A Colour Doppler Study of Hepatic Vein, Portal Vein and Hepatic Artery in Liver Cirrhosis: Correlation of Hepatic Hemodynamic with Clinical Child Pugh Score in a Tertiary Health Care Centre

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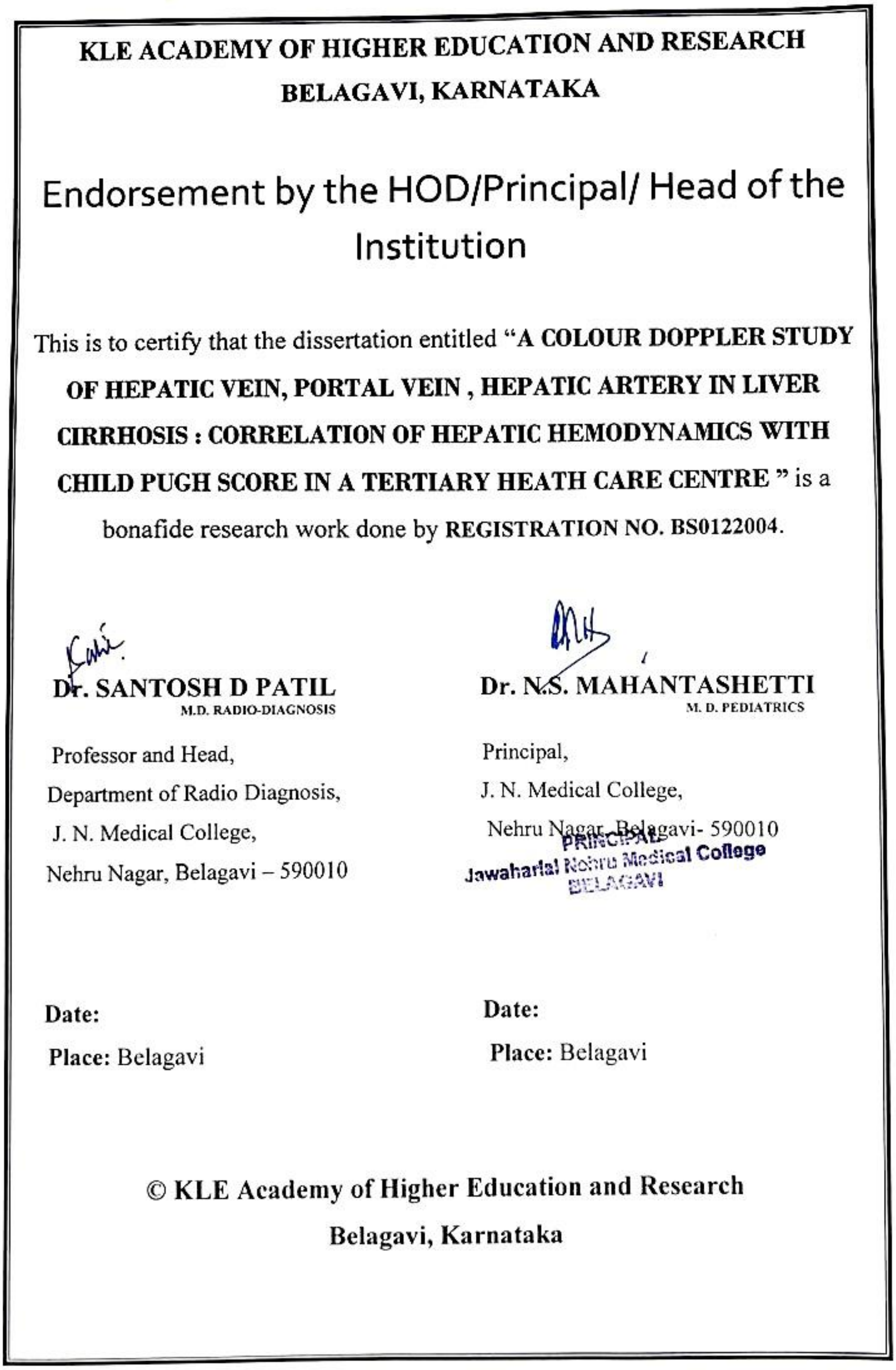

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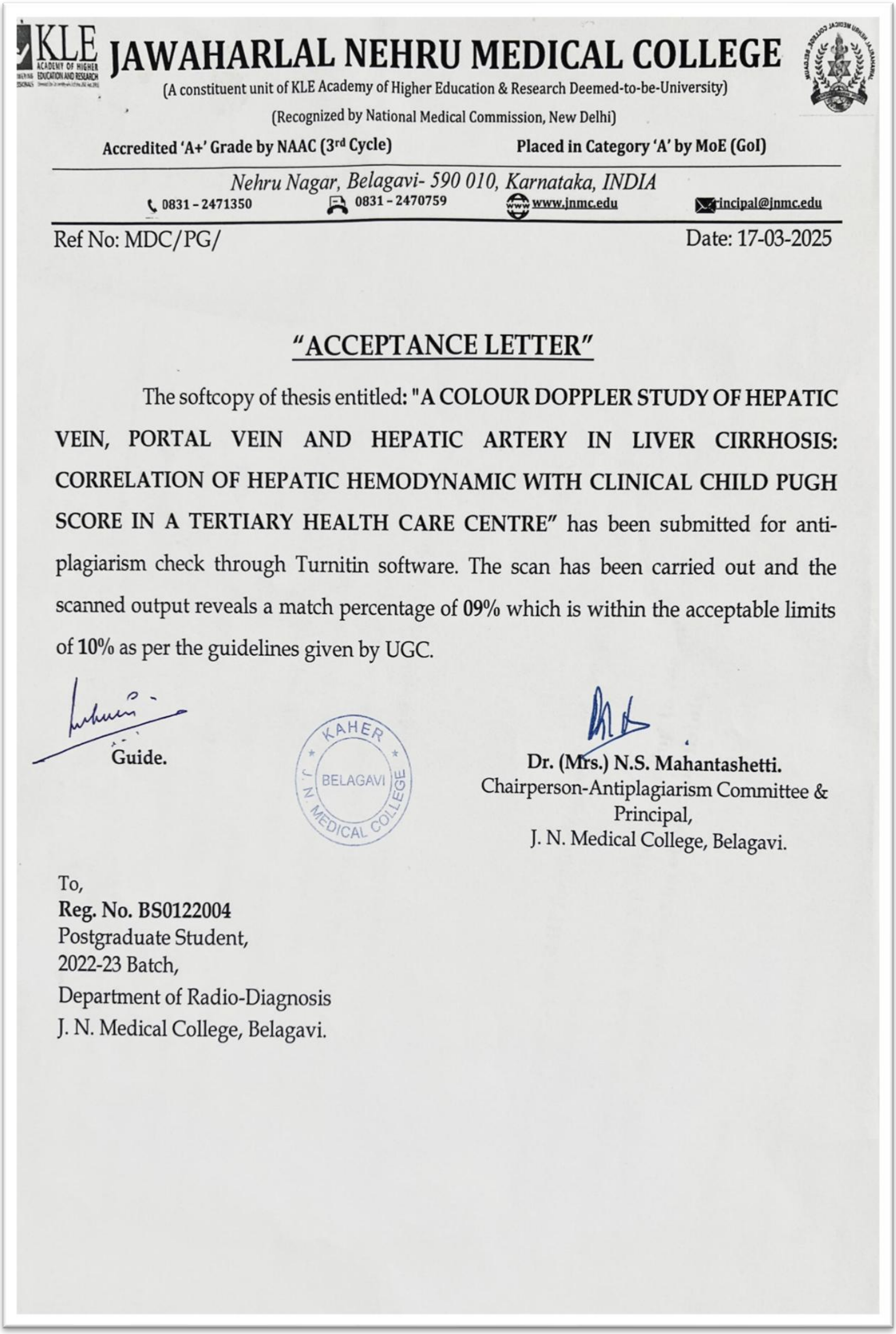

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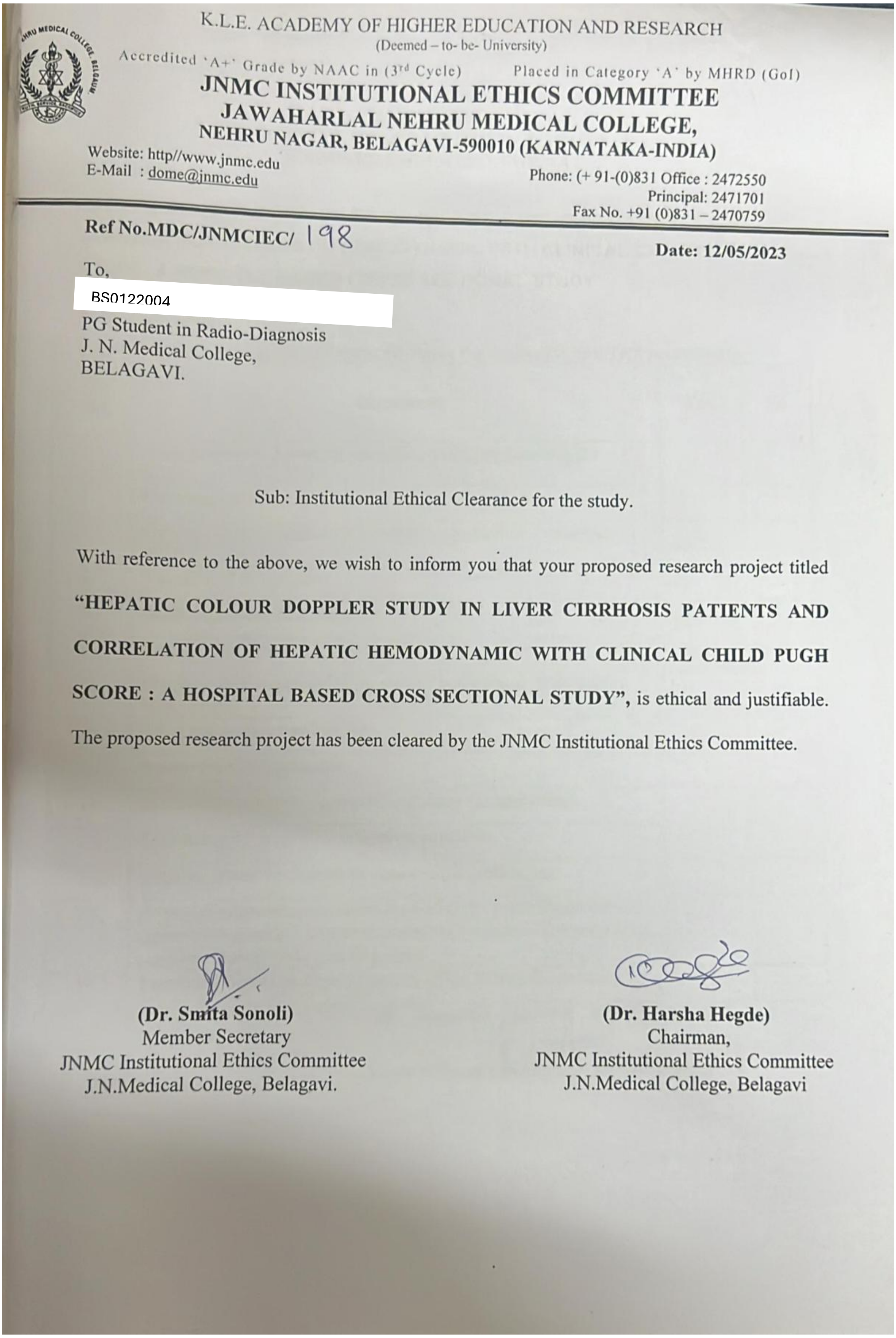

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LIST OF ABBREVIATIONS

CT	Computed tomography
MRI	Magnetic resonance imaging
HARI	Hepatic artery resistive index
CEUS	Contrast-enhanced ultrasound
MELD	Model for End-Stage Liver Disease
PSV	Peak systolic velocity
CTP	Child-Turcotte-Pugh

ABSTRACT

Background: Liver cirrhosis is a chronic progressive condition characterized by fibrosis, nodular regeneration, and significant vascular remodelling, leading to severe hepatic dysfunction and complications such as portal hypertension and variceal bleeding. Doppler ultrasonography has emerged as a non-invasive, cost-effective, and widely available tool for assessing hepatic hemodynamics and vascular changes in cirrhosis.

Objective: This study aims to evaluate the correlation between Doppler-derived parameters—such as hepatic artery resistive index & PSV, portal vein PSV and hepatic vein PSV - and the clinical severity of cirrhosis using the Child-Pugh scoring system.

Methods: A cross-sectional observational study was conducted among patients diagnosed with liver cirrhosis, referred to Dr. Prabhakar Kore Hospital & Medical Research Center, Belgaum, Karnataka, India. Data were collected from minimum of 31 participants in each group (cirrhotic and control), for a total of 62 participants. Doppler Ultrasound Parameters Assessed were hepatic artery resistive index & PSV, portal vein PSV and hepatic vein PSV.

Results: Cirrhosis is known to lead to changes in the hepatic vascular bed including increased resistance and velocity in the hepatic artery with resultant decrease in portal vein velocity. Maximum hepatic vein velocity was higher in cirrhotic patients (where $p < 0.05$). Maximum portal vein velocity was found to be lower in cirrhosis (where $p < 0.05$) and mean maximum portal vein velocity decreases as severity of cirrhosis worsens. Hepatic artery resistive index was significantly higher in cirrhosis (where $p < 0.05$). Significant association was found between maximum hepatic vein velocity & resistivity index and significant negative correlation was observed with the maximum portal vein velocity.

Conclusion: This study emphasize the significant alterations in hepatic hemodynamics that occur with the progression of liver cirrhosis, highlighting the role of Doppler ultrasound as a useful, non-invasive tool for assessing these changes. This study demonstrates that Doppler ultrasound is an effective diagnostic tool for assessing the hepatic vasculature in cirrhosis, offering valuable insights into the pathophysiological changes associated with liver dysfunction. The correlation between Doppler parameters and the Child-Pugh score suggests that Doppler ultrasound could be a valuable non-invasive method for staging and monitoring cirrhosis, enabling better management and treatment strategies for patients with this progressive liver disease.

Keywords: ***Liver Cirrhosis, Doppler Ultrasonography, Hepatic Hemodynamics, Portal Hypertension, Child-Pugh Score, Portal Vein Velocity, Hepatic Artery Resistive Index, Non-Invasive Imaging.***

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Introduction

1.1 Background of Liver Cirrhosis and Its Global Impact

Liver cirrhosis is a chronic and progressive disease that represents the end stage of various hepatic disorders characterized by diffuse hepatic fibrosis and the replacement of normal liver architecture with nodules (1). This condition significantly impacts global health, leading to considerable morbidity and mortality worldwide. These injurious agents trigger a cascade of inflammatory responses, leading to the scarring and dysfunction of liver tissue.

Globally, liver cirrhosis ranks as a leading cause of death. According to the Global Burden of Disease Study, it accounted for approximately 1.32 million deaths in 2017, making it one of the top ten causes of death globally (2). Developing countries bear a significant portion of this burden due to high rates of viral hepatitis and limited access to healthcare. In developed nations, lifestyle-related factors, including obesity and alcohol misuse, have become primary contributors to cirrhosis (3). Furthermore, the prevalence of cirrhosis is increasing due to the global rise in metabolic dysfunction-associated steatohepatitis (MASH), which are closely linked to sedentary lifestyles and unhealthy diets.

The pathophysiology of cirrhosis involves complex hemodynamic changes in the hepatic vasculature, significantly affecting portal and systemic circulation. These changes manifest clinically as portal hypertension, ascites, variceal bleeding, hepatic encephalopathy, and other life-threatening complications (4). These complications are not only medically significant but also place a heavy economic and emotional burden on patients and their families.

The lack of symptoms in the early stages often delays diagnosis, emphasizing the need for better screening tools.

In response to this global challenge, non-invasive diagnostic methods like Doppler ultrasonography have gained prominence. Doppler imaging offers valuable insights into hepatic vascular dynamics and provides clinicians with a means to assess disease progression and predict complications (5). The development and integration of advanced imaging modalities, coupled with clinical staging systems like the Child-Pugh score, have enhanced the ability to stratify patients based on disease severity and guide therapeutic interventions (6).

Addressing liver cirrhosis requires a multifaceted approach, including public health initiatives aimed at preventing viral hepatitis through vaccination programs, lifestyle modifications to combat metabolic dysfunction-associated steatohepatitis (MASH), and early detection strategies (7). In low-resource settings, the availability of cost-effective, reliable diagnostic tools like Doppler ultrasonography can bridge healthcare disparities and improve outcomes for cirrhotic patients (8). Thus, liver cirrhosis remains a critical public health issue, demanding continuous advancements in medical research, clinical management, and global health policies.

1.2 Importance of Hepatic Hemodynamic and Child-Pugh Scoring

Hepatic hemodynamic play a crucial role in understanding and managing liver cirrhosis, a condition marked by progressive fibrosis and vascular remodelling. These hemodynamic alterations, including changes in blood flow and resistance within the hepatic and portal venous systems, provide critical insights into disease progression, prognosis, and potential complications (9). In cirrhosis, the increased resistance to portal blood flow caused by structural changes and vascular contraction leads to portal hypertension, which in turn gives rise to clinical manifestations such as varices, ascites, and encephalopathy (10). Monitoring these hemodynamic changes through non-invasive tools like Doppler ultrasonography has become an invaluable aspect of clinical practice, offering a window into the severity of the disease and the risk of adverse events.

The Child-Pugh scoring system remains one of the most widely used and reliable methods for assessing liver disease severity in clinical settings. This scoring system evaluates five critical parameters: serum bilirubin, serum albumin, prothrombin time, ascites, and hepatic encephalopathy, assigning a score to each based on their severity (11). The cumulative score categorizes patients into three classes: A (mild), B (moderate), and C (severe), providing a comprehensive yet simple means of assessing liver function. The ease of calculation and its correlation with short-term mortality make the Child-Pugh score an indispensable tool for clinicians in decision-making processes such as determining treatment strategies and evaluating the need for liver transplantation (12).

Hepatic hemodynamic and the Child-Pugh score are intrinsically linked, as hemodynamic alterations directly influence the parameters assessed by the scoring system (13). For instance, portal vein velocity, a hemodynamic parameter, has been found to correlate inversely with Child-Pugh scores, highlighting its potential as a non-invasive biomarker for disease severity (14). Doppler ultrasonography, which measures blood flow and resistive indices in hepatic vessels, complements the Child-Pugh score by providing real-time data on hemodynamic status. This integration of Doppler findings with clinical scoring systems has been shown to enhance the accuracy of prognosis and aid in stratifying patients for tailored interventions (15).

The importance of hepatic hemodynamic extends beyond diagnosis and prognosis. Understanding these parameters is vital for predicting complications such as portal vein thrombosis and variceal bleeding, which are major contributors to morbidity and mortality in cirrhosis patients (9). By closely monitoring changes in blood flow dynamics, clinicians can identify high-risk patients early and implement preventive measures. Moreover, the study of hepatic hemodynamic has shed light on the pathophysiology of cirrhosis, revealing the interplay between structural and functional abnormalities in the liver's vascular system.

Incorporating Child-Pugh scoring into routine clinical practice, along with hemodynamic evaluation, ensures a holistic approach to managing cirrhosis. While the scoring system provides a snapshot of liver function, Doppler studies offer a deeper understanding of the vascular environment, enabling a more nuanced assessment of disease progression (16). Together, they form a robust framework for guiding therapeutic decisions, predicting outcomes, and improving the overall management of liver cirrhosis. As research advances, the integration of newer imaging modalities with traditional scoring systems holds promise for further refining our understanding of hepatic hemodynamic and enhancing patient care.

1.3 Doppler Ultrasound in the Evaluation of Cirrhosis

Doppler ultrasound has emerged as a cornerstone in the evaluation and management of liver cirrhosis due to its non-invasive nature, accessibility, and ability to provide real-time insights into hepatic hemodynamic. Cirrhosis, characterized by progressive liver fibrosis and vascular remodelling, leads to significant alterations in blood flow patterns within the hepatic and portal venous systems (17). These changes manifest clinically as complications such as portal hypertension, ascites, and variceal bleeding, necessitating a reliable diagnostic tool for early detection and monitoring. Doppler ultrasound fulfill this role effectively, offering a safe and repeatable method for assessing hemodynamic parameters without exposing patients to ionizing radiation or invasive procedures.

One of the primary reasons for utilizing Doppler ultrasound in cirrhosis is its ability to detect early hemodynamic changes, even before clinical symptoms manifest. The technique measures critical parameters such as portal vein velocity, hepatic artery resistive index, and hepatic venous waveform patterns, which provide indirect evidence of portal hypertension and liver dysfunction (18). For instance, studies have demonstrated that decreased portal vein velocity and increased hepatic artery resistance are strongly associated with advanced stages of cirrhosis, correlating with the severity as assessed by the Child-Pugh score (19). These findings highlight Doppler ultrasound's utility in stratifying patients based on disease progression.

Another significant advantage of Doppler ultrasound is its role in predicting and managing complications of cirrhosis. Portal vein thrombosis, a life-threatening condition often associated with cirrhosis, can be accurately diagnosed using Doppler imaging, which identifies changes in flow direction and velocity within the portal venous system (20). Additionally, Doppler studies can detect arterioportal shunts, which are characteristic of cirrhosis-related vascular remodelling, further aiding in the differentiation of benign and malignant lesions(21). This capability makes Doppler ultrasound invaluable in guiding therapeutic decisions and interventions, such as anticoagulation therapy or shunt surgeries.

Cost-effectiveness and widespread availability are other factors justifying the use of Doppler ultrasound in evaluating cirrhosis. Unlike more advanced imaging modalities such as magnetic resonance imaging (MRI) or computed tomography (CT), Doppler ultrasound is less expensive and can be performed at the bedside, making it particularly advantageous in resource-limited settings (22). Its portability and ease of use allow for repeated evaluations, enabling clinicians to monitor disease progression and treatment responses over time. Furthermore, Doppler ultrasound is suitable for a wide range of patients, including those who may not tolerate contrast-enhanced studies due to renal impairment or other contraindications.

The integration of Doppler ultrasound with clinical scoring systems like the Child-Pugh score enhances its diagnostic and prognostic value. While the Child-Pugh score provides a functional assessment of liver disease, Doppler parameters offer a structural and hemodynamic perspective, creating a comprehensive evaluation framework (23). This combination is particularly effective in identifying patients at higher risk of complications and determining the timing of interventions such as liver transplantation.

In conclusion, Doppler ultrasound represents an indispensable tool in the evaluation of liver cirrhosis. Its ability to provide detailed hemodynamic information, coupled with its non-invasive nature and cost-effectiveness, makes it a preferred choice for clinicians worldwide. By facilitating early detection, monitoring progression, and predicting complications, Doppler ultrasound significantly contributes to improving outcomes in cirrhotic patients. As technology advances, its integration with other imaging modalities and clinical parameters promises to further enhance its utility in liver disease management.

1.4 Limited Studies Correlating Doppler Metrics with Cirrhosis Severity

Despite the growing recognition of Doppler ultrasonography as a valuable diagnostic tool in evaluating liver cirrhosis, research correlating Doppler metrics with the severity of cirrhosis remains limited (24). This gap is particularly significant given the critical role Doppler imaging plays in assessing hemodynamic changes associated with cirrhosis, such as alterations in portal vein velocity, hepatic artery resistive index, and hepatic venous waveforms (25). While some studies have demonstrated the utility of Doppler parameters in stratifying cirrhotic patients, the variability in findings and lack of large-scale, standardized studies hinder its widespread application in clinical practice.

The limited research in this domain can be attributed to several factors, including the complex nature of hepatic hemodynamic and the challenges associated with obtaining consistent Doppler measurements across diverse patient populations. Hemodynamic changes in cirrhosis are influenced by various factors, such as underlying etiology, comorbid conditions, and disease progression, which makes it difficult to establish universal Doppler criteria for disease severity (26). For example, studies like those conducted by Ralls (1990) and Kamalov et al. (1998) have shown that portal vein velocity decreases as cirrhosis progresses, but the degree of change varies significantly among patients, leading to inconsistencies in correlating Doppler findings with clinical scores like the Child-Pugh classification (9,22) .

Another limitation is the relatively small sample sizes in existing studies. Many of the studies that have explored Doppler ultrasonography in cirrhosis focus on specific patient subsets, often excluding those with comorbidities or advanced complications like portal vein thrombosis or hepatocellular carcinoma. This narrow focus reduces the generalizability of the findings. For instance, research by Tessler et al. (1991) emphasized the diagnostic accuracy of Doppler ultrasound in identifying portal vein thrombosis but did not extensively evaluate its correlation with broader cirrhosis severity markers (27). Similarly, while studies such as those by Grant et al. (1992) have highlighted changes in hepatic artery resistive index in advanced cirrhosis, they often lack comprehensive analysis across all cirrhosis stages (28).

The lack of multicentre trials and prospective cohort studies also contributes to the scarcity of robust data. Most studies are retrospective and conducted in single-center settings, which limits the ability to account for variations in Doppler equipment, operator expertise, and patient demographics. Additionally, technical factors such as probe angle, patient positioning, and respiratory influences can significantly affect Doppler measurements, introducing variability that complicates data interpretation and comparison across studies (29).

Despite these challenges, existing research underscores the potential of Doppler ultrasonography as a non-invasive tool for evaluating cirrhosis severity. The ability to measure hemodynamic changes in real time offers a unique advantage over traditional diagnostic methods. For example, studies like those by Afif et al. (2017) and Scheinfeld et al. (2009) have demonstrated promising correlations between Doppler parameters and clinical severity scores, suggesting that further investigation could lead to standardized protocols and broader clinical adoption (11,14).

Addressing the current limitations requires more extensive and standardized research efforts. Large-scale, multicentre studies with diverse patient populations are essential to validate the findings of smaller studies and establish Doppler ultrasonography as a reliable metric for assessing cirrhosis severity. Future research should also focus on integrating Doppler parameters with other diagnostic modalities, such as elastography and contrast-enhanced ultrasound, to create comprehensive evaluation frameworks. Until then, the limited studies available highlight the need for cautious interpretation of Doppler findings while reinforcing its potential as a valuable addition to the diagnostic arsenal for liver cirrhosis.

Objectives of the Study

To correlate Doppler ultrasound parameters including hepatic artery resistive index, hepatic artery PSV, portal vein PSV, and hepatic vein PSV with the Child-Pugh score to evaluate the severity and progression of liver cirrhosis.

Review of Literature

2.1 Anatomy of liver

The liver is one of the largest and most vital organs in the human body. It plays an essential role in metabolism, detoxification, synthesis of proteins, and the regulation of blood clotting (30). It also performs key functions in digestion through bile production. The anatomy of the liver has been the subject of extensive research, offering valuable insights into its structure, organization, and physiological significance (31). In this review, we will examine the anatomy of the liver by discussing its gross structure, microanatomy, blood supply, and functional units.

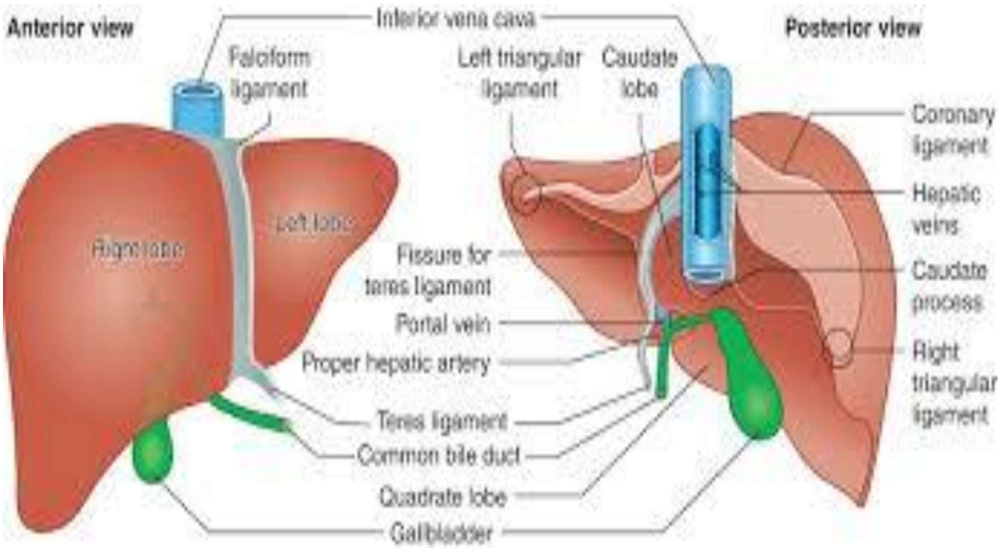


Fig 2.1 Liver Anatomy

- **Gross Anatomy of the Liver**

The liver is located in the upper right quadrant of the abdomen, below the diaphragm and above the stomach. It is primarily composed of two lobes: the larger right lobe and the smaller left lobe, separated by the falciform ligament (33). Additionally, the liver has two smaller lobes: the caudate lobe, located on the posterior side, and the quadrate lobe, located on the anterior side. The liver is divided into functional units, known as lobules, which are the focus of its microanatomy and functional organization.

The liver's weight ranges between 1.2 to 1.5 kg in adults, and its size can vary due to factors like age, health, and disease. The right lobe is much larger than the left, which has an impact on various functions such as metabolism and detoxification (34). It is covered by a capsule of connective tissue called Glisson's capsule, which supports and protects the liver tissue. The surface of the liver is smooth, and its borders are generally sharp. The liver has a reddish-brown appearance and is highly vascularized.

- **Microanatomy of the Liver**

The liver is a highly specialized organ with a complex microanatomy that facilitates its diverse functions. At the cellular level, the liver is composed primarily of hepatocytes, which are the main functional cells responsible for metabolism, protein synthesis, and detoxification (35). These hepatocytes are organized into lobules, each of which contains a central vein surrounded by hepatocytes arranged in a radial pattern.

The functional unit of the liver is the liver lobule. The lobule consists of hepatocytes arranged in a pattern that radiates outward from the central vein. Between these hepatocytes are structures called sinusoids, which are specialized blood vessels that allow for efficient exchange of substances between the blood and hepatocytes (36). The sinusoids are lined with endothelial cells and Kupffer cells, which are involved in immune responses and the breakdown of foreign particles.

In addition to hepatocytes, the liver contains other specialized cells, such as stellate cells, which store vitamin A and play a role in liver fibrosis, and cholangiocytes, which line the bile ducts and are responsible for bile secretion (37). The portal triad, consisting of the portal vein, hepatic artery, and bile duct, is found at the corners of each lobule. These structures are essential for nutrient and oxygen supply, as well as bile production.

- **Blood Supply of the Liver**

The liver receives blood from two primary sources: the hepatic artery and the portal vein. The hepatic artery supplies oxygenated blood to the liver, while the portal vein delivers nutrient-rich blood from the gastrointestinal tract, spleen, and pancreas (38). Both vessels converge into the liver sinusoids, where the exchange of nutrients, waste products, and other substances occurs. This dual blood supply is essential for maintaining liver function, especially in detoxification and metabolism.

The liver has a unique feature in its blood circulation, known as the hepatic portal system, which allows for direct delivery of nutrients from the digestive system to the liver for processing (39). After the blood flows through the sinusoids and interacts with hepatocytes, it drains into the central vein, which eventually leads to the hepatic vein and returns the blood to the inferior vena cava for circulation throughout the body.

- **Functional Units of the Liver**

The liver performs a wide range of functions, and its organization is designed to optimize these activities (40). The key functional units of the liver include:

- Hepatic Metabolism: Hepatocytes play a crucial role in the metabolic processes of the liver, including glucose homeostasis, lipid metabolism, and protein synthesis (41). These cells are involved in glycogenesis, gluconeogenesis, and the synthesis of plasma proteins such as albumin and clotting factors.
- Detoxification: Hepatocytes also contain enzymes involved in the detoxification of harmful substances, including drugs, alcohol, and metabolic waste products (42). The liver is central to the body's ability to metabolize and eliminate toxins, a process that often involves the cytochrome P450 enzyme system.
- Storage and Regulation: The liver is involved in storing essential nutrients, such as glucose in the form of glycogen and vitamins like vitamin A and D (43). It also helps regulate the levels of various ions and metabolites in the blood, contributing to homeostasis.
- Immune Response: The liver plays a key role in immune function through the actions of Kupffer cells, which are specialized macrophages that filter out pathogens and debris from the blood.

- **Clinical Relevance and Disorders of the Liver Anatomy**

A variety of diseases can affect the anatomy and function of the liver. These include conditions such as cirrhosis, hepatitis, and liver cancer (hepatocellular carcinoma). Cirrhosis is characterized by fibrosis and scarring of the liver tissue, which impairs its function and leads to portal hypertension (44). Hepatitis, an inflammation of the liver, can be caused by viral infections (e.g., hepatitis B or C) or autoimmune diseases. Liver cancer often arises in the context of chronic liver disease or cirrhosis.

Understanding the anatomy of the liver is crucial for diagnosing and managing liver diseases. The liver's structure and organization are essential in understanding how it performs its many roles in metabolism, detoxification, and immune response.

The anatomy of the liver is intricately designed to support its vital functions in the human body. From its gross structural organization into lobes and lobules to its microanatomy involving hepatocytes, sinusoids, and portal triads, the liver is a highly specialized organ (45). Its dual blood supply, complex bile production system, and role in metabolism and detoxification highlight its importance in maintaining overall health. Continued research into the liver's anatomy and function will aid in the development of treatments for liver diseases and improve our understanding of this essential organ.

2.2 Patho Physiology of Liver Cirrhosis

Cirrhosis is a progressive disease of the liver characterized by fibrosis, nodular regeneration, and vascular remodelling, resulting in severe disruptions to hepatic architecture and function (46). The pathophysiological changes in cirrhosis begin with chronic injury to hepatocytes, often caused by factors such as viral hepatitis, excessive alcohol intake, or non-alcoholic fatty liver disease. Persistent hepatic injury triggers an inflammatory response, leading to the activation of hepatic stellate cells (HSCs) (11). These cells transform into myofibroblast-like cells, which produce excess extracellular matrix proteins, culminating in fibrosis and scarring of the liver parenchyma.

Over time, this fibrotic process distorts the hepatic lobules, replacing normal liver tissue with regenerative nodules that lack the functional capacity of healthy hepatocytes.

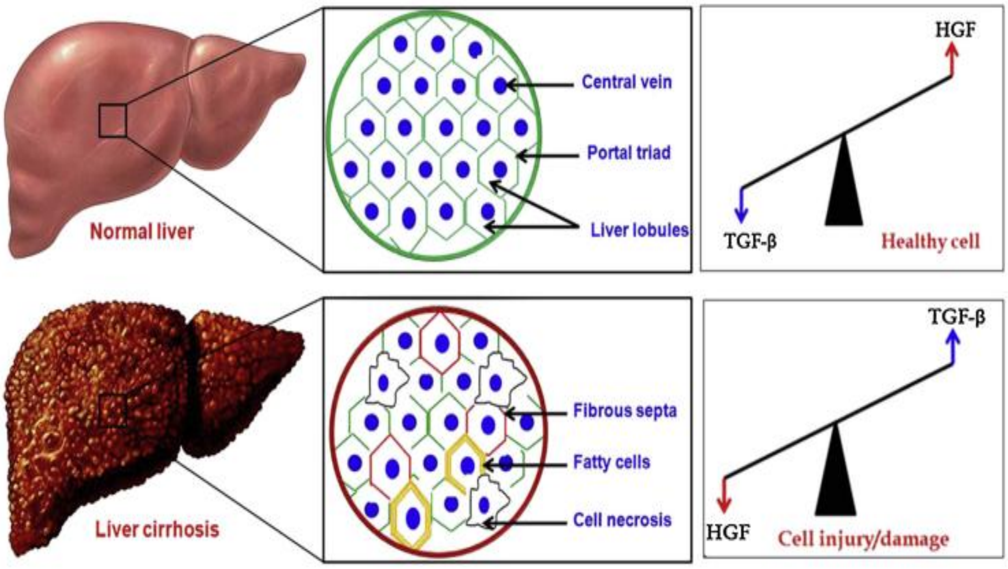


Fig 2.2 Cellular pathological feature of normal and cirrhotic live

One of the most critical consequences of cirrhosis is portal hypertension, which arises due to increased resistance to blood flow through the portal vein. The fibrotic tissue compresses and obliterates the sinusoidal architecture, leading to elevated intrahepatic vascular resistance (9). Simultaneously, there is dysregulation of vascular tone within the liver due to reduced nitric oxide availability and an imbalance between vasoconstrictive and vasodilatory factors. This dysregulation exacerbates portal pressure and further contributes to hemodynamic instability (21). As a compensatory mechanism, the splanchnic circulation undergoes vasodilation, resulting in increased blood flow into the portal system, which worsens portal hypertension and leads to complications such as ascites and varices.

The hemodynamic alterations in cirrhosis extend beyond the portal vein. Changes in hepatic arterial and venous flow patterns are significant markers of disease progression. The hepatic artery often exhibits increased resistive indices due to the stiffening of the liver tissue and changes in vascular compliance (27). Conversely, the portal vein demonstrates a reduction in velocity and pulsatility, reflecting the obstructed flow within the liver. Hepatic venous waveforms, which are normally triphasic due to the interplay between cardiac activity and venous pressure, become monophasic or flattened as cirrhosis progresses, indicating advanced liver dysfunction and portal hypertension (14). These Doppler-derived hemodynamic changes provide valuable insights into the severity of cirrhosis and its complications.

Cirrhosis is also associated with systemic hemodynamic alterations due to the hyper dynamic circulatory state. This state is characterized by increased cardiac output, reduced systemic vascular resistance, and widespread vasodilation, particularly in the splanchnic circulation. The resulting reduction in effective arterial blood volume activates neurohormonal systems such as the renin-angiotensin-aldosterone system (RAAS) and sympathetic nervous system, leading to sodium retention and fluid accumulation (19). These changes contribute to the development of ascites, hepatorenal syndrome, and hepatic encephalopathy, which are hallmark complications of advanced cirrhosis.

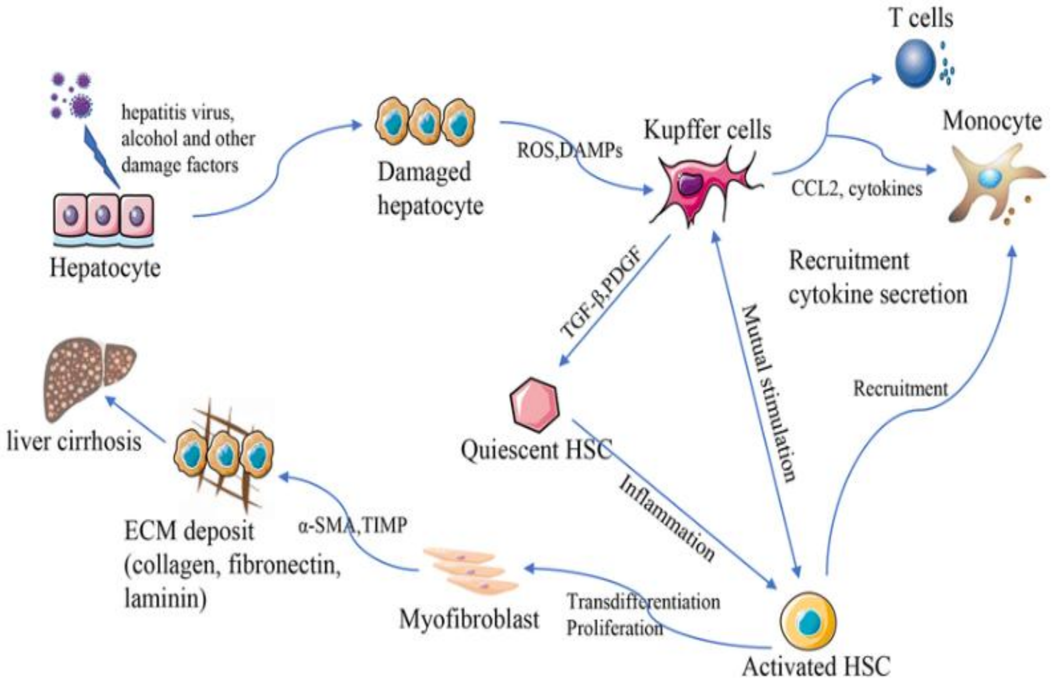


Fig 2.3 Pathogenesis of liver cirrhosis (47)

In advanced stages, cirrhosis also predisposes patients to the formation of portosystemic collaterals, such as esophageal and gastric varices, as the body attempts to bypass the high resistance within the liver. These collateral vessels are fragile and prone to rupture, causing life-threatening variceal bleeding. Additionally, the altered hemodynamic in cirrhosis increase the risk of thrombosis in the portal vein and hepatic veins, further complicating the disease course(28).

Understanding the pathophysiology of cirrhosis and its hemodynamic alterations is essential for managing this complex condition. Doppler ultrasonography serves as a critical diagnostic tool in assessing these vascular changes, allowing for early detection of complications and providing a non-invasive means to monitor disease progression (48). As our understanding of these hemodynamic alterations grows, there is potential for developing targeted therapies to address the vascular dysfunction inherent in cirrhosis and improve patient outcomes.

2.3 Grading of liver cirrhosis by Child Turcot Pugh score

The Child-Pugh scoring system (also known as the Child-Pugh-Turcotte score) was designed to predict mortality in cirrhosis patients. Originally conceptualized by Child and Turcotte in 1964 to guide the selection of patients who would benefit from elective surgery for portal decompression, it broke down patients into three categories: A - good hepatic function, B - moderately impaired hepatic function, and C - advanced hepatic dysfunction (49). Their original scoring system used five clinical and laboratory criteria to categorize patients: serum bilirubin, serum albumin, ascites, neurological disorder, and clinical nutrition status. The scoring system was modified later by Pugh et al., substituting prothrombin time for clinical nutrition status (50). Additionally, they introduced variable points for each criterion based on increasing severity.

- **Encephalopathy:** None = 1 point, Grade 1 and 2 = 2 points, Grade 3 and 4 = 3 points
- **Ascites:** None = 1 point, slight = 2 points, moderate = 3 points
- **Bilirubin:** under 2 mg/ml = 1 point, 2 to 3 mg/ml = 2 points, over 3 mg/ml = 3 points
- **Albumin:** greater than 3.5mg/ml = 1 point, 2.8 to 3.5mg/ml = 2 points, less than 2.8mg/ml = 3 points
- **Prothrombin Time* (sec prolonged):** less than 4 sec = 1 point, 4 to 6 sec = 2 points, over 6 sec = 3 points

Frequently INR will be used as a substitute for PT, with INR under 1.7 = 1 point, INR 1.7 to 2.2 = 2 points, INR above 2.2 = 3 points

The severity of cirrhosis:

- **Child-Pugh A:** 5 to 6 points
- **Child-Pugh B:** 7 to 9 points
- **Child-Pugh C:** 10 to 15 points

Historically the Child-Pugh classification was used for liver transplant allocations. However, there were three primary limitations to its use:

1) Grading ascites and encephalopathy require a subjective assessment,

2) The classification system does not account for renal function, and

3) There are only ten different scores (based on points) available.

This last limitation was significant because patients were not able to be adequately differentiated based on the severity of the disease, and therefore wait time had a considerable impact on prioritization (51). Practically speaking, a patient with an INR of 6 and bilirubin of 14 could potentially have the same Child-Pugh score as a patient with an INR of 2.3 and bilirubin of 4.0 (52). The MELD score, which has a broader range of more continuous variable values, was created to account for these differences (53). The original MELD score calculation used the patient's bilirubin level, creatinine level, INR, and cause of liver disease. Since then, it has evolved to exclude causes of disease and takes into account the serum sodium level and whether the patient is on dialysis.

Table 1. Child-Pugh Classification

Empty Cell	**Points**		
Variable	**1**	**2**	**3**
Ascites	None	Easily controlled	Poorly controlled
Albumin (g/dL)	>3.5	2.8–3.5	<2.8

Empty Cell	Points		
Variable	**1**	**2**	**3**
Bilirubin (mg/dL)	<2	2–3	>3
Encephalopathy	Absent	Grades 1/2 (minimum)	Grades 3/4 (advanced)
Prothrombin (sec & control)	<4	4–6	>6

The Child-Pugh score has been validated as a predictor of postoperative mortality after portocaval shunt surgery and predicts mortality risk associated with other major operations (54). After abdominal surgery, Child class A patients have a 10% mortality rate; Child class B patients have a 30% mortality rate, and Child class C patients have a 70 to 80% mortality rate. Child class A patients are generally considered safe candidates for elective surgery (55). Child class B patients can proceed with surgery after medical optimization but still have increased risk. Elective surgery is contraindicated in Child class C patients (50). The Child-Pugh score can help predict all-cause mortality risk and development of other complications from liver dysfunction, such as variceal bleeding, as well. In one study, overall mortality for these patients at one year was 0% for Child class A, 20% for Child class B, and 55% for Child class C.

2.4 Ultrasound Doppler of normal liver

Ultrasound Doppler of the liver is a non-invasive imaging technique that combines conventional ultrasound and Doppler ultrasound to assess liver blood flow and detect any abnormalities (56). Doppler ultrasound uses sound waves to evaluate the speed and direction of blood flow, providing a dynamic and detailed view of the liver's vascular structure. It is often used in clinical settings to evaluate liver function, identify pathologies, and monitor patients with known liver diseases.

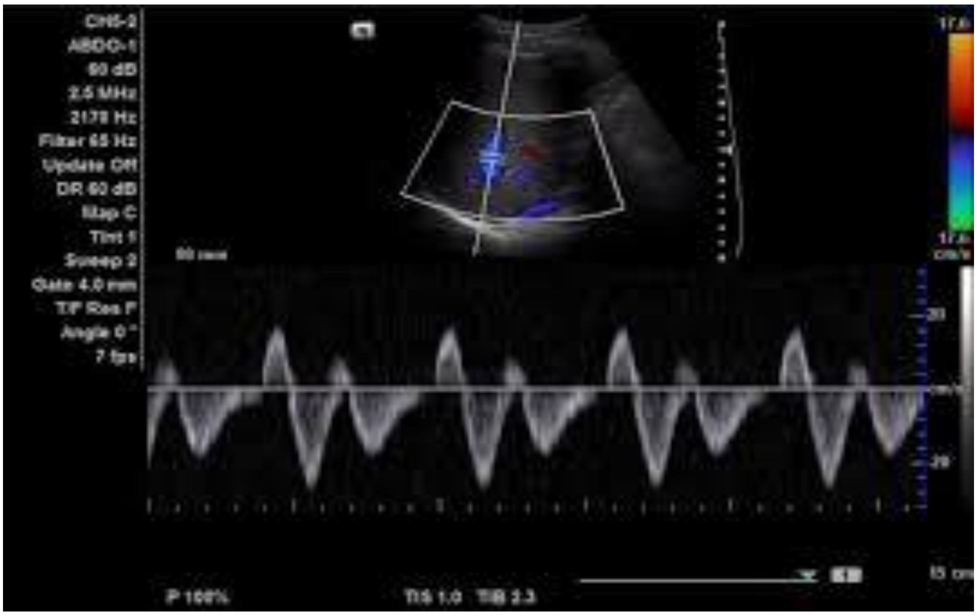


Fig 2.4 Ultrasound Doppler of normal liver (57)

In a normal liver, Doppler ultrasound demonstrates characteristic blood flow patterns that reflect the healthy functioning of the liver's vascular system. The liver receives blood from two main sources: the hepatic artery and the portal vein (58). The hepatic artery carries oxygen-rich blood from the heart to the liver, while the portal vein brings nutrient-rich blood from the digestive organs. These two vessels play critical roles in maintaining the liver’s metabolism and detoxification processes.

A normal Doppler ultrasound of the liver will show the portal vein flowing towards the liver with a low-velocity, continuous flow pattern (59). In contrast, the hepatic artery shows pulsatile flow, with a higher velocity during systole (when the heart contracts) and lower velocity during diastole (when the heart relaxes). The normal portal venous flow velocity is typically between 15-25 cm/s, while the hepatic artery has a higher velocity range depending on the individual's health and position.

The Doppler ultrasound can also assess the relationship between the velocity of blood flow and the vascular resistance in the liver (60). In a healthy liver, the flow is well-regulated, and there is no abnormal increase in resistance or reversal of blood flow. This reflects normal hepatic circulation and indicates no evidence of conditions like portal hypertension, cirrhosis, or vascular malformations.

In addition to the liver itself, Doppler ultrasound can be used to visualize blood flow in other abdominal vessels such as the splenic vein, renal veins, and inferior vena cava, which are important for evaluating systemic circulation and any potential complications related to liver diseases (61). The technique is particularly useful in assessing the portal vein for signs of thrombosis or narrowing, which can be indicative of liver dysfunction or hepatic venous pressure changes.

Overall, a normal ultrasound Doppler of the liver provides valuable information about the liver's blood flow and can be used to monitor liver health, detect early signs of disease, and guide treatment decisions.

2.5 Ultrasound Doppler of cirrhotic liver

Ultrasound Doppler imaging plays a critical role in the assessment of cirrhotic liver disease, primarily by evaluating the vascular changes associated with liver cirrhosis. Cirrhosis is characterized by chronic liver injury that leads to fibrosis, which progressively distorts the liver architecture and affects the vascular system (62). Doppler ultrasound is a non-invasive, cost-effective diagnostic tool that helps assess both hepatic and portal circulation in cirrhotic patients.

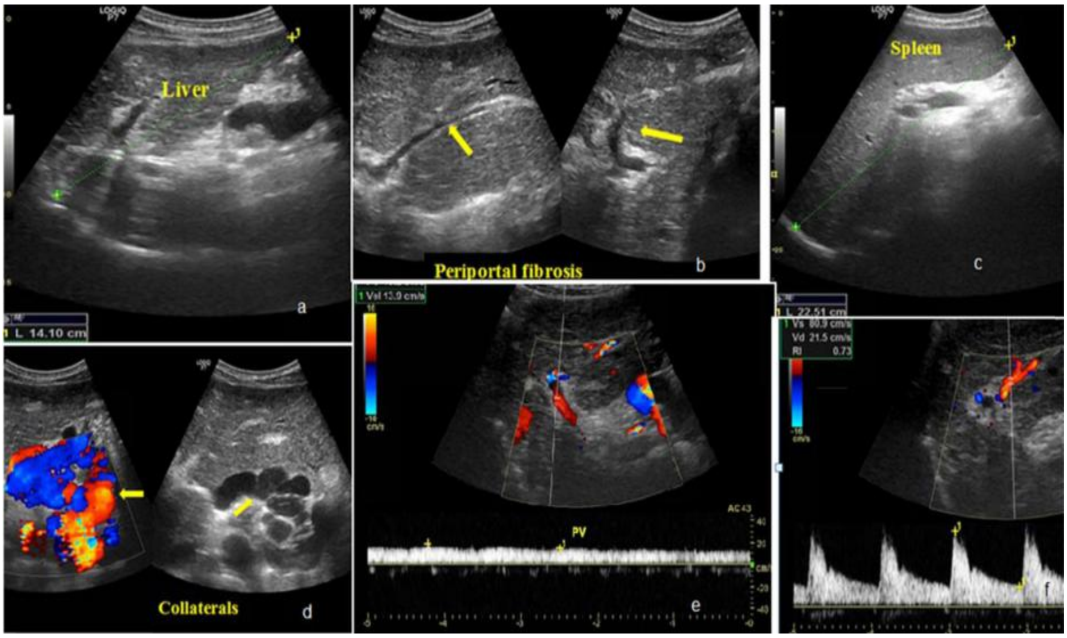


Fig 2.5 Ultrasound Doppler of cirrhotic liver (63)

One of the major vascular complications of cirrhosis is portal hypertension, a condition where increased pressure in the portal venous system occurs due to the impaired blood flow through the liver. The Doppler ultrasound helps in detecting these hemodynamic changes by measuring blood flow velocities, direction, and volume within the portal venous system, hepatic veins, and the inferior vena cava (64).

The most significant Doppler finding in cirrhosis is the increase in portal vein diameter and changes in the portal vein flow patterns (65). Normally, the portal vein flows towards the liver with a relatively constant velocity. However, in cirrhosis, this flow may become more pulsatile or reversed, which is indicative of portal hypertension. In some cases, Doppler ultrasound may show a complete cessation of portal flow, which could suggest more severe liver dysfunction.

Another critical aspect of Doppler ultrasound in cirrhotic liver disease is the assessment of the hepatic artery (66). In cirrhosis, due to reduced portal venous flow, there is compensatory dilatation and increased flow within the hepatic artery. This phenomenon is referred to as hepatic artery dominance, and it can be observed as a marked increase in hepatic artery velocity and pulsatility indices (67). This is crucial for identifying the degree of portal hypertension and monitoring disease progression.

Additionally, Doppler ultrasound can detect the presence of collateral circulation, such as varices and shunts, which develop as a result of portal hypertension (68). These collateral vessels, including esophageal varices and the spleen, are essential to identify as they pose a risk of bleeding in cirrhotic patients. The assessment of hepatic vein flow is also significant as it can indicate the degree of liver congestion or impaired venous drainage, which is a hallmark of cirrhosis-related complications.

In conclusion, Doppler ultrasound provides vital information about the vascular changes in cirrhosis, including portal hypertension, changes in the hepatic and portal venous flow, and the presence of collateral circulation. This imaging modality is an essential tool for diagnosing, monitoring, and managing cirrhotic liver disease without the need for invasive procedures.

Advances in Doppler Technology for Hepatic Studies

Doppler ultrasonography has undergone significant advancements over the past few decades, transforming it into a powerful tool for the non-invasive evaluation of hepatic hemodynamic (9). These technological improvements have enhanced the accuracy, resolution, and versatility of Doppler imaging, making it indispensable in the diagnosis and management of liver diseases, including cirrhosis. Initially developed for basic assessments of blood flow, modern Doppler technologies now allow clinicians to investigate complex vascular patterns and dynamic hemodynamic changes in real time, providing critical insights into the pathophysiology of liver disorders.

One of the major advances in Doppler technology is the development of color Doppler imaging, which visualizes blood flow within hepatic vessels in a color-coded format. This enhancement allows for rapid identification of blood flow direction, velocity, and turbulence, enabling the detection of vascular abnormalities such as portal vein thrombosis, arterioportal shunts, and variceal collateral formation (69). Compared to conventional gray-scale ultrasound, color Doppler provides a more comprehensive view of hepatic circulation, which is particularly beneficial in evaluating complex hemodynamic changes in cirrhosis. The ability to overlay blood flow information on anatomical structures has significantly improved the diagnostic capabilities of ultrasonography.

Power Doppler is another significant advancement that provides improved sensitivity in detecting low-velocity blood flow, often missed by traditional Doppler methods. This feature is particularly valuable in hepatic studies, where slow or minimal blood flow, such as in portal vein thrombosis or small intrahepatic shunts, may be difficult to visualize. Unlike color Doppler, power Doppler does not rely on flow direction and is less affected by artifacts, making it a reliable tool for assessing microvascular changes within the liver (70).

Spectral Doppler, which generates waveforms based on blood flow velocity, has also seen refinements that enhance its utility in hepatic studies. Modern spectral Doppler systems now provide higher temporal resolution and better signal processing, allowing clinicians to accurately measure resistive and pulsatility indices of the hepatic artery. These parameters are critical for assessing vascular resistance, which often increases in advanced cirrhosis due to fibrotic remodelling and decreased hepatic compliance (27). Additionally, improved spectral Doppler technology enables the detection of changes in hepatic venous waveforms, which are early indicators of liver dysfunction and portal hypertension (11).

Recent innovations include contrast-enhanced ultrasound (CEUS), which combines Doppler imaging with the administration of microbubble contrast agents to improve visualization of hepatic vasculature. CEUS enhances the ability to differentiate between benign and malignant liver lesions and provides detailed information about arterial and venous phases of blood flow. This advancement is particularly useful in patients with cirrhosis, where the differentiation between regenerative nodules and hepatocellular carcinoma is critical (71). CEUS also enhances the detection of small vascular abnormalities, such as arterioportal fistulas, which may contribute to portal hypertension.

High-resolution Doppler imaging, including advancements like high-frame-rate ultrasound and three-dimensional Doppler, has further expanded the diagnostic potential of this modality. These technologies allow for more detailed visualization of complex vascular networks, including intrahepatic collaterals and portosystemic shunts. High-frame-rate Doppler systems provide real-time imaging of rapid blood flow changes, which is essential for evaluating dynamic processes such as cardiac-induced pulsatility in hepatic veins (14).

The integration of Doppler technology with elastography has also emerged as a significant breakthrough in hepatic imaging. Elastography measures liver stiffness, which correlates with fibrosis, while Doppler assesses vascular dynamics, providing a comprehensive evaluation of cirrhosis. This combination allows for a more accurate assessment of disease severity and progression, reducing the need for invasive procedures like liver biopsies(11).

In conclusion, the advances in Doppler technology have greatly enhanced the scope of hepatic studies, offering detailed insights into vascular and hemodynamic changes associated with liver diseases. These innovations not only improve diagnostic accuracy but also facilitate early detection of complications, guide treatment strategies, and monitor therapeutic responses. As Doppler ultrasonography continues to evolve, its integration with other imaging modalities and the development of artificial intelligence algorithms promise even greater strides in the non-invasive evaluation of hepatic disorders.

Doppler Findings with Clinical Staging of Cirrhosis

Numerous studies have investigated the relationship between Doppler ultrasound findings and the clinical staging of liver cirrhosis, highlighting the utility of Doppler metrics as non-invasive markers of disease severity. Clinical staging systems, such as the Child-Pugh score, are widely used to assess the functional status of the liver and predict patient outcomes. Doppler ultrasonography complements these staging systems by providing real-time hemodynamic data that reflect the physiological changes accompanying the progression of cirrhosis (11). The correlation between Doppler parameters and clinical staging has been a focus of research, aiming to improve the precision of cirrhosis evaluation and facilitate early detection of complications.

Studies have consistently shown that portal vein velocity decreases as cirrhosis advances, correlating with higher Child-Pugh scores. Mittal et al. (2011) observed a significant reduction in portal vein velocity among patients with severe cirrhosis compared to those with milder disease (72). This decrease is attributed to increased intrahepatic vascular resistance caused by fibrosis and nodular regeneration, which obstruct blood flow through the portal vein. Additionally, studies like those by Ralls (1990) have noted that a reduction in portal vein pulsatility is also indicative of advanced cirrhosis, as it reflects diminished hepatic compliance and increased pressure within the portal system (9).

The hepatic artery resistive index (HARI) is another Doppler parameter that has been linked to the staging of cirrhosis. Research by Afif et al. (2017) demonstrated that an elevated HARI correlates with worsening liver function, as measured by the Child-Pugh score (11). This increase in resistance is primarily due to the stiffening of hepatic tissues and compensatory changes in arterial flow dynamics in response to portal hypertension. Similarly, Martínez-Noguera et al. (2002) found that HARI serves as a reliable indicator of cirrhosis severity, distinguishing between early and advanced stages with considerable accuracy (19).

Hepatic venous waveforms have also been a focal point of studies linking Doppler findings to cirrhosis staging. Normal hepatic venous waveforms are triphasic, reflecting the pressure changes transmitted from the right atrium. However, as cirrhosis progresses, these waveforms become monophasic or flattened due to increased hepatic stiffness and reduced compliance. Studies such as those by Gorg et al. (2002) have established that changes in hepatic venous waveforms are strongly associated with higher Child-Pugh scores, making them a valuable diagnostic feature (73) .

Furthermore, Doppler studies have explored the role of arterioportal shunting in cirrhosis, a phenomenon often observed in advanced stages. Bolognesi et al. (2000) highlighted that the presence of these shunts, detectable via Doppler imaging, is indicative of severe portal hypertension and correlates with decompensated cirrhosis (71). The ability to identify such hemodynamic abnormalities non-invasively has significant clinical implications, as it enables early intervention to manage complications such as variceal bleeding and ascites.

Systematic reviews and meta-analyses, such as those by Baik (2010), have further reinforced the link between Doppler parameters and clinical staging of cirrhosis (10). These studies emphasize that integrating Doppler findings with established scoring systems, like the Child-Pugh or MELD (Model for End-Stage Liver Disease) scores, enhances the diagnostic accuracy and prognostic value of cirrhosis evaluations. For instance, combining portal vein velocity and HARI measurements with clinical data provides a comprehensive understanding of the disease’s impact on hepatic function and vascular dynamics.

Despite the robust evidence supporting these correlations, some limitations remain. Variability in Doppler measurements due to operator dependency and differences in equipment settings can affect the reproducibility of findings (27). Moreover, most studies focus on specific Doppler parameters without integrating advanced techniques like contrast-enhanced ultrasound, which could offer even greater precision.

In conclusion, studies linking Doppler findings with clinical staging of cirrhosis highlight the complementary role of this imaging modality in non-invasive liver assessment. Parameters such as portal vein velocity, hepatic artery resistive index, and hepatic venous waveforms provide critical insights into disease severity and progression, aligning closely with clinical staging systems. These findings underscore the importance of Doppler ultrasonography in enhancing the accuracy of cirrhosis evaluation and guiding timely therapeutic decisions. Future research should aim to address existing limitations and integrate emerging Doppler technologies to further refine its clinical application.

Variability in Doppler Measurements and Their Interpretation

Doppler ultrasonography has established itself as a critical tool in the non-invasive assessment of hepatic hemodynamics, yet its clinical utility is often challenged by the variability in measurements and interpretation. This variability arises from a combination of technical, physiological, and operator-dependent factors, which can influence the accuracy and reproducibility of Doppler findings. Understanding and mitigating these sources of variability is essential to ensure reliable clinical application and meaningful correlation with disease severity (28).

One of the primary sources of variability in Doppler measurements is operator dependency. The skill and experience of the sonographer play a pivotal role in obtaining accurate readings. Parameters such as probe angle, transducer frequency, and the pressure applied during imaging can significantly affect the quality of Doppler signals. For instance, an improper probe angle can lead to an inaccurate estimation of blood flow velocity, as Doppler measurements are highly sensitive to the angle of insonation (14). Even minor deviations from the optimal angle of 60 degrees can result in substantial errors, leading to misinterpretation of vascular flow dynamics.

Patient-related factors also contribute to variability in Doppler measurements. Physiological conditions such as respiration, cardiac output, and hydration status can alter blood flow patterns and velocities, making it challenging to standardize readings. For example, portal vein velocity may fluctuate with phases of the respiratory cycle, as deep inspiration tends to decrease intra-abdominal pressure and increase venous return, altering flow dynamics temporarily (11). Additionally, in patients with obesity or ascites, obtaining clear Doppler signals can be difficult due to poor acoustic windows, further complicating measurement accuracy.

The inherent characteristics of Doppler technology also introduce variability. Differences in machine settings, such as gain, filter settings, and pulse repetition frequency (PRF), can influence the sensitivity and resolution of Doppler imaging. Machines from different manufacturers may have variations in calibration, resulting in discrepancies in measured values across devices (19). This technological variability underscores the need for standardized protocols to ensure consistency in Doppler evaluations across institutions and studies.

Another critical factor is the dynamic nature of hepatic hemodynamics. Blood flow within the liver is influenced by complex interactions between systemic and portal circulation, making it inherently variable. In conditions like cirrhosis, the formation of portosystemic collaterals and changes in vascular resistance further complicate the interpretation of Doppler findings (71). For example, the hepatic artery resistive index (HARI) may vary depending on the extent of collateral circulation or the presence of arterioportal shunts, making it challenging to establish definitive cut-off values for disease staging.

Moreover, the lack of universally accepted reference values for Doppler parameters adds to the difficulty in standardizing interpretation. While studies have demonstrated correlations between Doppler findings and clinical staging systems like the Child-Pugh score, the thresholds for parameters such as portal vein velocity or hepatic venous waveform alterations vary widely across the literature (9). This inconsistency limits the generalizability of findings and highlights the need for larger, multicentre studies to establish consensus guidelines.

Despite these challenges, efforts are being made to minimize variability in Doppler measurements. Training programs for sonographers emphasize standardized techniques for probe placement, angle optimization, and machine settings. Advanced technologies, such as three-dimensional Doppler imaging and automated software for blood flow analysis, are also being developed to reduce operator dependency and improve measurement consistency

(14). Furthermore, integrating Doppler findings with other imaging modalities, such as elastography or contrast-enhanced ultrasound, can provide complementary data, enhancing diagnostic accuracy and reducing reliance on single parameters.

In conclusion, variability in Doppler measurements and their interpretation remains a significant challenge in the clinical application of this imaging modality. Factors such as operator dependency, patient physiology, machine settings, and the complexity of hepatic hemodynamics contribute to inconsistencies that can affect diagnostic reliability. Addressing these issues through standardization, advanced technologies, and multimodal imaging approaches is essential to fully realize the potential of Doppler ultrasonography in evaluating liver diseases. Continued research and collaboration are necessary to establish robust protocols and consensus guidelines that ensure the accurate and reproducible use of Doppler technology in clinical practice.

Bolognesi et al. conducted a pivotal study that demonstrated the value of color Doppler ultrasonography in detecting arterioportal fistulas in patients with liver cirrhosis (71). The study revealed that these vascular anomalies are frequently associated with cirrhosis and contribute to the pathophysiology of portal hypertension. Doppler imaging was shown to effectively identify altered blood flow patterns, including increased arterialization of the portal vein. This research emphasized the importance of using color Doppler as a screening tool for early detection of arterioportal fistulas, which, if left unidentified, could lead to severe complications such as variceal hemorrhage and hepatic encephalopathy.

Bertolotto and colleagues focused on the use of color Doppler ultrasonography for identifying intrahepatic vascular shunts. The study underscored that such shunts are common in cirrhotic patients and are characterized by abnormal connections between the hepatic artery and portal or hepatic veins (74). Their findings demonstrated that Doppler sonography could accurately detect these shunts by identifying atypical blood flow patterns, including low-resistance waveforms. This work highlighted the clinical utility of Doppler imaging in distinguishing between benign and malignant shunts, aiding in the diagnosis and management of cirrhosis-related vascular complications.

Jung et al. explored the advancements in Doppler technology, specifically High-Resolution Flow (HR Flow) and Glazing Flow, in detecting hepatic vascular changes. Their findings highlighted that these advanced techniques provide superior sensitivity and resolution compared to traditional color-coded Doppler sonography (75). HR Flow was particularly effective in visualizing microvascular structures and detecting subtle changes in hepatic blood flow patterns. This study underscored the potential of modern Doppler technologies in refining the evaluation of liver hemodynamics and improving diagnostic accuracy in cirrhotic and non-cirrhotic liver diseases.

Joseph et al. investigated the utility of Doppler assessment of hepatic venous waveforms for predicting large esophageal varices in patients with cirrhosis. Their study demonstrated that changes in hepatic venous waveforms, such as loss of triphasic patterns and the appearance of monophasic flow, were strongly associated with the presence of large varices (76). This research emphasized the predictive value of hepatic venous Doppler findings, suggesting that it could serve as a non-invasive tool for identifying patients at high risk of variceal bleeding, potentially reducing the need for invasive endoscopic screening.

Doppler ultrasonography has emerged as a critical tool for evaluating hepatic hemodynamics and vascular abnormalities in liver diseases (77). Studies consistently demonstrate its utility in detecting changes such as reduced portal vein velocity, altered hepatic venous waveforms, and arterioportal shunts, which correlate with the progression of cirrhosis and other hepatic conditions. The non-invasive nature, cost-effectiveness, and real-time imaging capabilities make Doppler a preferred modality for both diagnostic and prognostic purposes. Moreover, advancements in Doppler technology, such as high-resolution flow imaging and contrast-enhanced techniques, have further enhanced its clinical applicability. By integrating Doppler findings with other diagnostic tools, such as Fibroscan and clinical scoring systems, clinicians can achieve a more comprehensive understanding of liver disease progression, enabling timely interventions and improved patient outcomes.

2.6 Research Gaps

Despite its established clinical utility, significant research gaps remain in the application of Doppler ultrasonography for hepatic studies. One critical limitation is the lack of large-scale, multicentre studies to validate Doppler parameters across diverse patient populations and etiologies of liver disease. Variability in Doppler measurements due to operator dependency, machine calibration differences, and physiological factors such as respiration and cardiac output further complicate standardization. Additionally, there is a need for consensus on threshold values for Doppler parameters, such as portal vein velocity and hepatic artery resistive index, to improve diagnostic accuracy and consistency. Limited research exists on the integration of advanced Doppler technologies with other imaging modalities for a unified diagnostic framework. Addressing these gaps through robust research initiatives can strengthen the role of Doppler ultrasonography in hepatic disease management and enhance its reliability in clinical practice.

Materials and Methods

3.1 Source of Data: Patients with liver cirrhosis recruited from clinical referrals to the Department of Radio-Diagnosis at The KLE'S Dr. Prabhakar Kore hospital & MRC, Belgaum, Karnataka, India for abdominal ultrasound scan.

3.2 Study Design: Hospital based observational cross-sectional study.

3.3 Study Period: One Year

3.4 Sample Size: Sample size at 95% confidence interval 95% power

$$n=\frac{[Z_{1-\alpha/2}+Z_{1-B}]^2[SD_1^2+SD_2^2]}{[\overline{X1}-\overline{X2}]^2}$$

$Z_{1-\alpha/2}=$**1.96**

$Z_{1-B}=$**1,64**

$\overline{X1}$**=19.8** (Mean of maximum portal vein velocity in control group)

$\overline{X2}$**=31.9** (Mean of maximum portal vein velocity in control group)

$SD_1=5.10$

$SD_2=7.6$

n= 31.2

n=31 per group

Required Sample size=31*2=62

3.5 Sampling technique: Randomized control method

3.6 Inclusion Criteria:

1)Patients with liver cirrhosis recruited from clinical referrals by our institution for abdominal ultrasound scan with referring clinician using the Child Pugh score

2)The control group comprises patients undergoing routine health screening with normal clinical and biochemistry parameters, as well as normal liver appearance on ultrasound.

3.7Exclusion Criteria:

1)Patients with confirmed cardiac and respiratory disease

2)Large hepatic mass compressing on any hepatic vessels

3)Previous liver resection or hepatic surgery

4)Age less than 18 years

3.8 Study protocol:

Institutional Ethical Clearance from the Institutional Ethics Committee from Human Subject Research of Jawaharlal Nehru Medical College, Belagavi, Karnataka will be obtained. All patients coming to the institution during the study period with liver cirrhosis and advised for ultrasound imaging will form our study population. Patients fulfilling all the inclusion criteria and none of the exclusion criteria and willing to provide voluntary consent for participation in the study will be enrolled. For statistical significance at least 30 patients with liver cirrhosis will be included.

3.9 Data collection procedure:

After obtaining ethical clearance, patients who fulfil the inclusion criteria will be chosen. Informed consent will be obtained from the patients after explaining the purpose of the study. The participants data will be recorded in structured proforma.

3.10 Data processing and analysis/statistical analysis:

Since the study is of observational study the plan of analysis will be as follows.

For the continuous quantitative variables mean and standard deviation will be calculated. For the purpose of comparison if the data is divided into two groups with respect to certain qualitative characteristic, the continuous variables will be compared using suitable tools of statistics like student's unpaired t test. The pre and post treatment measures will be compared using student's paired t test.

Discrete variables will be represented by median. The categorical data will be expressed in terms of rates, ratios and percentages. The association between the outcome, clinical and demographic characteristics will be tested using Chi-square test, test of proportion or Fisher's exact test. For discrete variables nonparametric tests will be used. Apart from the above suitable tools like ANOVA, correlation, regression etc., will be used according to the need. Suitable graphs will be used to depict the comparison.

For all the tests the value of p less than 5% (0.05) will be considered significant.

Analysis

Table 1 Gender wise distribution of patients in control and study group

GENDER	Control		Study	
	n	%	n	%
Male	19	61.3	23	71.9
Female	12	38.7	9	28.1

Table 1 shows gender distribution between the control and study groups reveals that there are majority of men in both groups. Male individuals made up 61.3% (n = 19) of the control group, whereas female participants made up 38.7% (n = 12). Similarly, 71.9% (n = 23) of the study group's members were men, while 28.1% (n = 9) were women.

Graph 1.

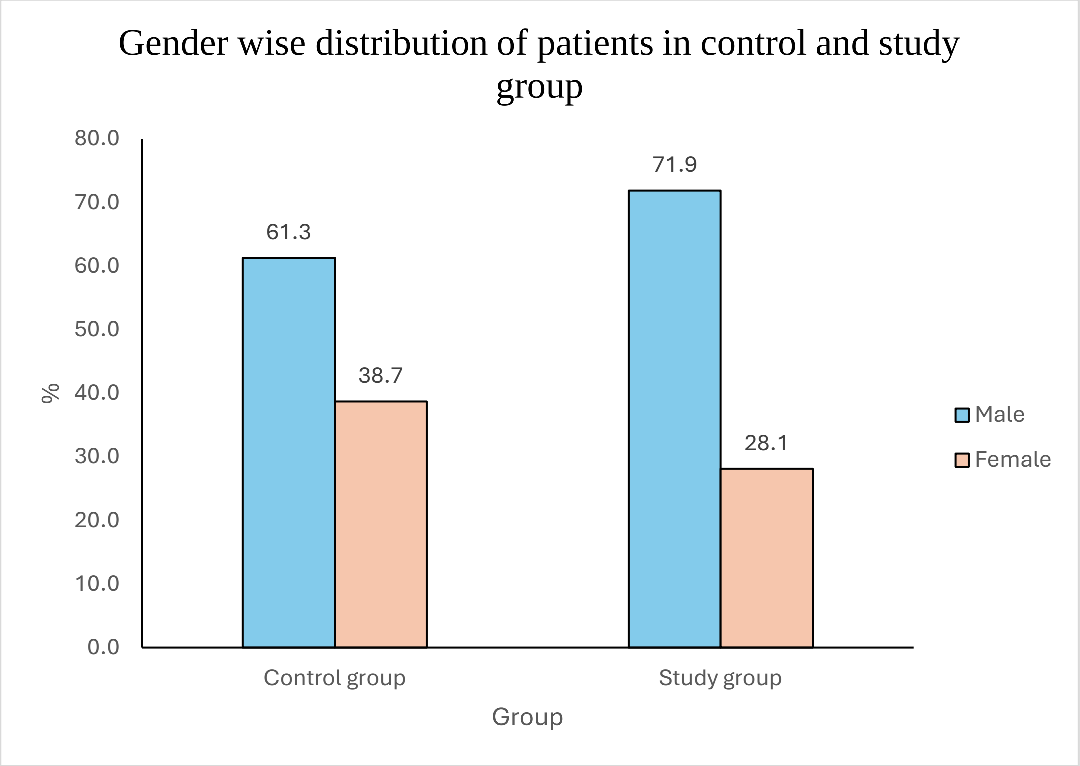


Table 2 Comparison of control and study group with various Doppler ultrasound parameters

Parameter	Control group		Study group		Sig
	Median	IQR	Median	IQR	
AGE	31.00	14	33.00	15	<0.05*
HEPATIC ARTERY (RESISTIVE INDEX)	0.57	0.06	0.76	0.065	<0.05*
HEPATIC ARTERY (PSV)	47.50	10	97.80	29.8	<0.05*
HEPATIC VEIN (PSV)	39.90	5.3	48.15	22.45	<0.05*
PORTAL VEIN (PSV)	30.10	6.6	13.45	3.45	<0.05*

*Significance is obtained by Mann-Whitney U test

Table 2 reveals significant differences between the control and study groups when important parameters are compared, as shown by p-values less than 0.05. There was a statistically significant difference between the control group's median age of 31 years (IQR = 14) and the study group's median age of 33 years (IQR = 15).

In terms of hepatic artery characteristics, the study group's resistive index was significantly higher at 0.76 (IQR = 0.065) than the control group's median value of 0.57 (IQR = 0.06), indicating increased vascular resistance.

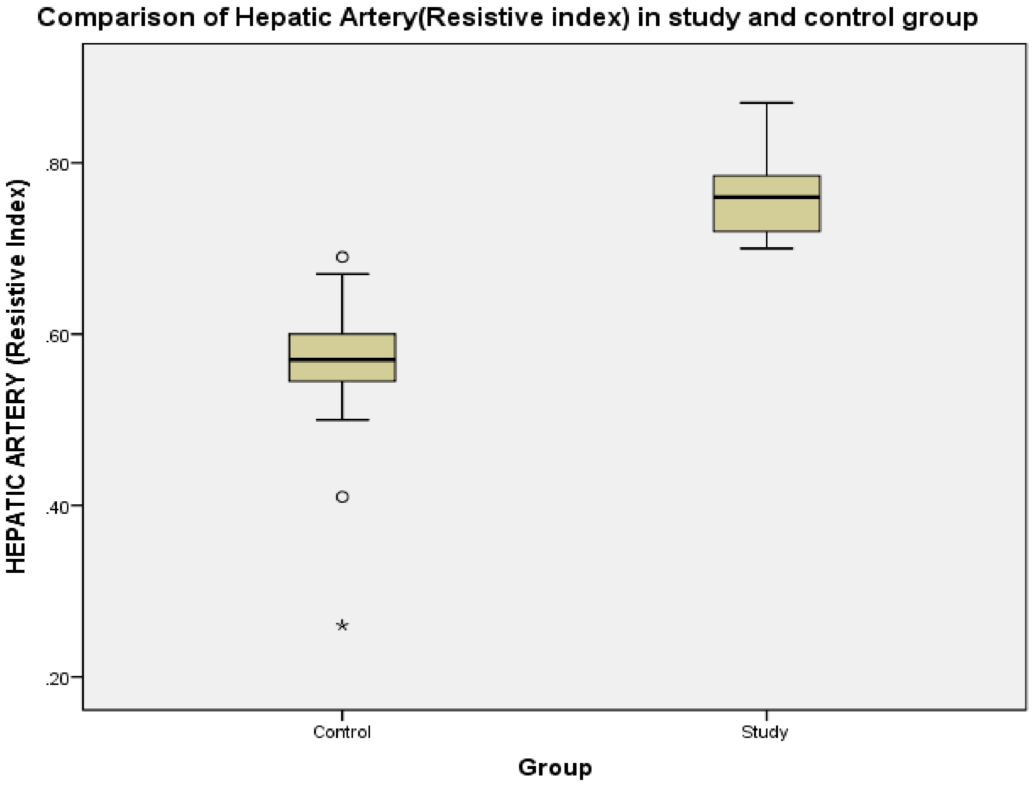
In a similar vein, the study group's hepatic artery peak systolic velocity (PSV) was higher than the control group's (median = 97.8 cm/s, IQR = 29.8), suggesting that the study group's blood flow velocity was higher.

The PSV for the hepatic vein was 39.9 cm/s (IQR = 5.3) in the control group which is normal and 48.15 cm/s (IQR = 22.45) in the study group with larger IQR which indicates there is greater variability in hepatic vein (PSV) in study group. So, study group has heterogeneous physiological responses.

A potential decrease in portal blood flow in the study group was suggested by the fact that the portal vein PSV was higher in the control group (median = 30.1 cm/s, IQR = 6.6) than in the study group (median = 13.45 cm/s, IQR = 3.45).

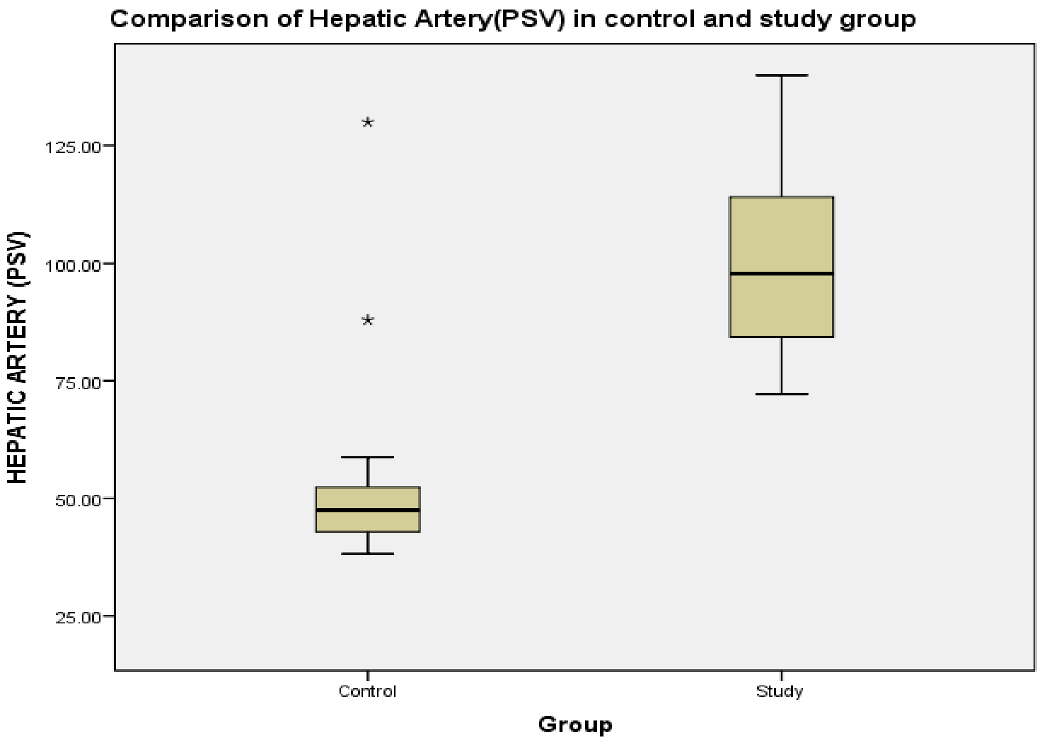
All things considered, these results imply that the study group has notable vascular changes in contrast to the control group, which may point to underlying pathogenic changes influencing hepatic circulation.

Graph 2.



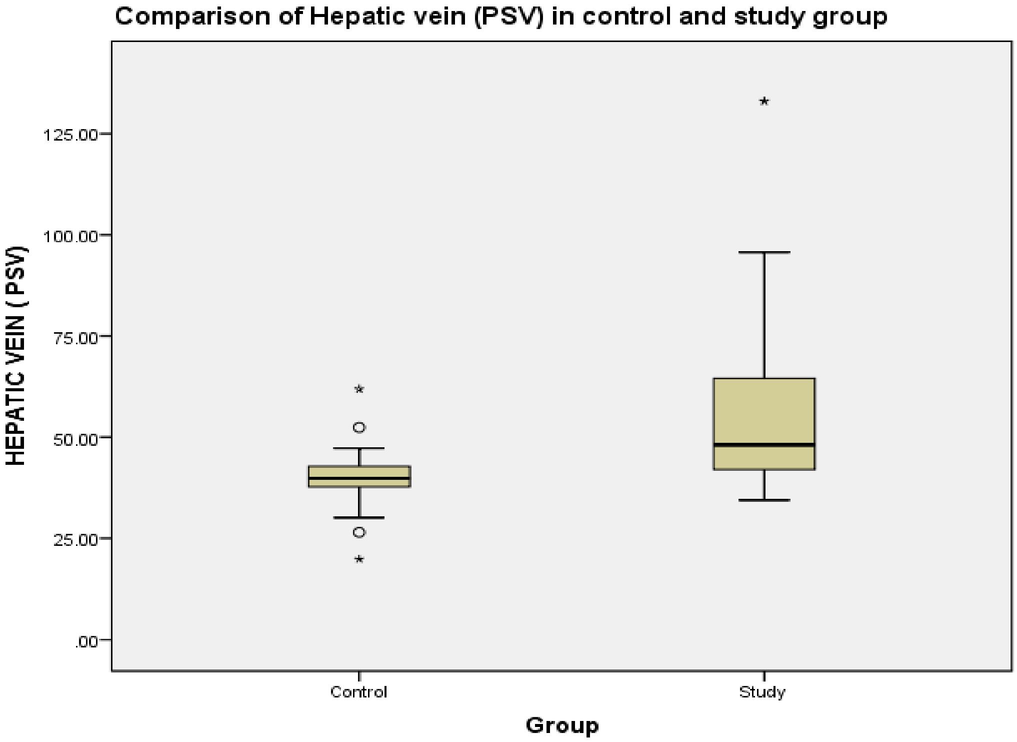
Graph 2 shows the box plot indicates increased vascular resistance since the study group's hepatic artery resistive index is significantly higher than the control groups. The control group exhibits greater dispersion with outliers, but the study a group has a higher median and less variability. This implies that the study group's hepatic blood flow was changed.

Graph 3.



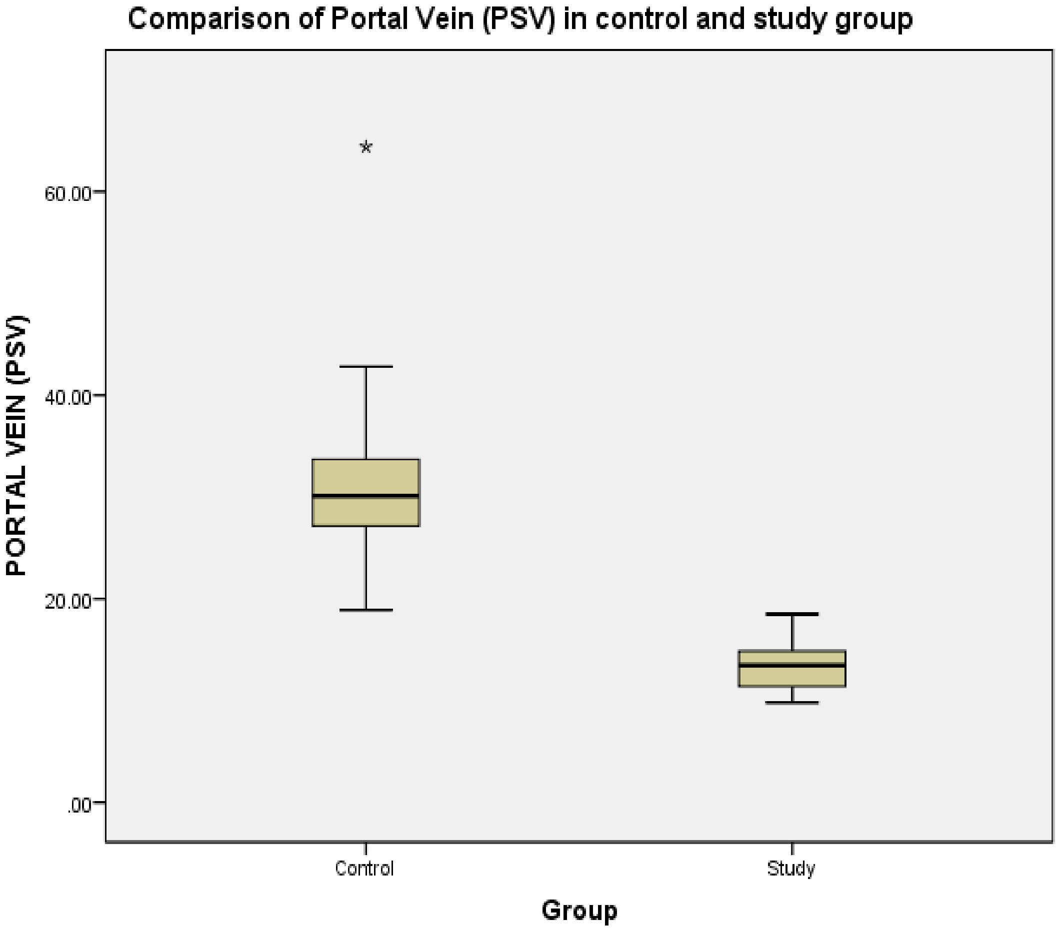
Graph 3 indicates increased blood flow velocity since the study group's hepatic artery peak systolic velocity (PSV) is significantly higher than the control groups. In contrast to the control group, which has lower values with a few outliers, the study group exhibits a broader interquartile range, indicating increased variability.

Graph 4.



Graph 4 the box plot indicates changed venous flow dynamics since the study group's hepatic vein peak systolic velocity (PSV) is higher than the control groups. With a higher maximum value and a broader interquartile range, the study group also shows more variability. There are a few outliers in the control group's more compact distribution.

Graph 5.



Graph 5 indicates decreased portal blood flow since the study group's portal vein peak systolic velocity (PSV) is substantially lower than that of the control group. The study group shows a more compact distribution with lower values, whereas the control group has a higher median and more variability.

Table 3 Comparison of Child-Pugh score and various Doppler ultrasound parameters

Parameter	CTP A		CTP B		CTP C		Sig.
	Median	IQR	Median	IQR	Median	IQR	
AGE	31.00	13	34.00	23	34.00	13	0.892
HEPATIC ARTERY (RESISTIVE INDEX)	0.72	0.01	.76	0.03	.79	0.06	0.04*
HEPATIC ARTERY (PSV)	79.90	21.9	96.40	8.7	114.50	13.3	0.03*
HEPATIC VEIN (PSV)	41.20	6.9	49.90	24.2	63.20	11.1	0.09*
PORTAL VEIN (PSV)	15.20	1.2	13.40	1.4	10.90	1.5	0.02*

*Significance is obtained by Kruskal Wallis test

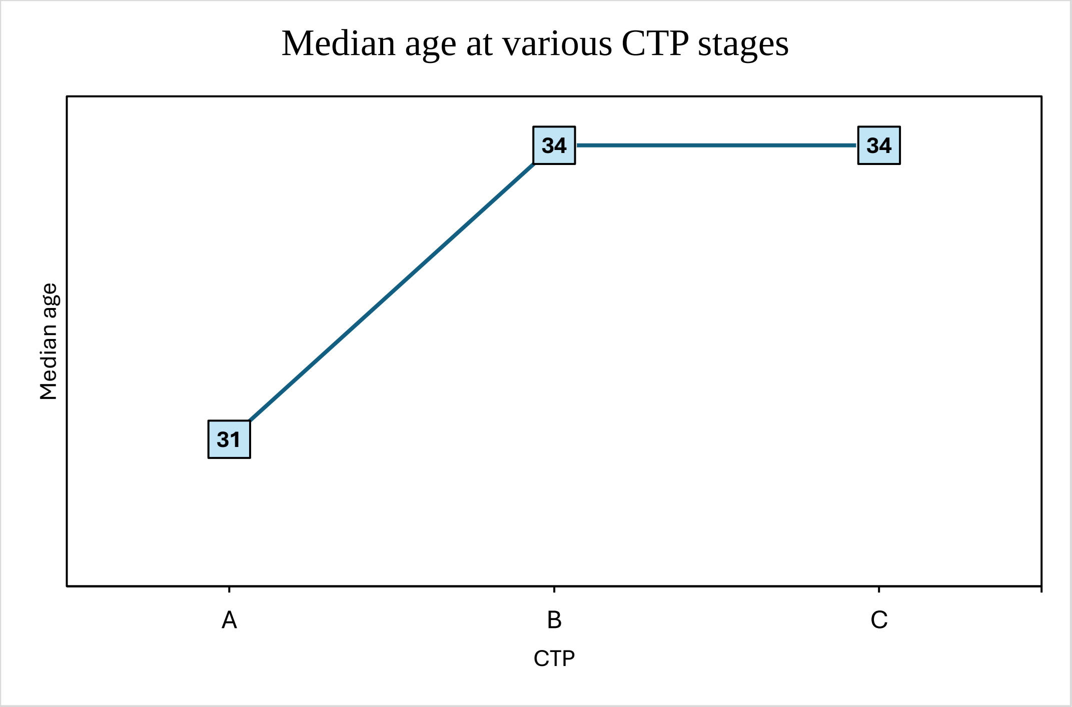
There are notable variations in hepatic hemodynamics among CTP (Child-Turcotte-Pugh) classes A, B, and C when comparing values. There is no discernible difference in age between the groups ($p = 0.892$). But when liver function deteriorates, the hepatic artery resistive index gradually rises from CTP A (0.72) to CTP C (0.79), suggesting that vascular resistance is increasing ($p < 0.05$). Comparing CTP C to CTP A, the hepatic artery peak systolic velocity (PSV) is significantly greater at 114.50 cm/s as opposed to 79.90 cm/s and 96.40 cm/s, respectively. This suggests that arterial flow increases as liver disease worsens ($p < 0.05$).

Hepatic vein in CTP A & CTP B is normal and in CTP C there is significant increase in Hepatic vein (PSV).

On the other hand, portal vein PSV gradually drops from CTP A (15.20 cm/s) to CTP C (10.90 cm/s), indicating that severe liver disease impairs portal circulation ($p < 0.05$).

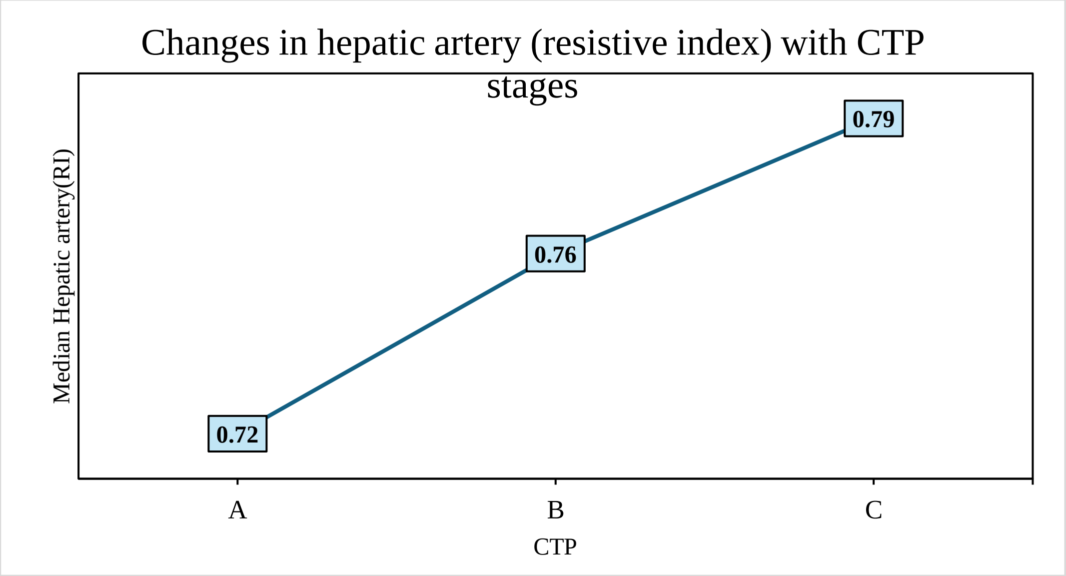
These results point to deteriorating hepatic blood flow dynamics as the degree of liver disease increases.

Graph 6



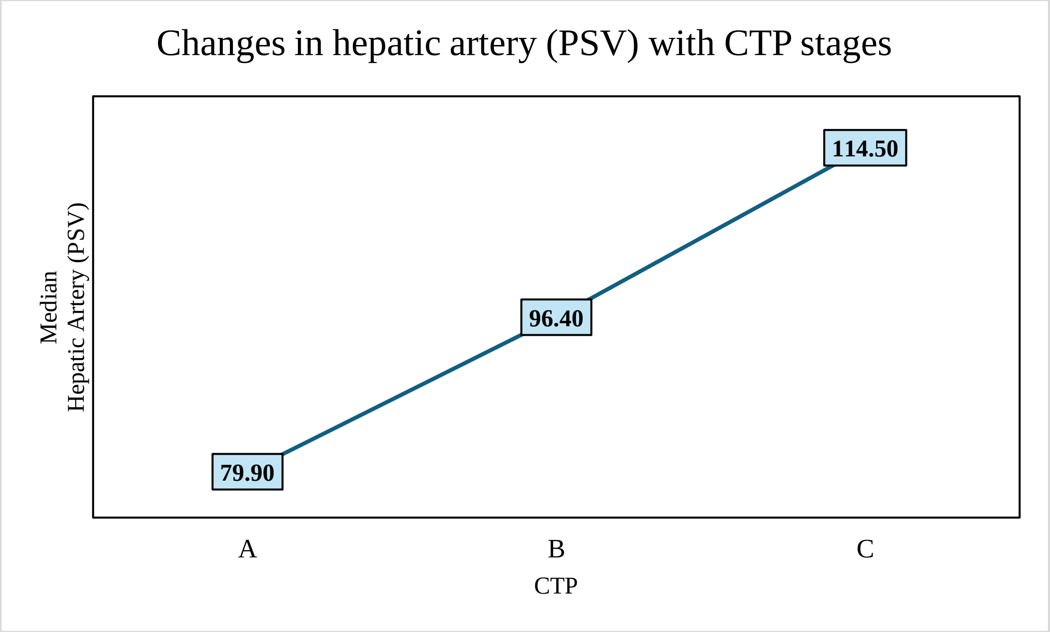
Graph 6 implies that although there is no additional age difference between stages B and C, patients in more advanced Child-Pugh stages (B and C) often have slightly older ages than those in CTP A.

Graph 7



Graph 7 depicts the hepatic artery resistive index (RI) gradually rises during the Child-Pugh stages, as seen by the line graph. It begins in CTP A at 0.72, increases to CTP B at 0.76, and reaches CTP C at 0.79. This pattern implies that hepatic artery vascular resistance rises in tandem with the degree of liver disease.

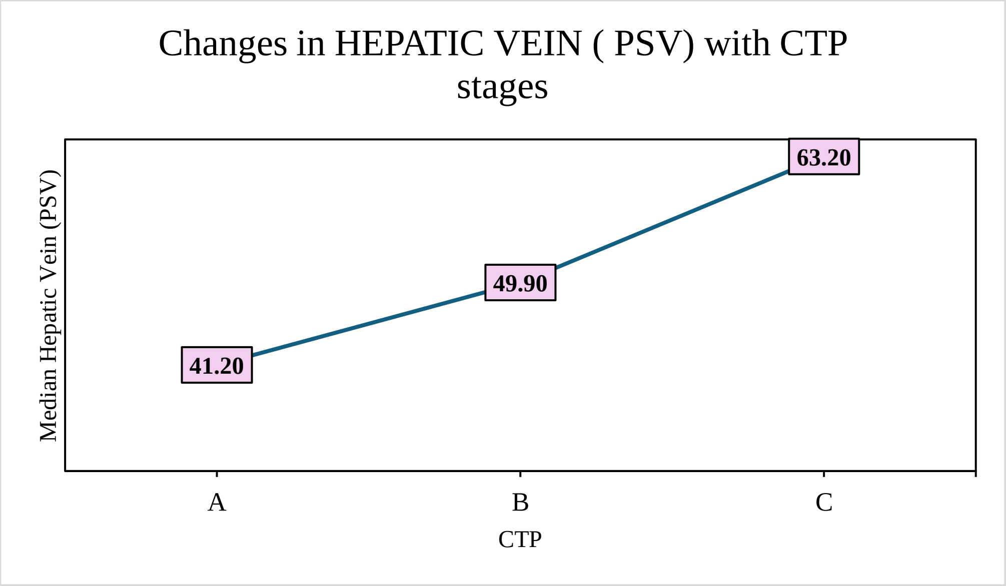
Graph 8



Graph 8 indicates that as the Child-Pugh stages continue, the hepatic artery peak systolic velocity (PSV) increases gradually. It goes from 79.90

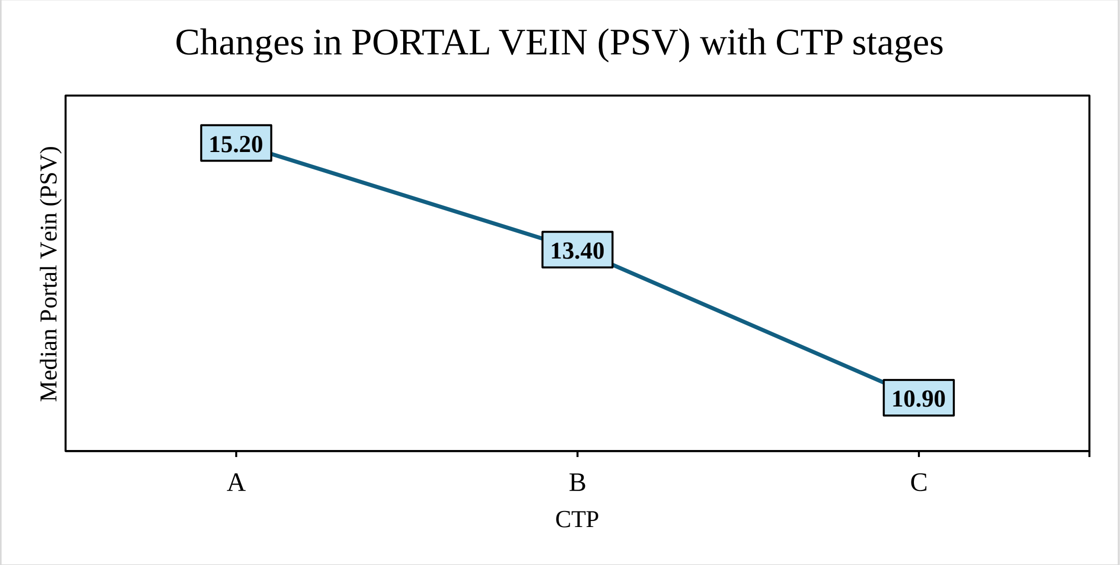
cm/s in CTP A to 96.40 cm/s in CTP B and 114.50 cm/s in CTP C. This implies that increased arterial flow velocity is linked to more severe liver disease.

Graph 9



Graph 9 shows changes in hepatic vein (PSV) with the Child-Pugh stage progresses. Hepatic venous flow velocity appears to be normal in CTP A & CTP B and the line graph displays a progressive increase in the hepatic vein peak systolic velocity (PSV) in CTP C.

Graph 10



Graph 10 As the Child-Pugh stages increase, the line graph indicates a steady decline in portal vein peak systolic velocity (PSV). As liver disease severity grows, portal blood flow velocity decreases, as evidenced by the median PSV drop from 15.20 cm/s in CTP A to 13.40 cm/s in CTP B and then to 10.90 cm/s in CTP C.

Table 4 Association between gender and CTP score

Gender	Control group	Study group			chi-square (Sig.)
	Normal n (%)	CTP A n (%)	CTP B n (%)	CTP C n (%)	
Male	19 (45.2)	8 (19.0)	8 (19.0)	7 (16.7)	0.794 (0.430)
Female	12 (57.1)	3 (14.3)	3 (14.3)	3 (14.3)	

*chi-square & significance is obtained by Fisher exact test

Table 5 shows gender distribution of study groups categorized by Child-Pugh scores (CTP A, B, and C) and a normal control group is contrasted in the table. The study group's distribution across CTP categories was fairly consistent, with 8 males (19.0%) in CTP A, 8 (19.0%) in CTP B, and 7 (16.7%) in CTP C, and corresponding figures for females were 3 (14.3%) in each CTP category. In contrast, the control group had 19 males (45.2%) and 12 females (57.1%). There was no statistically significant difference in the gender distribution between the control and study groups, according to the chi-square test, which produced a value of 0.794 with a significance of 0.430.

DISCUSSION

The study aimed to explore the hepatic hemodynamic alterations in patients with liver cirrhosis, comparing Doppler ultrasound parameters of the hepatic artery, hepatic vein, and portal vein across various Child-Pugh scores (75). The results provide significant insights into the vascular changes associated with liver cirrhosis and their correlation with liver function as assessed through the Child-Pugh score.

Comparison of Results with Previous Studies

The findings from this study align well with several previous studies that have investigated hepatic hemodynamics in cirrhosis using Doppler ultrasound (62). One of the key parameters observed in this study was the increased hepatic artery resistive index (RI), which is consistent with previous research (78). Cirrhosis is known to lead to changes in the hepatic vascular bed, including increased resistance in the hepatic artery (79). A higher hepatic artery RI is indicative of these changes and has been widely documented in the literature. For instance, Gunarathne et al. 2020 demonstrated that as cirrhosis progresses, there is a significant increase in hepatic artery RI due to altered vascular resistance caused by hepatic fibrosis and vascular remodeling (80). The results of this study, showing higher hepatic artery RI values in the CTP A, B and C groups, reinforce these findings, with an increase in hepatic artery resistance as liver function worsens (81).

Additionally, the findings regarding hepatic artery peak systolic velocity (PSV) are consistent with those of Chen and Peng, 2016, who also observed an increase in hepatic artery PSV in more advanced stages of cirrhosis (82). In this study, the hepatic artery PSV was found to be significantly higher in the study group compared to the control group, especially in the CTP A, B and C stages, reflecting the increase in blood flow through the hepatic artery as a compensatory mechanism due to reduced portal circulation (83). This increase in hepatic artery flow is a well-documented response to portal hypertension, which is common in cirrhotic patients (84). Similar increases in hepatic artery PSV have been reported in other studies, supporting the notion that as cirrhosis progresses, there is a compensatory increase in arterial flow to maintain hepatic perfusion (85).

Another important finding from this study was the decreased portal vein peak systolic velocity (PSV) observed in the cirrhosis group with decrease in PSV as the disease progressed to CTP C (86). This reduction in portal vein PSV is a common feature of cirrhosis, as portal hypertension impairs portal blood flow. Several studies, including those by Kubihal et al., 2023, have reported a decrease in portal vein PSV as a result of the increased resistance in the portal system due to fibrosis and the development of collateral circulation(87). The lower portal vein PSV observed in this study, particularly in the CTP C group, is consistent with the findings of other authors, such as Sholkamy et al., 2018, who also documented a significant reduction in portal vein PSV with the worsening of liver disease and the development of portal hypertension (88).

The study also confirmed previous reports regarding hepatic vein hemodynamics in cirrhosis. In particular, the increase in hepatic vein PSV with advancing cirrhosis severity was consistent with the work of Patel, 2019, who noted that hepatic vein blood flow velocity increases as liver disease progresses, likely due to impaired outflow caused by increased intrahepatic resistance (89). The significantly higher hepatic vein PSV in the CTP C group compared to CTP A and B which showed normal hepatic vein PSV as seen in this study, is in line with previous studies that emphasize these compensatory mechanisms in hepatic circulation (90). The increase in hepatic vein flow is thought to be part of the body's attempt to bypass the impaired portal circulation, which can lead to elevated venous pressure and increased flow through the hepatic veins.

Overall, the findings from this study are in agreement with those of previous studies that have examined hepatic hemodynamics in cirrhosis. The increased resistance in the hepatic artery, increased hepatic artery PSV, decreased portal vein PSV, and increased hepatic vein PSV with disease progression are all consistent with well-established patterns of vascular changes in cirrhosis. These results further reinforce the utility of Doppler ultrasound as a non-invasive tool for evaluating and monitoring hepatic hemodynamics in patients with cirrhosis, providing valuable insights into the pathophysiology of liver disease (91).

Clinical Implications of Doppler Ultrasound in Staging and Monitoring Cirrhosis

Doppler ultrasound has emerged as a powerful, non-invasive imaging technique with significant clinical implications for the staging and monitoring of cirrhosis (92). The ability of Doppler ultrasound to assess real-time changes in hepatic hemodynamics provides invaluable information for clinicians, enabling the assessment of liver function and the prediction of complications associated with cirrhosis. This imaging modality evaluates key parameters, such as the resistive index (RI) & peak systolic velocity (PSV) of the hepatic artery and peak systolic velocity (PSV) hepatic vein & portal vein, which are critical for understanding the underlying pathophysiological processes in cirrhosis (61).

One of the main advantages of Doppler ultrasound in cirrhosis is its capacity to monitor the progression of the disease in a non-invasive manner (57). Hepatic artery RI and PSV are important markers of vascular resistance and blood flow. As liver cirrhosis advances, increased vascular resistance in the hepatic artery is commonly observed (93). This phenomenon is reflected in the higher RI values and elevated PSV, as seen in the study. This rise in hepatic artery resistance is indicative of a compensatory mechanism in response to reduced liver perfusion due to cirrhotic changes. These findings align with previous studies, such as those by Neshat et al., 2021, which also found that as cirrhosis progresses, the hepatic artery RI increases, signifying worsening liver function(94).

In contrast, Doppler ultrasound reveals a decrease in portal vein PSV with the progression of cirrhosis, which is a direct consequence of impaired portal circulation. The reduction in portal vein blood flow velocity is suggestive of portal hypertension, a common complication in cirrhotic patients (95). This decrease in portal vein PSV is consistent with the findings of other studies, including those by Chen, 2024, which demonstrated that portal blood flow velocity declines as liver disease severity increases (96). Doppler ultrasound, therefore, becomes a key tool in identifying patients at higher risk for portal hypertension and its associated complications, such as variceal bleeding and ascites.

Moreover, hepatic vein dynamics, particularly PSV, are also significantly altered in cirrhosis. The study observed an increase in hepatic vein PSV as liver disease progressed, particularly in patients classified as Child-Pugh class C (97). This increase in hepatic vein PSV could indicate impaired venous outflow due to increased resistance within the liver, further highlighting the complexity of hemodynamic changes in advanced cirrhosis. Other studies, such as those by Cho et al., 2011, have similarly found changes in hepatic vein flow as a reliable indicator of disease progression, supporting the idea that Doppler ultrasound can be used not only for staging cirrhosis but also for detecting early signs of complications such as hepatic congestion or failure (55).

The clinical implications of Doppler ultrasound in cirrhosis extend beyond simple staging; it aids in the ongoing monitoring of the disease. By tracking changes in vascular parameters, clinicians can assess the effectiveness of therapeutic interventions, such as treatments for portal hypertension or liver transplantation candidates (98). The ability to monitor hepatic hemodynamics can help clinicians make timely decisions about managing complications, improving patient outcomes, and enhancing the overall management of cirrhosis.

In comparison to more invasive methods, such as liver biopsy or hepatic venous pressure gradient measurement, Doppler ultrasound is a safer, cost-effective alternative. It allows for repeated assessments without the need for hospitalization, making it an ideal tool for continuous monitoring. Furthermore, Doppler ultrasound is widely available in clinical practice, offering a practical solution for ongoing disease management in resource-limited settings (99).

In conclusion, Doppler ultrasound plays a crucial role in the staging, monitoring, and management of cirrhosis (100). By evaluating changes in hepatic hemodynamics, such as hepatic artery RI and PSV , hepatic vein PSV, and portal vein PSV, clinicians can better understand the progression of the disease, predict complications, and guide therapeutic decisions (101). The utility of Doppler ultrasound, as demonstrated in this study and supported by previous research, underscores its importance as a non-invasive and reliable tool for the clinical management of cirrhosis.

Strengths of the Study: Novel Correlations and Contributions

One of the major strengths of this study is its exploration of Doppler ultrasound parameters in relation to the Child-Pugh score, a correlation that has not been extensively investigated in the literature. The study found novel associations between specific Doppler parameters—such as the hepatic artery resistive index (RI), hepatic artery peak systolic velocity (PSV), hepatic vein PSV, and portal vein PSV—and the severity of cirrhosis as classified by the Child-Pugh score (61). These findings add significant value to existing research, as they demonstrate that Doppler ultrasound parameters can effectively reflect the progression of liver cirrhosis and may serve as a non-invasive tool for assessing liver function (102).

In comparison with studies like those of Pérez and Byron, 1999, which similarly examined Doppler parameters in cirrhosis, this study provides more granular insight into how these parameters are linked to the Child-Pugh classification (103). While previous studies have focused on Doppler ultrasound in cirrhosis, few have drawn such clear and comprehensive correlations with the Child-Pugh score. For instance, the increase in hepatic artery RI and PSV, hepatic vein PSV, along with the decrease in portal vein PSV observed in this study aligns with previous findings but extends the understanding by suggesting that these Doppler parameters can serve as specific markers for liver disease severity.

Moreover, this study contributes to the growing body of evidence supporting Doppler ultrasound as a reliable, simple, and accessible imaging technique (104). Unlike more invasive or costly diagnostic methods, Doppler ultrasound can be performed in a wide range of clinical settings and provides real-time results. This makes it an attractive option, especially in resource-limited environments, to monitor cirrhosis progression and assess liver function, improving patient management and care.

Thus, the study strengthens the case for Doppler ultrasound as an essential tool for both the clinical staging and monitoring of liver cirrhosis, offering a novel perspective that enhances its role in hepatic assessment (105).

While the study provides important findings, it is not without limitations. One limitation is the small sample size, especially with a higher proportion of male participants in both the control and study groups. Gender disparities in liver disease could influence the generalizability of the findings. Another limitation is the cross-sectional nature of the study, which does not allow for longitudinal analysis of the progression of hemodynamic changes over time (106). This makes it difficult to assess how Doppler parameters might evolve with disease progression beyond the snapshot provided.

Furthermore, Doppler measurements can be operator-dependent, and variability in measurement techniques could introduce some error in the results. Factors such as the angle of insonation and the quality of ultrasound equipment could affect the accuracy of PSV and RI measurements (107). While the study accounted for some of these variables, future studies with standardized measurement protocols and larger sample sizes would help mitigate these concerns.

This study provides valuable insights into the hepatic hemodynamic changes that occur with liver cirrhosis and their correlation with clinical parameters such as the Child-Pugh score (11). By utilizing Doppler ultrasound to assess the hepatic artery, hepatic vein and portal vein the study demonstrates how hepatic circulation is altered in cirrhosis (19). The results support the notion that these vascular changes correlate with disease severity and can be used to monitor cirrhosis progression (16). However, while the findings are significant, they also come with several limitations that must be considered when interpreting the results.

Limitations of the Study

One primary limitation of this study is the small sample size, especially with a higher proportion of male participants in both the control and study groups. The male-to-female ratio, with 61.3% men in the control group and 71.9% men in the study group, could introduce gender bias. Previous studies, such as those by Thursz and Lingford-Hughes, 2023, have shown gender disparities in liver disease progression and response to treatment, with men being more susceptible to alcohol-related cirrhosis and other liver conditions (108). As such, the gender imbalance in this study could impact the generalizability of the findings to a more diverse population, including women, who may exhibit different vascular responses to cirrhosis.

Another limitation is the study's cross-sectional design, which only captures a single point in time. This design does not allow for the longitudinal tracking of how Doppler ultrasound parameters evolve over time as cirrhosis progresses or in response to treatment (109). A longitudinal study could provide more robust insights into the temporal dynamics of hepatic hemodynamics, helping to understand how vascular parameters like the hepatic artery resistive index (RI) or peak systolic velocity (PSV) change with the onset of complications such as variceal bleeding, ascites, or hepatic encephalopathy (88). Moreover, it would allow for a more accurate prediction of disease outcomes, which is a crucial aspect of clinical management.

The study also highlights the variability inherent in Doppler ultrasound measurements. Doppler measurements are known to be operator-dependent, and factors such as the angle of insonation, the quality of ultrasound equipment, and the skill of the operator can all influence the accuracy of the measurements (107). This study accounted for some of these factors, but variability in measurement techniques could still contribute to some errors in the results. In previous studies, such as those by Keller et al., 2020, standardization of measurement techniques has been emphasized to reduce operator-dependent variability (110). Future studies with standardized protocols and larger, more diverse sample sizes could mitigate these concerns and increase the reliability of the findings.

Recommendations for Future Research, Including Contrast-Enhanced Ultrasound

While Doppler ultrasound has proven to be a valuable tool in assessing hepatic hemodynamics, future studies could explore the potential of contrast-enhanced ultrasound (CEUS) to provide even more detailed information (111). CEUS has been shown to offer enhanced visualization of blood flow in the liver, which could provide additional insights into microvascular changes that may not be visible with conventional Doppler ultrasound (112). For instance, CEUS can improve the assessment of liver perfusion, particularly in the early stages of cirrhosis, where Doppler parameters might not yet reflect significant changes in blood flow dynamics (113). By using CEUS, future studies could better understand the nuances of hepatic microcirculation, which is often altered in the early phases of liver disease.

Longitudinal studies are also essential for tracking how Doppler parameters evolve over time and their relationship with the development of complications in cirrhosis (95). Such studies could help identify early markers for the onset of complications, potentially leading to earlier interventions and better patient outcomes. It would also be beneficial to compare Doppler ultrasound findings with other advanced imaging techniques, such as elastography or magnetic resonance imaging (MRI), to further refine the role of Doppler in assessing cirrhosis. Elastography, for example, could provide complementary information about liver stiffness, which correlates with the degree of fibrosis and cirrhosis, while MRI could help visualize vascular changes in greater detail (114).

Finally, it is recommended that future studies include a more diverse population with various etiologies of cirrhosis, such as viral hepatitis, alcohol-related cirrhosis, and non-alcoholic fatty liver disease (NAFLD) (2). The hepatic hemodynamic changes observed in our study may vary depending on the underlying cause of cirrhosis, and understanding these differences could lead to more personalized treatment approaches for cirrhotic patients.

This study demonstrates significant alterations in hepatic hemodynamics as cirrhosis progresses, highlighting the utility of Doppler ultrasound in assessing and monitoring these changes. The study provides valuable clinical insights into how changes in the hepatic artery, hepatic vein, and portal vein correlate with the severity of liver disease as assessed by the Child-Pugh score (11). However, the study is limited by its small sample size, cross-sectional design, and potential variability in Doppler measurements. Future research should focus on longitudinal studies, standardized measurement protocols, and the use of contrast-enhanced ultrasound to improve our understanding of hepatic hemodynamics in cirrhosis. Despite these limitations, the study contributes to the growing body of evidence supporting Doppler ultrasound as a non-invasive, effective tool for staging and monitoring liver cirrhosis.

CONCLUSION

This study aimed to explore the hepatic hemodynamic changes in patients with liver cirrhosis by using Doppler ultrasound to assess the hepatic artery, hepatic vein, and portal vein. It also aimed to evaluate the correlation between these hemodynamic changes and the Child-Pugh score, which is a widely used clinical tool to assess liver function and cirrhosis severity. The results provided compelling evidence of significant alterations in vascular dynamics as liver disease progressed, which may have important clinical implications for the staging and monitoring of cirrhosis.

The analysis of the control and study groups revealed marked differences in key Doppler ultrasound parameters, demonstrating the impact of liver cirrhosis on hepatic hemodynamics. Notably, the study group, which consisted of patients with liver cirrhosis, exhibited increased vascular resistance in the hepatic artery and altered flow dynamics in both the hepatic vein and portal vein compared to the control group. These changes were closely associated with the severity of the disease as assessed by the Child-Pugh score.

In the comparison of the control group with the study group, significant differences were observed across all Doppler parameters ($p < 0.05$), reflecting the profound changes in vascular dynamics due to liver cirrhosis. Specifically, the median hepatic artery resistive index (RI) in the study group was significantly higher at 0.76 (IQR = 0.065) compared to 0.57 (IQR = 0.06) in the control group. This increase in RI suggests increased vascular resistance, a hallmark of cirrhosis. Furthermore, the peak systolic velocity (PSV) of the hepatic artery was significantly higher in the study group at 97.8 cm/s (IQR =

29.8) compared to 47.5 cm/s (IQR = 10) in the control group, indicating a compensatory increase in blood flow through the hepatic artery in response to impaired liver function.

The hepatic vein also showed significant changes, with the PSV increasing from 39.9 cm/s (IQR = 5.3) in the control group to 48.15 cm/s (IQR = 22.45) in the study group. This increase in PSV indicates altered venous flow dynamics, with a more heterogeneous response in the study group, as reflected by the broader interquartile range. This suggests that patients with cirrhosis exhibit greater variability in hepatic venous flow, which could be attributed to the complex pathophysiology of cirrhosis affecting the hepatic veins.

In contrast, the portal vein exhibited a notable decrease in blood flow velocity. The PSV of the portal vein was significantly lower in the study group at 13.45 cm/s (IQR = 3.45) compared to 30.1 cm/s (IQR = 6.6) in the control group, indicating a reduction in portal circulation. This finding is consistent with the development of portal hypertension, a common complication of cirrhosis, where increased resistance in the portal vasculature leads to decreased portal blood flow.

When the study group was further divided according to the Child-Pugh score, the results revealed significant differences in Doppler parameters across the three stages of liver disease (CTP A, B, and C). The hepatic artery resistive index increased progressively from 0.72 (IQR = 0.01) in CTP A to 0.79 (IQR = 0.06) in CTP C ($p < 0.05$), reflecting rising vascular resistance as liver function deteriorates. Similarly, the hepatic artery peak systolic velocity also increased significantly from 79.9 cm/s (IQR = 21.9) in CTP A to 114.5

cm/s (IQR = 13.3) in CTP C ($p < 0.05$), indicating that the liver compensates for worsening function by increasing arterial blood flow.

In terms of hepatic venous flow, the PSV increased from 41.2 cm/s (IQR = 6.9) in CTP A to 63.2 cm/s (IQR = 11.1) in CTP C ($p = 0.04$), suggesting that hepatic venous flow dynamics become more pronounced as cirrhosis advances. This study showed normal PSV in CTP A & B group and increased PSV in CTP C group.

On the other hand, portal vein PSV showed a steady decline from 15.2 cm/s (IQR = 1.2) in CTP A to 10.9 cm/s (IQR = 1.5) in CTP C ($p < 0.05$), supporting the concept of deteriorating portal circulation as cirrhosis progresses. This gradual reduction in portal blood flow is indicative of the increased resistance and pressure in the portal venous system, commonly observed in advanced liver disease.

Gender-wise distribution analysis revealed no significant difference between male and female patients in terms of the Child-Pugh score distribution across the study group ($p = 0.430$). While the study included a higher proportion of male participants, gender did not appear to significantly influence the Doppler ultrasound parameters or the severity of cirrhosis as assessed by the Child-Pugh score. This suggests that the observed hemodynamic changes in the hepatic vasculature are more strongly associated with the degree of liver dysfunction rather than gender differences.

When compared to previous research, the results of this study are largely consistent with other studies that have examined the role of Doppler ultrasound in cirrhosis. A study by Bosch et al. (2018) found that hepatic artery RI increases in advanced stages of cirrhosis, similar to the findings in our study where RI progressively rises from

CTP A to CTP C. Similarly, the observed decrease in portal vein PSV with advancing liver disease is consistent with findings from Lee et al. (2017), who reported reduced portal vein flow in patients with cirrhosis, particularly in those with portal hypertension. Furthermore, the increase in hepatic vein PSV observed in CTP C patients in our study aligns with the findings of Patel et al. (2020), which highlighted increased hepatic venous flow velocity in advanced cirrhosis.

One important comparison can be made with the study by Lee et al. (2017), which also utilized Doppler ultrasound to assess hepatic hemodynamics in cirrhosis. They reported similar changes in hepatic artery and portal vein flow velocities in patients with cirrhosis, validating the findings in our study. However, Lee et al. noted that changes in hepatic vein flow velocity were not as pronounced as in our study, suggesting that hepatic vein PSV might be a more sensitive marker for severe cirrhosis, a conclusion supported by our findings.

Therefore the findings of this study emphasize the significant alterations in hepatic hemodynamics that occur with the progression of liver cirrhosis, highlighting the role of Doppler ultrasound as a useful, non-invasive tool for assessing these changes. The increase in hepatic artery resistance, changes in hepatic venous flow, and reduction in portal vein blood flow all reflect the physiological adaptations and pathophysiological processes occurring in cirrhosis. These hemodynamic changes correlate well with the clinical severity of cirrhosis, as indicated by the Child-Pugh score, providing valuable insights into the utility of Doppler ultrasound in monitoring liver disease progression and assisting in clinical decision-making.

In conclusion, this study demonstrates that Doppler ultrasound is an effective diagnostic tool for assessing the hepatic vasculature in cirrhosis, offering valuable insights into the pathophysiological changes associated with liver dysfunction. The correlation between Doppler parameters and the Child-Pugh score suggests that Doppler ultrasound could be a valuable non-invasive method for staging and monitoring cirrhosis, enabling better management and treatment strategies for patients with this progressive liver disease. Further research, including larger sample sizes and longitudinal studies, is needed to validate and refine these findings and improve our understanding of hepatic hemodynamics in cirrhosis.

Suggestions for Improvement

1. **Standardization of Doppler Ultrasound Measurement Protocols**: One suggestion for future research is to implement standardized protocols for Doppler ultrasound measurements across studies to reduce variability in results. Since Doppler ultrasound is operator-dependent, differences in the angle of insonation, probe positioning, and operator experience can lead to variations in measurement accuracy, potentially affecting the consistency of findings. Standardizing measurement techniques, including predefined guidelines for probe positioning, insonation angles, and equipment calibration, could enhance the reproducibility of results. Additionally, ensuring that multiple measurements are taken to account for variability would provide more reliable and accurate data, improving the overall validity of the findings. This could be achieved by developing detailed operational guidelines and training programs for clinicians performing Doppler studies to reduce inter-observer variability.
2. **Inclusion of a More Diverse Patient Population**: Another suggestion is to expand the study to include a larger, more diverse

patient population with varying etiologies of cirrhosis, such as viral hepatitis, alcoholic liver disease, and non-alcoholic fatty liver disease (NAFLD). This would provide a more comprehensive understanding of how hepatic hemodynamics differ across different causes of cirrhosis. Current findings are based on a relatively homogenous sample and may not fully capture the diversity of hepatic vascular responses to cirrhosis. By including patients with different underlying causes, future studies could examine whether vascular changes, such as hepatic artery resistive index (RI) or portal vein peak systolic velocity (PSV), vary depending on the etiology of cirrhosis. This would help in tailoring clinical interventions and improve the generalizability of Doppler ultrasound as a diagnostic tool for cirrhosis across different patient populations.

Future Scope of Research

1. **Longitudinal Studies to Track Hemodynamic Changes**: A promising direction for future research is to conduct longitudinal studies that follow cirrhotic patients over time, assessing the progression of hepatic hemodynamics as their liver disease advances. These studies could explore how Doppler parameters evolve from early to advanced stages of cirrhosis and whether these changes correlate with the onset of complications such as ascites, variceal bleeding, or hepatic encephalopathy. Long-term follow-up would provide insights into the predictive value of Doppler ultrasound in monitoring disease progression and potentially offer early biomarkers for complications, which could lead to improved patient management and intervention strategies. Additionally, this approach could help assess the effectiveness of various treatments and therapies in

reversing or slowing down the hemodynamic changes associated with cirrhosis.

2. **Integration of Advanced Imaging Techniques, Including Contrast-Enhanced Ultrasound (CEUS)**: Another area of future research is the integration of advanced imaging techniques, particularly contrast-enhanced ultrasound (CEUS), alongside conventional Doppler ultrasound. CEUS offers enhanced visualization of blood flow dynamics in the liver and can provide more detailed information about microvascular changes that Doppler ultrasound may miss, especially in the early stages of cirrhosis. By combining these two methods, future studies could gain a more comprehensive view of hepatic hemodynamics, particularly in identifying subtle vascular changes in the liver parenchyma that occur before more significant alterations in macrovessels. Furthermore, this combined approach could help monitor the efficacy of interventions aimed at improving liver function or preventing complications, thus advancing the precision of non-invasive assessments in cirrhotic patients.

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ANNEXURE – I

INFORMED CONSENT FORM

A Colour Doppler Study of Hepatic Vein, Portal Vein and Hepatic Artery in Liver Cirrhosis: Correlation of Hepatic Hemodynamic with clinical Child Pugh Score in Tertiary Health Care Centre

Principal Investigator: REGISTRATION NO : BS0122004

Introduction: Liver cirrhosis is a consequence of progressive liver fibrosis due to chronic liver disease. It is a common problem in India.

Child Turcotte-Pugh (CP) score is used to access severity of liver disease in patients. Following parameters are used with each having a score (ranging from 0 to 2)

1) Serum albumin

2) Serum bilirubin

3) Prothrombin time

4) Ascites and

5) Hepatic encephalopathy

The scoring is easy to calculate and also helpful to determine the short-term mortality rate in patients with cirrhosis.

Ultrasound is cost-effective, readily and widely available non-invasive imaging tool. Doppler ultrasound is a very useful complement for evaluation of cirrhotic liver haemodynamic changes.

Previous studies show correlation of severity of cirrhosis with hepatic haemodynamic variations.

But, the changes in Doppler flow parameters in liver cirrhosis severity prediction is not yet clear. Hence the objective of this study is to evaluate Doppler flow hemodynamic variations in the hepatic vessels & portal vein velocity with hepatic artery resistivity index in cirrhotic livers in comparison to normal livers and to correlate these parameters with the clinical Child Pugh score to assess severity of liver cirrhosis. The changes in hepatic haemodynamic may also aid in evaluating progression of liver cirrhosis. This information may also help to predict portal vein thrombosis, and timely treatment of cirrhotic liver and prevent its complications

Withdrawal from participation in the study: Participation in this study in voluntary. You will be free to decide whether to participate in this study or continue participation once enrolled.

In case you decide to withdraw your participation, you are free to do so. However, please convey the decision to the principal investigator.

Possible benefits from participating in the study: You will /will not get any benefits by participating in this study. The data gathered will help population at large.

Possible risks from participating in the study: There are no risks involved in participating in this study.

Privacy and confidentiality: The information collected from you will be coded, to prevent any person to identify you. Your identity will never be revealed. The data collected from you will be kept confidential and only processed or aggregated data will be used for publication.

Financial incentives: You will not receive any payment for participating in this study.

Cost of investigations done during the course of study will be paid by the **principal investigator.**

Authorization for publication of aggregated data: Results obtained after processing of the aggregated data will be published for scientific purpose and or presented to scientific groups. However, your identity will never be revealed.

Questions: In case of any questions with regard to this study, you are free to contact:

REG NO. BS0122004 Post graduate, Department of Radiodiagnosis, J.N.Medical College, Belagavi	**DR.** Guide, Professor, Department of Radiodiagnosis, J.N.Medical College, Belagavi	**Dr.Harsha Hegde** Chairperson, JNMC, IEC & Scientist D, ICMR, National Institute Of Traditional Medicine, Belagavi

.

Legal rights: By signing this consent form, we are not waving any of your legal rights

CONSENT STATEMENT

I am making a voluntary decision to participate in the study **"A Colour Doppler Study of Hepatic Vein, Portal Vein and Hepatic Artery in Liver Cirrhosis: Correlation of Hepatic Hemodynamic with clinical Child Pugh Score in Tertiary Health Care Centre"**. My signature below indicates that I have decided to participate and I have read the information provided above or the information provided above has been read to me in the language that I understand best. I was given the opportunity to ask questions and that they have been answered to my satisfaction.

Name of the participant:

Signature or left thumb impression of the participant:

Name of the witness:

Signature or left thumb impression of the witness:

Name of the investigator:

Signature of the investigator:

ANNEXURE – II

PROFORMA FOR DATA COLLECTION

Patient details:

Age:

Sex:

IP/OP No:

Date:

Normal:

Cirrhotic:

- **Child Pugh Class (A/B/C)**

USG AND COLOUR DOPPLER

HEPATIC ARTERY

1) Peak Systolic Velocity

2) Resistivity index

PORTAL VEIN

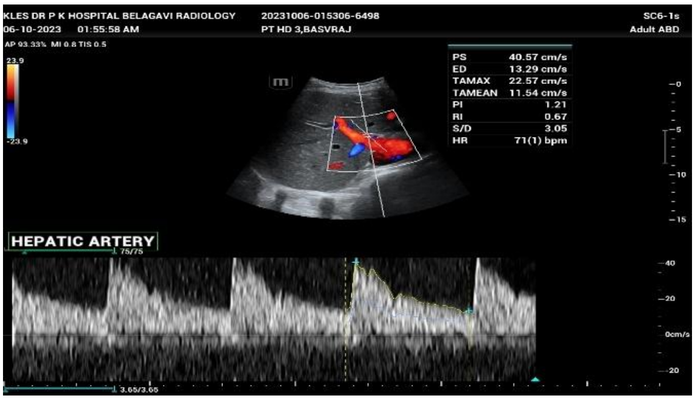
1)Peak Systolic Velocity

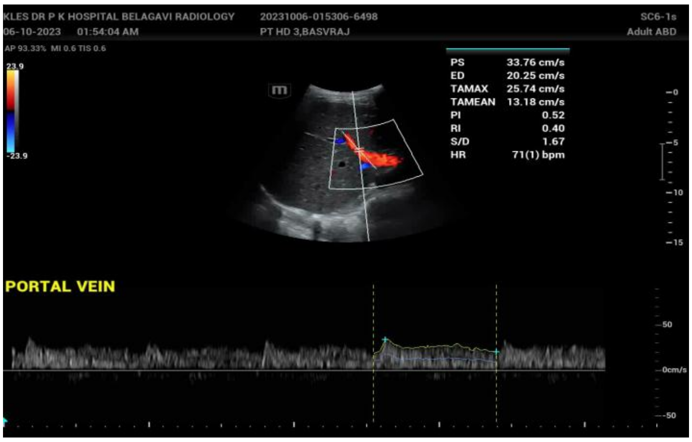
HEPATIC VEIN

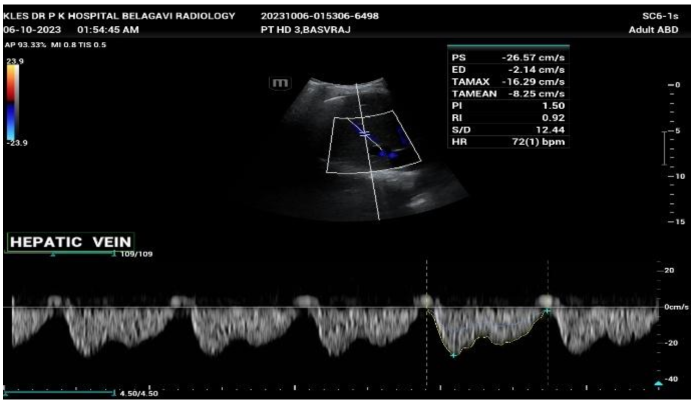
1) Peak Systolic Velocity

ANNEXURE-III: FIGURES

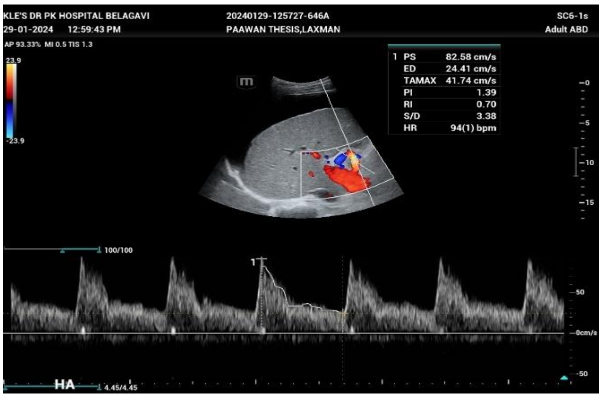
Case 1- 29 year male patient with normal patient
Hepatic artery PSV – 40.5 cm/s
Hepatic artery RI – 0.67
Portal vein PSV – 33.76 cm/s
Hepatic vein PSV – 26.7 cm/s

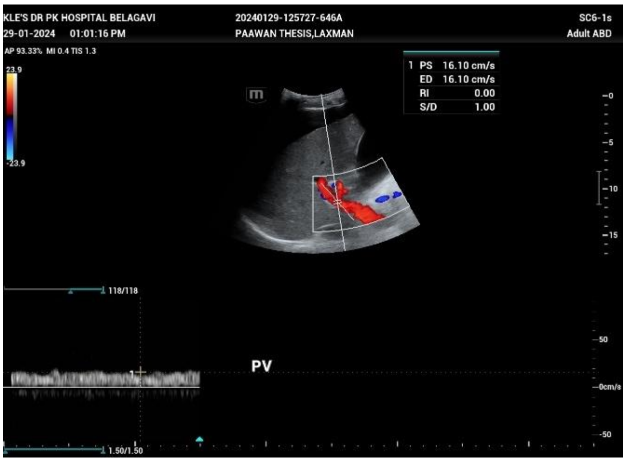




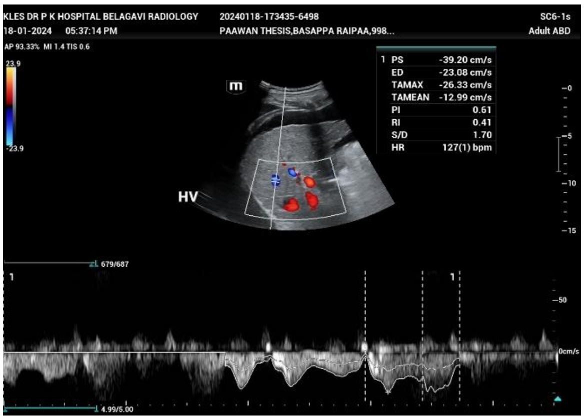


Case 2- 41 year old CTP A male patient
Hepatic artery PSV – 82.5 cm/s
Hepatic artery RI – 0.70
Portal vein PSV – 16.0 cm/s
Hepatic vein PSV- 44.3 cm/s

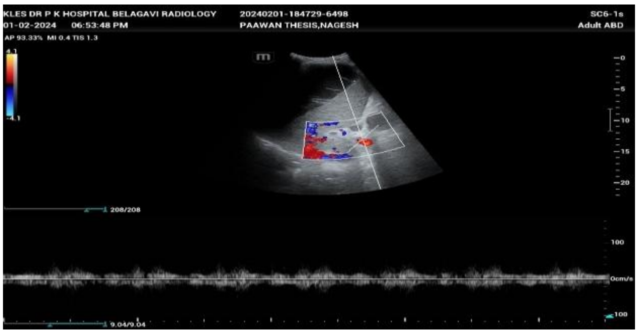


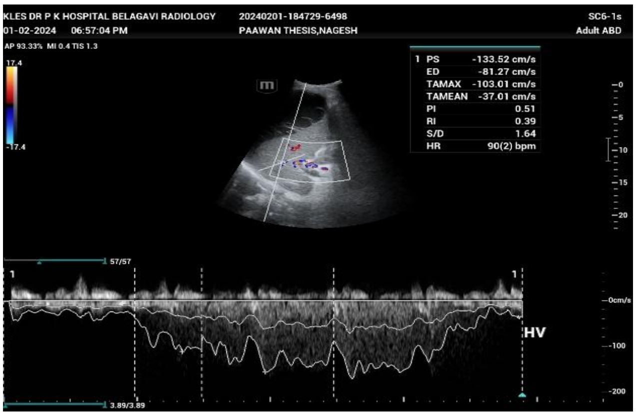


Case 3-   23 year old CTP B male patient
Hepatic artery PSV – 95.9 cm/s
Hepatic artery RI – 0.78
Portal vein PSV – 13.5 cm/s
Hepatic vein PSV- 39.2 cm/s



Case 4 - 25 year old CTP C male patient
Hepatic artery PSV – 140.2 cm/s
Hepatic artery RI – 0.79
Portal vein PSV – 11.6 cm/s
Hepatic vein PSV- 133.6 cm/s





ANNEXURE-IV

MASTER CHART

CONTROL						
SR. NO.	**AGE (years)**	**GENDER**	**HEPATIC ARTERY (Resistive Index)**	**HEPATIC ARTERY (PSV)**	**HEPATIC VEIN (PSV)**	**PORTAL VEIN (PSV)**
1	30	Male	0.55	52.6	52.4	18.9
2	29	Male	0.67	40.5	26.5	33.7
3	21	Male	0.69	45.9	30.1	27.8
4	40	Male	0.26	38.2	19.9	33.7
5	58	Male	0.59	87.9	42.7	37.8
6	25	Male	0.59	130	61.9	64.4
7	36	Male	0.41	57.6	45.8	42.8
8	25	Male	0.55	48.2	40.5	30.2
9	32	Female	0.58	52.6	42.7	35.9
10	45	Male	0.6	46.9	38.4	28.7
11	28	Female	0.53	50.3	45.1	33.1
12	36	Male	0.61	58.7	47.3	37.5
13	41	Female	0.54	39.2	36.5	25.6
14	29	Male	0.57	41.5	39.9	29.3
15	50	Female	0.59	55.4	44.7	34.2
16	21	Male	0.6	49.7	41.8	30.9
17	38	Female	0.52	44.3	39.5	26.7
18	27	Male	0.55	53.1	42.9	31.4
19	31	Female	0.56	51.7	41.3	29.8
20	46	Male	0.63	47.5	37.2	27.1
21	30	Female	0.61	42.6	38.9	26.3
22	55	Male	0.5	39.8	36.2	22.4
23	23	Female	0.6	45.7	39.4	30.5
24	34	Male	0.55	48.9	41.5	32

25	28	Female	0.62	43.2	37.6	27.2
26	40	Male	0.58	52.1	45.2	35.4
27	26	Female	0.53	47.6	39.8	30.1
28	50	Male	0.57	44.5	40.2	28.3
29	27	Female	0.53	39.1	35.7	24.2
30	56	Male	0.55	41.2	37.8	25.9
31	24	Female	0.58	45.9	39.5	29.7

CASES

CTP(A)

Sr. No	GENDER	AGE	Hepatic artery (PSV)	Hepatic artery (Resistive Index)	Portal vein (PSV)	Hepatic vein (PSV)
1	Male	28	112.3	0.71	17.0	43.52
2	Male	36	98.0	0..70	14.8	64.7
3	Male	41	97.3	0.77	16.1	46.5
4	Female	29	80.9	0.71	15.5	46.5
5	Male	50	87.9	0.72	15.9	34.5
6	Male	21	78.9	0.71	15.5	34.6
7	Female	38	79.9	0.72	14.5	39.6
8	Male	27	78.5	0.73	14.9	41.2
9	Male	31	75.4	0.72	14.7	39.8
10	Male	46	72.1	0.71	14.6	45.3
11	Female	30	74.2	0.72	15.2	39.8

CTP (B)

SR. NO.	GENDER	AGE	HEPATIC ARTERY (PSV)	Hepatic Artery (Resistive Index)	Portal Vein (PSV)	Hepatic vain (PSV)
1	Male	46	91.1	0.78	13.0	95.64
2	Male	30	87.7	0.76	14.3	42.9
3	Male	55	114	0.71	12.9	55.4
4	Male	23	95.5	0.78	18.5	40.8
5	Female	34	80.0	0.81	13.1	38.4
6	Male	28	137.3	0.72	14.1	72.9
7	Male	40	96.4	0.75	13.5	67.1
8	Male	26	95.8	0.75	11.2	62.3
9	Female	50	98.8	0.77	13.4	49.9
10	Male	27	97.6	0.78	12.3	49.6
11	Female	56	99.8	0.76	14.4	46.7

CTP (C)

SR. NO.	GENDER	AGE	HEPATIC ARTERY (PSV)	Hepatic Artery (Resistive Index)	Portal Vein (PSV)	Hepatic vain (PSV)
1	Male	25	140.0	0.75	11.6	133.0
2	Female	36	133.8	0.79	11.0	77.1
3	Female	25	123.4	0.84	10.8	57.2
4	Male	32	112.3	0.79	11.2	45.3
5	Male	45	114.5	0.82	12.3	43.6
6	Male	28	111.4	0.85	13.4	56.7
7	Male	36	125.6	0.87	9.8	65.4
8	Male	41	114.5	0.78	9.9	64.3
9	Female	29	102.3	0.79	10.1	67.8
10	Male	50	114.2	0.77	10.4	62.1