**Name of Journal:** *World Journal of Hepatology*

**Manuscript NO:** 64599

**Manuscript Type:** MINIREVIEWS

**Liver kidney crosstalk: Hepatorenal syndrome**

Nassar M *et al*. Hepatorenal syndrome

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**Received:** February 28, 2021

**Revised:** May 12, 2021

**Accepted:** July 30, 2021

**Published online:**

**Abstract**

The dying liver causes suffocation of the kidneys, a simplified way of describing the pathophysiology of hepatorenal syndrome (HRS). HRS is characterized by reversible functional renal impairment due to reduced blood supply and glomerular filtration rate secondary to increased vasodilators. Over the years, HRS has gained much attention and focus among hepatologists and nephrologists. HRS is a diagnosis of exclusion, and in some cases, it carries a poor prognosis. Different classifications have emerged to better understand, diagnose, and promptly treat this condition. This targeted review aims to provide substantial insight into the epidemiology, pathophysiology, diagnosis, and management of HRS, and shed light on various milestones of this condition up to our current understanding.

**Key Words:** Hepatorenal syndrome; Liver; Kidney; Crosstalk; Acute kidney injury

Nassar M, Nso N, Medina L, Ghernautan V, Novikov A, El-Ijla A, Soliman KM, Kim Y, Alfishawy M, Rizzo V, Daoud A. Liver kidney crosstalk: Hepatorenal syndrome. *World J Hepatol* 2021; In press

**Core Tip:** The dying liver causes suffocation of the kidneys, a simplified way of describing the pathophysiology of hepatorenal syndrome (HRS). This targeted review aims to provide a substantial insight of the epidemiology, pathophysiology, diagnosis, and management of HRS, and shed the light on various milestones of this condition up to our current understanding.

**INTRODUCTION**

***Incidence and prevalence***

Hepatorenal syndrome (HRS) has been a challenge for clinicians and patients for many years. It is imperative to have a proper understanding of risk factors, patient populations involved, and possible preventive measures to be taken to minimize the progression of this complicated clinical state.

Older and more recent studies have revealed that acute kidney injury (AKI) is diagnosed in almost 50% of cases of hospitalized cirrhotic patients, and HRS-AKI represents 11% to 20% of those cases[1]. HRS occurs in approximately 10% to 40% of patients with ascites and advanced liver cirrhosis[2,3], with a 1-year probability of developing HRS estimated to be 18% and a 5-year probability of 39%[4]. Fortunately, the prevalence of the syndrome is not elevated when no precipitating factors are detected. The most common precipitating events contributing to HRS development are infections, gastrointestinal hemorrhage, and large-volume paracentesis (LVP)[4,5].

AKI-HRS is associated with an increased risk of mortality by 30% during the hospital stay. A comprehensive meta-analysis study revealed mortality rates of 58% at 1 mo and 63% at 1-year[3]. Broader knowledge is needed to identify the predictors of HRS potentially and to stratify the individual risk score. Three independent predictors have been implicated on multivariate analysis: no evidence of enlarged liver, elevated plasma renin activity, and hyponatremia[5].

**Pathophysiology and progression of HRS**

HRS is a reversible functional renal impairment seen in hepatic cirrhosis with portal vein hypertension and is caused by multiple pathophysiological changes[6]. Renal dysfunction commonly occurs in cirrhotic patients, and is associated with high morbidity and mortality[5].

Historically, there were two types of HRS described. Type 1 was defined as a fast deterioration of renal function over 2 weeks with a serum creatinine level > 2.5 mg/dL and type 2, described as a subtle impairment over months. According to the more recent definition proposed by the Acute Kidney Injury Network in 2007 and supported by the International Club of Ascites (ICA) and Acute Dialysis Quality Initiative in 2011, HRS was divided into subgroups based on the underlying pathologic process[1]: HRS-AKI and non-HRS AKI. The distinction between these is that HRS-AKI is a functional renal impairment that is reversible with liver transplantation, and non-HRS AKI is a structural pathology of the renal parenchyma caused by various injuries. ICA specific criteria for HRS-AKI were defined as an increase in serum creatinine of ≥ 0.3 mg/dL or ≥ 1.5 times baseline creatinine or 50% increase within 48 h from baseline, no response to diuretic discontinuation, the presence of cirrhosis with ascites, no evidence of shock, no history of administering nephrotoxic medications, and no signs of organic renal disease[3,5].

Several mechanisms are involved in the pathophysiology of HRS, such as circulatory dysfunction and splanchnic arterial vasodilation, increased vasoconstrictor effects on renal vasculature, cardiac impairment, systemic inflammation, and adrenal insufficiency[1]. Portal hypertension in cirrhosis causes a structural strain on the endothelium leading to the release of endogenous vasodilators like nitric oxide, prostacyclin, carbon monoxide, and endocannabinoids[5,7]. Gut bacterial translocation in the mesenteric lymph nodes and then into the bloodstream, along with the nitric oxide and other vasodilators, also contributes to intense splanchnic vasodilation and pooling of large plasma volume into the splanchnic vascular bed[2,4]. This creates low effective circulatory volume, which stimulates the baroreceptors in the carotid body and aortic arch. Counterregulatory systemic vasoconstrictor pathways, such as the sympathetic nervous system, renin-angiotensin-aldosterone system (RAAS), and the non-osmotic release vasopressin, will be triggered[6,8]. Consequently, hyperdynamic circulation occurs with increases in cardiac output, heart rate, sodium and water retention, renal vasoconstriction leading to the development of ascites and subsequent renal dysfunction. RAAS and vasopressin act on sodium and exacerbate free water retention, further worsening the developing ascites and aggravating renal impairment[1].

In incipient stages, the kidneys maintain an adequate glomerular filtration rate (GFR), due to renal prostaglandins, which keep the afferent arterioles dilatated. However, cirrhosis progression intensifies both splanchnic and systemic vasodilation and contributes to decreased mean arterial pressure, prolonged renal vasoconstriction with reduced renal blood flow, and GFR[5]. Overall, a state of renal hypoperfusion occurs. Therefore, HRS is a prerenal type of renal failure which is not responsive to fluids.

Cardiac dysfunction in HRS is caused by the diseased liver itself and less commonly by the same etiologic factor of the cirrhosis (*e.g.*, alcohol). Myocardial impairment is complex and has several contributory mechanisms: increased neurohumoral activity leading to myocardial hypertrophy and fibrosis with affected relaxation and inhibitory effects of the cytokines on the ventricular function[6]. Generally, inotropic and chronotropic functions become altered in hepatocardiorenal syndrome[9].

Non-infectious systemic inflammatory response syndrome was identified in almost half of the patients with AKI-HRS[5]. On the other hand, HRS is often preceded by bacterial infections. Inflammation in cirrhosis is induced by macrophage activation, oxidative stress, and inflammatory molecules[9]. Pathogen-associated molecular patterns emerge from translocation of the gut bacteria and damage-associated molecular patterns from the damaged hepatocytes. In turn, these inflammatory molecules activate cytokine release, leading to increased vasodilator production, with the result being reduced systemic arterial resistance and mean arterial pressure[6].

Relative adrenal insufficiency (RAI) is observed in less than half of the patients with advanced cirrhosis and may develop HRS. The mechanisms are not well established; however, depletion of the substrates for cortisol production and dysfunction of the hypothalamus-pituitary axis by the pro-inflammatory cytokines were implied[6]. Other mechanisms were theorized to contribute to the HRS, but mainly the hepatorenal reflex. The hepatorenal reflex is thought to be the result of abnormal hepatic blood flow directly affecting kidney hemodynamics. Evidence to support this theory is strengthened by the transjugular intrahepatic portosystemic shunt placement, leading to the HRS's amelioration by reducing portal hypertension[8].

Reduction in GFR and decreases in renal blood flow progress along with the degree of cirrhosis. Objective evidence that renal impairment in cirrhotic patients is functional includes: no evidence of morphological changes and largely preserved tubular function on kidney biopsy; resolution of AKI-HRS following liver transplant; and successful cadaveric transplantation of kidneys from patients with HRS[1] (Figure 1).

**HRS Diagnosis**

The diagnostic criteria for the HRS were first developed in 1994, and since then, it has undergone multiple modifications[10]. In previous years, AKI in cirrhotic patients was defined as a serum creatinine level of ≥ 1.5 mg/dL[11]. The latest guidelines of the ICA reveal that the definition of AKI in this population has changed based on modifications of the Kidney Disease Improving Global Outcomes (KDIGO) criteria[12]. The removal of this static value has led to earlier identification of this condition in patients with chronic liver disease (CLD)[12].

AKI is now defined as an increase of serum creatinine of ≥ 0.3 mg/dL within 48 h and/or increase of ≥ 50% from the patient's baseline within 7 d (or within the past 3 mo before admission if a value within the previous week is not available). Furthermore, the ICA classifies AKI in 3 stages based on serum creatinine levels, stage 1 when there is an increase of ≥ 0.3 mg/dL or an increase of ≥ 1.5-fold to 2-fold from baseline; stage 2 when there is an increase of > 2 fold to 3-fold from baseline; and stage 3, when there is an increase of > 3-fold from baseline or serum creatinine ≥ 4.0 mg/dL with an acute increase ≥ 0.3 mg/dL or the initiation of renal replacement therapy (RRT)[11].

The use of urine output as a criterion for AKI in CLD was subsequently removed[11]. Despite this fact, in a retrospective study, Amathieu *et al*[13] found that the addition of urine output as a criterion, along with serum creatinine for identification of AKI in patients with CLD, showed increased sensitivity for identification of this pathology, and that the presence of transient oliguria was associated with an increase in mortality rates[13]. Therefore, an acute decrease in urine output should be considered, particularly in patients with transient oliguria in this population.

HRS is diagnosed when a patient with cirrhosis and ascites has stage ≥ 2 AKI per the ICA guidelines as above, has no response to diuretic withdrawal or to a trial of treatment with albumin for volume expansion (1 g/kg per day with a maximum of 100 g/d) for a total of 2 d, and has no evidence of other etiologies causing kidney injury (*i.e.* absence of shock, no recent use of nephrotoxic drugs, no macroscopic signs of structural kidney injury, such as the presence of proteinuria, microhematuria, or abnormal findings on renal ultrasonography)[10,12,14,15].

The HRS was previously classified as HRS-type 1 and HRS-type 2, based on the acuity of kidney function deterioration. HRS-type 1 was defined as a doubling of serum creatinine above 2.5 mg/dL within 2 wk, and type 2 was defined as a slower increase in serum creatinine to a value > 1.5 mg/dL. These definitions have been renamed from HRS-type 1 to HRS-AKI and HRS-type 2 to HRS-chronic kidney disease[12].

New biomarkers have been identified for HRS diagnosis, including the urinary neutrophil gelatinase-associated lipocalin (NGAL) and the serum cystatin C. The use of these biomarkers has been shown to help diagnose early HRS and prognostic assessment in patients with decompensated cirrhosis[16]. A systematic review by Puthumana *et al*[17] revealed that both interleukin (IL) 18 and NGAL might be useful in the differentiation between AKI due to acute tubular necrosis (ATN) and HRS. These and other markers have not been included in the diagnostic criteria at the time of this review, but might be considered in the future.

**HRS Prevention**

A proper understanding of HRS's underlying pathophysiology is crucial in preventative strategies used in today's clinical practice. Discussed below are some strategies found beneficial for the prevention of HRS. All strategies' focus revolves around reversing the poor perfusion to the kidney due to a combination of renal vessels' constriction and decreased renal blood flow in response to systemic vasodilation.

***Role of diuretics***

Diuretic therapy may cause intravascular volume contraction and result in compensatory vasoconstriction, further predisposing patients to worsening of an already impaired renal function. In severely decompensated patients, diuretic therapy may induce HRS. The current recommendation for patients with ascites is to receive spironolactone treatment not exceeding 400 mg daily and divided doses of Furosemide not exceeding 160 mg daily. In hospitalized patients, the addition of albumin to diuretic regimens may prevent diuretic-induced changes in creatinine and BUN[18].

Large-volume paracentesis can lead to deterioration of kidney function. Plasma renin activity and baseline creatinine measurements, and daily monitoring should be performed and help identify patients deemed at high risk of developing post-paracentesis HRS. Such patients should receive supplementation with albumin, recommended dosing 6-8 gm/L of ascitic fluid removed[19].

***Spontaneous bacterial peritonitis***

It is a known fact that SBP is a common precipitant of HRS. Prompt recognition and treatment of SBP and managing the patient in a monitored setting are crucial in preventing HRS development. For patients with impaired renal function and bilirubin levels of > 4 mg/dL, IV albumin infusion at 1.5 mg/kg should be initiated[20].

***Rifaximin***

In a study by Ibrahim *et al*[21], published in the European Journal of Gastroenterology and Hepatology, prolonged therapy with Rifaximin showed benefits due to decreased cirrhosis-related complications, SBP, and recurrent hepatic encephalopathy, and also hemodynamic and renal improvement in patients with alcoholic hepatitis. Furthermore, patients on Rifaximin therapy for 12 weeks showed more stable renal function than placebo[21].

Finally, another study by Dong *et al*[22] reports a lower incidence of acute renal injury in patients treated with Rifaximin for at least 90 d.

**Differential Diagnoses**

HRS-AKI is considered a diagnosis of exclusion, and the ICA defines it as: AKI (an increase in serum creatinine of 0.3 mg/dL or more within 48 h) in the setting of cirrhosis and ascites, with failure to improve after 48 h of diuretic withdrawal and volume expansion with albumin, in the absence of shock, nephrotoxic drugs, and signs of structural kidney injury (proteinuria > 500 mg/d, microhematuria > 50 RBC/HPF, or abnormal renal imaging)[23-25].

AKI is reported in about 20%-30% of hospitalized cirrhotic patients[24,26], with 6-fold higher mortality[26], and although HRS is unique to cirrhosis, AKI in cirrhotic patients can be due to other causes, including prerenal azotemia and ATN[23,24]. Other causes like glomerulonephritis and post-renal AKI should also be considered[24]. As these causes differ markedly in their treatment options and prognosis, early differentiation is key to improving outcomes[23,24,27].

In studies involving cirrhotic patients, hypovolemic AKI was reported as the most common cause of AKI stage IA (stage I with sCr < 1.5 mg/dL), which has better survival (90 d survival rate of 82%) than AKI stage IB (stage I with sCr ≥ 1.5 mg/dL) (90 d survival rate of 55%), where HRS and ATN were more frequent[23]. It was also reported that acute, chronic liver failure was more likely with AKI stage IB[24].

Prerenal AKI: Renal hypoperfusion without tubular or glomerular lesion usually occurs in GI bleeding, dehydration, and/or diuretic use[28]. It is differentiated from the other causes of AKI by improvement after volume replacement with albumin and/or fluids and diuretics withdrawal[23,29].

ATN: Tubular cell necrosis is usually the result of an ischemic (in the setting of shock) or toxic (*e.g.*, nephrotoxic drugs) insult[28]. As with HRS, there is no improvement with withdrawing diuretics and giving albumin[29]. Intrinsic AKI is excluded using the ICA-HRS criteria[29].

The Use of UNa and FeNa to differentiate causes of AKI is deemed less useful in cirrhosis: Pre-renal AKI and HRS have urinary Na excretion < 20 mEq/L and FeNa < 1%, Whereas ATN classically has UNa > 40 mEq/L and FeNa > 1%[28].

Limitations to this rule are that patients with cirrhosis can be on diuretics, which will falsely increase UNa[28]. Also, as cirrhosis is a sodium acid state, some ATN cases were reported to have FeNa < 1%[24,28].

The presence of urinary casts may not be helpful either in cirrhosis, as granular and epithelial cell casts (classically seen in ATN) can be present as nonspecific findings in cirrhosis due to hyperbilirubinemia[28].

The use of urinary biomarkers to differentiate the various AKI etiologies in cirrhotic patients is promising: NGAL (a glycoprotein that is overexpressed by injured kidney tubular epithelia) is the most studied, but other urinary markers, like IL-8, albumin, and liver fatty acid-binding protein, have also been investigated and show similar performance[24]. Higher levels were found in intrinsic AKI/ATN, compared to HRS. Meanwhile, prerenal had the lowest levels[23,24]. One study that was done on 94 patients with decompensated cirrhosis showed a median urine neutrophil gelatinase-associated lipocalin (uNGAL) of 1217.50 in ATN, 465.00 in HRS, and 95.50 in prerenal AKI (*P* < 0.001)[23]. It also determined the optimal cutoffs for the various diagnoses to be: ATN likely with uNGAL more than 650 ng/mL (100% sensitivity, 83.78% specificity), HRS likely with uNGAL between 299-650 ng/mL (87.9% sensitivity, 96.3% specificity), while prerenal is likely with uNGAL less than 299 ng/mL[23].

uNGAL and IL-8 were also found to predict prognosis, where the higher the biomarker levels, the higher the short-term mortality[23,24].

To be noted that leucocytes can also produce uNGAL. Hence levels of uNGAL can be elevated in the setting of urinary tract infection and should be cautiously interpreted in these settings[24].

***HRS treatment***

The definitive treatment for HRS is liver transplant[30]. The goal of therapy is to maintain adequate kidney function before the patient undergoes a liver transplant, which can be achieved by optimizing the mean arterial blood pressure and cardiac output[31,32]. Patients should be screened thoroughly for signs of infection, and if necessary, empiric antibiotic therapy should be started[33]. Therapy for the treatment of viral hepatitis, if present, should be continued. Diuretic therapy should be stopped, as these have been identified to be a provoking factor for HRS development.

Patients should receive volume expansion with albumin, as it has shown to significantly reduce mortality in this population, which has not been seen with other volume expanders. The protective effects of albumin are thought to be also driven by its anti-inflammatory and antioxidative effects [5]. Several vasodilators have been studied in the past as potential treatment options for HRS, including dopamine, prostaglandins, and endothelin receptor blockers, which have not been effective in improving kidney function[34,35]. The use of vasoconstrictors, such as terlipressin, norepinephrine, or a combination of midodrine, octreotide, and albumin showed improved renal function and are considered the first line of therapy for HRS[36,37]. The rationale behind its use is the reversal of splanchnic vasodilatation thought to cause renal impairment in this population. The choice of therapy depends on different factors, including which drugs are available at the treatment time, if the patient is admitted to the intensive care unit or medical floors, and if they qualify for a liver transplant[32].

In patients who have no response to pharmacological alternatives, non-pharmacological approaches should be considered. This includes transjugular intrahepatic portosystemic shunt, RRT, and molecular adsorbent recirculating system (MARS)[33].

***Vasoconstrictive therapy***

**Terlipressin and albumin:** Terlipressin (a vasopressin analog) and albumin are the most effective medical therapy for HRS[30]. It has been associated with reducing mortality and increased renal function in patients with type 1 HRS (HRS-AKI per new definition)[38]. It is the most commonly used combination of vasoconstrictive agents (however, not available worldwide) with efficacy ranging between 25%-75%[36]. Several studies have compared the efficacy of albumin alone *vs* albumin combined with terlipressin, showing that their combination is significatively more efficacious[39].

Terlipressin should be administered either by intravenous bolus (0.5-1 mg every 4-6 h) or continuous infusion with an initial dose of 2 mg/d. If there is no appropriate response to therapy (defined as a decrease of at least 25% of creatinine levels), the intravenous bolus dose may be increased up to 2 mg every 4 h, or the continuous infusion increased to a maximum of 12 mg/d. Albumin should be administered by intravenous bolus for the first 2 d, with doses of 1 g/kg (with a maximum dose of 100 g/d) and later continued with 25-50 g/d until terlipressin therapy is stopped[32,36].

Terlipressin has been associated with an increased risk of cardiovascular events and ischemia induction[32,36,38,40]. However, it has a relatively good safety profile as adverse events are reported in < 1% of patients[41]. Factors that help determine response to therapy are increased mean arterial pressure of ≥ 5 mmHg, and decreased serum bilirubin levels to < 10 mg/dL on day 3 of therapy[42]. In a recent phase 3 trial conducted by Wong *et al*[43], the combination of terlipressin and albumin was reported to be significantly more effective when compared to placebo. However, its use was associated with significant adverse events, including respiratory failure.

**Norepinephrine and albumin:** Norepinephrine is an acceptable alternative to terlipressin[30]. It is used as a continuous intravenous infusion rate of 0.5 mg/h to 3 mg/h[30]. Its use is limited as the patient needs a central venous catheter for its administration, therefore, it is usually administered in the intensive care setting[33]. Terlipressin is superior to norepinephrine at decreasing RRT's need and increasing survival in this population[44].

**Midodrine, octreotide, and albumin:** The combination of midodrine, octreotide, and albumin improves hemodynamics, leading to increased GFR and decreased mortality[45,46]. Midodrine is dosed at 7.5 mg every 8 h, and can be increased to a maximum dose of 15 mg every 8 h. Octreotide can be given as a continuous infusion at a rate of 50 μg/h or subcutaneously at doses of 100 μg to 200 μg every 8 h. Albumin is added to an intravenous bolus, with doses of 1 g/kg[32]. In a study by Wang *et al*[47], terlipressin was reported to be superior to octreotide for improved kidney function but did not show superiority to norepinephrine. This combination is usually used in countries where terlipressin is not yet available[36]. The use of this combination is acceptable in non-intensive care settings, such as inpatient medical floors[30].

***Non-vasoconstrictive therapy***

**Transjugular intrahepatic portosystemic shunts:** Transjugular intrahepatic portosystemic shunts (TIPS) has been shown to improve renal function in patients with HRS[48]. However, its use is limited mainly due to its complications, including a higher incidence of hepatic encephalopathy[49]. A study by Song *et al*[50], in which 128 patients with HRS were treated with TIPS, revealed a pooled rate of hepatic encephalopathy of 49%, with a pooled rate of renal function improvement of 93% and 83% in HRS type 1 and 2, respectively (HRS-AKI and HRS-CKD per new definitions).

**Renal replacement therapy:** The indications for RRT in patients with HRS are the same as those without it[10]. RRT may be effective until liver transplantation is available[36,51]. In a retrospective study by Sourianarayanane *et al*[52], where 380 patients were reviewed, there was no significant improvement in survival rates in patients undergoing RRT who did not receive liver transplantation. Other studies suggest that mechanical ventilation might play a role as an independent risk factor for worse outcomes at the time of initiation of RRT. Furthermore, RRT initiation in these patients might be futile compared to those not mechanically ventilated[53].

**Molecular adsorbent recirculating system MARS:** Albumin dialysis with MARS has been shown to decrease creatinine levels in patients with HRS. However, there have been no significant changes in survival rates among patients receiving this treatment[36,51,54].

**Emerging therapies:** Serelaxin, a recombinant human relaxin 2, is a molecule that acts on renal vasculature, increasing perfusion. It has been suggested that Serelaxin could be used for the treatment for HRS, given that in animal models, it has been shown to exert renal vasodilatation[5].

Pentoxifylline is a phosphodiesterase inhibitor that has also been suggested as a potential therapeutic option. A small study showed that it is safe to use along with albumin, midodrine, and octreotide[55]. However, further studies are needed to evaluate the effectiveness of these therapies.

**Mortality/Comorbidity of HRS**

HRS is a significant illness linked to poor prognosis in patients with cirrhosis[56]. Patients with Type I HRS have a mortality rate of 80% 2 wk after confirmation of the disease, increasing to 100% within months. Patients with type II HRS have a median survival of 3-6 mo after presentation[57]. In 24%-47% of patients with chronic ascites and liver disease, RAI is observed, influencing HRS progression[58].

**CONCLUSION**

***Prognosis after intervention for HRS***

The most crucial objectives in HRS treatment is to reverse AKI and enable additional medications to be provided to the patients before orthotopic liver transplant (OLT). A recently published study reported that patients with HRS who received treatment before OLT had a significantly higher 3-year survival rate, lower incidence of renal dysfunction and of serious and acute infections, and lesser number of days in the ICU and the hospital compared to patients who received transplants without HRS and normal renal function[59]. HRS is closely linked to hyponatremia, and when serum sodium levels fall below 130 mmol/L, the incidence of HRS due to hyponatremia increases[60]. Raising serum sodium levels leads to hemodynamic recovery. OLT is the best treatment strategy for HRS[61]. Most clinicians use the Model for End-Stage Liver Disease-Sodium (MELDNa) score to determine the prognosis of CLD, especially in cirrhosis. In patients with cirrhosis, the MELDNa score was superior to the MELD score to predict postoperative 90-d mortality[62].

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**Footnotes**

**Conflict-of-interest statement:** The authors confirm the absence of personal and financial interests impacting the outcomes of this research study.

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**Manuscript source:** Invited manuscript

**Peer-review started:** February 28, 2021

**First decision:** May 2, 2021

**Article in press:**

**Specialty type:** Gastroenterology and hepatology

**Country/Territory of origin:** United States

**Peer-review report’s scientific quality classification**

Grade A (Excellent): 0

Grade B (Very good): B

Grade C (Good): 0

Grade D (Fair): 0

Grade E (Poor): 0

**P-Reviewer:** Lenz K **S-Editor:** Gao CC **L-Editor:** Filipodia **P-Editor:**

**Figure Legends**



**Figure 1 Pathophysiology of hepatorenal syndrome.** Figure created with BioRender.com. RAAS: Renin-angiotensin-aldosterone system; SNS: Sympathetic nervous system.