Hepatorenal Syndrome – AKI in Decompensated Liver Disease: Clinical Characteristics, Risk Factors, Ultrasound Applications, and Outcomes

Articoli originali

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ABSTRACT

Background. Acute kidney injury (AKI) is a common and serious complication in patients with decompensated liver disease (DLD), often resulting from ischemic acute tubular necrosis or hepatorenal syndrome. This study examines the role of biochemical markers and ultrasound parameters, such as right atrial pressure, right ventricular hypertrophy, inferior vena cava diameter, hepatic venous flow dynamics, left ventricular diastolic dysfunction, the E/e' ratio, renal peak systolic velocity, renal end-diastolic velocity, and renal resistive index (RI), in predicting AKI severity and outcomes.

Methods. A prospective observational study was conducted on 50 DLD patients with AKI, admitted to a tertiary care Hospital. Biochemical parameters including serum creatinine, bilirubin, and albumin along with ultrasound parameters were assessed. AKI was classified according to KDIGO criteria, and renal recovery and mortality were monitored. Diagnostic accuracy was evaluated through ROC analysis.

Results. 30% of patients had stage 3 AKI, with 60% of them being male (average age 54 ± 12 years). Stage 3 AKI was a significant predictor of mortality (OR 3.5, $p < 0.001$), along with renal resistive index (OR 2.8, $p = 0.003$). ROC analysis showed that serum creatinine and the E/e' ratio, along with the RI, were significant predictors for AKI severity and mortality. Renal recovery occurred in 58%.

Conclusion. The simultaneous assessment of clinical, biochemical, and ultrasound parameters enhances the prediction of AKI severity and patient outcomes in DLD. This approach facilitates earlier detection and better management of AKI in this population.

KEYWORDS: Hepatorenal syndrome, acute kidney injury, decompensated liver disease, risk factors, ultrasound

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Introduction

A large sector of hospitalized patients is commonly affected by Decompensated Liver Disease (DLD), which is characterized by ascites, portal hypertension, hepatic failure, and encephalopathy, and is frequently linked with acute kidney injury (AKI) as a consequence [1, 2]. AKI affects approximately 20-30% of hospitalized patients globally, contributing significantly to morbidity and mortality [3]. However, in patients with DLD, the incidence of AKI is notably higher, ranging from 20% to 50%, with mortality rates exceeding 60% in advanced stages [4, 5]. Two primary causes of AKI are related to hepatorenal syndrome (HRS) and non-HRS-related reasons [6]. 10–20% of patients with HRS-AKI are characterized by portal hypertension-induced splanchnic circulation blood pooling, systemic vasodilation, and substantial renal vasoconstriction [7]. Non-HRS causes include ischemic acute tubular necrosis (ATN), nephrotoxicity from drugs, sepsis-associated AKI, and prerenal azotemia from volume loss [8]. These mechanisms are affected by neurohormonal responses and systemic hemodynamic alterations [9].

In spite of advanced knowledge about HRS, renal failure is diagnosed too late through indicators such as serum creatinine [10]. In order to spot AKI in high-risk patients, non-invasive, more sensitive diagnostic techniques are required [11]. Biochemical evaluations and real-time imaging techniques have been combined in recent years, and multimodal ultrasonography provides a dynamic, non-invasive method of assessing kidney perfusion and systemic hemodynamics [12]. The combination of this method with traditional biochemical indicators may improve the early diagnosis of AKI in DLD patients [13].

Assessment of cardiac and renal functions is crucial for the prompt identification of AKI in people with DLD [14]. The E/E' ratio, right ventricular hypertrophy (RVH), right atrial pressure (RAP), and left ventricular diastolic dysfunction (LVDD) are critical cardiac measures for evaluating heart function [15–17]. Additionally, hepatic measurements like the diameter of the inferior vena cava (IVC) and the systolic reversal of hepatic venous flow offer crucial insights into the dynamics of hepatic blood flow [18]. When assessing renal function, renal Doppler ultrasonography tests, including the renal resistive index (RI), end-diastolic velocity (EDV), and peak systolic velocity (PSV), are useful in figuring out kidney perfusion [19].

Therefore, the main objectives of the study are to assess the severity of acute kidney injury using clinical characteristics and biochemical parameters with hepatic, renal and cardiac ultrasound in patients with DLD.

Materials and Methods

Study Design and Population

This prospective observational study was conducted at a tertiary care hospital between November 2023 and June 2024. The study included 50 adult patients aged 18 years or older, who were diagnosed with DLD and admitted with AKI. The primary objective was to identify clinical, biochemical, and ultrasound predictors of AKI severity and outcomes, including renal recovery and mortality, in patients with established AKI. Patients with a history of chronic kidney disease, pregnancy, or acute inflammatory conditions such as sepsis were excluded to focus on HRS-related AKI. Written informed consent was obtained from all participants, and the study was approved by the institutional ethics committee and conducted as per the revised Declaration of Helsinki (2008) guidelines.

Clinical and Ultrasound Assessments

A comprehensive clinical evaluation, including evaluation of liver and renal function as well as hemodynamic measures, was performed on all recruited patients upon admission. Within 24 hours

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after admission, standard laboratory tests were performed, including coagulation profiles, liver enzymes, serum bilirubin, serum creatinine, and complete blood count.
Using GE Voluson S8 ultrasound equipment, a thorough ultrasound assessment was conducted within 24 hours after hospital admission in addition to biochemical markers. Using point-of-care ultrasonography (POCUS), a nephrologist with specific expertise in renal, hepatic, and cardiac evaluation performed the ultrasound. Evaluations of cardiac, renal, and hepatic markers were included in the assessment. Right ventricular hypertrophy (RVH), right atrial pressure (RAP), renal peak systolic velocity (PSV), renal end-diastolic velocity (EDV), renal resistive index (RI), inferior vena cava (IVC) diameter, systolic reversal of hepatic venous flow, left ventricular end-diastolic diameter (LVEDD), and mitral E/E' ratio were among the particular ultrasound parameters that were measured. These metrics were selected because they offer important information on systemic hemodynamics and renal perfusion. As poor cardiac function can result in decreased renal perfusion, right atrial pressure (RAP) and right ventricular hypertrophy (RVH) can be indicators of cardiac function and its effect on renal blood flow.

Renal perfusion and vascular resistance were evaluated by renal Doppler measurements (PSV, EDV, and RI), which facilitate the detection of renal disease. When it comes to treating individuals with DLD, the Inferior Vena Cava (IVC) diameter offers valuable information on central venous pressure and fluid status. Increased right atrial pressure and decreased cardiac output may be signs of systolic reversal of hepatic venous flow, which reflects hemodynamic alterations in advanced liver illness and their impact on renal perfusion. Due to fluid overload and related cardiac dysfunction, patients with DLD frequently have decreased diastolic function and left ventricular filling pressures, which are reflected by the left ventricular end-diastolic diameter (LVEDD) and mitral E/E' ratio. The danger of congestion and its possible effects on renal function are evaluated with the aid of these measurements.

Data Collection

Patient information was gathered prior to and throughout the hospital stay. Laboratory data, clinical features, ultrasound readings, and demographic information were noted. At the time of admission, demographic and clinical information was gathered, including age, gender, comorbidities, and the cause of liver disease. Serum creatinine, urine output (mL/kg/hr), AST and ALT levels (U/L), serum bilirubin (mg/dL), albumin (g/dL), and electrolytes (sodium and potassium levels in mmol/L) were among the laboratory tests used to evaluate renal and liver function. The APACHE II score was also estimated, and coagulation indicators such as activated partial thromboplastin time (APTT, s), prothrombin time (PT, s), and international normalized ratio (INR) were evaluated.

During the hospitalization, outcomes like mortality and the use of diuretics, albumin, vasopressors, and dialysis were documented. Renal recovery was defined as the restoration of kidney function, indicated by serum creatinine levels returning to baseline or near-baseline values (less than 1.5 times the baseline) by the time of discharge. In addition, renal recovery required normalization of urine output (>0.5 mL/kg/hour) and the absence of the need for renal replacement therapy at discharge. Patients failing to meet these criteria were classified as non-recovering.

AKI Definition and Staging

The Kidney Disease Improving Global Outcomes (KDIGO) criteria, which depends on variation in serum creatinine and urine output, were used to identify and categorize AKI.
Stage 1 AKI: Serum creatinine rises to 1.5-1.9 times baseline or by ≥0.3 mg/dL in 48 hours.
Serum creatinine rises to 2.0-2.9 times baseline in stage 2 AKI.
Stage 3 AKI: Serum creatinine rises to 3.0 times the baseline level or renal replacement treatment is started.

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Statistical Analysis

Data were analyzed using SPSS version 26.0, employing descriptive statistics to summarize baseline characteristics. Continuous variables were reported as mean ± standard deviation or median with interquartile range (IQR), based on distribution. Univariate analysis used Student's t-test for normally distributed variables and Mann-Whitney U test for non-normally distributed data, while categorical variables were compared using chi-square or Fisher's exact test. Multivariate logistic regression assessed the combined influence of ultrasound, clinical, and laboratory markers on AKI prediction, with results reported as odds ratios (OR) and 95% confidence intervals (CI). ROC curves evaluated predictive accuracy.

Result

In the overall study population of 50 patients with decompensated liver disease, the mean age was 54 ± 12 years, with a male predominance (60% male vs 40% female). The most common etiology of liver disease was alcoholic liver disease (40%) and viral hepatitis (36%), followed by non-alcoholic fatty liver disease (24%). The patients also exhibited a variety of comorbidities, including hypertension (30%), diabetes mellitus (26%), cardiovascular disease (10%), and obesity (34%) as given in Table 1.

Parameter	Total no of patients n = 50 (%)
Age (years) (Mean ± SD)	54 ± 12
Gender	
Male	60%
Female	40%
Etiology of liver disease	
Alcoholic liver disease	40%
Viral hepatitis	36%
Non-alcoholic liver disease	24%
Co-morbidities	
Hypertension	30%
Diabetes Mellitus	26%
Cardiovascular Disease	10%
Obesity	34%

Table 1. General Characteristics of the Study Population.

AKI Stage Distribution represents the distribution of patients across the three stages of acute kidney injury (AKI) as given in Figure 1. In this cohort of patients with decompensated liver disease, 40% of the patients were categorized as having Stage 1 AKI, indicating early kidney injury. Both Stage 2 AKI and Stage 3 AKI were present in 30% of the patients each, showing a significant proportion of patients with more advanced kidney impairment.

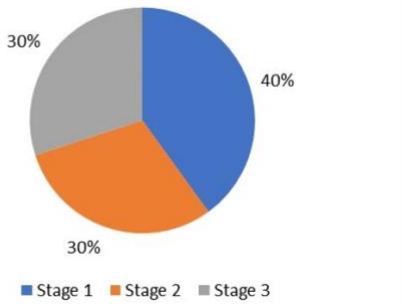

Figure 1. AKI Stage Distribution. In patients with decompensated liver disease, 40% of the patients were categorized as having Stage 1 AKI, indicating early kidney injury. Both Stage 2 AKI and Stage 3 AKI were present in 30% of the patients each, showing a significant proportion of patients with more advanced kidney impairment.

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Table 2 shows significant changes in laboratory parameters across AKI stages in decompensated liver disease (DLD) patients. Serum creatinine increased from 1.5 mg/dL in Stage 1 to 4.2 mg/dL in Stage 3 ($p < 0.001$), while urine output declined from 1.2 to 0.3 mL/kg/hr ($p < 0.001$). Serum bilirubin rose ($p = 0.02$), and albumin dropped ($p = 0.03$) as AKI progressed. Haemoglobin decreased from 12.5 to 10.5 g/dL ($p = 0.01$), WBC count increased from 7.0 to 9.5 $\times 10^3/\mu L$ ($p = 0.03$), and platelet count fell from 180 to 120 $\times 10^3/\mu L$ ($p = 0.02$). Sodium and potassium levels also changed significantly ($p = 0.01$, $p = 0.02$), while the APACHE II score increased ($p < 0.001$) with worsening AKI.

Parameter	Stage 1 AKI (n=20)	Stage 2 AKI (n=15)	Stage 3 AKI (n=15)	p-value
Serum Creatinine (mg/dL)	1.5 ± 0.3	2.8 ± 0.4	4.2 ± 0.5	< 0.001*
Urine Output (mL/kg/hr)	1.2 (0.9–1.5)	0.6 (0.4–0.8)	0.3 (0.1–0.4)	< 0.001*
AST (U/L)	45 (35–60)	48 (38–62)	50 (40–65)	0.25
ALT (U/L)	40 (32–55)	42 (33–58)	43 (34–60)	0.30
Serum Bilirubin (mg/dL)	1.2 ± 0.3	1.6 ± 0.4	2.0 ± 0.5	0.02*
Albumin (g/dL)	3.8 ± 0.4	3.3 ± 0.5	2.9 ± 0.6	0.03*
Sodium (mmol/L)	138 ± 3	136 ± 4	134 ± 5	0.01*
Potassium (mmol/L)	4.0 ± 0.3	4.5 ± 0.4	5.0 ± 0.5	0.02*
APACHE II Partial	10.0 ± 2.5	15.5 ± 3.2	22.0 ± 4.0	< 0.001*
Prothrombin Time (PT, s)	12.5 ± 1.2	13.0 ± 1.4	13.5 ± 1.5	0.15
INR	1.1 ± 0.1	1.3 ± 0.2	1.5 ± 0.3	0.02*
APTT (s)	30.0 ± 2.5	35.0 ± 3.0	38.5 ± 4.0	0.04*
Hemoglobin (g/dL)	12.5 ± 1.5	11.8 ± 1.2	10.5 ± 1.0	0.01*
WBC count ($10^3/\mu L$)	7.0 ± 2.0	8.5 ± 2.5	9.5 ± 3.0	0.03*
Platelet count ($10^3/\mu L$)	180 ± 40	150 ± 30	120 ± 25	0.02*

Notes: Data is expressed as mean ± SD. *p< 0.001 is significant.
AST-aspartate aminotransferase; ALT-alanine transaminase; APACHE-acute physiology and chronic health evaluation; INR-International Normalized Ratio; APTT-activated partial thromboplastin time; WBC-white blood cell.

Table 2. Comparison of Laboratory Parameters.

Table 3 compares ultrasound parameters across AKI stages in patients with decompensated liver disease. Right atrial pressure (RAP) increased from 5.0 mmHg in Stage 1 to 10.0 mmHg in Stage 3 ($p = 0.001$), indicating increased central venous pressure. Right ventricular hypertrophy (RVH) increased from 3.0 mm to 6.0 mm ($p = 0.003$), and left ventricular end-diastolic diameter (LVEDD) rose from 48.0 mm to 56.0 mm ($p = 0.02$). The E/E' ratio increased significantly from 8.0 to 16.0 ($p < 0.001$), reflecting worsening diastolic dysfunction.

Parameter	Stage 1 AKI (n=20)	Stage 2 AKI (n=15)	Stage 3 AKI (n=15)	p-value
Right Atrial Pressure (RAP, mmHg)	5.0 ± 1.2	7.5 ± 1.5	10.0 ± 2.0	0.001*
Right Ventricular Hypertrophy (RVH, mm)	3.0 ± 0.5	4.5 ± 0.7	6.0 ± 1.0	0.003*
Left Ventricular End-Diastolic Diameter (LVEDD, mm)	48.0 ± 5.0	52.0 ± 4.5	56.0 ± 6.0	0.02*
E/E' Ratio (Cardiac)	8.0 ± 1.0	12.0 ± 1.2	16.0 ± 1.5	0.001*

Notes: Data is expressed as mean ± SD. *P< 0.001 is significant.

Table 3. Comparison of cardiac Parameters.

Table 4 compares renal Doppler indices across different stages of AKI in patients with decompensated liver disease. Renal peak systolic velocity (PSV) decreased significantly from 120.0 cm/s in Stage 1 to 90.0 cm/s in Stage 3 ($p = 0.004$), reflecting reduced renal blood flow. Similarly, end-diastolic velocity (EDV) dropped from 45.0 cm/s to 25.0 cm/s ($p = 0.003$).

The renal resistive index (RI) increased from 0.60 to 0.85 ($p < 0.001$), indicating worsening vascular resistance. Additionally, inferior vena cava (IVC) diameter and systolic reversal of hepatic venous flow increased with AKI severity ($p = 0.001$ and $p = 0.008$, respectively).

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Parameter	Stage 1 AKI (n=20)	Stage 2 AKI (n=15)	Stage 3 AKI (n=15)	p-value
Renal Peak Systolic Velocity (PSV, cm/s)	120.0 ± 10.5	105.0 ± 12.0	90.0 ± 15.0	0.004*
Renal End Diastolic Velocity (EDV, cm/s)	45.0 ± 5.0	35.0 ± 6.0	25.0 ± 7.0	0.003*
Renal Resistive Index (RI)	0.60 ± 0.05	0.75 ± 0.06	0.85 ± 0.08	0.001*
Inferior Vena Cava (IVC) Diameter (mm)	15.0 ± 1.5	18.0 ± 1.8	21.0 ± 2.0	0.001*
Systolic Reversal of Hepatic Venous Flow (%)	5.0 ± 1.0	8.0 ± 1.2	12.0 ± 1.5	0.008*
Notes: Data is expressed as mean ± SD. *p< 0.001 is significant.				

Table 4. Comparison of Renal and hepatic Doppler Indices.

Renal recovery was observed in 58% of patients (29/50) by the time of hospital discharge. Among patients with Stage 1 AKI, 85% achieved renal recovery, while 60% of those with Stage 2 AKI and only 20% of Stage 3 AKI patients recovered renal function (shown in Figure 2).

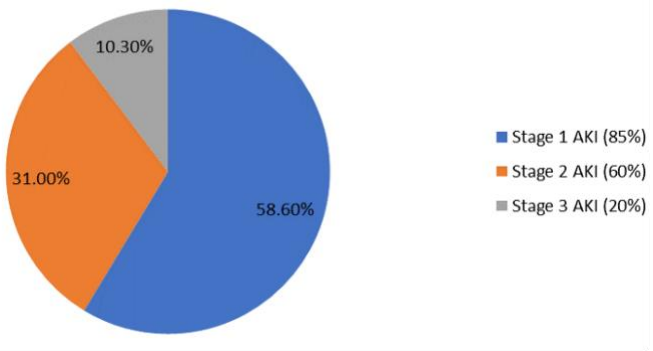

Figure 2. Renal Recovery by AKI stage at Hospital Discharge. Renal recovery was observed in 58% of patients (29/50) by the time of hospital discharge. Among patients with Stage 1 AKI, 85% achieved renal recovery, while 60% of those with Stage 2 AKI and only 20% of Stage 3 AKI patients recovered renal function.

Figure 3 illustrates the mortality distribution among patients with varying stages of acute kidney injury (AKI). The overall mortality rate was 11(22%), with 78% of patients surviving their AKI-related complications. The second pie chart details the mortality group: 14% of patients were in Stage 3 AKI, indicating a high mortality risk, while 8% were in Stage 2 AKI. This suggests that although mortality is less frequent in Stage 2, it still presents a significant risk compared to Stage 3.

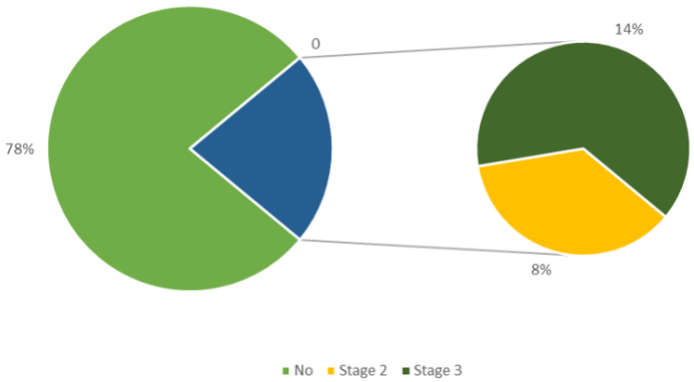

Figure 3. Mortality rate. The overall mortality rate was 11 (22%), with 78% of patients surviving their AKI-related complications. The second pie chart details the mortality group: 14% of patients were in Stage 3 AKI, indicating a high mortality risk, while 8% were in Stage 2 AKI. This suggests that although mortality is less frequent in Stage 2, it still presents a significant risk compared to Stage 3.

In the multivariate logistic regression model, renal resistive index (OR 2.5, 95% CI 1.4–4.1, p = 0.002), inferior vena cava diameter (OR 1.8, 95% CI 1.2–2.9, p = 0.015), and reduced urine output (OR 2.2, 95% CI 1.5–3.6, p = 0.001) were identified as independent predictors of AKI. Baseline serum creatinine also remained a significant predictor (OR 2.0, 95% CI 1.3–3.2, p = 0.01) (Table 5).

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Predictor	Odds Ratio (OR)	95% CI	p-value
Urine Output	2.2	1.5-3.6	0.001*
Baseline Serum Creatinine	2	1.3-3.2	0.01*
Inferior Vena Cava (IVC) Diameter	1.8	1.2-2.9	0.015*
Renal Resistive Index (RI)	2.5	1.4-4.1	0.002*
Notes:*p< 0.001 is significant			

Table 5. Multivariate Analysis for predictors of AKI.

Table 6 presents the multivariate analysis results for mortality predictors in patients with decompensated liver disease and AKI. Stage 3 AKI was the strongest independent predictor of mortality, with an odds ratio (OR) of 3.5 (95% CI: 2.1–5.8, $p < 0.001$). The renal resistive index (RI) also significantly predicted mortality (OR 2.8, 95% CI: 1.7–4.5, $p = 0.003$), indicating that higher renal vascular resistance correlates with increased risk. Additionally, larger inferior vena cava (IVC) diameter (OR 2.0), reduced urine output (OR 1.9), and elevated E/E' ratio (OR 2.3) were significant predictors, emphasizing the impact of renal and cardiac dysfunction on mortality outcomes. Systolic reversal of hepatic venous flow (OR 1.8) also indicated poorer prognoses.

Predictor	Odds Ratio (OR)	95% CI	p-value
Stage 3 AKI (Acute Kidney Injury)	3.5	2.1–5.8	0.001*
Renal Resistive Index (RI)	2.8	1.7–4.5	0.003*
Baseline Serum Creatinine	2.2	1.5–3.8	0.007*
Inferior Vena Cava (IVC) Diameter	2.0	1.3–3.4	0.015*
Urine Output	1.9	1.2–3.0	0.012*
E/E' Ratio (Cardiac)	2.3	1.5–3.7	0.009*
Systolic Reversal of Hepatic Venous Flow	1.8	1.1–3.2	0.021*
Notes: *p< 0.001 is significant.			

Table 6. Multivariate Analysis for Predictors of Mortality.

The distribution of treatment intensity across different stages of acute kidney injury (AKI) shows a marked increase in intervention as severity rises. Diuretic use decreased from 60% in Stage 1 to 40% in Stage 3 ($p = 0.318$), while albumin infusions rose from 30% to 70% ($p = 0.519$). Vasopressor usage increased from 10% to 50% ($p = 0.197$), and dialysis was required in 60% of Stage 3 patients ($p = 0.005$) (Table 7).

Treatment Type	Stage 1 AKI (n=20)	Stage 2 AKI (n=15)	Stage 3 AKI (n=15)	p-value
Diuretics	60%	50%	40%	0.318
Albumin Infusions	30%	50%	70%	0.519
Vasopressors	10%	30%	50%	0.197
Dialysis	0%	20%	60%	0.005*
Notes: *p< 0.001 is significant.				

Table 7. Distribution of Treatment Intensity Based on AKI Severity.

In Figure 4, the ROC (Receiver Operating Characteristic) curve illustrates the diagnostic performance of various biochemical and ultrasound parameters for AKI detection. The combined model shows the highest AUC (0.90), outperforming individual parameters like serum creatinine (AUC = 0.85) and renal resistive index (RI) (AUC = 0.82). Other parameters, such as urine output (AUC = 0.81) and the E/E' ratio (AUC = 0.80), also demonstrate good predictive value.

In Figure 5, the ROC curve evaluates the predictive performance of biochemical and ultrasound parameters for mortality, plotting the True Positive Rate against the False Positive Rate. The combined model achieves the highest AUC of 0.88, with serum creatinine at 0.85. The renal resistive index (RI) and E/E' ratio follow at 0.82 and 0.80, respectively, while hepatic venous flow has the lowest AUC of 0.76.

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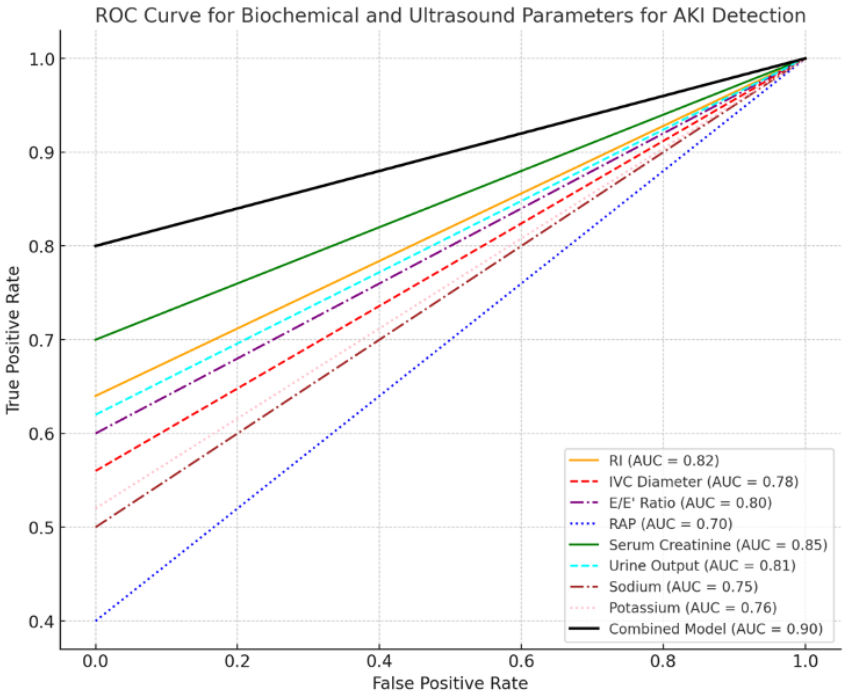

Figure 4. ROC Curve Analysis for Biochemical and Ultrasound Parameters for AKI prediction. ROC (Receiver Operating Characteristic) curve illustrates the diagnostic performance of various biochemical and ultrasound parameters for AKI detection. The combined model shows the highest AUC (0.90), outperforming individual parameters like serum creatinine (AUC = 0.85) and renal resistive index (RI) (AUC = 0.82). Other parameters, such as urine output (AUC = 0.81) and the E/E' ratio (AUC = 0.80), also demonstrate good predictive value.

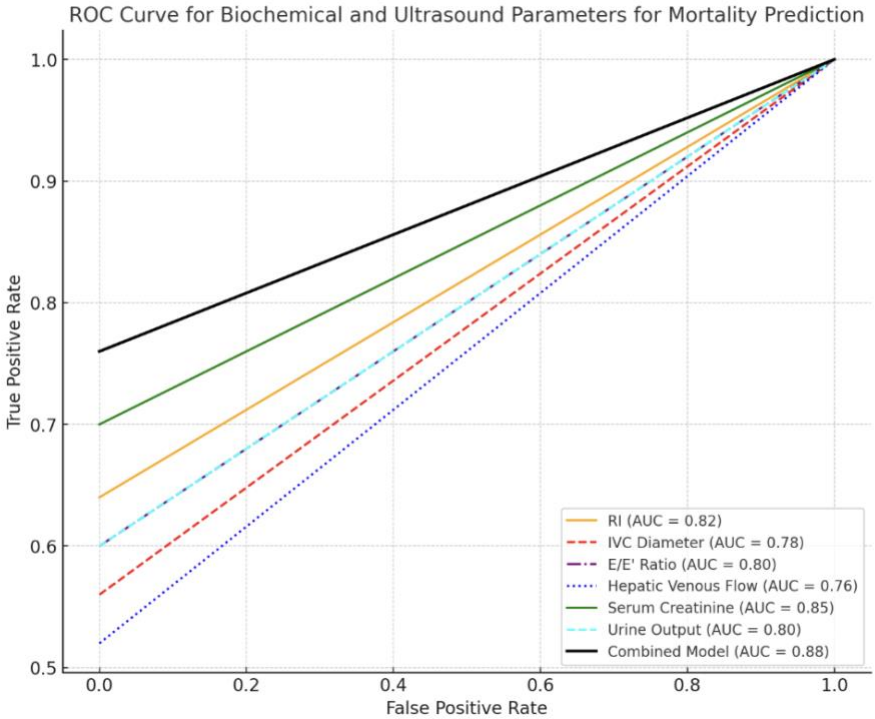

Figure 5. ROC Curve Analysis for Biochemical and Ultrasound Parameters for Mortality prediction. The ROC curve evaluates the predictive performance of biochemical and ultrasound parameters for mortality, plotting the True Positive Rate against the False Positive Rate. The combined model achieves the highest AUC of 0.88, with serum creatinine at 0.85. The renal resistive index (RI) and E/E' ratio follow at 0.82 and 0.80, respectively, while hepatic venous flow has the lowest AUC of 0.76.

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Discussion

Our results showed that 60% of DLD patients developed advanced AKI, consistent with Wong et al.'s finding of up to 50% AKI incidence in cirrhotic patients [20]. Angeli et al. demonstrated that AKI severity correlates with mortality, with Stage 3 AKI being the strongest predictor [10]. Serum creatinine increased and urine output declined, reflecting worsening renal function [21]. Ultrasound analysis revealed higher right atrial pressure, right ventricular hypertrophy, and left ventricular end-diastolic diameter, with elevated E/E' ratios indicating diastolic dysfunction, underscoring the critical cardiac-renal interaction in AKI development [17].

The alterations in renal Doppler indices, particularly the renal resistive index (RI), highlight the role of impaired renal hemodynamic in AKI progression. Elevated RI is linked with worsening renal vascular resistance and predicts AKI severity and mortality [19]. Our study also found that an increased inferior vena cava (IVC) diameter and systolic reversal of hepatic venous flow suggest venous congestion, consistent with findings in cirrhotic patients [11]. Increased IVC diameter reflects portal hypertension and hepatic venous congestion, contributing to renal hypoperfusion and vascular resistance.

Multivariate analysis identified Stage 3 AKI, elevated RI, baseline serum creatinine, and increased IVC diameter as independent predictors of mortality. Elevated RI emerged as a strong mortality predictor, echoing research showing RI as a key marker of poor outcomes in hepatorenal syndrome [22, 23]. Additionally, increased E/E' ratio, indicating cardiac dysfunction, further emphasizes the importance of cardiac stress in cirrhotic patients with AKI [10, 16]. IVC diameter and systolic reversal of hepatic venous flow were also significant mortality predictors. These parameters reflect portal hypertension and its systemic effects on renal and circulatory function.

In our study, elevated baseline serum creatinine (OR 2.2, p = 0.007) and renal resistive index (RI) (OR 2.8, p = 0.003) were significant mortality predictors. This aligns with findings by Surya et al. and Popov et al., who highlighted RI as a marker of renal dysfunction in cirrhotic patients [22, 24], and Ginès et al., who identified both RI and serum creatinine as key predictors of poor outcomes and mortality in hepatorenal syndrome [23].

Our study highlighted cardiac dysfunction as a major contributor to mortality in AKI and DLD patients, demonstrated by the significant rise in the E/E' ratio (OR 2.3, p = 0.009). Abd-El-Aziz et al. demonstrated the role of left ventricular diastolic dysfunction, reflected by an elevated E/E' ratio, in cirrhotic patients [16]. Wong et al. similarly found that left ventricular diastolic dysfunction, reflected by an elevated E/E' ratio, predicts mortality in cirrhotic patients with AKI [20]. Behera et al. confirmed that diastolic dysfunction exacerbates renal impairment in cirrhosis, worsening outcomes [17]. Inferior vena cava diameter (OR 2.0, p = 0.015) and systolic reversal of hepatic venous flow (OR 1.8, p = 0.021) were significant mortality predictors in our study, highlighting venous congestion. Banegas-Deras et al. demonstrated how point-of-care ultrasound parameters, such as IVC diameter and hepatic venous flow, play a crucial role in assessing venous congestion, portal hypertension, and AKI progression in cirrhotic patients [18]. Additionally, elevated INR and APTT in advanced AKI reflect worsening coagulopathy, consistent with findings from Garcia-Tsao et al. [11] and Moreau et al. [25]. Overall, our 22% mortality rate aligns with the 20-30% reported by Wong et al. [20] and Angeli et al. [10], who emphasized the role of systemic complications in cirrhotic patients with AKI.

The ROC curve analysis for biochemical and ultrasound parameters underscores the utility of combining multiple diagnostic factors to improve AKI detection and mortality prediction. In both scenarios, the combined models outperformed individual parameters, as demonstrated by Banegas-Deras et al., Onwuka et al., and Popov et al., suggesting an integrative approach enhances clinical decision-making [18, 19, 24]. For AKI detection, the combined model achieved the highest AUC of

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0.90, surpassing individual markers. Serum creatinine (AUC = 0.85) and the renal resistive index (AUC = 0.82) were the strongest predictors, confirming their reliability as kidney function indicators [18, 19, 24]. Urine output (AUC = 0.81) and the E/E' ratio (AUC = 0.80) also contributed valuable insights, while RAP (AUC = 0.70) and potassium (AUC = 0.76) showed lower predictive power. This variability highlights the need for comprehensive diagnostic models in AKI diagnosis [26, 27].

For mortality prediction, the combined model demonstrated superior performance with an AUC of 0.88. Serum creatinine remained the strongest individual predictor (AUC = 0.85), followed by RI (AUC = 0.82) and urine output (AUC = 0.80), as supported by Kellum et al. and Onwuka et al [19, 26]. While the E/E' ratio and IVC diameter performed well (AUC = 0.80 and 0.78), hepatic venous flow (AUC = 0.76) was less predictive, indicating its secondary role. These results emphasize that combining biochemical and ultrasound parameters provides a holistic assessment, leading to improved prediction outcomes [18].

Limitations

This study's limitations include small sample size, single-centre design, and potential institutional biases and specific patient characteristics, which may limit generalizability. Future research should involve larger, multicentre cohorts with extended follow-up and more detailed comorbidity analysis in AKI progression.

Conclusion

The analysis revealed significant correlations between AKI stages and various biochemical and ultrasound markers, such as the renal resistive index, inferior vena cava diameter, and cardiac function parameters. These markers closely correlate with patient outcomes, particularly the risk of mortality, with Stage 3 AKI identified as the strongest independent predictor of death. Integrating clinical, ultrasound parameters with biochemical and hemodynamic data offers valuable prognostic insights. This comprehensive approach enhances risk stratification, informing clinical decision-making and potentially improving patient management strategies.

Data availability

All data generated or analyzed during this study are included in this article. Further enquiries can be directed to the corresponding author

Abbreviations:

DLD: Decompensated Liver Disease; AKI: Acute Kidney Injury; HRS: Hepato Renal Syndrome; RAP: Right Atrial Pressure; RVH: Right Ventricular Hypertrophy; IVC: Inferior Vena Cava; LVDD: Left Ventricular Diastolic Dysfunction; E/E' ratio: Ratio of early mitral inflow velocity (E) and early diastolic mitral annular velocity (E'); PSV: Peak Systolic Velocity; EDV: End-Diastolic Velocity; RI: Resistive Index; CKD: Chronic Kidney Disease;

ATN: Acute Tubular Necrosis; AST: aspartate aminotransferase; ALT: alanine transaminase.

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