



The Role of Pranayama Yogic Breathing in Maintaining Liver Health: A Physiological Review of Physiological Mechanism and Clinical Evidences

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How to cite this paper: Aditya Angiras. (2025) The Role of Pranayama Yogic Breathing in Maintaining Liver Health: A Physiological Review of Physiological Mechanism and Clinical Evidences. *Health and Prevention Journal*, 2(1), 103-118. DOI: 10.26855/hpj.2025.12.009

Received: October 2, 2025

Accepted: November 23, 2025

Published: December 19, 2025

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Abstract

Pranayama, a form of controlled breathing integral to yoga, has garnered attention in Physio-psychological field of research for its potential therapeutic benefits. This essay critically analyses the clinical impact of pranayama on mental and physical health both, focusing on its mechanisms and positive psycho-physical outcomes. By synthesizing existing literature, the analysis reveals how pranayama influences stress reduction, emotional regulation, and overall psychological well-being and how the functioning of internal organs get rectified. The findings suggest that pranayama may serve as a valuable adjunctive therapy in clinical settings, particularly for anxiety and depression, hypertension/Diabetes along with maintaining a normal lipid profile. However, gaps in the literature highlight the need for further empirical studies to establish standardized protocols and explore the long-term effects of pranayama practice. This essay concludes with implications for clinical practice and future research directions.

Keywords

Yoga; Pranayama; Liver Health; Liver studies; Health benefits; Wiser way of Indian Knowledge system

Introduction

The practice of pranayama, which translates to "control of breath," is a fundamental aspect of yoga that has been practiced for centuries [2]. In recent years, there has been a growing interest in the clinical applications of pranayama within the field of psycho-physiology. This paper posits that pranayama can significantly impact psycho-physiology health by enhancing emotional regulation, reducing stress, and improving overall psychological well-being thereby effecting liver function in a positive manner. The analysis may indicate that while pranayama offers promising therapeutic benefits, a comprehensive understanding of its mechanisms and effects is essential for its integration into clinical practice.

Functioning of Liver Analysed

The liver's singular role as the central regulatory and detoxification hub of the mammalian body is predicated upon its unique anatomical location and specialized circulatory configuration [3]. This structure necessitates that the liver acts as an obligate metabolic and immunological intermediary, positioned strategically between the gastrointestinal tract and the systemic circulation.

The Obligate Intermediary The inflow of blood to the liver is characterized by a unique dual supply, setting it apart from standard systemic organs [4]. While the hepatic artery provides oxygenated systemic blood, the hepatic portal system represents an exception to the conventional circulatory rule that veins carry blood directly toward the heart.

Instead, the veins within this system send nutrient-rich and potentially toxin-laden blood from abdominal organs to the liver for primary processing before recirculation [5].

The main blood vessel defining this configuration is the portal vein, which begins just posterior to the neck of the pancreas, anterior to the inferior vena cava (IVC). Anatomically, the portal vein forms at the confluence of the superior mesenteric vein (SMV) and the splenic vein. From this convergence point, the portal vein extends upward and to the right, passing behind the hepatic artery until it reaches the porta hepatis (liver hilum). Upon entering the liver hilum, the vessel bifurcates into the left and right portal veins, which further subdivide to supply different hepatic sectors.

The function of the portal vein is critically vital to the entire system as it delivers blood from organs located in the abdomen, including the spleen, pancreas, and the entire gastrointestinal tract, to the hepatocytes for processing and filtration [6]. This architecture ensures that all absorbed nutrients, metabolic substrates, hormones, and potentially harmful substances, such as bacterial metabolites and endotoxins absorbed from the gut, are filtered and detoxified by the liver. If the liver's capacity for this initial processing or filtering fails, the toxic load bypasses the hepatic detoxification mechanisms and immediately enters the systemic circulation, causing profound extra-hepatic organ damage [7].

Systemic Integration via Hepatic Veins and the Inferior Vena Cava (IVC)

Following filtration and processing within the hepatic parenchyma, the deoxygenated blood exits the liver through the hepatic veins. These veins, typically comprising the right, middle, and left hepatic veins (with variations often observed, such as the middle and left merging into a common trunk), collect blood drained from the central veins—tiny vessels that gather blood from capillaries throughout the liver. The hepatic veins exit the posterior aspect of the liver and immediately enter the inferior vena cava (IVC) near the spine, just inferior to the diaphragm. This blood then flows through the IVC into the heart's right atrium, subsequently moving through the pulmonary circulation for oxygenation before returning to the systemic circulation. This arrangement completes the obligatory route, ensuring that only processed blood is distributed throughout the rest of the body [8].

The structural connection of the liver to the digestive system is not solely vascular but also secretory, maintained through the biliary system. The liver produces bile, a substance indispensable for the adequate breakdown and absorption of dietary fats.

This produced bile is transported to the gallbladder, a pouch-shaped organ whose primary function is to store and concentrate the bile. When required, typically in response to a meal, the bile moves out of the gallbladder via the common bile duct, which is shared with the liver, and into the duodenum, the first segment of the small intestine. In the duodenum, bile acts as an emulsifier, breaking down fats to facilitate their subsequent digestion and absorption. The dual nature of the liver's gastrointestinal relationship—managed by vascular inflow (portal vein for substrates and toxins) and secretory outflow (bile duct for digestion and excretion)—is fundamental. Impairment in bile production or flow (cholestasis) can lead to impaired nutrient absorption (specifically fat malabsorption), while failure in the vascular filtration mechanism results in systemic toxicity [9]. Furthermore, bile provides the primary excretory route for various detoxified metabolic products, bilirubin, and cholesterol back into the gastrointestinal tract, contributing to the crucial enterohepatic circulation.

The liver is recognized as the principal organ responsible for maintaining systemic metabolic equilibrium [10]. This control involves complex integration with other organs, particularly the pancreas, adipose tissue, and muscle, regulating the metabolism of glucose, lipids, and key hormones [11].

A. The Hepato-Pancreatic Axis: Glucose Homeostasis and Hormonal Cross-Talk

The liver represents the primary effector site for pancreatic endocrine signalling, integrating signals from insulin (promoting glucose storage) and glucagon (promoting glucose release) to maintain blood glucose concentrations within a narrow physiological range.

B. Glucagon Receptor Signalling (GCGR) and Counter-Regulation

Glucagon, synthesized by the pancreatic alpha cells, exerts its action via the Glucagon Receptor (GCGR) predominantly in the liver. The best-known action of hepatic GCGR signalling is its powerful counter-regulatory effect on insulin, primarily through the promotion of hepatic gluconeogenesis (GNG). Hepatic GNG is regulated by GCGR signalling through two distinct mechanisms: the transcriptional induction of key GNG enzymes and their subsequent allosteric modulation.

Furthermore, the liver's response to glucagon extends beyond mere glucose balance [12]. Mounting evidence indicates that hepatic glucagon signalling is a potent regulator of energy balance, lipid homeostasis, and the mobilization of fat mass. Glucagon also regulates multiple components of lipid metabolism, demonstrating that the hepato-pancreatic axis is central to global energy substrate management, not just carbohydrate metabolism. If glucagon action is aberrantly activated or poorly regulated, the liver itself can drive systemic hyperglycaemia, underscoring its

central role in the pathogenesis of Type 2 Diabetes Mellitus.

C. The Liver-Adipose-Muscle Axis: Lipid and Energy Metabolism

Adipose Tissue Dysfunction and Insulin Resistance

The liver's metabolic status is deeply intertwined with that of adipose tissue. Excess fat accumulation (adiposity) and subsequent dysfunction of adipocytes result in the dysregulation of a wide array of secretory factors known as adipokines. This dysregulation contributes significantly to the development of various metabolic diseases through mechanisms involving altered glucose and lipid homeostasis and the promotion of systemic inflammatory responses. A critical factor in modulating insulin sensitivity is the promotion of free fatty acid (FFA) release into the circulation from adipocytes [13]. High circulating FFA levels are strongly linked to the development of hepatic insulin resistance [14].

The Lactate Shuttle and Cori Cycle: The liver collaborates intimately with peripheral organs, particularly skeletal and cardiac muscle, to manage energy substrates and recycle metabolic by-products, notably lactate. Historically viewed as a mere by-product of anaerobic metabolism, lactate is now understood to be continuously formed and utilized under both anaerobic and aerobic conditions.

The lactate shuttle hypothesis describes the movement of lactate both within cells (intracellularly) and between cells (intercellularly). Lactate produced at sites of high glycolysis (e.g., active muscle) is shuttled to adjacent or remote sites, including the liver, where it serves as a gluconeogenic precursor. This recycling mechanism, known as the Cori cycle, is essential for replenishing systemic glucose stores. The continuous flow of lactate between the muscle and the liver implies that muscle-to-liver communication is not limited to fuel provision but also encompasses systemic metabolic signalling. Lactate has been recognized as having additional roles in redox signalling, gene expression, and lipolytic control, leading to its designation as a "lactormone". Hepatic utilization and clearance of lactate is therefore vital, as dysfunction not only disrupts energy cycling but also impairs these critical systemic communication networks encoded in metabolic intermediates.

A. Endocrine Modulation: Thyroid Hormone Activation and Signalling:

The liver is a crucial site for the peripheral metabolism and activation of thyroid hormones (TH), which are required for normal development and the regulation of adult metabolism. T4 to T3 Conversion and Hepatic Sensitivity.

The local activation of the precursor thyroxine to the biologically active form, triiodothyronine is a key mechanism of TH regulation of metabolism. This conversion is largely catalysed by deiodinase type 2, an enzyme expressed in various tissues, including the liver. The active hormone, modulates hepatic insulin sensitivity, a function particularly important for the suppression of hepatic gluconeogenesis.

Furthermore, signalling in the liver regulates cholesterol and carbohydrate metabolism through direct actions on gene expression and complex cross-talk with other nuclear receptors, such as peroxisome proliferator-activated receptor (PPAR) and liver X receptor (LXR), as well as bile acid signalling pathways [15]. The liver's ability to process and regulate TH activity means that hepatic function provides central feedback on systemic metabolic rates, integrating nutritional status and hormone signaling with the adrenergic nervous system peripherally and centrally.

The profound control the liver exerts over core metabolic pathways is summarized below.

Table 1. The Liver's Role in Inter-Organ Metabolic Control

| Organ Partner | Communication Mechanism | Key Metabolic Output | Relevance to Liver Function |
|------------------------------|------------------------------------|--|---|
| Pancreas | Insulin, Glucagon, GCGR Signalling | Glucose production/uptake regulation, Lipid homeostasis | Counter-regulatory effects on GNG; potent regulation of fat mobilization |
| Adipose Tissue | Adipokines, Free Fatty Acids (FFA) | Modulation of systemic and hepatic Insulin Sensitivity Links excess fat accumulation to altered glucose/lipid homeostasis and inflammation | Skeletal Muscle |
| Lactate Shuttle (Cori Cycle) | Gluconeogenic Precursor (Lactate), | Signalling Lactormone | Recycles lactate for hepatic glucose synthesis and influences systemic signalling Thermogenesis, Cholesterol Metabolism, Hepatic Insulin Sensitivity |
| Thyroid Gland | Thyroxine | Triiodothyronine | Local activation of T4-T3 and cross-talk with other nuclear receptors |

Detoxification and Fluid Balance: The Hepato-Renal Axis:

The functional interdependence between the liver and the kidneys establishes the critical Hepato-Renal Axis, vital for maintaining systemic detoxification, electrolyte balance, and hemodynamic stability. Compromise in one organ frequently precipitates failure in the other, culminating in severe conditions such as Hepatorenal Syndrome (HRS).

A. Shared Responsibilities in Systemic Clearance and Homeostasis

The liver and kidneys work in synchronized collaboration to prevent the systemic accumulation of harmful metabolites. This synergy encompasses multiple physiological domains:

B. Nutrient Processing and Utilization: The liver processes absorbed nutrients, while the kidneys maintain the balance of electrolytes and fluids necessary for the efficient absorption and cellular utilization of those nutrients. **Blood Circulation Regulation:** Both organs are essential in governing blood flow dynamics. The liver contributes biochemically by synthesizing proteins necessary for hemostasis and blood clotting. Concurrently, the kidneys adjust the volume of blood in circulation by controlling fluid and electrolyte balance, often through mechanisms like the Renin-Angiotensin-Aldosterone System (RAAS). The liver's role in synthesizing albumin, the most abundant circulating protein, also significantly impacts plasma oncotic pressure and fluid partitioning across the body.

C. Ammonia Metabolism and Reciprocal Pathology

Ammonia, a highly neurotoxic byproduct of amino acid and protein catabolism, is largely generated by intestinal bacteria and absorbed via the portal vein. Its primary detoxification is conducted by the liver through the urea cycle.

D. Hepatic Failure and Renal Compensation. In severe liver disease, particularly cirrhosis, the capacity for urea synthesis in the liver significantly decreases, impairing the primary mechanism for systemic ammonia removal. This failure leads to hyperammonemia, which is highly toxic, particularly to the central nervous system.

E. The kidney's response to this hepatic failure is paradoxical. While the kidney normally participates in homeostasis, it transitions into a source of pathology in liver failure. The kidney attempts to compensate for metabolic acidosis, but simultaneously, the activity of glutaminase in the small intestine of cirrhotic patients increases, and glutamine catabolism in the kidneys intensifies. This renal catabolism of glutamine produces and releases additional ammonia into the systemic circulation, severely exacerbating blood ammonia levels (hyperammonemia) and accelerating Hepatic Encephalopathy (HE) [16]. Further evidence of synchronized failure is observed in models of liver damage, showing decreased expression of key ammonia detoxification enzymes (Glul and Glud) not only in the liver but also in the kidney. This synchronized impairment suggests a breakdown of the inter-organ detoxification synergy.

Pathophysiological Consequences: The Hepatorenal Syndrome (HRS)

The ultimate failure of the Hepato-Renal Axis is often manifested as HRS, a life-threatening form of functional acute kidney injury (AKI) specific to advanced liver disease. This condition is rooted in profound circulatory dysfunction initiated by the diseased liver.

Chronic liver disease, such as cirrhosis, causes portal hypertension which induces marked peripheral arterial vasodilation [17]. This vasodilation primarily affects the splanchnic arterial circulation, resulting in a dramatic reduction in systemic vascular resistance (SVR) [18]. The underlying mechanisms include enhanced production and activity of potent vasodilatory factors, such as nitric oxide, endogenous cannabinoids, and carbon monoxide, often triggered by abnormal bacterial translocation from the gut secondary to portal hypertension [19].

To counteract the resultant systemic hypotension caused by low SVR, the body activates powerful compensatory systemic vasoconstrictor systems, chiefly the RAAS and the sympathetic nervous system [20]. Although this maintains systemic blood pressure, the intense vasoconstriction is preferentially directed toward the renal circulation, leading to severe under-perfusion of the kidneys despite normal or even high cardiac output (a state known as hyperdynamic circulation) [21]. This insufficient effective circulating volume results in functional renal failure—the defining feature of HRS [22]. The kidney is forced to operate under a hyper-constricted state due to liver-driven systemic hemodynamic instability [23].

The liver is a central organ of the immune system, constantly filtering and neutralizing immune challenges originating from the gut. This function is tightly linked to the spleen via the Hepatosplenic Axis, which dictates systemic immune status and the progression of portal hypertension.

Hepatic Innate Immunity: The Role of Kupffer Cells (KCs)

The liver's function as an immune gatekeeper is primarily executed by Kupffer cells (KCs), resident macrophages strategically situated within the hepatic sinusoids. Their unique location ensures intimate contact with circulating blood, allowing them to rapidly clear bacterial products (such as lipopolysaccharide or endotoxins) and other particulate matter absorbed from the portal circulation.

Table 2. The Collaborative and Reciprocal Pathology of the Hepato-Renal Axis

| Function | Liver Role | Kidney Role | Consequence of Dysfunction |
|------------------------|---|--|--|
| Detoxification | Primary site for Urea synthesis (Ammonia clearance) | Secondary site for Glutamine catabolism (Ammonia production) | Hyperammonemia and Hepatic Encephalopathy |
| Circulation Regulation | Production of Clotting Factors/Albumin; SVR modulation (vasodilator production) | Fluid and Electrolyte Volume Control; RAAS activation | Impaired hemostasis; Splanchnic vasodilation; Hepatorenal Syndrome (HRS) |
| Nutrient Processing | Processes ingested nutrients and vitamins | Maintains electrolyte/fluid balance for nutrient utilization | Systemic nutrient imbalance and fluid overload (Ascites) |

KCs play an integral role in the innate immune response and exhibit functional plasticity, capable of mediating both immunogenic (pro-inflammatory) and tolerogenic (immunosuppressive) reactions [24]. They are critical for antibacterial defence, including the recruitment of neutrophils and the protection of hepatocytes from infection [24]. However, the immune filtering capability of KCs makes them highly vulnerable to metabolic and toxic insults. They are centrally implicated in the pathogenesis of various liver diseases, including Non-Alcoholic Fatty Liver Diseases (NAFLDs), alcoholic liver diseases, hepatitis, fibrosis, and liver cancer. When KCs become dysfunctional due to chronic disease, their filtering capacity is compromised. This allows gut-derived toxins and inflammatory mediators to escape hepatic surveillance and enter the systemic circulation, directly fueling systemic inflammation and neurotoxicity—a critical preparatory step for complications like HE.

The Hepatosplenic Axis and Portal Hypertension

The Hepatosplenic Axis recognises the complex, reciprocal relationship between the liver and the spleen. The spleen is not merely a passive organ affected by congestion; it is an active hemodynamic and immune partner in chronic liver disease.

Splenomegaly and Hypersplenism:

A common clinical manifestation of advanced liver disease is splenomegaly (spleen enlargement), driven by chronic congestion due to portal hypertension and the concurrent enlargement and hyperactivation of splenic lymphoid tissue. This condition leads to hypersplenism, characterized by increased sequestering and breakdown of circulating blood components, predominantly platelets. The resultant thrombocytopenia exacerbates the coagulopathy caused by the impaired synthesis of clotting factors in the cirrhotic liver, contributing to the disposition toward bleeding events [25].

Spleen's Pathogenic Contribution:

The spleen plays a direct role in regulating portal flow and actively contributes to the progression of liver cirrhosis. This involvement refutes the earlier view of the spleen as an unnecessary or passive bystander. The concept of the spleen as a regulatory organ that maintains portal flow is integral to the "forward flow theory" of portal hypertension. Mechanistically, splenic immune cell dysregulation, potentially initiated by circulating damage-associated molecular patterns (DAMPs) or High-Mobility Group Box 1 (HMGB1) released from the diseased liver, actively modulates hepatic pathology [26]. These splenic contributions accelerate cirrhosis progression through several pathways: the modulation of hepatic fibrogenesis, the dysregulation of the liver immune microenvironment, and the impairment of liver regeneration, all mediated by the chemotactic egress of spleen-derived cells or the release of splenic soluble factors. Recognising the spleen's active role in driving fibrosis and immune pathology indicates that therapeutic strategies for portal hypertension must extend beyond simple pressure reduction to include the modulation of splenic immunological activity.

A; Systemic Pathological Axes: Brain and Cardiovascular Impact

The systemic pathological consequences of hepatic dysfunction define the most severe clinical complications, mediated by the Gut-Liver-Brain and Hepato-Cardiovascular Axes. These cascades demonstrate how liver failure translates into catastrophic neurological and hemodynamic instability.

The Gut-Liver-Brain Axis and Neuro-inflammation:

Hepatic Encephalopathy (HE), including Minimal HE (MHE), is a significant neuropsychiatric complication of severe acute or chronic liver disease [27]. The disease represents a systemic metabolic and immunological infrastructure failure to protect the central nervous system (CNS) [28].

The Pathogenic Cascade:

The aetiology of HE is complex, stemming from a synergistic sequence rooted in the gut.

* Gut Dysbiosis and Toxin Production:

Abnormalities in the gut microbiota (dysbiosis) are critical, leading to the increased production of toxic nitrogenous metabolites, notably ammonia, and the release of inflammatory ligands [29].

* Hyperammonaemia:

The combination of impaired ammonia detoxification via the hepatic urea cycle and the paradoxical increase in ammonia production via renal glutamine catabolism results in toxic, systemic hyperammonaemia [29].

* Systemic Inflammation and Neuroinflammation:

Gut microbiota dysbiosis induces systemic inflammation and endotoxemia (circulation of bacterial toxins), which subsequently trigger neuroinflammation within the brain via the established gut-liver-brain axis [30].

Cellular and Molecular Pathology

Ammonia, while toxic, acts synergistically with inflammatory cytokines to mediate CNS damage [31]. This combined assault leads to astrocyte dysfunction and swelling, which is the primary driver of brain oedema in acute HE. In chronic HE, this inflammatory process and hyperammonaemia contribute to neurobehavioral deficits.

The molecular pathway involves the translocation of bacterial endotoxins (e.g., lipopolysaccharide) from the portal circulation into the systemic flow, triggering the activation of Toll-like Receptor 4 (TLR4) pathways in the CNS [32]. This activation leads to the downstream release of inflammatory mediators, including reactive oxygen and nitrogen species (RONS) and prostaglandins, ultimately impacting astrocyte function and promoting brain pathology [33]. The recognition that HE is fundamentally a disease of synergistic metabolic and inflammatory failure mandates that therapeutics must target both ammonia clearance and the underlying gut dysbiosis and neuroinflammation.

B. The Hepato-Cardiovascular Axis

The liver's influence on the cardiovascular system is extensive, involving the production of circulating components and the regulation of hemodynamic stability.

Haemostasis and Albumin Synthesis

The liver synthesises the majority of the pro- and anticoagulant factors, making it vital to the physiological process of haemostasis. Liver insufficiency impairs this synthesis, resulting in a complex condition known as "rebalanced haemostasis" in cirrhotic patients, characterised by deficiencies in both anticoagulant proteins (e.g., antithrombin III, protein S or C) and increases in procoagulant factors (e.g., Factor VIII, von Willebrand factor). This rebalanced state is inherently volatile, predisposing patients to unpredictable bleeding or thrombotic events.

The liver is also the sole source of albumin, the most abundant circulating protein [34]. Decreased albumin synthesis by hepatocytes, coupled with fluid and sodium retention, leads to hypoalbuminemia in advanced cirrhosis. This reduction in plasma oncotic pressure is a major contributing factor to the accumulation of extravascular fluid, manifesting clinically as ascites and generalised oedema.

The Hyperdynamic Circulation of Cirrhosis

The hallmark hemodynamic disorder in advanced liver disease is the hyperdynamic circulation [35]. As discussed previously, portal hypertension induces primary vasodilation of the splanchnic arterial circulation, driven by increased local production of vasodilators (nitric oxide, endogenous cannabinoids). This results in a profound reduction in SVR [36].

To compensate for the low SVR and maintain adequate mean arterial pressure, the body must significantly increase cardiac output, leading to a state of volume overload and high cardiac output. While circulatory volume is expanded, the effective circulating volume is often inadequate due to excessive pooling in the splanchnic bed, forcing the compensatory activation of vasoconstrictor systems (RAAS) and ultimately leading to the renal failure observed in HRS [37]. This defines a state of systemic hypotension combined with volume expansion.

Cardio-Hepatic Feedback Loops

The intersection of metabolic liver disease and cardiac pathology is exemplified by the relationship between Non-Alcoholic Fatty Liver Disease (NAFLD) and Heart Failure with preserved Ejection Fraction (HFpEF). NAFLD actively produces inflammatory markers that enter the systemic circulation. These inflammatory signals increase the heart's susceptibility to inflammation, promote fat accumulation within the myocardium, and directly increase myocardial stiffness.

Insulin resistance and systemic inflammation, common factors in both NAFLD and cardiac dysfunction, establish a vicious cycle where the conditions mutually exacerbate one another [38]. Early structural changes in NAFLD, such as increased intrahepatic resistance and portal pressure, already increase cardiac output and volume overload,

contributing to left ventricular remodelling and diastolic dysfunction. This creates a pathway where chronic metabolic dysfunction originating in the liver directly drives primary structural and functional cardiac pathology.

Liver Function and the Rationale for Integrative Interventions

Defining Chronic Liver Disease and Metabolic Dysfunction-associated Steatotic Liver Disease (MASLD) Chronic liver diseases, particularly those linked to metabolic syndrome, represent a significant global health burden. The condition formerly known as Non-Alcoholic Fatty Liver Disease (NAFLD), now termed Metabolic Dysfunction-associated Steatotic Liver Disease (MASLD), is highly prevalent and is projected to rise due to sedentary lifestyles [39]. Given the current limitations in specific pharmacological treatments for MASLD, lifestyle modifications—including diet, physical activity, and stress reduction—are recognized as essential preventive and curative measures. The progressive nature of these diseases, often fuelled by chronic inflammation and systemic stress, necessitates a holistic approach that targets root metabolic and neuroendocrine imbalances. Consequently, complementary interventions like Pranayama (yogic breathing techniques) are increasingly being studied for their potential to support hepatic health and function [40].

Clinical and Biochemical Markers of Liver Injury and Function

The clinical assessment of liver status relies on a panel of biochemical markers categorized by what they measure: injury or function.

Hepatocellular Injury Markers The most sensitive indicators of acute hepatocellular injury are the aminotransferases, Alanine Aminotransferase (ALT) and Aspartate Aminotransferase (AST). ALT is generally considered more specific to liver injury due to its highest concentration within hepatocytes, whereas AST is also found in extrahepatic organs such as the heart, brain, and skeletal muscle [41]. It is important to note clinically that the measured degree of elevation of these aminotransferases in the serum does not reliably correlate with the absolute extent of liver cell damage. Elevations in ALT and AST that are disproportionately higher than elevations in alkaline phosphatase (ALP) and bilirubin denote a hepatocellular disease pattern [42].

Cholestatic and Function Markers Alkaline phosphatase (ALP) and Gamma Glutamyl-Transferase (GGT) are enzymes found on the canalicular membrane of hepatocytes. While ALP elevation can stem from bone disease, GGT elevation typically accompanies hepatobiliary disease and is used to confirm that the liver is the source of the elevated ALP. GGT, alongside lipid biomarkers, serves as a common indicator for evaluating the severity of MASLD and related metabolic dysfunction. When ALP and bilirubin are elevated disproportionately to ALT and AST, this suggests a cholestatic pattern.

Synthetic Function Markers The actual synthetic capacity of the liver is measured based on its ability to produce essential proteins and clotting factors [43]. Albumin, the most abundant plasma protein synthesized exclusively by hepatocytes, has a half-life of two to three weeks. A decrease in albumin typically suggests liver disease that has persisted for at least this period. However, albumin is a non-specific marker, as its levels can also drop due to inflammation, malnutrition, fluid overload, or nephrotic syndrome [44]. The production of vitamin K-dependent clotting factors (measured via Prothrombin Time/INR) is also crucial for grading hepatic function.

Systemic Metabolic Correction: Beyond Enzyme Reduction

While many studies documenting the effects of yogic interventions on liver health focus on the reduction of elevated liver enzymes such as ALT and AST, it is critical to interpret these changes within the systemic context of MASLD [45]. MASLD is fundamentally a disease of metabolic dysfunction, involving glucose and lipid dysregulation [46]. Therefore, for an intervention to be truly therapeutic, it must correct these underlying metabolic issues, thereby relieving secondary hepatic stress. Evidence supporting this requirement indicates that effective yogic protocols achieve simultaneous improvements in liver enzymes, blood sugar, and blood lipids, including total cholesterol and serum triglycerides [47]. Lipid metabolism indicators such as total cholesterol (TC), triacylglycerol (TG), and low-density lipoprotein cholesterol (LDL-C), along with GGT, are utilized to assess the severity of MASLD and its association with metabolic abnormalities. This demonstrates that the benefits of Pranayama are not merely localized detoxification or temporary enzyme modulation, but rather an upstream correction of the systemic metabolic milieu. Future clinical trials should thus employ a comprehensive panel of metabolic and inflammatory biomarkers, extending beyond simple liver enzyme checks, to accurately quantify the depth and breadth of the therapeutic effect of Pranayama [48].

Physiological and Neuroendocrine Mechanisms of Pranayama on the Liver

The positive effects of Pranayama on the liver are mediated by its influence on the body's regulatory systems, particularly the nervous, circulatory, and cellular signalling systems.

Modulation of the Autonomic Nervous System (ANS) Balance

The Autonomic Nervous System (ANS) controls essential, involuntary bodily processes such as heart rate,

secretion by digestive organs, and breathing. The ANS comprises the sympathetic system (governing fight-or-flight responses) and the parasympathetic system (governing rest-and-digest responses). Yogic practices, especially controlled breathing, offer a mechanism for regulating the ANS, heart function, and the vagus nerve [49]. Systematic reviews suggest that yogic practices shift the balance of the ANS from primarily sympathetic activation toward parasympathetic dominance [50]. This transition is achieved by directly enhancing parasympathetic output. By reducing perceived stress and lowering key neuroendocrine markers such as catecholamine and cortisol levels, Pranayama mitigates the chronic sympathetic activation that is detrimental to systemic health.

The Vagus Nerve and the Central-Liver Axis

The Vagus nerve (Cranial Nerve X) is an essential conduit in this neurobiological modulation, acting as a crucial information superhighway between the brain and the viscera, extending from the brain stem to the lungs, stomach, pancreas, digestive tract, spleen, and liver. The Vagus nerve is the critical component of the parasympathetic system that unlocks the relaxation response and is known to regulate heart rate, respiration, and digestion. Crucially, the Vagus nerve acts as a major modulator of inflammation [51], which is a key driver in chronic diseases, including chronic liver injury. Deep breathing and meditation—core elements of Pranayama—are activities that demonstrably increase vagus nerve activity and tone [52]. Techniques like Nadi Shodhana (Alternate Nostril Breathing) and Bhramari (Humming Bee Breath) are specifically employed to increase vagal tone, thereby modulating systemic inflammation. The beneficial changes observed in liver enzymes and the concomitant improvement in cognitive performance reported in MASLD patients are considered downstream effects of this central nervous system modulation [52]. The fact that high-intensity Pranayama, such as Kapalabhati, can produce cardiovascular improvements similar to physical exercise through parasympathetic activation further underscores the Vagus nerve's role as the unified neurobiological mechanism through which Pranayama exerts its systemic effects [53].

Impact on Oxidative Stress (OS) and Cellular Protection Oxidative stress (OS) plays a pivotal role in the pathogenesis and progression of steatotic liver diseases, leading directly to hepatocyte damage and eventual fibrosis [54]. Pranayama interventions contribute to hepatic protection by positively influencing the cellular environment. Breathing exercises have been shown to improve the main biological indicators of OS, shifting the balance toward an anti-oxidation state. This effect is achieved through increasing levels of antioxidants while simultaneously reducing oxidative markers. Malondialdehyde (MDA) level is frequently used as the most sensitive and common indicator to evaluate the efficacy of breathing interventions on the OS state. Specific stimulating practices, such as Kapalabhati Pranayama, are suggested to positively affect hepatic pathology by decreasing oxidative stress levels and enhancing the vital process of bile secretion [55]. This anti-oxidative action suggests that Pranayama supports liver function not by physically forcing molecules out, often described inaccurately in lay terms as "pumping out toxins" [56], but by optimising the cellular environment. By reducing OS and inflammation, Pranayama protects the integrity of the hepatocytes, allowing the liver's natural detoxification and metabolic pathways to function at peak efficiency [57].

Hemodynamic and Circulatory Effects

Pranayama also exerts mechanical effects on the liver, primarily through the dynamic interaction between the diaphragm and the abdominal viscera. Vigorous techniques, such as Kapalabhati (Skull Shining Breath), involve rapid, forced exhalations that engage active abdominal muscle contractions [58]. This rhythmic motion is described as a "massage" of the internal organs, which is believed to stimulate liver function by enhancing blood circulation and increasing oxygenation [59]. In the context of chronic liver disease, scar tissue buildup (fibrosis/cirrhosis) restricts oxygenation and blood flow within the liver parenchyma [60]. Protocols including Kapalabhati aim to stimulate the liver, ensuring a freer flow of oxygen and blood through the organ [61]. This mechanical and circulatory enhancement complements the neurobiological effects, supporting the liver's ability to perform its vital functions.

Clinical Evidence:

Pranayama in Chronic Liver Pathologies The clinical evidence base for Pranayama, though growing, is predominantly derived from studies focusing on chronic metabolic diseases, where positive preliminary outcomes have been reported.

Pranayama in the Management of MASLD/NAFLD

Pranayama's most compelling clinical evidence concerns its role as an adjunct therapy for MASLD (formerly NAFLD). Retrospective case series have shown that a comprehensive yogic intervention—including Kapalabhati Pranayama, various asanas (e.g., Ardha Matsyendrasana, Gomukhasana), and meditation (Dhyana)—yielded beneficial outcomes in affected patients [62]. The observed biomarker improvements were substantial: the intervention was associated with the correction of elevated liver enzymes, significant reductions in blood lipids (total cholesterol and

serum triglycerides), and improved blood sugar levels [63]. Furthermore, yogic intervention showed potential to address liver fibrosis, with one preliminary study noting significant changes in Liver Stiffness Measurement (LSM) on Fibroscan reports and normalisation of ultrasound results in a subset of patients [64]. This indicates a capacity to not only manage symptoms but also potentially slow fibrosis progression. Since weight loss and physical activity are established keys to improving the histopathological features of MASLD, the metabolic corrective function of practices like Kapalabhati, which acts on lipid and glucose metabolism, integrates perfectly with established treatment guidelines [64]. The robust clinical benefits observed—covering enzyme reduction, metabolic correction, and fibrosis improvement—have primarily been documented when Kapalabhati is executed as part of a complete, integrated yogic protocol that also includes asanas and meditation [65]. This structure suggests that Pranayama is best conceptualized not as a monotherapy, but as a potent component of a comprehensive lifestyle modification strategy. The asanas contribute to improved intra-abdominal pressure dynamics and circulation, while meditation provides the necessary stress control and ANS regulation, creating a synergistic therapeutic effect [66].

Supportive Role in Other Liver Conditions

Research also extends the scope of yogic practices to other hepatic conditions and clinical scenarios [67]. In the domain of Alcohol-Related Liver Disease (ALD), exploratory studies investigating yoga's role in addiction recovery have also tracked the impact on liver function, specifically measuring SGPT (ALT) levels in individuals with alcohol addiction [68]. These findings provide preliminary support for yoga as a complementary therapy in improving liver health within this specific context. Additionally, the role of breathing techniques is acknowledged in perioperative and post-transplant care. Clinical trials are currently comparing the efficacy of breathing yoga (encompassing techniques like Sama Vritti, Abdominal Breathing, Nadi Shodhana, and Kapalabhati) against Progressive Muscle Relaxation Techniques in mitigating respiratory complications, pain, and kinesiophobia in liver transplant recipients [69]. This acknowledges the integral role of controlled breathing in enhancing cardiopulmonary function critical for complex surgical recovery [70].

Pranayama's Effect on Systemic Inflammation and Co-Morbidities

The influence of Pranayama extends beyond hepatocyte protection to positively impact systemic inflammation and related co-morbidities, especially concerning the brain-liver axis. MASLD patients often experience subclinical cognitive impairment linked to chronic inflammation and insulin resistance [71]. In clinical studies, the combined practice of Pranayama (e.g., Nadi Shodhana and Bhramari) and an aerobic component (Suryanamaskar) resulted in a measurable and significant improvement in cognitive performance in MASLD patients [72]. This cognitive benefit is hypothesised to be achieved by modulating vagal tone and systemic inflammation. The regulation of the autonomic nervous system through breathing techniques thus indicates a profound, bidirectional involvement with the liver-brain axis, presenting an integrative solution for both metabolic and neurological aspects of chronic liver disease.

Classification of Techniques and Targeted Liver Effects (The Energetic and Mechanical Divide)

Pranayama techniques vary significantly in their physiological impact, categorised broadly as stimulating (heating) or calming (cooling). This differentiation is crucial for tailoring interventions to specific hepatic pathologies [73].

Stimulating and Cleansing Techniques (Kapalabhati, Bhastrika).

Stimulating practices like Kapalabhati (Skull Shining Breath) are defined by vigorous, rapid, and active exhalations driven by forceful abdominal engagement [74]. Kapalabhati is classified as a Shatkarma (cleansing technique) aimed at building heat and clearing the air passages. Physiologically, these practices promote an enhanced metabolic rate and help normalise liver enzymes. [75] The rhythmic, forced movement is believed to provide a physical "massage" to abdominal organs, stimulating liver function, improving localised circulation, and aiding in removing congestion [76]. In Ayurvedic philosophy, these techniques are classified as highly heating, meaning they significantly increase the Pitta Dosha. They are traditionally recommended primarily for individuals with a Kapha constitution, who often exhibit traits of sluggishness or metabolic heaviness. For early-stage MASLD driven primarily by metabolic stagnation, this stimulating, "heating" effect is therapeutic.

Calming and Balancing Techniques (Nadi Shodhana, Bhramari)

Calming techniques emphasise slow, deep, and coherent breathing, directly engaging the parasympathetic nervous system. Nadi Shodhana (Alternate Nostril Breathing) is noted for its ability to oxygenate the blood, improve circulation, and calm the nervous system. It is characterised as a grounding practice that effectively balances Vata, Pitta, and Kapha Doshas, making it generally safe and suitable for reducing stress and promoting mental peace [77]. By mitigating chronic sympathetic activation, Nadi Shodhana indirectly supports liver health by reducing the systemic stressors (cortisol, catecholamines) that burden hepatic function. Bhramari Pranayama (Humming Bee Breath) also

demonstrates a significant positive impact on the autonomic nervous system by increasing parasympathetic dominance. This practice involves a humming sound that creates air oscillations, which reportedly increases the exchange of air and stimulates the production of Nitric Oxide (NO) in the paranasal sinuses. NO acts as a potent anti-inflammatory agent, and the increased vagal tone achieved through Bhramari helps regulate the central inflammatory response.

Cooling Practices and Traditional Hepatoprotection (Sheetali/Sitkari)

The traditional Ayurvedic perspective holds the liver as the primary seat of the Pitta Dosha, which governs heat, metabolism, and transformation [78]. Therefore, chronic liver distress, often manifested as chronic inflammation (hepatitis or steatohepatitis), is associated with excessive internal heat or "Pitta aggravation." [79] Cooling techniques are specifically indicated to counter this heat. Sheetali (Cooling Breath) and Sitkari are performed by inhaling through a pursed or curled tongue, relying on evaporative cooling. These practices are highly effective at dissipating excess Pitta, reducing internal heat, and soothing the revved-up nervous system [80]. Sheetali is historically noted in classical texts for its capacity to remove illness of the liver, spleen, and gallbladder, reinforcing its ancient recognition as a hepatoprotective practice focusing on temperature and irritation control.

Table 3. Comparative Analysis of Pranayama Techniques for Liver Health

| Technique | Physiological Mechanism | Primary Liver Benefit | Ayurvedic Classification (Pitta Dosha) | Critical Safety Warnings |
|-----------------------------------|---|--|---|--|
| Kapalabhati (Skull Shining) | Vigorous diaphragmatic movement, increased metabolic rate, parasympathetic activation | Enzyme normalization, metabolic correction, reduced oxidative stress, physical stimulation/massage | Increases Pitta (heating), best for Kapha constitution. | Strict contraindication in severe liver disease/cirrhosis, portal hypertension, high/low BP, heart disease, hernia |
| Nadi Shodhana (Alternate Nostril) | Balances sympathetic/parasympathetic nervous systems, increases oxygenation. | Stress reduction, nervous system calming, balances the liver-brain axis. | Balances all three Doshas (Vata, Pitta, Kapha). | Generally safe; recommended for most patients. |
| Sheetali/Sitkari (Cooling Breath) | Cooling through evaporation (inhalation via tongue), vagal nerve soothing. | Pacifies Pitta (reducing inflammation/heat), traditionally hepatoprotective | Strongly pacifies Pitta (cooling) | Generally safe; gentle practice |
| Bhramari (Humming Bee Breath) | Increased parasympathetic dominance, increased Nitric Oxide (NO) production, enhanced vagal tone. | Stress reduction, improved sleep, anti-inflammatory effect | Pacifies Pitta (cooling) | Generally safe; gentle practice. |

Stratifying Technique Selection by Disease Stage

The clinical choice of the Pranayama technique must be carefully matched to the patient's disease stage and underlying pathology. The divergence between the functional benefit of Kapalabhati (metabolic correction in MASLD) [80] and the traditional warning that it is Pitta-increasing is instructive. For patients with early, non-inflammatory MASLD driven by metabolic sluggishness (a Kapha-like presentation), the stimulating nature of Kapalabhati may be beneficial. However, in cases marked by high, chronic inflammation (severe steatohepatitis or advancing fibrosis, representing significant Pitta aggravation), the therapeutic priority shifts to reducing systemic stress [81]. In such inflammatory scenarios, the gentle, calming, and cooling practices like Nadi Shodhana, Bhramari, and Sheetali are physiologically superior, aligning modern anti-inflammatory goals with traditional principles of Pitta pacification. Thus, the intervention must be dynamically tailored to the individual's inflammatory and metabolic profile. Section 5: Safety Profile and Critical Contraindications in Advanced Liver Disease (The Haemodynamic Risk) While Pranayama offers profound therapeutic potential, an assessment of safety is critical, particularly for patients with advanced or unstable liver pathology. The distinction between early metabolic disease and end-stage cirrhosis is paramount.

Standard Contraindications for Vigorous Pranayama

Vigorous, high-pressure breathing techniques such as Kapalabhati and Bhastrika are known to generate significant internal pressure. Consequently, these practices carry several absolute contraindications, including pre-existing cardiovascular and abdominal pathology. Individuals with high or low blood pressure, heart disease, hernia, gastric ulcer,

epilepsy, vertigo, migraine headaches, glaucoma, detached retina, history of stroke, or recent abdominal surgery must avoid these techniques [82]. The risk is amplified when techniques are performed incorrectly. Practitioners who improperly execute Kapalabhati, such as jerking the entire upper torso, create an extreme physical "jolt" that forces air pressure downward, potentially straining internal organs and leading to complications like a lapsed abdominal wall or hernia development [83]. Proper instruction and progressive graduation from simpler techniques are essential to prevent iatrogenic injury.

Risks Associated with Advanced Fibrosis and Cirrhosis

The most severe safety concern arises in patients with advanced liver fibrosis and cirrhosis. Cirrhosis is characterised by increased fibrogenesis, leading to chronic vasoconstriction, hypertension, and eventually portal hypertension [84]. Portal hypertension frequently results in the formation of oesophageal varices—dilated, fragile veins in the oesophagus that are susceptible to rupture. Forceful abdominal manoeuvres, such as the rapid, piston-like exhalations central to Kapalabhati and Bhastrika, transiently yet significantly increase intra-abdominal and intrathoracic pressure [85]. In a cirrhotic patient, this acute rise in pressure is transmitted, potentially exacerbating portal pressure. For a patient with known esophageal varices, this sudden hemodynamic stress poses a critical, potentially life-threatening risk of haemorrhage or varietal rupture [86]. Based on this hemodynamic risk profile, any high-pressure, vigorous abdominal pranayama technique (Kapalabhati, Bhastrika) must be strictly contraindicated in patients with known cirrhosis, high Liver Stiffness Measurement (LSM) indicating advanced fibrosis, or established portal hypertension and ascites.

Gut-Liver Axis and Abdominal Stress.

Patients suffering from liver cirrhosis commonly exhibit significant gut dysfunction, including disturbances in gut motility, delayed gut transit, and increased gastric sensitivity. Furthermore, portal hypertension is associated with intestinal barrier dysfunction, leading to bacterial translocation and the permeation of bacterial products, which contribute to the pathogenesis and complications of cirrhosis. The mechanical stress or "jolt" imposed on internal organs by aggressive or incorrect forceful breathing could potentially aggravate these existing gut motility disturbances [86]. Applying repeated, high internal pressure may stress an already compromised intestinal barrier, promoting bacterial translocation, which is highly detrimental in the context of advanced liver failure [87]. In light of these concerns, only extremely gentle, slow, and consciously diaphragmatic breathing focused purely on parasympathetic calming should be considered, and only under expert medical supervision.

Integration Protocols and Professional Guidance

Pranayama must be positioned transparently as a complementary therapy used to enhance overall well-being and manage symptoms such as stress. It should never be utilised as an alternative or curative treatment for severe, treatable diseases like Hepatitis C. Healthcare providers must exercise diligence in distinguishing evidence-based yogic practices from potentially dangerous Complementary and Alternative Medicine (CAM) products, such as certain hepatotoxic herbs or high-dose supplements [88], which are known causes of Drug-Induced Liver Injury (DILI) and can interfere with standard medications.

For maximal benefit and safety, especially with advanced techniques, proper instruction from a qualified yoga teacher or healthcare professional is mandatory. Clinical recommendations should be carefully stratified based on the disease stage and severity of fibrosis, recognising the distinct safety and efficacy gradient. Pranayama protocols are potentially curative or reversing in early-stage MASLD (Stage 0-2 fibrosis). They are supportive and mitigating in chronic but stable liver disease. However, they are potentially hazardous in advanced cirrhosis (Stage 3-4 fibrosis) with portal hypertension.

Conclusion and Evidence-Based Clinical Recommendations

Scientific inquiry supports the conclusion that Pranayama acts as a potent non-pharmacological intervention for liver health, primarily via two major pathways: neurobiological modulation and metabolic optimisation. Mechanistically, controlled breathing shifts the Autonomic Nervous System toward parasympathetic dominance through enhanced Vagal Tone [89], which serves to reduce systemic inflammation and stress, critical drivers of chronic liver disease progression. Metabolically, Pranayama contributes to the reduction of oxidative stress, protection of hepatocytes, and correction of associated disorders, including dyslipidaemia and hyperglycaemia [90], which are the hallmarks of MASLD. Clinical evidence, although derived predominantly from high-impact case series rather than large-scale randomised controlled trials (RCTs), indicates that integrated yogic interventions can improve objective outcomes in MASLD, including the normalisation of liver enzymes (ALT/AST), correction of lipid profiles, and even reduction

of liver fibrosis [91]. Future research must prioritise rigorous RCTs, incorporating high-resolution markers like Heart Rate Variability (HRV) for vagal tone and Liver Stiffness Measurement (LSM) for fibrosis, to standardise effective protocols and establish clear dosage guidelines.

Stratified Clinical Recommendations Based on the current understanding of physiological mechanisms and safety data, the integration of Pranayama into liver health management should adhere to a stratified, stage-specific approach:

- For Early-Stage Metabolically Dysfunctional-associated Steatotic Liver Disease (MASLD/NAFLD, Fibrosis Stage F0-F2):
 - Goal: Metabolic correction, anti-inflammation, and stress management.
 - Recommended Techniques: A comprehensive, integrated protocol combining specific asanas, meditation, and Pranayama is encouraged. Moderate practice of Kapalabhati Pranayama may be included, provided the patient is thoroughly screened for standard contraindications (BP, heart condition, hernia) [92].
 - Rationale: The stimulating and metabolic-corrective effects of Kapalabhati are valuable for addressing the underlying sluggishness often seen in early MASLD. Calming breaths like Nadi Shodhana and Bhramari should be used to regulate the ANS and combat systemic inflammation [93].
- For Chronic, Inflammatory Liver Disease (e.g., Chronic Hepatitis, Advanced Fibrosis F3):
 - Goal: Stress reduction, reduction of systemic inflammation, and Pitta pacification. * Recommended Techniques: Vigorously stimulating practices should be used with extreme caution or excluded entirely. Focus must be placed on cooling and calming techniques, specifically Nadi Shodhana, Bhramari, and Sheetal/Sitkari.
 - Rationale: These techniques provide robust parasympathetic activation and stress reduction without imposing undue mechanical strain on the viscera, thus mitigating the inflammatory component of the disease.
- For Advanced Cirrhosis, Portal Hypertension, and Ascites (Fibrosis Stage F4):
 - Goal: Maximal safety, gentle symptom palliation, and absolute avoidance of hemodynamic stress.
 - Mandatory Contraindications: Kapalabhati and Bhastrika Pranayama are strictly contraindicated due to the potentially life-threatening risk of acutely increased intra-abdominal pressure that could precipitate variceal rupture or exacerbate gut dysfunction.

Permitted Practice: Only gentle, slow, comfortable diaphragmatic and nasal breathing, performed without strain or forceful abdominal contraction, may be considered under strict professional guidance. The primary aim is limited to calming the nervous system.

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