.15

Table 2: Baseline characteristics of patient groups by fluid strategy

Variable	*Restrictive (n = 1)*	*Moderate (n = 34)*	*Liberal (n = 56)*
Age (mean ± SD)	48.0 ± N/A	44.62 ± 14.77	48.86 ± 11.88
MELD (mean ± SD)	15.0 ± N/A	15.56 ± 4.33	15.09 ± 3.99
Child-Pugh (mean ± SD)	9.0 ± N/A	8.0 ± 2.04	7.75 ± 1.91
Crystalloids (mL)	6900.0 ± N/A	4942.79 ± 896.27	7423.75 ± 2204.03
Colloids (mL)	1390.0 ± N/A	483.82 ± 483.82	852.86 ± 852.86
Albumin (mL)	800.0 ± N/A	679.71 ± 116.55	754.11 ± 160.55
RBCs (mL)	1250.0 ± N/A	414.41 ± 386.95	852.50 ± 729.03
FFP (mL)	0.0 ± N/A	530.29 ± 419.80	985.89 ± 545.50
Platelets (units)	0.0 ± N/A	0.0 ± 0.0	76.61 ± 183.99
AKI cases	0	0	17

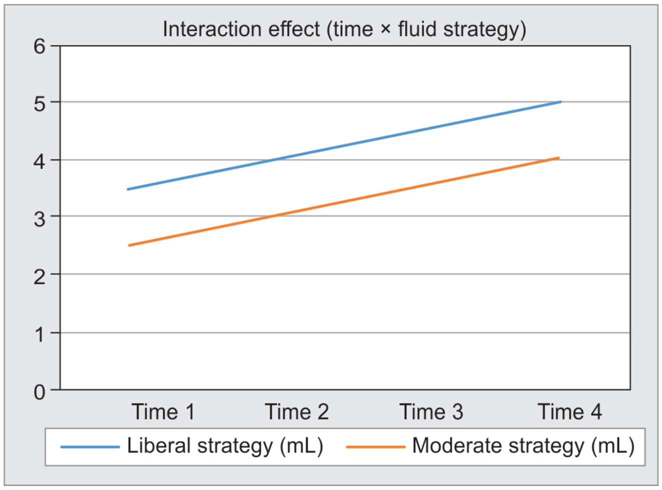

Fig. 4: Changes in fluid balance (mL) over the postoperative period for liberal and moderate fluid strategies

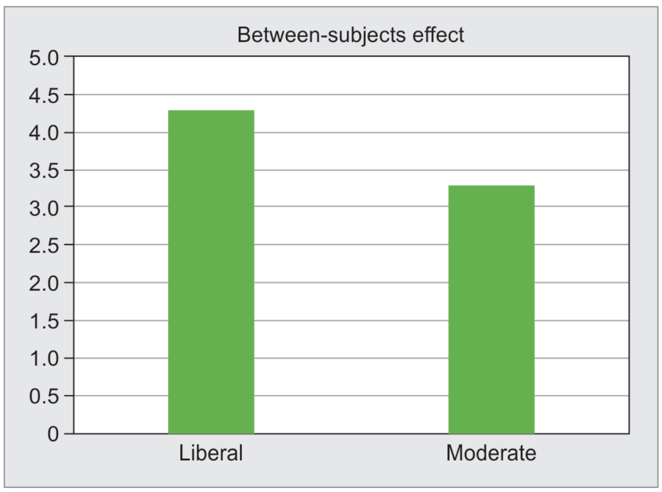

Fig. 5: Comparison of overall average fluid balance (mL) between liberal and moderate fluid strategies

(F(2, 24) = 3.45, p = 0.045, η^2 = 0.15), with moderate strategies providing the best outcomes.

Peak Serum Creatinine (SCr)

Table 4 shows that one-way ANOVA results for peak SCr were not statistically significant (F(2, 88) = 3.004, p = 0.055, η^2 = 0.07), though trends suggest lower renal stress in the moderate group (1.02 ± 0.25 mg/dL) compared to the liberal group (1.40 ± 0.92 mg/dL). The restrictive group, comprising one patient, also showed positive outcomes but lacked statistical comparability (Fig. 6).

Urine Output

ANOVA revealed no significant differences in urine output [F(2, 88) = 1.798, p = 0.172, η^2 = 0.04]. The liberal group had the highest output (5.066 ± 1.683 mL), while the moderate group maintained stable output (4.447 ± 1.151 mL). However, higher output in the liberal group did not translate to better renal outcomes due to elevated SCr levels.

Length of Stay (LOS)

LOS in the ICU was nearly significant [F(2, 88) = 3.075, p = 0.051, η^2 = 0.06], while hospital LOS was significant [F(2, 88) = 3.953, p = 0.023, η^2 = 0.08]. Patients in the moderate group had the shortest stays (ICU: 2.47 ± 0.62 days; hospital: 7.38 ± 0.74 days) compared to the liberal group (ICU: 2.88 ± 0.83 days; hospital: 8.30 ± 1.82 days).

Table 4: Descriptive statistics for fluid strategies

Variable	*Fluid strategy*	*Mean*	*Standard deviation (SD)*	*Sample size (N)*
Fluid balance (FB) at 24 hours (FB24)	Moderate	−720.00	1103.09	2
	Liberal	846.43	601.60	7
	Total	498.33	949.03	9
Fluid balance (FB) at 48 hours (FB48)	Moderate	−300.00	183.85	2
	Liberal	1232.14	1786.40	7
	Total	891.67	1689.41	9
Fluid balance (FB) at 72 hours (FB72)	Moderate	−395.00	148.49	2
	Liberal	647.50	60.10	2
	Total	140.00	608.11	4

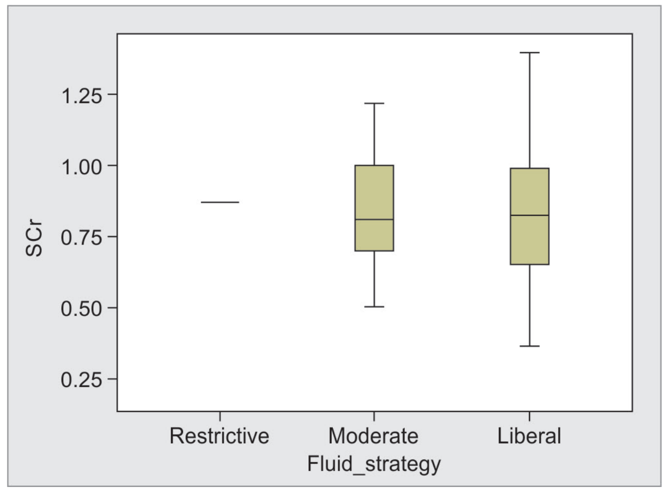

Fig. 6: Peak serum creatinine (SCr) levels across fluid strategies (restrictive, moderate, liberal). The moderate group shows lower median SCr values and narrower variability compared to the liberal group, suggesting reduced renal stress

Assumptions Testing for Renal Function Analyses

Tests of homogeneity showed significant differences between fluid strategies for peak SCr (p < 0.001) and urine output (p = 0.039). Table 5 confirms variability in renal outcomes, validating the stratified analysis approach.

Predictive Modeling of AKI Risk

Logistic Regression for AKI Prediction

Table 6 shows the logistic regression model fit (χ^2 = 87.646, p < 0.001), indicating fluid strategies significantly influence AKI risk. The classification model accurately predicted AKI in all cases (74 without AKI, 17 with AKI).

Chi-square Analysis of AKI Incidence

Chi-square tests (Table 7) did not find significant differences in AKI incidence between fluid strategies (χ^2 = 55.955, df = 47, p = 0.174). However, a linear-by-linear association (p = 0.01) suggested interactions requiring further testing.

Table 5: The One-Way ANOVA results for effects of different fluid management strategies on renal function indicators in liver transplant recipients[1]

Parameter		*Sum of squares*	*df*	*Mean square*	*F*	*Sig.*
Serum creatinine (SCr)	Between groups	0.001	2	0.000	0.007	0.993
	Within groups	5.018	88	0.057		
	Total	5.019	90			
Peak SCr	Between groups	3.292	2	1.646	3.004	0.055
	Within groups	48.233	88	0.548		
	Total	51.525	90			
Urine output	Between groups	8156781.054	2	4078390.527	1.798	0.172
	Within groups	199554643.671	88	2267666.405		
	Total	207711424.725	90			
Fluid balance at 24 (FB24)	Between groups	17404147.465	2	8702073.732	9.356	0.000
	Within groups	81848234.953	88	930093.579		
	Total	99252382.418	90			
Fluid balance at 48 (FB48)	Between groups	60071041.461	2	30035520.731	13.914	0.000
	Within groups	189964052.495	88	2158682.415		
	Total	250035093.956	90			
Fluid balance at 72 (FB72)	Between groups	118738208.024	2	59369104.012	18.202	0.000
	Within groups	287030902.416	88	3261714.800		
	Total	405769110.440	90			
LOS ICU	Between groups	3.536	2	1.768	3.075	0.051
	Within groups	50.596	88	0.575		
	Total	54.132	90			
LOS hospital	Between groups	17.955	2	8.978	3.953	0.023
	Within groups	199.869	88	2.271		
	Total	217.824	90			

[1]"Mean" indicates the average value, and "Standard Deviation (SD)" reflects variability in measurements. Sample size (N) refers to the number of patients in each group for the corresponding fluid strategy

Table 6: Homogeneity of variances test results for key renal function indicators[1]

Renal indicator	*Levene statistic*	*df1*	*df2*	*p-value*
Serum creatinine (SCr)	0.464	1	88	0.498
Peak serum creatinine	19.025	1	88	<0.001
Urine output	4.392	1	88	0.039
FB24 (Fluid balance)	3.002	1	88	0.087
FB48 (Fluid balance)	4.502	1	88	0.037
FB72 (Fluid balance)	5.215	1	88	0.025
Length of stay (ICU)	0.184	1	88	0.669
Length of stay (Hospital)	19.373	1	88	<0.001

[1]SCr: Serum Creatinine, measured in milligrams per deciliter (mg/dL). FB24/FB48/FB72: Fluid balance at 24, 48, and 72 hours, respectively, measured in milliliters (mL). "Levene Statistic" tests whether variances between groups are equal. A *p*-value > 0.05 indicates no significant variance differences between fluid strategies

Table 7: Omnibus tests of model coefficients – provides additional context on model fit

Test name		*Chi-square*	*df*	*Sig.*
Step 1	Step	87.646	39	0.000
	Block	87.646	39	0.000
	Model	87.646	39	0.000

Table 8: Classification table (logistic regression) – shows the predictive accuracy of AKI based on fluid strategy, which is vital for assessing risk factors

	Predicted AKI		
Observed AKI	*No*	*Yes*	*Percentage correct*
No	74	0	100.0%
Yes	0	17	100.0%
Overall			100.0%

Note: The cut-off value for classification is 0.500

Chi-square Test for Colloid Administration and AKI Incidence

Table 8 showed a significant association between colloids and AKI (χ^2 = 24.464, df = 12, p = 0.018), supported by a directional trend (p = 0.002). These findings warrant further exploration into the protective effects of colloids.

Chi-square Test for Blood Product Transfusions and AKI Incidence

Table 9 revealed a significant relationship between blood transfusions and AKI incidence (χ^2 = 40.804, df = 20, p = 0.004), with a strong trend (p = 0.002). Further studies should assess which transfusion strategies affect AKI outcomes.

Chi-square Test for Crystalloid Restriction and AKI Incidence

Table 10 demonstrated a significant association between crystalloid restriction and AKI incidence (χ^2 = 14.440, df = 5, p = 0.013), with a strong directional trend (p = 0.001). These results highlight the importance of restricting crystalloids in reducing AKI risk.

Table 9: Chi-square test evaluating the overall relationship between fluid management strategies (crystalloid, colloid, and blood products) and AKI incidence[1]

Statistical test	*Value*	*df*	*Asymp. Sig. (2-sided)*
Pearson Chi-square	55.955a	47	0.174
Likelihood ratio	56.445	47	0.163
Linear-by-linear association	16.339	1	0.000
N of valid cases	91		

[1]Pearson Chi-square tests whether there is a statistically significant association between fluid strategies and AKI incidence. df: Degrees of freedom, indicating the number of independent comparisons. Asymp. Sig.: The *p*-value for the test; values < 0.05 indicate a statistically significant relationship. The findings suggest no overall significant association between fluid strategies and AKI incidence ($p = 0.174$), but trends be present (see linear-by-linear association)

Table 10: Chi-square test evaluating the relationship between colloid administration and AKI incidence

Variable	*Value*	*df*	*Asymp. Sig. (2-sided)*
Pearson Chi-square	24.464[a]	12	0.018
Likelihood ratio	22.279	12	0.035
Linear-by-linear association	9.777	1	0.002
N of valid cases	91		

[a]23 cells (88.5%) have an expected count of less than 5. The minimum expected count is .19.

Table 11: Chi-square test evaluating the association between blood product transfusions and AKI incidence[1]

Outcome	*Value*	*df*	*Asymp. Sig. (2-sided)*
Pearson Chi-square	40.804[a]	20	0.004
Likelihood ratio	39.168	20	0.006
Linear-by-linear association	9.164	1	0.002
N of valid cases	91		

[a]39 cells (92.9%) have an expected count of less than 5. The minimum expected count is .19; [1]Pearson Chi-square tests whether blood product administration is associated with AKI development. A statistically significant result ($p = 0.004$) suggests that blood transfusions impact renal outcomes, warranting further analysis. Linear-by-linear association tests for a directional trend, with $p = 0.002$ indicating such a trend exists

Multiple Linear Regression for Predicting AKI Risk

A regression analysis was conducted, as shown below in Table 11, to evaluate the relationship between fluid types (colloids vs crystalloids) and renal outcomes.

Colloid Proportion

Regression analysis revealed that a higher proportion of colloid fluid use significantly improved renal outcomes (coefficient = 0.907, $p = 0.035$), indicating colloids' role in enhancing postoperative renal function.

Total Fluid Volume

Increased total fluid volume was positively associated with renal outcomes (coefficient = 0.000092, $p < 0.001$), though the small effect size highlights the importance of balanced fluid management.

Patient Factors

Age, sex, and weight showed no significant impact on renal outcomes, emphasizing fluid management as a critical determinant.

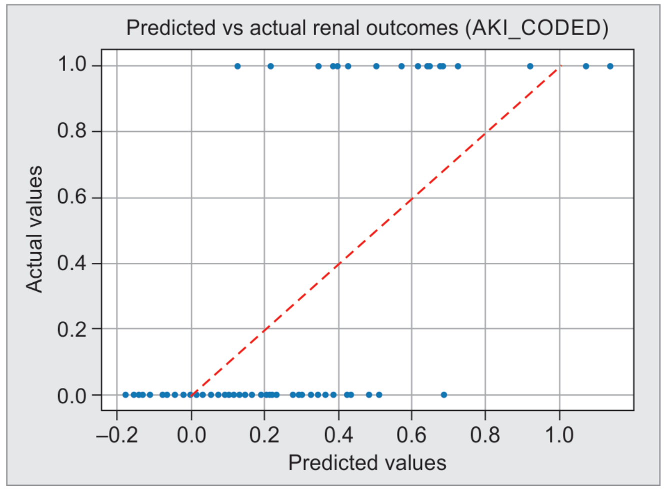

Fig. 7: Scatter plot comparing predicted and actual renal outcomes (AKI_CODED), featuring a diagonal red line representing perfect prediction alignment

Table 12: Chi-square test evaluating the relationship between crystalloid restriction and AKI incidence

Parameter	*Value*	*df*	*Asymp. Sig. (2-sided)*
Pearson Chi-square	14.440[a]	5	0.013
Likelihood ratio	11.777	5	0.038
Linear-by-linear association	10.855	1	0.001
N of valid cases	91		

[a]10 cells (83.3%) have an expected count of less than 5. The minimum expected count is .19.

The regression model demonstrated strong predictive alignment between actual and predicted renal outcomes, with variability observed at extremes as shown in Figure 7. This underscores the potential benefits of colloid-based strategies while identifying areas for model refinement.

Relationship between Total Fluid Volume and Renal Outcomes

Correlation Analysis

Table 12 presents the correlation matrix, which highlights relationships among total fluid input (TFI), renal markers, and patient characteristics. The findings reveal several noteworthy associations:

Correlation and multiple regression analyses assessed the impact of total fluid intake (TFI) on renal outcomes, highlighting:

- **TFI and peak SCr:** Moderate positive correlation ($r = 0.369$, $p < 0.001$), suggesting higher TFI is linked to elevated SCr, indicating potential renal stress.
- **TFI and crystalloid administration:** Strong positive correlation ($r = 0.548$, $p < 0.001$), showing crystalloids form a major portion of TFI and influence renal outcomes.
- **TFI and colloid administration:** Weaker, but significant, correlation ($r = 0.246$, $p < 0.05$), suggesting colloids contribute less to TFI's effect on renal outcomes.
- **TFI and patient characteristics:** No significant correlation with weight or age, implying fluid management practices were not systematically adjusted based on these factors.

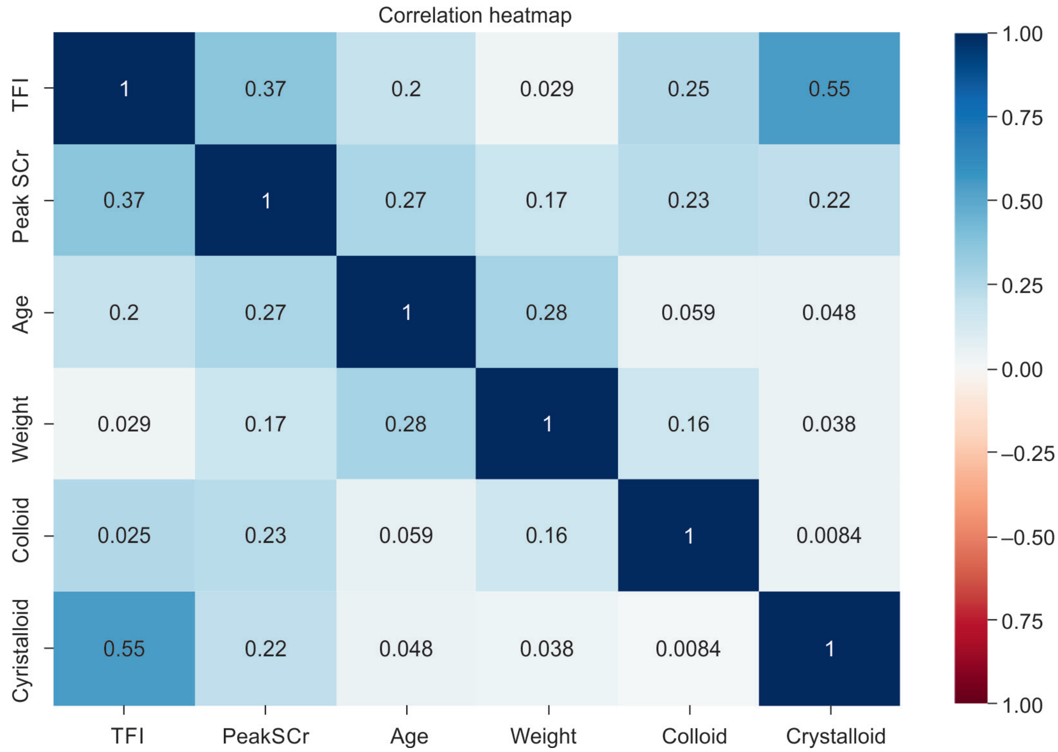

Fig. 8: Heatmap displaying correlations among key variables related to renal function in liver transplant recipients

Table 13: Regression analysis results evaluating the impact of fluid type proportions (colloids vs crystalloids), total fluid volume, and patient factors on renal outcomes[1]

	Variable	*Coefficient*	*p-value*	*95% CI lower*	*95% CI upper*
0	Const	−0.7774651434	0.0004437515	−1.2003489509	−0.3545813359
1	Proportion_Colloid	0.9066002077	0.0353055663	0.0638796773	1.7493207382
2	Total_Fluid	0.0000922388	0	0.0000714899	0.0001129876
3	Age	−0.000753044	0.772635242	−0.00591862	0.0044125319
4	Sex_Binary	−0.0720705537	0.3095880542	−0.2122544304	0.068113323
5	Weight	0.0021935541	0.459183267	−0.0036718467	0.008058955

[1]Coefficient: Indicates the direction and magnitude of the association between each variable and the outcome (e.g., AKI risk or renal function). Std Error: Reflects the precision of the coefficient estimate. *p*-value: Significance of the variable's contribution to the model; $p < 0.05$ indicates a significant predictor. CI Lower/Upper: 95% confidence interval for the coefficient, showing the range of plausible values. A higher proportion of colloids was significantly associated with improved renal outcomes ($p = 0.035$), while total fluid volume showed a small but significant effect on renal stress ($p < 0.001$)

The correlation heatmap (Fig. 8) visually represents these associations, with stronger correlations depicted in darker shades.

The findings highlight the critical balance of fluid volume and composition in renal outcomes during liver transplantation. Colloid-based strategies show promise in improving renal function, while excessive fluid volumes, particularly crystalloids, may contribute to renal stress. These results support tailored fluid management to minimize AKI risk and optimize renal outcomes.

Regression Analysis: TFI and Renal Outcomes

Total Fluid Input (TFI)

Multiple linear regression revealed a significant positive association between TFI and peak serum creatinine (SCr) levels (coefficient = 0.000083, $p = 0.006$), suggesting that higher fluid intake may cause renal stress due to overhydration (Table 13).

Age

Age demonstrated a near-significant positive effect (coefficient = 0.011, $p = 0.053$), indicating older patients might experience slightly higher SCr levels with increased fluid intake, warranting further study.

Other Factors

Weight, colloid intake, and crystalloid intake did not significantly influence peak SCr ($p > 0.1$), showing their minimal impact when TFI is the primary predictor.

The scatter plot (Fig. 9) illustrates a positive correlation between TFI and peak SCr levels, with an upward-trending regression line indicating renal stress at higher fluid volumes. A separate visualization (Fig. 10) highlights TFI as the most significant predictor among the regression coefficients, emphasizing its critical role in renal outcomes.

Regression analysis underscores TFI as a major determinant of renal stress, with higher volumes linked to increased peak SCr. While age approached significance, other factors such as weight and fluid type showed minimal effects. These findings stress the importance of managing fluid volumes carefully in liver transplant patients to protect renal function.

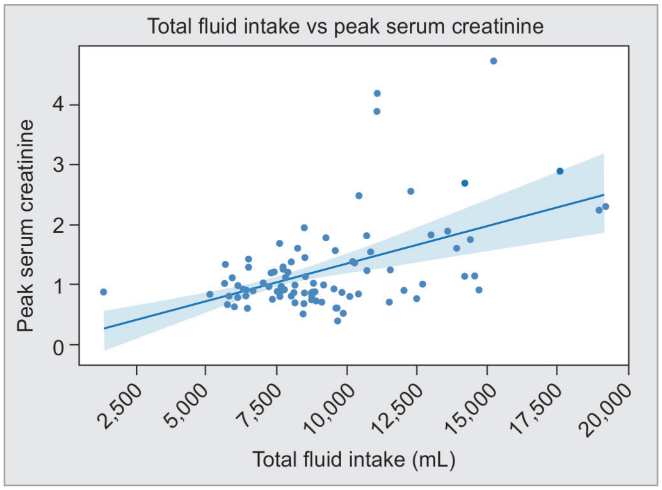

Fig. 9: Scatter plot illustrating the relationship between total fluid intake (mL) and peak serum creatinine levels, showing a positive correlation with a fitted regression line and confidence interval

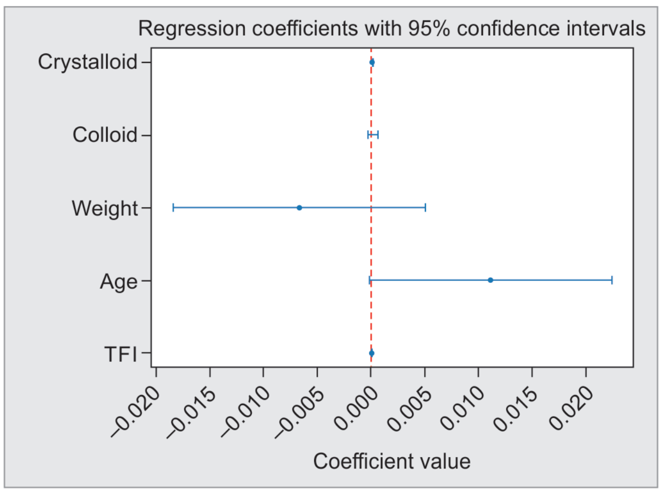

Fig. 10: Regression coefficients plot showcasing significant predictors from the multiple linear regression analysis

Timing of Fluid Administration and Renal Outcomes

Intraoperative Fluid Administration

Kaplan–Meier survival analysis (Tables 14 to 16) revealed that intraoperative fluid administration had the highest survival probability, indicating its effectiveness in reducing AKI risk (Fig. 11).

Postoperative Fluid Administration

Postoperative fluid management showed lower survival probabilities, reflecting a delayed protective effect on renal outcomes.

Preoperative Fluid Administration

Pre-op fluid strategies demonstrated variable effectiveness based on patient-specific factors like pre-existing renal function and total fluid volumes.

The Kaplan–Meier analysis in Figure 11 indicates that intraoperative fluid administration is the most effective in preventing AKI, with the highest survival probabilities over time. Postoperative fluid administration appears less effective, emphasizing the importance of timely fluid management during surgery. These findings highlight the need for precise timing of fluid interventions to optimize renal outcomes and minimize the risk of AKI in liver transplant recipients.

Discussion

This study examines the impact of different fluid management strategies on renal function in liver transplant patients. It aims to enhance fluid management in liver transplantation, a crucial area of medicine.[23–25] The research focuses on three categories of fluid management approaches: restrictive, moderate, and liberal. It also investigates how these strategies affect the kidneys of the liver transplant patient and how colloid, blood, and blood products protect the kidney during the perioperative period.[19,26,27]

Main Findings Overview

The study explores fluid management strategies for liver transplant patients, focusing on moderate, liberal, and restrictive approaches. Moderate fluid management yields better renal outcomes, while liberal strategies increase renal stress. Restrictive fluids reduce

Table 14: Correlation matrix for relationships among TFI, renal markers, and patient characteristics

Correlation variables	*Total fluid intake (TFI)*	*Peak SCr*	*Age*	*Weight*	*Colloid*	*Crystalloid*
TFI	1.000***	0.369***	0.202	0.029	0.246*	0.548***
PeakSCr	0.369***	1.000***	0.267*	0.165	0.228*	0.215*
Age	0.202	0.267*	1.000***	0.282**	0.059	0.048
Weight	0.029	0.165	0.282**	1.000***	0.158	0.038
Colloid	0.246*	0.228*	0.059	0.158	1.000***	0.008
Crystalloid	0.548***	0.215*	0.048	0.038	0.008	1.000***

*$p < 0.05$ statistically significant; **$p < 0.01$ highly significant; ***$p < 0.001$ very highly significant

Table 15: Regression analysis of total fluid intake and renal outcomes

Regression variables	*Coefficient*	*Std. Error*	*t-value*	*p-value*	*CI lower*	*CI upper*
Const	0.064377037	0.4762075966	0.1351869173	0.893	–0.8824512445	1.0112053185
TFI	0.0000832628	0.0000297528	2.7984815576	0.006**	0.0000241062	0.0001424194
Age	0.0111171516	0.0056728595	1.9597085898	0.053	–0.000162013	0.0223963161
Weight	–0.0066713429	0.0059049157	–1.1297947587	0.262	–0.0184118973	0.0050692116
Colloid	0.000187073	0.0002381831	0.7854167677	0.434	–0.0002864988	0.0006606447
Crystalloid	0.0000902533	0.0000609288	1.4812925011	0.142	–0.0000308894	0.0002113961

**$p < 0.01$ highly significant

Table 16: Summary of survival probabilities for each fluid strategy

Fluid strategy	*Survival probability*
Preoperative (1)	1.00
Intraoperative (2)	1.00
Postoperative (3)	0.00

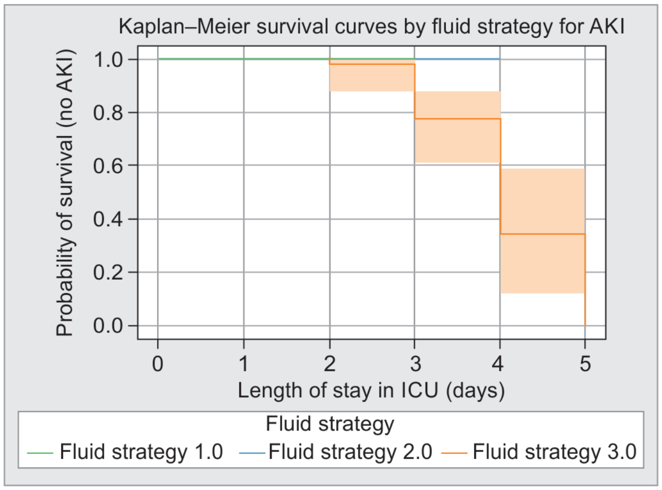

Fig. 11: Kaplan–Meier survival curve depicting survival probabilities for each fluid strategy concerning the occurrence of AKI

damage, and colloid use improves outcomes. Intraoperative fluid administration prevents AKI during liver transplantation.[28]

Comparison of Fluid Strategies

Moderate fluid management is linked to better renal outcomes, showing lower peak serum creatinine (SCr) and improved fluid balance compared to liberal strategies, which are associated with higher SCr and renal stress.[19,29,30] Moderate strategies provide optimal fluid administration without causing fluid overload or related complications.[1,31] Restrictive strategies, underreported due to limited sample size, may reduce fluid overload, a key predictor of AKI but require further research with larger patient groups.[1,13,32]

Impact of Fluid Strategies on Renal Function in Liver Transplantation: Benefits of Moderate vs Liberal Approaches

Moderate fluid strategies minimize renal damage by avoiding both overload and insufficient renal blood flow, reducing interstitial edema, renal venous pressure, and AKI risk.[3,33,34] They also limit the use of vasopressors, which can harm the kidneys.[8] Liberal strategies, by contrast, increase the risk of fluid overload, leading to pulmonary edema, higher intra-abdominal pressure, impaired renal flow, elevated SCr, and reduced renal function.[35,36] While liberal approaches enhance urine output, they do not provide optimal renal benefits due to the heightened risk of fluid overload in liver transplant patients.

Influence of Colloid and Crystalloid Fluids on Renal Outcomes in Liver Transplantation: A Comparative Analysis

Regression analysis supports better renal outcomes with colloids over crystalloids. Colloids, such as albumin, maintain intravascular volume and hemodynamic stability, minimizing interstitial fluid accumulation and reducing fluid overload, a key factor in post-transplant renal dysfunction.[37–39] In contrast, crystalloids are linked to higher TFI, leading to extracellular fluid accumulation and renal strain, highlighting the importance of both fluid type and total volume in renal outcomes.[40–42]

The Role of Total Fluid Volume and Fluid Overload in Renal Outcomes During the Perioperative Period

Total perioperative fluid volume critically influences renal outcomes, with fluid overload from either colloids or crystalloids contributing to AKI.[22,42] Proper volume replacement, avoiding overhydration, is vital, especially for patients with pre-existing renal issues, as excessive fluids exacerbate renal failure.[3]

The Role of Blood Products in Fluid Therapy

Blood product transfusions, while essential for hemodynamic stability and perfusion pressures during transplantation, show no clear link to renal outcomes. Adequate blood replacement may reduce hypotension risks, but the specifics of their role in renal preservation remain uncertain, varying by patient and procedure.[43,44]

Impact of Fluid Administration Timing on Renal Outcomes

The study found that intraoperative fluid administration during liver transplant surgery has the highest survival probability, preventing AKI.[45] This is due to its ability to replace volume loss and maintain hemodynamics, preventing renal stress and damage. However, postoperative fluid management is delayed and has a lower survival probability for AKI prevention.[23,46,47] The study emphasizes the importance of administering appropriate fluid bolus during surgery to reduce AKI incidence and improve renal outcomes post-transplantation.

Clinical Implications of the Study

The study suggests that moderate fluid restriction is most suitable for minimizing AKI in liver transplant patients.[48–52] Clinicians should use a conservative fluid management plan to avoid fluid congestion and depletion of renal function and hemodynamic stability.[53–56] Early optimization of intraoperative fluid administration is crucial to avoid renal hypoperfusion and AKI.[57] Colloids have a superior renal safety profile compared to crystalloids, offering better hemodynamic control and less interstitial edema formation.[58] Monitoring fluid volume is essential to prevent AKI, and non-nephrotoxic drugs should be prioritized to prevent damage.[59] To improve renal outcomes, hospitals, and policymakers should develop protocols focusing on moderately restrictive fluid management and intraoperative monitoring.[60,61]

Clinical Significance

This study underscores the critical role of PFM in liver transplantation, highlighting that moderate fluid strategies, particularly with intraoperative fluid administration, significantly reduce the risk of AKI and improve renal outcomes. These findings can guide clinical practices, emphasizing the importance of individualized fluid therapy to minimize renal complications and optimize recovery in liver transplant recipients. By identifying the optimal fluid management approach, this research provides actionable insights to enhance postoperative care and patient outcomes in liver transplantation.

Limitations of the Study

The study's small sample size, retrospective nature, and lack of standardized methods limit generalization and causality. Limited follow-up data and systematic errors also pose limitations, necessitating further research.

Conclusion

The study highlights the importance of PFM in liver transplantation, particularly in renal outcomes. Moderate fluid strategies were found to be better for renal function, lower serum creatinine, and stable management. Intraoperative fluid therapy prevented AKI, while postoperative fluid management was significant. Further research is needed to confirm these findings.

Ethical Approval Statement

This study, titled "The Effect of Perioperative Fluid Therapy on Postoperative Renal Functions in Patients Receiving Liver Transplantation from Living Donors," was approved by the Clinical Research Ethics Committee (Klinik Araştırmalar Etik Kurulu, KAEK) of Yeditepe University, Istanbul, Turkey. The study was reviewed during the committee meeting on February 10, 2021, and deemed ethically and scientifically appropriate for conduct (KAEK Decision No: 1377).

Due to the retrospective design of the study, the requirement for informed consent was waived as per the committee's regulations.

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