Bile Cast Nephropathy: A Comprehensive Review

Manoj R. Somagutta 1, 2, Molly S. Jain 3, 5, Maria Kezia Lourdes Pormento 5, 2, Siva K. Pendyala 1, 2, Narayana Reddy Bathula 1, 2, Nagendra B. Jarapala 5, 2, Ashwini Mahadevaiah 6, 2, Nayana Sasidharan 7, 2, Mohamed A. Gad 8, 7, Greta Mahmutaj 9, 7, Namrata Hange 10, 2

1. Department of Medicine and Research, Avalon University School of Medicine, Willemstad, CUW 2. Department of Research, California Institute of Behavioral Neurosciences & Psychology, Fairfield, USA 3. Medicine, Saint James School of Medicine, Park Ridge, USA 4. Medicine, Atenso de Manila School of Medicine and Public Health, Quezon City, PHIL 5. Department of Medicine, Atlantic University School of Medicine, Gross Islet, LCA 6. Department of Medicine, Jagadguru Sri Shivarathreshwara (ISS) University, Mysore, IND 7. Department of Medicine, Academy of Medical Sciences, Trivandrum, IND 8. Department of Family and Community Medicine, Saint George’s School of Medicine, Saint George’s, GRD 9. Department of Medicine, The University of Medicine, Tirana, Tirana, ALB 10. Public Health, Eurasian Cancer Research Council, Mumbai, IND

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Abstract
Bile cast nephropathy (BCN) or cholemic nephropathy (CN) is an acute renal dysfunction, including acute kidney injury (AKI) in the setting of liver injury. It is a common phenomenon in patients with liver disease and is associated with significant morbidity and mortality. CN is characterized by hemodynamic changes in the liver, kidney, systemic circulation, intratubular cast formation, and tubular epithelial cell injury. CN has been overlooked as a differential diagnosis in chronic liver disease patients due to more importance to hepatic injury. However, frequent and considerable reporting of case reports recently has further investigated this topic in the last two decades. This review determines the evidence behind the potential role of bile acids and bilirubin in acute renal dysfunction in liver injury, summarizing the implied pathophysiology risk factors, and incorporating the therapeutic mechanisms and outcomes.

Categories: Internal Medicine, Gastroenterology, Nephrology
Keywords: acute kidney injury, bile acid, bilirubin, cholemic nephropathy, bile cast nephropathy and renal failure

Introduction And Background
The term bile cast nephropathy (BCN), also known as cholemic nephropathy, icteric nephrosis, or cholemic nephrosis, is described as acute renal dysfunction, including acute kidney injury (AKI) in the setting of liver injury [1]. Quincke first reported it in 1899 during autopsy examinations of patients with acute jaundice and renal insufficiency. BCN is a multidimensional entity resulting in tubular and interstitial inflammation, tubular obstruction, direct bile salt-induced tubular toxicity, and altered renal hemodynamics [2, 5]. The attribution of AKI to bile acids and bilirubin is debatable due to bilirubin’s protective effects [1, 4]. This topic was actively discussed in the early 1900s but somehow not well investigated, contributing to its limited appearance in the current medical literature [1, 4]. The probable reasons it was overlooked may be because of a lack of consensus in the mechanism of the CN and diagnostic modalities in confirming the diagnosis [1, 3].

The AKI in cholestatic liver dysfunction is usually linked with other unfavorable factors such as hypovolemia, endotoxemia, and exposure to nephrotoxins [5]. On the other hand, the AKI in chronic liver injury patients is frequently attributed to hepatorenal syndrome (HRS), which is characterized by alternating intrarenal vasoconstriction and splanchnic vasodilation leading to functional and hemodynamic changes in the kidney [2, 5, 6]. HRS could be described as type 1 and type 2. Type 1 HRS is a rapid renal failure with a serum creatinine level rising greater than 2.5 mg/dL in less than two weeks and is known for causing AKI. On the contrary, type 2 HRS is defined as a slower moderate decline in renal function with serum creatinine levels ranging between 1.5 and 2.5 mg/dL resulting in refractory ascites [7]. The definitive diagnosis of BCN is made by renal biopsy. However, the presence of impaired coagulation profile in most liver injury patients at the time of presentation makes kidney biopsy almost impracticable to perform, thus posing a diagnostic challenge [1, 2, 6]. For all these reasons, BCN is frequently overlooked as a differential diagnosis of AKI in obstructive jaundice patients. However, van Slambrouck et al. suggest a notable overlap between the two entities as the reason for AKI [5]. Moreover, several case reports have been reported where patients with suspected BCN treated presumptively have shown striking outcomes. Further, frequent and considerable reporting of case reports in the last two decades has yielded the need for further investigation in this topic.

BCN is underdiagnosed and is witnessed as a neglected injury found in the autopsy of patients with hyperbilirubinemia and renal dysfunction. The pathophysiology of AKI in the setting of hyperbilirubinemia is multifactorial and involves a wide range of mechanisms. This review aims to determine the evidence behind the potential role of bile acids and bilirubin in acute renal dysfunction in liver injury. It also summarizes the implied pathophysiology risk factors and incorporates the therapeutic mechanisms and outcomes.

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Review

Bilirubin and cholemic nephropathy

Excess bilirubin has detrimental effects on kidney tubule function and intracellular mitochondrial function. Bilirubin aids in oxidative stress to kidney tubular epithelium leading to damage to the tubules and associated renal structures [2,4,8]. A significant finding for this damage is tubular hypertrophy, as seen in 73.5% of autopsies of jaundiced patients [4]. Additionally, more histological findings noticed that bilirubin’s disastrous effects included tubular epithelium swelling, hypertrophy, and hyperplasia of the parietal layer of Bowman’s capsule and the formation of pigmented casts [2,4]. These kidney architectural changes are irreversible in pathology, forming fibrosis in the kidney interstitial tissue, leading to tubular atrophy [4,8].

Moreover, hyperbilirubinemia can cause uncoupling oxidative phosphorylation in the mitochondria [2,8]. Oxidative phosphorylation is significant in forming adenosine triphosphate (ATP), the central energy-producing molecule in human cells. This decrease in ATP contributes to electrolyte imbalance and cell membrane penetration with increased cell volume leading to significant reversible and irreversible changes in the mitochondria [4,8]. Additionally, inhibition of Na-H, Na-K, Na-Cl pumps due to bile salts can result in cast formation, causing pH alterations in the proximal tubule and loop of Henle, leading to tubular toxicity [3,4]. Hyperbilirubinemia decreases angiotensin II-mediated arterial hypertension by reducing the production of superoxide and sodium reabsorption in the thick ascending loop of Henle [9]. Moreover, AKI induced by elevated bilirubin has been evidenced histologically with loss of expression of aquaporin-2 channels in collecting ducts in the patients diagnosed with CN [10]. The potential mechanism of CN is illustrated in Figure 1.

FIGURE 1: Summary of the Pathophysiological Mechanism of Cholemic Nephropathy

Original image created by the authors.
NADH: nicotinamide adenine dinucleotide; ATP: adenosine triphosphate

In contrast to bilirubin’s harmful effects, it also exhibits debatable renoprotective effects [1]. It is attributed
to the lack of heme and iron, which contribute to renal injury [4]. Moreover, several animal studies have shown an increase in the enzyme heme oxygenase due to common bile duct ligation, which has anti-inflammatory, anti-apoptotic, and anti-oxidant effects exhibiting even more cytoprotective effects [1]. Hence, it is questionable if bilirubin is entirely harmful to kidneys, and more research is needed to investigate further.

**Bile acids and cholemic nephropathy**

Most bile acids are usually reabsorbed in the ileum and transported via portal blood circulation back to the liver. It is estimated that the liver does not take up about 10-50% of reabsorbed bile acids, making them escape in the peripheral circulation leaving behind 100 μmol bile acids per day prone to glomerular filtration [1,6]. Organic solute transporters such as apical sodium-dependent bile acid transporter (ASBT) in proximal tubules control the renal-hepatic circulation reabsorbing the filtered bile acids [1]. Under normal physiologic conditions, approximately 1-2 μmol per day of bile acids are excreted in urine [1].

With the above theory in context, it is worth noting how these mechanisms are affected in the event of cholestatic diseases such as obstructive jaundice, primary biliary cirrhosis, and primary sclerosing cholangitis. To counteract the rising bile salts in these pathologies, hepatocytes heighten basolateral hepatocellular export and enhance renal filtration and tubular secretion in the proximal tubules via organic anion transporters and multidrug resistance-associated proteins [1,6]. There seems to be an imbalance between tubular reabsorption and tubular secretion, with excessive bile salts getting excreted, thereby exceeding the maximum capacity of proximal tubules contributing to renal injury [4,6]. In Krones et al.’s study, they noticed that long-term common bile duct ligation (CBDL) in a mice model led to cholemic nephropathy because of severe cholestasis and renal instead of bile secretion of bile acids leading to tubular epithelial injury, cast formation, basement membrane defects, and ultimately kidney fibrosis [11]. In another study by Fickert et al., excess urinary elimination of bile acids was potentially toxic to the renal tubular epithelial cells, causing kidney injury, which affected the region of aquaporin-2–collecting ducts, further strengthening the detrimental effects of bile acids on renal physiology [12]. Bile acids also directly mediate the formation of vasoactive mediators that cause renal vasoconstriction and a decrease in glomerular filtration rate (GFR) [1,4].

**Hemodynamic changes due to hyperbilirubinemia**

HRS is a life-threatening complication that compromises renal function, especially in patients with advanced liver disease [7-10]. The underlying mechanism is not entirely understood but is attributed to the changes in physiological aspects of HRS. Significant events in advanced cirrhosis such as severe portal hypertension, splanchnic vasodilation and arterial underfilling, and vasoconstrictor activation (renin-angiotensin-aldosterone, endothelin) lead to renal vasoconstriction and hypoperfusion, eventually causing AKI [4,13]. Studies performed on mice have demonstrated adverse chronotropic and inotropic effects on the heart due to hyperbilirubinemia leading to renal hypoperfusion [4]. Furthermore, treating hyperbilirubinemia has been shown to improve "jaundiced heart," a common term reflecting a decline in cardiac performance in advanced hepatic dysfunction [4]. The evidence suggests that systemic endotoxins release due to excess bilirubin, leading to renal blood flow redistribution, causes hypotension and hypoperfusion. It eventually leads to corticomedullary junction ischemia and results in tubular injury [1,4]. A similar mechanism is linked with concomitant sepsis-related-AKI in these patients [4].

Moreover, in patients with liver cirrhosis, endotoxins are released due to the translocation of bacteria and pathogen-associated molecular patterns (PAMPs) from the gut and prompt systemic inflammation [1,4]. Specifically, toll-like receptor 4 (TLR4) was observed to be increased in the urine of patients with liver dysfunction, AKI, and inflammatory insults [1,4]. Altogether, these factors contribute to lowering the GFR and causing AKI. We summarized the available evidence supportive of CN in Table 1.
| Reference | Year | Disease | Host Cell | Pathology | Treatment | Outcome |
|-----------|------|---------|-----------|-----------|-----------|---------|
| Redwood et al., 2011 | 2011 | EBN infection | 28.5 (D) | 3.25 | ATN features abundant bile casts | Hemodialysis | Resolution of infection and hyperbilirubinemia. Discontinuation of hemodialysis. |
| Rabl et al., 2013 | 2013 | Cholangiocarcinoma | 20.9 (D) | 6 | Presence of tubular damage, loss of brush border, tubular necrosis. Bile casts and thrombi in proximal and distal tubules | Renal replacement therapy | Patient passed away |
| Van Staveren et al., 2013 | 2013 | Obstructive cholestasis | 24.9 (T) | - | Bile casts with involvement of distal nephron segments | - | - |
| Luciano et al., 2014 | 2014 | Anatomic stenosis of the common bile duct | 39.9 (T) | 7.35 | Bile casts, reactive changes of tubular epithelial cells | Hemodialysis, biliary drain | Improvement of kidney function after 5 weeks |
| Jain et al., 2015 | 2015 | Colorectal cancer s/p wedge resection of liver | 42.5 (T) | 2.72 | Intratubular bile casts | - | - |
| Tatibabae et al., 2015 | 2015 | Stenostal condition | 26 (D) | 2.7 | Preserved glomerular. Degeneration of cortical tubules. Bile casts present in some tubules | Hemodialysis | C r level decreased at 2 months |
| Alhussaini et al., 2016 | 2016 | Anatomic stenosis of the common bile duct | 29.9 (D) | 2.6 | Glomeruli were unremarkable. Acute tubular injury with luminal ectasia. Dark green bile casts within tubular lumen | Supportive care only, no hemodialysis | Serum Cr returned to normal and serum total bilirubin dropped to 1.8 mg/dL at 3-month follow-up |
| Seconda and Gu, 2015 | 2015 | Acute alcoholic hepatitis | 20 (D) | 9.2 | Normal glomerular and tubular bile casts shown by Hall’s stain. | Hemodialysis | Liver output improved gradually, however, the patient continued to need dialysis for poor clearance |
| Alabawi et al., 2015 | 2015 | Acute liver injury | 7 (T) | 7.3 | Positive Fouchet stain indicating presence of bilirubin casts | Seven sessions of hemodialysis | Recovered kidney function. Discharge Cr = 1.1 mg |
| Flores et al., 2016 | 2016 | Anatomic stenosis-induced cholestasis | 53 (T) | 2.3 | Yellow, brown intratubular bile casts. Flattening and simplification of the epithelial lining | Five sessions of plasmapheresis, no hemodialysis | Bilirubin level decreased Cr level decreased and the patient recovered kidney function |
| Amezuelo et al., 2016 | 2016 | Fibrinous-induced liver injury | 34 (D) | 6.6 | Normal glomerular. Positive bile stain and bile casts in tubules | No hemodialysis | Bilirubin level decreased Cr level decreased to stabilize at 1.85 mg/dL |
| Sene et al., 2016 | 2016 | TCD2 mutation-induced biliary duct dysplasia | 15.2 (D) | 5.3 | Acute tubular injury and dilated tubules with flattened epithelium greenish-brown intratubular casts | Hemodialysis 9 ECAD:1 MARS and 8 SPAD sessions | The patient underwent simultaneous liver-kidney transplant |
| Malikraja et al., 2019 | 2019 | Severe hepatitis dysfunction | 41.7 (T) 23.4 (D) | 8.2 | Bile casts in renal tubules on Hall’s stain with bile staining of necrotic cells and tubular casts | No hemodialysis | Patient died |
| Patel et al., 2016 | 2016 | Acute liver injury | 29 (D) | 5.47 | Proximal and distal tubules containing bile casts | Hemodialysis | The patient underwent simultaneous liver and kidney transplants. Normalization of kidney and hepatic indices |
| Wernert et al., 2016 | 2016 | Painless jaundice due to cholangiocellular carcinoma | - | - | Dilated tubules, bile casts | Hemodialysis, bile duct stent | Resolution of renal function after restoration of cholestasis |
| Misapatra et al., 2016 | 2016 | Severe bile/parafoam malabsorption complicated with jaundice | 26.5 (T) | - | Numerous tubular casts, acute tubular necrosis but maintained glomerular architecture | - | Recovery time of renal dysfunction 15.1 ± 6.5 days |
| Lederer et al., 2022 | 2022 | Drug-induced hepatic injury | Brown casts clog the tubular lumen, brown deposits in the tubules | - | - | Improvement of kidney function after withdrawal of the drug. |
dialysis; CBD: common bile duct; ERCP: endoscopic retrograde cholangiopancreatography; Md: median

*computed from mmol/L to mg/dL; (T): total bilirubin; (D): direct bilirubin; EBV: Epstein–Barr virus; ATN: acute tubular necrosis; Cr: creatinine; s/p: status post; TCF2: transcription factor 2; ECAD: extracorporeal albumin dialysis; MARS: molecular adsorbents recirculation system; SPAD: single-pass albumin dialysis; CBD: common bile duct; ERCP: endoscopic retrograde cholangiopancreatography; Md: median

TABLE 1: Summary of clinical features seen in case reports of cholemic nephropathy

*computed from mmol/L to mg/dL; (T): total bilirubin; (D): direct bilirubin; EBV: Epstein–Barr virus; ATN: acute tubular necrosis; Cr: creatinine; s/p: status post; TCF2: transcription factor 2; ECAD: extracorporeal albumin dialysis; MARS: molecular adsorbents recirculation system; SPAD: single-pass albumin dialysis; CBD: common bile duct; ERCP: endoscopic retrograde cholangiopancreatography; Md: median

**Approach and diagnosis**

Currently, a kidney biopsy is the gold standard diagnostic test for CN. In autopsy evaluations of CN patients, the kidney’s cortex and medulla appear yellow due to bilirubin. After fixation with formalin, color changes to green due to bilirubin oxidation and conversion to biliverdin [1,27]. On histological diagnosis, yellow or green-brown casts will be seen obstructing the tubular lamina, especially in the distal tubule resembling...
similar mechanism as myoglobin casts formation seen in rhabdomyolysis [1]. In Nayak et al.’s study, they were able to detect BCN in 44.8% of all the postmortem renal biopsy specimens and in 72.1% of the patients with acute on top of chronic liver failure [37]. These bile casts are formed by sloughed tubular epithelial cells. The Hall (or Fouchet) histochemical stain highlighting green to yellow casts or periodic-acid Schiff (PAS) stain showing red to dark red colored casts are used to confirm the presence of bilirubin [1,3]. The kidney may also show variable degrees of acute tubular injury, such as vacuolization of tubular cells and tubular necrosis. Contraindications in obtaining a kidney biopsy in liver disease and caogulopathic patients, coupled with difficulty securing distal nephron segments with conventional biopsy methods, have significant limitations in diagnosing this condition [1,3,10,30]. It is unclear whether bilirubin is truly nephrotoxic, but there is an increased likelihood that a patient may develop bile casts with prolonged exposure to increased bilirubin levels (i.e., bilirubin >20 mg/dL) [10,43,44]. Several case reports have documented bilirubin and creatinine levels in patients with BCN during their disease and most of the case reports detail that kidney function is noted to deteriorate as bilirubin concentration increases [2,5,8,9,18,19,32,34,38,42]. The majority of the studies show a parallel increase in creatinine with bilirubin.

### Biomarkers

AKI is associated with high morbidity and mortality and can occur in patients with severe liver disease. Proximal tubule cells are sensitive to hypoxic injury, leading to a release of proteins into the urine. Several promising urinary biomarkers may be used to evaluate AKI. The most studied is neutrophil gelatinase-associated lipocalin (NGAL), a 25 kDa iron-transporting protein excreted in nephrotic or ischemic kidney injury. Urinary(serum) NGAL levels in CN were shown to be suitable to monitor tubular epithelial damage and therapeutic effects under experimental conditions [1,45]. The diagnostic odds ratio (DOR) and sample size-weighted area under the curve for the receiver-operating characteristic (AUC-ROC) for NGAL to predict AKI were 18.6 (95% CI: 9.0-38.1)/0.815 (95% CI: 0.732-0.892) in a meta-analysis study of 19 studies with AKI [46]. Another marker, interleukin 18 (IL-18), is a known factor that induces interferon-γ and is closely related to the IL-1 cytokine family. It is found in dendritic cells, macrophages, and epithelial cells, which generate Th1 response, activate natural killer (NK) and cytotoxic T cells, and aid in proliferating T cells [47]. A marker known as kidney injury molecule (KIM-1), also known as T cell Ig and mucin domain 1 (TIM-1), is a phosphatidylserine receptor that aids in phagocytosis of apoptotic bodies and oxidized lipids, especially in chronic kidney injury. It interacts with p85 and downmodulates PI3K-dependent nuclear factor-κB [48]. A novel biomarker is the human liver-type fatty acid-binding protein (hL-FABP) which binds long-chain fatty acids and plays a role in fatty acid metabolism, thus being renoprotective as it promotes lipid excretion peroxidation products [49]. Biomarkers; however, they have not yet been included for laboratory testing and are used exclusively for research [1]. A summary of the possible markers for kidney injury is seen in Table 2.

![Table 2: Potential markers for kidney tubular injury.](image)

| Tubular injury biomarkers | Source | Description | Rationale | Studies in BCN |
|--------------------------|--------|-------------|-----------|----------------|
| NGAL                    | Urine  | 25 kDa protein bound to gelatinase in the specific granule of neutroph | Expression upregulated in kidney proximal tubule cells and urine following ischemic-induced renal injury | Increased urinary expression in CBDL mouse model, Increased mRNA expression CBDL mouse model |
| IL-18                   | Urine  | Interleukin 18 is a 24 kDa protein | Expressed in distal tubule, strong immunoreactivity in proximal tubules with transplant rejection, upregulated in ischemic injury | None |
| KIM-1                   | Urine  | Type-1 cell membrane glycoprotein | Upregulated in distalrealted proximal tubule epithelial cells following injury | Increased mRNA expression in CBDL mouse model |
| L-FABP                  | Urine  | 14 kDa protein found in the cytoplasm of human renal proximal tubules | Expression in proximal tubule epithelial cells | None |

**TABLE 2: Potential markers for kidney tubular injury.**

NGAL: neutrophil gelatinase-associated lipocalin; CBDL: common bile duct ligation; IL-18: interleukin-18; KIM-1: kidney injury molecule-1; L-FABP: human liver-type fatty acid-binding protein; mRNA: messenger RNA; kDa: kilodalton

### Treatment strategies and outcomes

The definitive diagnosis and subsequent treatment of CN are challenging, especially considering that a few case reports are diagnosed postmortem through autopsy, and adequate treatment was not provided. Treatment of CN is primarily based on treating the underlying cause of hyperbilirubinemia to prevent kidney injury [4]. In the case of biliary stones or tumors, endoscopic retrograde cholangiopancreatography, stent placement, and tumor resection may be done to relieve the obstruction. Extracorporeal therapies such as hemodialysis and plasma exchange are the other treatment options when CN is diagnosed; however, the number of sessions varies and the outcome [4]. Patients are reported to have clinical improvement and even complete kidney injury reversal evidenced by normalization of creatinine and reduction of bilirubin levels [14,16,19,20,22,39,42]. The time for recovery observed varied per study. Both Flores et al. and El Khoury et al.
describe a case of CN due to anabolic steroid use successfully treated with several sessions of plasma exchange [26,34]. We report a detailed list of the therapies and treatment outcomes in Table 1.

Extracorporeal therapies are possible treatment options in patients with CN and are divided into biologic and nonbiologic. Biologic therapies use living liver cells, while nonbiologic therapies use artificial membranes and adsorbents (i.e., plasmapheresis and albumin dialysis). These therapies can reduce inflammatory cytokines and bilirubin levels. Plasmapheresis is when plasma is separated from the blood, filtered, and returned to the patient. This therapy aids in the removal of excess toxins and bilirubin and replenishes albumin, coagulation factors, and hepatic regenerative stimulating substances to improve the symptoms of the patient [4].

On the other hand, hemodialysis is a complicated process involving blood filtration and regulating fluid balance. The case report by Sens et al. [27] utilizes a molecular adsorbent recycling system (MARS) as a treatment before the patient receives simultaneous liver and kidney transplants. MARS is a non-biological extracorporeal therapy that uses an albumin-enriched dialysate to selectively remove the albumin-bound toxins from the blood using two separate dialysis circuits [4,50]. Steroids, cholestyramine, ursodeoxycholic acid, and lactulose have minimal benefit in treating CN patients [8]. Interestingly, norursodeoxycholic acid has been proven to alleviate CN in the experimental scenario of CBDL mice. This study highlights the importance of bile acids with their hydrophilic nature, which aids in kidney function improvement and could be a potential medical treatment for patients with CN [11].

Future implications

There are no systematic guidelines for diagnosing, treating, and managing a patient presenting with CN. CN is a diagnostic dilemma, and more reasonable diagnostic alternatives are crucial in approaching suspecting patients with CN. The transjugular approach for kidney biopsy may be an effective option considering the associated coagulopathic risks with traditional kidney biopsy in liver cirrhosis patients [8]. However, studies should center on the non-invasive options for diagnosis, evaluating patients with absolute contraindications to invasive procedures. Treatment methods with albumin dialysis can help detoxify the albumin-bound compounds such as bilirubin, bile acids, and other hepatotoxins [4]. Prospective studies should be conducted to evaluate clinically meaningful treatment options despite most studies reporting clinical improvement and kidney function return with hemodialysis or plasma exchange. It is also sensible to further inquire about the newer extracorporeal therapies such as MARS, coupled plasma filtration adsorption (CPFA), and plasma filtration adsorption dialysis [8]. With the advancements in identifying biomarkers, specific urinary biomarkers such as NGAL can facilitate differential diagnosis along with the conventional techniques as markers of renal excretory function (serum creatinine, cystatin C, urine microscopy, and renal ultrasound [1].

Conclusions

CN is an uncommon diagnosis but a common finding in patients with liver disease. Suspicion and meaningful consideration should be given to BCN in non-respondents to HRS treatment. The kidney biopsy is an accurate diagnostic, and the transjugular approach can be a better alternative to traditional biopsy to expedite the diagnosis by simultaneously obtaining liver and kidney biopsies, also lessening the bleeding risk in high-risk patients. This review is crucial in suggesting the various mechanisms, diagnostic techniques, and treatment approaches to BCN.

Additional Information

Disclosures

Conflicts of interest: In compliance with the ICMJE uniform disclosure form, all authors declare the following: Payment/services info: All authors have declared that no financial support was received from any organization for the submitted work. Financial relationships: All authors have declared that they have no financial relationships at present or within the previous three years with any organizations that might have an interest in the submitted work. Other relationships: All authors have declared that there are no other relationships or activities that could appear to have influenced the submitted work.

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