Risk Factors for the Incidence and Severity of Acute Kidney Injury After Liver Transplantation

Dali Zhang[1,], Zhenwen Liu[1,*], Jing Feng Bi[2], Hongling Liu[1], Yinjie Gao[1]*

[1]*Liver Transplantation and Research Center, 302 Hospital, Beijing, China*
[2]*Research and Technology Service Center, 302 Hospital, Beijing, China*

Cite this article as: Zhang D, Liu Z, Feng Bi J, Liu H, Gao Y. Risk factors for the incidence and severity of acute kidney injury after liver transplantation. *Turk J Gastroenterol.* 2021; 32(1): 82-87.

ABSTRACT

Objective: *To explore risk factors of acute kidney injury (AKI) and its severity after liver transplantation*

Methods: *This was a retrospective cohort of consecutive adults undergoing orthotopic liver transplantation (OLT) at a referral hospital. Risk factors for AKI from 1week post-liver transplantation and 4-week outcomes were analysed. Further analyses of factors that influenced the severity of AKI were also performed.*

Results: *A total of 204 patients were included. AKI was found in 55.4% of patients in the first week after OLT. Risk factors for AKI were recipient's sex, BMI, preoperative creatinine, preoperative hepatic encephalopathy, cold ischaemia time, duration of surgery, duration of inferior vena clamping, postoperative peak lactate and postoperative peak AST, which were higher in the AKI group. Four weeks after liver transplantation, 20.4% of AKI patients still had abnormal renal function and a mortality rate of 3.6%, and these values were significantly higher than those of patients without AKI (P < .05).*

Conclusion: *Preoperative, intraoperative and postoperative factors can all lead to AKI after OLT.*

Keywords: *Liver transplantation, acute kidney injury, risk factor*

INTRODUCTION

Since the first liver transplantation was successfully performed in 1967, this procedure has developed into a well-established treatment modality for patients with end-stage liver disease (ESLD). However, liver transplantation may be associated with a variety of complications, such as acute kidney injury, infection, hypertension, malnutrition, anemia, electrolyte imbalance, and osteoporosis.[1] Acute kidney injury (AKI) has been in focus in recent years. It is associated with a high risk of chronic kidney disease, end-stage renal disease (ESRD), or 30-day mortality.[2,3] AKI during the first week after liver transplantation may be associated with preoperative, intraoperative, and postoperative factors.[4] The prevalence of ESRD is approximately 5-8% during the first year after liver transplantation and increases to 18-25% during the first 5 and 10 years, respectively.[5-7] AKI is influenced by many variables. Due to the different definitions of AKI, its prevalence varies from 17% to 95%.[8-10] Our liver transplantation center adopted the definition of the Kidney Disease Improving Global (KDIGO) in 2012.[11] To reduce the prevalence of AKI and to summarize the clinical experience, we analyzed our patient data to determine AKI prevalence and risk factors in the early stage of liver transplantation (1st week after liver transplantation) and outcomes in the 4th week post-OLT.

METHODS

Patients and Methods

This was a retrospective study of 242 patients who underwent standard orthotopic transplantation of livers from deceased donors, which came from the Donation after Cardiac Death program, from January 2015 to November 2017. No executed prisoners were used for this study. Full informed consent was obtained, and the study was approved by the local research ethics committee.

Patients who met the inclusion criteria were those who had undergone liver transplantation, were greater than 18 years of age, and had baseline serum creatinine less than 133 μmol/L before liver transplantation.

Patients who had advanced chronic kidney disease or renal insufficiency such as baseline creatinine >133 μmol/L before liver transplantation, patients who underwent other organ transplants, and those with incomplete follow-up were excluded.

**These authors contributed equally to this work.*

Corresponding authors: ***Hongling Liu*** *or* ***Yinjie Gao****, e-mail:* ***lhl7125@sina.com*** *or* ***gaoyj302@163.com***
Received: ***September 5, 2019*** *Accepted:* ***June 13, 2020*** *Available Online Date:* ***April 13, 2021***

DOI: ***10.5152/tjg.2020.19592***

AKI was defined as either an increase in serum creatinine (SCr) by ≥0.3 mg/dL (≥26.5 μmol/L) within 48 hours or an increase in SCr to ≥1.5 times the baseline within the previous 7 days (KDIGO criteria).[11] Baseline serum creatinine was defined as the most recent stable measurement within a week prior to admission for index hospitalization.

According to KDIGO criteria,[11] AKI was divided into three stages. Stage 1 was defined as either an increase to 1.5-1.9 times of baseline SCr or an increase by ≥0.3 mg/dL (≥26.5 μmol/L). Stage 2 was defined as an increase to 2.0-2.9 times of baseline SCr. Stage 3 was either an increase to more than 3.0 times of baseline SCr, a SCr increase to 353.6 μmol/L or initiation of renal replacement therapy.

Observation Indicators

Standard demographic, clinical, and laboratorial data were collected at the initiation of liver transplant and within 4 weeks after liver transplantation. Peak arterial lactate, peak alanine aminotransferase, peak aspartate aminotransferase (AST), and peak lactate dehydrogenase levels were all measured 4 weeks post-liver transplantation.

Statistical Analysis

Continuous data are presented as mean ± standard deviation (SD) or interquartile ranges (IQRs), and for categorical variables, proportions of patient were calculated. Mann–Whitney U test or chi-square test was performed to compare means. Multivariate logistic regression was used to explore risk factors for AKI and ordered logistic regression for AKI severity. All calculations were performed using SAS software, version 9.4. The results were considered significant when $P < .05$. The funding sources had no influence over the study design, data analysis, or article production.

RESULTS

AKI Rate in the First Week After Liver Transplantation

Among the 242 patients, 204 were included in this study. A total of 17 patients were excluded because their baseline creatinine was >133 μmol/L, and 21 patients lacked first month lab results due to non-regular follow-up. There were 113 AKI patients in first week after liver transplantation, including 99 males and 14 females, with median age of 49 years, along with 91 patients without AKI, including 64 males and 27 females, with median age of 50 years. The prevalence of AKI was 55.4%.

Demographic Characteristics of AKI Patients and Non-AKI Patients

There were preoperative, intraoperative, and postoperative differences in the AKI recipients in the first week after liver transplantation.

There were no significant differences in age, hypertension, diabetes mellitus, or MELD score between patients with and without AKI, while BMI, SCr, and hepatic encephalopathy were significantly different. Viral liver disease was the most frequent etiology in both AKI patients (68.14%) and non-AKI patients (60.44%) (Table 1).

For intraoperative variables, AKI patients seemed to require significantly longer times for inferior vena clamping, cold ischemia, and duration of surgery ($P < .05$) (Table 1).

After liver transplantation, the median duration of ICU stay of AKI patients was 37 hours, the median level of peak arterial lactate was 8.3 mmol/L, and the peak AST was 1943 U/L; these levels were significantly different compared to those of non-AKI patients (Table 1).

Risk Factors of AKI

BMI was divided into three stages, which were less than 24 kg/m^2, 24-27 kg/m^2, and more than 27 kg/m^2. BMI above 27 kg/m^2 as a risk factor is explicit and easy to perform in clinical work; thus, for better understanding, variables that differed between AKI and non-AKI patients were divided into two to three stages according to recognized classification, literature reports, or clinical experience. Multivariate analysis showed that a BMI above 27 kg/m^2, hepatic encephalopathy, preoperative serum creatinine level above 90 μmol/L, duration of inferior vena clamping longer than 56 minutes, postoperative peak lactate more than 4 mmol/L, and peak postoperative AST more than 3000 U/L were risk factors of AKI (Table 2).

Risk Factors of Severity in AKI Patients

In our consecutive cohort, there were 113 patients with AKI, among whom 47.79% (54/113) were at stage 1, and 33.91% (39/113) were at stage 2, and 17.70% (20/113) were at stage 3.

Depending on the severity of AKI, which were stage 1, stage 2, and stage 3, based on variables that differed between the AKI and non-AKI groups, ordered multivariate logistic regression was performed. In this model, independent variables were divided into two to three stages, according

Table 1. Preoperative, Intraoperative, and Postoperative Difference in Both AKI and Non-AKI Patients

Variables	AKI (113)	No AKI (91)	*P* value
Age(years) (IQR)	49 (43, 57)	50 (43.5, 55.5)	.492
Gender			.000
Female	14 (12.39%)	27 (29.67%)	
Male	99 (87.61%)	64 (70.33%)	
BMI (SD/IQR)	24.84 ± 3.64	23.56 (21.26, 25.22)	.015
Preoperative clinical parameters			
Hypertension	13 (11.5%)	6 (6.59%)	.363
Diabetes mellitus	23 (20.35%)	15 (16.48%)	.988
Viral hepatitis	77 (68.14%)	55 (60.44%)	.010
Ascites	206 (75.18%)	152 (77.94%)	.403
SBP	36 (13.14%)	16 (8.21%)	.094
Hepatic encephalopathy	13 (11.5%)	13 (14.29%)	.011
SCr (μmol/l) (IQR)	76 (65.0, 89.0)	68 (58.0, 78.0)	.001
MELD (IQR)	15 (11, 22.3)	14 (9, 19)	.233
Child-pugh (IQR)	10 (8.0, 11.0)	10 (9.0, 11.0)	.245
Intraoperative clinical parameters			
Duration of IVC (min) (IQR)	57.4 (47.2, 69.9)	53.5 (46.7, 68.4)	.047
CID (min) (IQR)	479 (324, 591)	368 (282, 565)	.036
Duration of surgery (h) (IQR)	10.0 (8.2, 11.7)	9.2 (8.0, 10.89)	.044
Postoperative clinical parameters			
Length of ICU stay (h) (IQR)	37 (23, 58)	34 (22, 39)	.076
Lactate (mmol/L) (IQR)	8.3 (4.2, 13.5)	6.4 (2.1, 12.3)	.000
Peak AST (U/L) (IQR)	1943 (914, 2992)	1170 (670, 1944)	.000
Peak ALT (U/L) (IQR)	737 (400, 1097)	611 (381, 877)	.047
Peak LDH (U/L) (IQR)	1206 (730, 1980)	1012.5 (631, 1573)	.042
Ventilator duration (h) (IQR)	15.5 (11, 25)	14 (11, 18)	.160

BMI, body mass index; SBP, spontaneous bacterial peritonitis; SCr, serum creatinine; IVC, inferior vena clamping; CID, cold ischemia duration; AST, aspartate aminotransferase; ALT, alanine aminotransferase; LDH, lactate dehydrogenase.

to recognized classification, literature reports, or clinical experience (see previous section). Results showed that preoperative creatinine greater than 90 μmol/L, duration of surgery longer than 8 hours, and a postoperative peak AST above 3000 U/L were all independent risk factors of severity of AKI after liver transplantation (Table 3).

Renal Function and Survival Status in the fourth Week after Liver Transplantation

Four weeks after liver transplantation, most AKI patients had normal renal function, and 20.4% (23/113) had continuous AKI; for the non-AKI patients, only 1 patient had elevated creatinine. In the fourth week, patients who had abnormal renal function were mostly AKI patients previously.

AKI patients seemed to exhibit higher mortality than those without AKI, but there were only 4 cases in the AKI group and 1 in the non-AKI group (Table 4).

DISCUSSION

AKI is a common complication after liver transplantation that influences outcomes and worsens prognosis and can even lead to the need for renal replacement therapy and kidney transplantation. The prevalence of AKI was 55.4% within 1 week after liver transplantation in this study, which was essentially the same as previously reported.[12] Within the first week of liver transplantation, calcineurin inhibitors had not been used or were used less frequently; thus, immunosuppressive agents had little influence on AKI. Therefore, it was important to analyze the preoperative, intraoperative, and postoperative variables of AKI.

There are many factors that result in AKI in liver transplantation.[13-16] Preoperative factors such as diabetes mellitus, MELD score, and elevated creatinine were reported to be risk factors of AKI.[17,18] Intraoperative factors such as duration of cold ischemia, duration of surgery, and surgery modality were significantly different in AKI patients compared to those without AKI patients.[19,20] Different liver transplant techniques impact the prevalence of AKI. As reported, venovenous bypass and the piggyback technique during liver transplantation decrease the prevalence of AKI post-liver transplantation.[21,22] Postoperative factors such as higher levels of lactate and higher peak AST are significantly different.[23]

In our study, gender and BMI were risk factors for AKI. This was consistent with a previous study.[24] The mechanism

Table 2. Risk Factors of Acute Kidney Injury

Factor	Group	*N*	OR	90% CI	*P* value
Gender	Male	164	1.000 (Reference)		
	Female	40	0.255	0.155-0.42	.001
BMI	<24 kg/m^2	84	1.000 (Reference)		
	24-27 kg/m^2	66	1.453	0.973-2.168	.125
	>27 kg/m^2	54	2.414	1.425-4.09	.006
SCr	<90 μmol/L	169	1.000 (Reference)		
	90-133 μmol/L	35	2.01	1.288-3.135	.010
HE	No	178	1.000 (Reference)		
	Yes	26	2.036	1.223-3.392	.022
IVC	<55 minutes	75	1.000 (Reference)		
	55-70 minutes	93	2.056	1.372-3.083	.003
	>70 minutes	36	2.258	1.244-4.099	.025
Lactate	<4 mmol/L	39	1.000 (Reference)		
	4-7 mmol/L	77	3.548	2.132-5.907	.001
	>7 mmol/L	88	4.826	2.878-8.093	.001
Peak AST	<1500 U/L	73	1.000 (Reference)		
	1500-3000 U/L	94	1.517	0.999-2.303	.101
	>3000 U/L	37	7.9	3.732-16.723	.001

BMI, body mass index; SCr, serum creatinine; HE, hepatic encephalopathy; IVC, inferior vena clamping; TBIL post-LT, total bilirubin post-liver transplantation; peak AST, aspartate aminotransferase.

is unknown. In our study, only 20% (41/204) of patients were female, which may be related to sample deviation. Patients with higher BMI were often obese and were apt to have ischemic injury, suggesting that patients with BMIs greater than 27 kg/m^2 can easily develop AKI.

Inferior vena clamping, lactate, and higher peak AST are risk factors of AKI. Patients who have ESLD often exhibit splanchnic vasodilatation, such as renal vasoconstriction, which can damage renal tubular epithelial cells. Although patients have normal serum creatinine levels,

Table 3. Risk Factors of Severity of AKI Patients

Factor	Group	*N*	OR	90% CI		*P* value
SCr	<90 μmol/L	86	1.000 (Reference)			
	90-133 μmol/L	27	0.421	0.255	0.695	.004
CID	<480 minutes	43	1.000 (Reference)			
	481-600 minutes	33	1.879	0.958	3.686	.124
	>600 minutes	37	2.544	1.47	4.404	.005
Surgery duration	<8 hours	6	1.000 (Reference)			
	8-10 hours	36	2.572	1.474	4.487	.005
	>10 hours	71	3.026	1.701	5.381	.002
Peak AST	<1500 U/L	32	1.000 (Reference)			
	1500-3000 U/L	53	1.262	0.775	2.055	.433
	>3000 U/L	28	4.077	2.308	7.202	.001

AKI, acute kidney injury; SCr, serum creatinine; CID, cold ischemia duration; peak AST, aspartate aminotransferase.

Table 4. Renal Function and Survival Status in Patients in Fourth Weeks After Liver Transplantation

Variables	AKI (113)	No AKI (91)
Renal function		
Normal	90 (79.6%)	90 (98.9%)
Abnormal	23 (20.4%)	1 (1.1%)
Survival status		
Survival	109 (96.5%)	90 (98.9%)
Death	4 (3.5%)	1 (1.1%)

AKI, acute kidney injury.

the changes in systemic hemodynamics impair renal function. Intraoperative factors, such as inferior portal vein clamping, which interrupt venous return, along with cardiac output and blood pressure reduction, decrease renal perfusion and contribute to AKI occurrence. During these periods, high amounts of lactate are produced, and high amounts of AST are released. It has been reported that the prevalence of AKI is lower in piggyback liver transplantation compared to orthotopic liver transplantation,[21,22] which can explain why inferior vena clamping, high lactate, and high peak AST are risk factors of AKI. In our center, all patients underwent orthotopic liver transplantation; based on our data analysis, patients with a high risk for AKI may choose piggyback liver transplantation or partial clamping of the vena cava afterwards.

The prevalence of AKI is significantly higher in cardiac death donors than in brain death donors.[25] The majority of donors in our center experienced cardiac death, which may heighten the prevalence of AKI. With the development of organ donation, the recognition of brain death in our country, and the increasing numbers of brain death donors, the prevalence of AKI post-liver transplantation may decline.

According to the 2012 guidelines, AKI was divided into three stages.[11] There are many risk factors that influence the severity of AKI. For example, preoperative creatinine, cold ischemia duration, duration of surgery, and postoperative peak AST are all independent risk factors of AKI severity in the first week after liver transplantation. Cold ischemia time is longer in stage 3 AKI patients, suggesting a possible occurrence of ischemia-reperfusion injury.[26] The longer the liver is exposed to ischemia, the higher the levels of reactive oxygen species, superoxide anion, hydrogen peroxide, and hypoxanthine. A long surgery duration means a long ischemia duration, which can also result in severe AKI. AKI is associated with long ICU stay and mortality. Many studies have shown that severe AKI can lead to the development of CKD, which impacts long-term survival.[27-29] Thus, patients who have risk factors, such as a high level of pre-liver transplantation creatinine, longer cold ischemia duration and duration of surgery, and a high level of peak AST have high risk of severe AKI or are prone to chronic kidney disease. We should pay more attention to those patients and provide prophylactic measures.

The impact of AKI on short-term renal function was evidenced in our study. Approximately 20.4% of AKI patients still had abnormal renal dysfunction during the fourth week after transplantation, while 98.9% of non-AKI patients had normal renal function. A long duration of AKI significantly increases the risk of chronic kidney disease or ESLD. In our study, the 30-day mortality rate was 3.5% among AKI patients, lower than another study,[2] which may be due to different criteria of AKI. Barreto AG defined AKI according to Acute Kidney Injury Network (AKIN), while we used KDIGO criteria which is more often used. Besides, we excluded patients with renal insufficiency before liver transplantation.

In summary, there are many risk factors for AKI and its severity after liver transplantation. Patients with high risk should try to shorten the durations of surgery and cold ischemia. If possible, patients can consider piggyback liver transplantation. After liver transplantation, monitoring peak AST and ALT levels, adjusting immunosuppressive agents according to renal function in a timely manner, and avoiding nephrotoxic drugs may improve the outcomes of AKI patients.

Ethics Committee Approval: The study protocol was approved by the Medical Ethics Committee of the 302 Military Hospital, Beijing, China, and adhered to the Declaration of Helsinki. Organ donation was conducted legally, following local regulations.

Informed Consent: Informed consent for liver biopsy was obtained from patients upon HBV recurrence. All patients provided the written informed consents for their blood samples and clinical records to be used in this study, and the information was anonymized and de-identified prior to analysis.

Peer-review: Externally peer-reviewed.

Author Contributions: Concept - Y.G., D.Z., Z.L. ; Design - Y.G., D.Z., Z.L.; X.X.; Materials - H.L., Z.L.; Analysis and/or Interpretation - J.B.; Writing - Y.G., D.Z.

Acknowledgments: We would like to thank all of the patients enrolled in this study for their kind understanding and support.

Conflicts of Interest: The authors have no conflict of interest to declare.

Financial Disclosure: This work was supported by Tianqing liver disease research fund (Grant No. TQGB20170133) with Department of Liver Transplantation Center. The department disclaims responsibility for the analysis and conclusions.

REFERENCES

1. Meirelles Júnior RF, Salvalaggio P, Rezende MB, et al. Liver transplantation: history, outcomes and perspectives. Einstein. 2015;13(1):149-152. [CrossRef]
2. Barreto AG, Daher EF, Silva Junior GB, et al. Risk factors for acute kidney injury and 30-day mortality after liver transplantation. Ann Hepatol. 2015;14(5):688-694. [CrossRef]
3. Chawla LS, Eggers PW, Star RA, Kimmel PL. Acute kidney injury and chronic kidney disease as interconnected syndromes. N Engl J Med. 2014;371(1):58-66. [CrossRef]
4. Umbro I, Rossi M, Tinti F, et al. Stages of early acute renal dysfunction in liver transplantation: the influence of graft Function. Transplant Proc. 2012;44(7):1953-1955. [CrossRef]
5. Chen HP, Tsai YF, Lin JR, Liu FC, Yu HP. Incidence and outcomes of acute renal failure following liver transplantation: a population-based cohort study. Medicine. 2015;94(52):e2320. [CrossRef]
6. Lucey MR, Terrault N, Ojo L, et al. Long-term management of the successful adult liver transplant: 2012 practice guideline by the American Association for the Study of Liver Diseases and the American Society of Transplantation. Liver Transpl. 2013;19(1):3-26. [CrossRef]
7. Bahirwani R, Forde KA, Mu Y, et al. End-stage renal disease after liver transplantation in patients with pre-transplant chronic kidney disease. Clin Transpl. 2014;28(2):205-210. [CrossRef]
8. Karapanagiotou A, Kydona C, Dimitriadis C, et al. Acute kidney injury after orthotopic liver transplantation. Transplant Proc. 2012;44(9):2727-2729. [CrossRef]
9. Rossi AP, Vella JP. Acute kidney disease after liver and heart transplantation. Transplantation. 2016;100(3):506-514. [CrossRef]
10. Andrassy KM. Comments on KDIGO 2012 clinical practice guideline the evaluation and management of chronic kidney disease. Kidney Int. 2013;84(3):622-623. [CrossRef]
11. Kidney Disease: Improving Global Outcomes CKD Work Group. KDIGO 2012 clinical practice guideline for the evaluation and management of chronic kidney disease. Kidney Int Suppl. 2012;3:1-150.
12. Pham PT, Pham PC, Wilkinson AH. Renal function outcomes following liver transplantation and combined liver-kidney transplantation. Nat Clin Pract Nephrol. 2007;3(9):507-514. [CrossRef]
13. Chae MS, Kim Y, Chung HS, et al. Predictive role of serum cytokine profiles in acute kidney injury after living donor liver transplantation. Mediators Inflamm. 2018;2018:8256193. [CrossRef]
14. Bärthel E, Rauchfuss F, Hoyer H, Breternitz M, Jandt K, Settmacher U. The PRAISE study: a prospective, multi-center, randomized, double blinded, placebo-controlled study for the evaluation of iloprost in the early postoperative period after liver transplantation (ISRCTN12622749). BMC Surg. 2013;13(1):1. [CrossRef]
15. Khajuria A, Tay C, Shi J, Zhao H, Ma D. Anesthetics attenuate ischemia-reperfusion induced renal injury: effects and mechanisms. Acta Anaesthesiol Taiwan. 2014;52(4):176-184. [CrossRef]
16. Rueggeberg A, Boehm S, Napieralski F, et al. Development of a risk stratification model for predicting acute renal failure in orthotopic liver transplantation recipients. Anaesthesia. 2008;63(11):1174-1180. [CrossRef]
17. Belcher JM, Sanyal AJ, Peixoto AJ, et al. Kidney biomarkers and differential diagnosis of patients with cirrhosis and acute kidney injury. Hepatology. 2014;60(2):622-632. [CrossRef]
18. Angeli P, Ginès P, Wong F, et al. Diagnosis and management of acute kidney injury in patients with cirrhosis: revised consensus recommendations of the international club of ascites. J Hepatol. 2015;62(4):968-974. [CrossRef]
19. Junghare M, Ibrahim HN. Not all types of acute kidney injury are equal in the setting of liver transplantation. Liver Transpl. 2012;18(5):507-508. [CrossRef]
20. Umbro I, Tinti F, Scalera I, et al. Acute kidney injury and post-reperfusion syndrome in liver transplantation. World J Gastroenterol. 2016;22(42):9314-9323. [CrossRef]
21. Sun K, Hong F, Wang Y, et al. Venovenous bypass is associated with a lower incidence of acute kidney injury after liver transplantation in patients with compromised pretransplant renal function. Anesth Analg. 2017;125(5):1463-1470. [CrossRef]
22. Brescia MD, Massarollo PC, Imakuma ES, Mies S. Prospective randomized trial comparing hepatic venous outflow and renal function after conventional versus piggyback liver transplantation. PLoS ONE. 2015;10(6):e0129923. [CrossRef]
23. Yeh HC, Ting IW, Tsai CW, Wu JY, Kuo CC. Serum lactate level and mortality in metformin-associated lactic acidosis requiring renal replacement therapy: a systematic review of case reports and case series. BMC Nephrol. 2017;18(1):229. [CrossRef]
24. Tinti F, Melandro F, Umbro I, et al. Female gender and overestimation of glomerular filtration rate: independent predictors of acute kidney injury after liver transplantation. Clin Nephrol. 2020;93(2):92-98. [CrossRef]
25. Leithead JA, Tariciotti L, Gunson B, et al. Donation after cardiac death liver transplant recipients have an increased frequency of acute kidney injury. Am J Transplant. 2012;12(4):965-975. [CrossRef]
26. Jochmans I, Meurisse N, Neyrinck A, Verhaegen M, Monbaliu D, Pirenne J. Hepatic ischemia/reperfusion injury associates with acute kidney injury in liver transplantation: prospective cohort study. Liver Transpl. 2017;23(5):634-644. [CrossRef]
27. Palevsky PM, Liu KD, Brophy PD, et al. KDOQI US commentary on the 2012 KDIGO clinical practice guideline for acute kidney injury. Am J Kidney Dis. 2013;61(5):649-672. [CrossRef]
28. Sutherland SM, Byrnes JJ, Kothari M, et al. AKI in hospitalized children: comparing the pRIFLE, AKIN, and KDIGO definitions. Clin J Am Soc Nephrol. 2015;10(4):554-561. [CrossRef]
29. Xu X, Nie S, Liu Z, et al. Epidemiology and clinical correlates of AKI in Chinese hospitalized adults. Clin J Am Soc Nephrol. 2015;10(9):1510-1518. [CrossRef]