# *The "streamline phenomenon" of the portal vein flow and its influence on liver involvement by gastrointestinal diseases: current concepts and imaging-based review*

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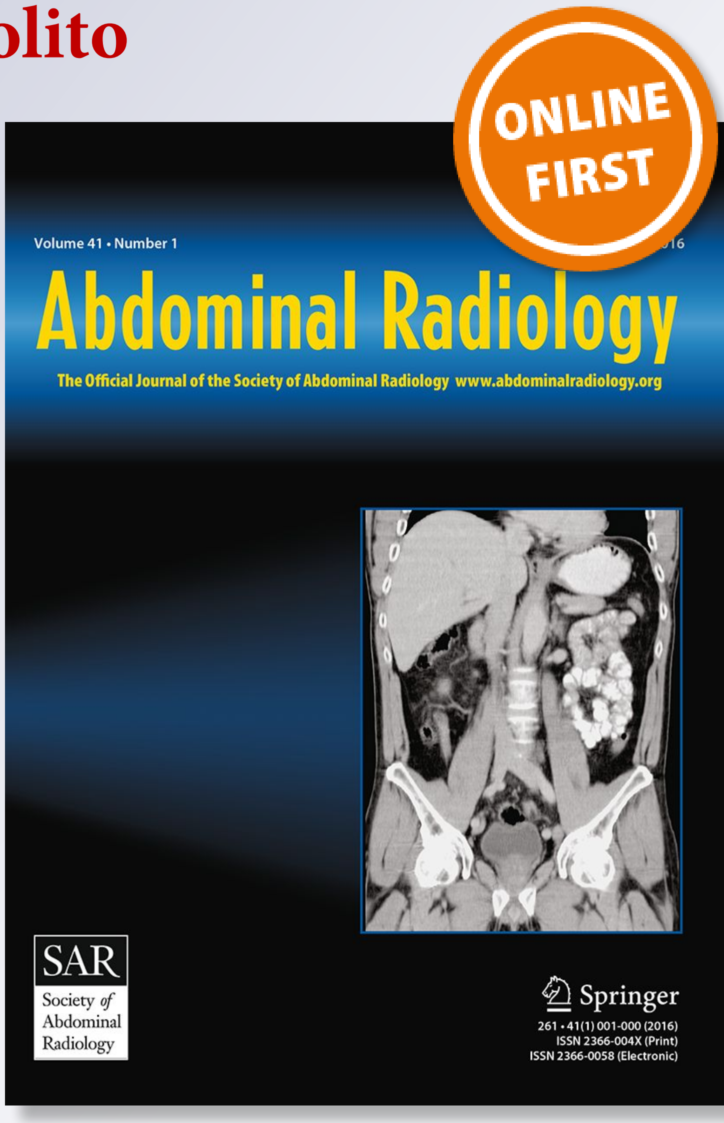


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REVIEW

# The "streamline phenomenon" of the portal vein flow and its influence on liver involvement by gastrointestinal diseases: current concepts and imaging-based review

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## Abstract

The streamline flow in the portal system is a phenomenon by which blood from superior mesenteric vein goes preferentially to the right hepatic lobe, while splenic and inferior mesenteric veins divert preferentially to the left lobe. Such a phenomenon results in different patterns of distribution of several liver diseases. The purpose of this article is to discuss the concepts behind the theory of streamline flow and to perform an imaging-based review of representative cases, demonstrating how it may influence the patterns of liver involvement in different gastrointestinal diseases.

**Keywords** Streamline · Liver · Portal vein · Hemodynamics · Vascular imaging

## Introduction

The streamline flow in the portal system is a physical phenomenon by which hepatic blood from the portal system flows in a binary pattern: blood from superior mesenteric vein goes preferentially to the right hepatic lobe, while splenic and inferior mesenteric veins divert preferentially to the left lobe [1, 2]. The occurrence and distribution of a variety of liver diseases may be influenced by the streamline phenomenon (SP), such as metastases of gastrointestinal tumors, abscesses, morphological changes in chronic liver disease etc. [3, 4]. In this review, we approach the theory behind the concept of the SP of the portal vein flow and discuss how it may influence the occurrence and patterns of liver involvement in a myriad of gastrointestinal diseases ranging from neoplastic to inflammatory and metabolic ones. Moreover, an imaging case-based review of such diseases is presented in the light of such a concept.

### Beyond human biology

In the Amazon basin, two rivers (Negro and Solimões) form the Amazon river. Throughout the extension of 6 km, their waters do not mix owing to physical (velocity and temperature) and chemical (potential of hydrogenation and sedimentation) differences inherent to both rivers' waters, which is known as streamline phenomenon [5] (Fig. 1).

### Liver and portal system anatomy

In order to introduce the SP, it is crucial to briefly recall some basic concepts on hepatic anatomy and portal irrigation. The Couinaud's classification is currently the most widely used system for describing the functional anatomy of the liver. It is the preferred anatomical classification system as it divides the organ into two planes (right and left—at the level of the middle hepatic vein and the Cantlie's line), two lobes (right and left at the level of the umbilical fissure), four parts (anterior and posterior at the right hepatic vein, lateral and medial at the level of the left hepatic vein), and eight independent functional units (termed segments). The segments are numbered in Roman numerals (I to VIII) and

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Fig. 1 The Negro river (dark water) and Solimões river (brown water) in the Amazon basin are tributaries of the Amazon river: the streamline phenomenon prevents their waters to mix. (Source: https://commons.wikimedia.org/wiki/File:Encontro_das_%C3%81guas_-_Manaus.jpg. Meeting (confluence) of the Waters, Manaus, Brazil. License: CC BY 3.0 BR)

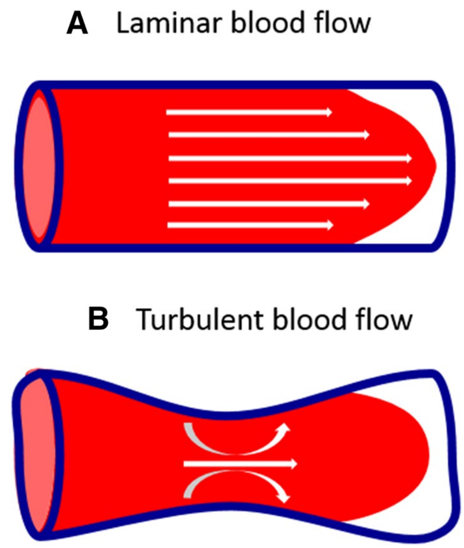



Fig. 3 Types of blood flow. **a** Laminar type has higher velocity in the central layers. **b** Turbulent type has a chaotic pattern of flow

were separated according to the hepatic veins and portal branches [6–9].

The portal vein (PV) is formed by the junction of the superior mesenteric vein (SMV) and the splenomesenteric trunk [formed by the junction of the splenic vein (SV) with the superior mesenteric vein (IMV)]. The portal trunk enters the hepatic hilum obliquely up to the right and slightly forward. The horizontalization of the PV is the most common variant. At the level of hepatic hilum, the conventional portal bifurcation (found in 70 to 80% of the cases) divides the PV into two branches (right and left) [7–10].

The short right branch usually forms an anterior division (supplying segments V and VIII) and a posterior one (supplying the segments VI and VII of right true/physiological lobe). The left branch is longer and takes a long extraparenchymatous course and tends to lie more horizontal than the right branch, but it is often of small caliber. It supplies the segments I (caudate), II, III, and IV of the liver [7–10].

Anatomical variations of the PV and its branches, however, are not uncommon; being found in up to 35% of imaging studies, it may have an impact on surgical decisions or even influence the occurrence of the streamline phenomenon (SP) [9–11] (Fig. 2).

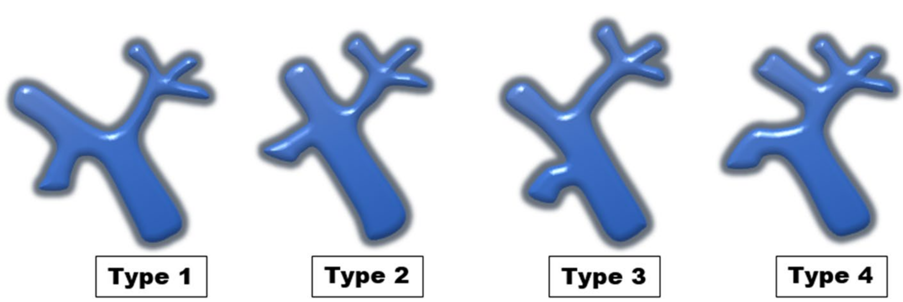



Fig. 2 Cheng's classification of portal intrahepatic variations. Type 1: bifurcation in right and left portal branches (70.9 to 86.2%); type 2: trifurcation with a right posterior sectorial vein, a right anterior sectorial vein, and a left portal branch arising from the same site (10.9 to 15.0%); type 3 or type Z: the right posterior sectorial vein comes directly from the portal vein and appears first in the lower part of the hepatic hilum (0.3 to 7.0%); type 4: the right anterior sectorial vein comes from the left portal branch (0.9 to 6.4%)

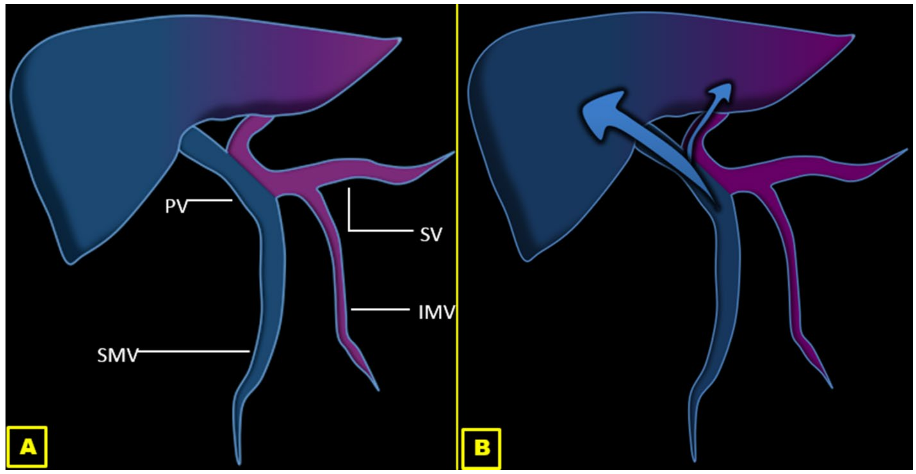



**Fig. 4** Hepatic blood from portal system follows a binary flow pattern: the right lobe has a flow predominantly derived from the SMV, while the left lobe has a flow derived by SV/IMV (**a**). Despite the binary pattern, there is a blood mixture in the portal vein (**b**)

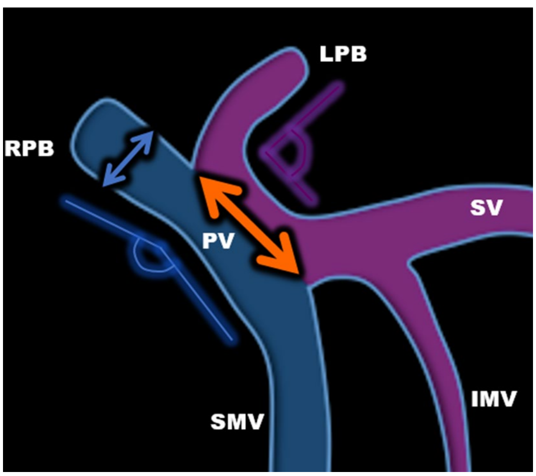



**Fig. 5** The short portal vein (orange arrow) and the larger caliber and smoothly angled configuration of the right portal branch (RPB, blue arrow) is thought to facilitate the streamline flow. *LPB* left portal branch, *RPB* right portal branch, *PV* portal vein, *SV* splenic vein, *SMV* superior mesenteric vein, *IMV* inferior mesenteric vein

## Concepts about the streamline phenomenon

### Blood flow occurs in two ways [1] (Fig. 3)

- Laminar flow: in this pattern, the blood flow is constant through a long vessel, with each layer of blood remaining at the same distance from the vessel wall (i.e., concentric layers of blood moving in parallel). The fluid molecules touching the walls barely move because of adherence to the vessel wall; the next layer slips over these, the third layer slips over the second and so on. In this sense, the flow occurs at different rates, creating a parabolic profile, the velocity being higher in the center of the vessel and lower towards the vessel wall. Laminar flow is the normal condition for blood flow throughout most of the circulatory system.

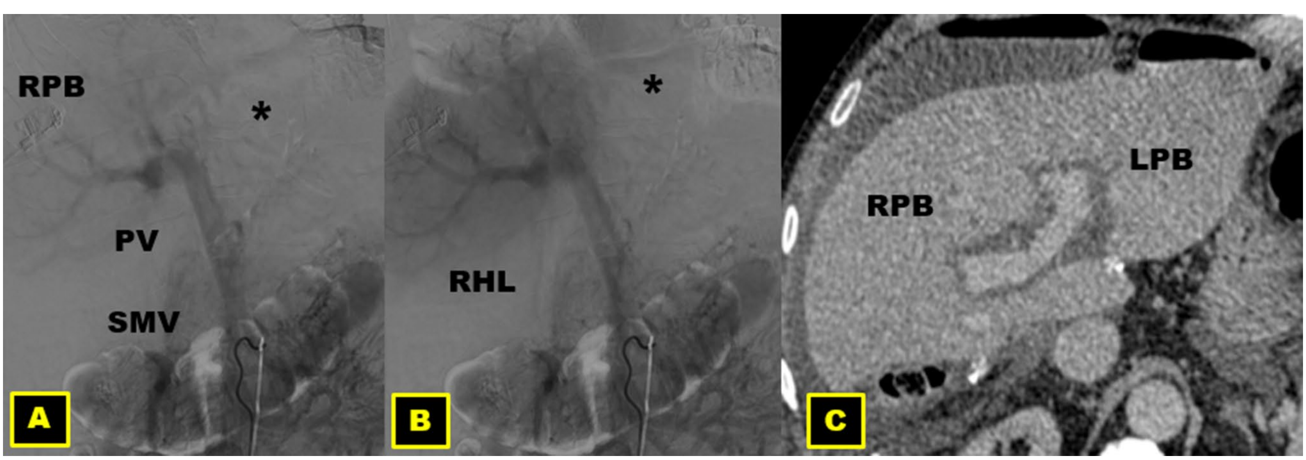



**Fig. 6** Indirect portal venography with catheterization of the superior mesenteric artery. Images in **a** and **b** were acquired with a difference of small fraction of seconds. Contrast opacification of SMV, PV, and RPB (**a**), followed by contrast opacification of the right hepatic lobe, RHL (**b**). Note the absent opacification of LPB (*). CT of the same patient demonstrates the LPB without alterations (**c**)

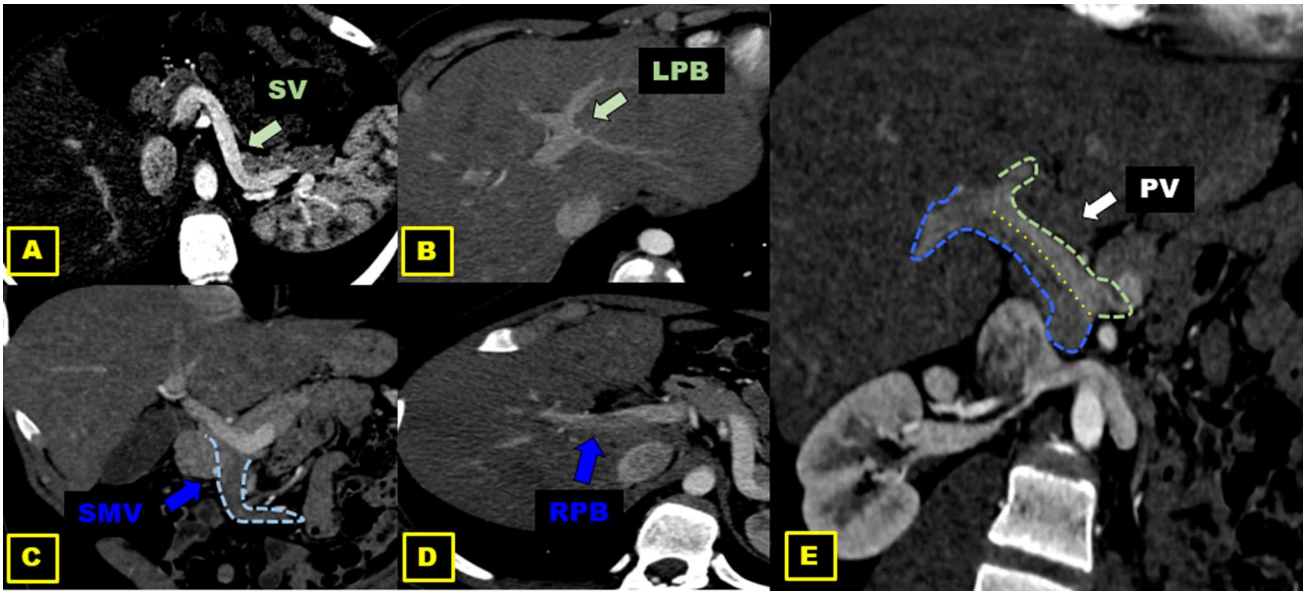
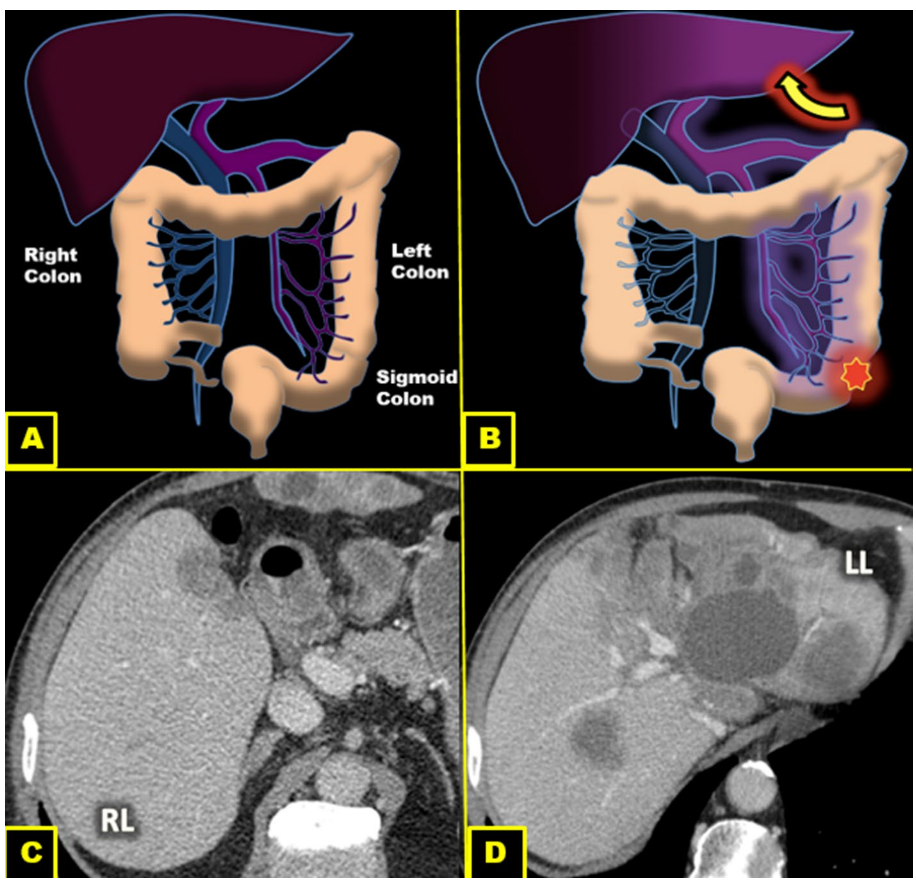



**Fig. 7** CT in early arterial phase demonstrates contrast enhancement of the SV (**a**) and subsequently of the LBP (**b**); no contrast enhancement of the SMV (**c**) or RPB (**d**) is seen. PV partially enhanced (**e**), the portion receiving flow from SV showing contrast enhancement and the portion receiving flow from SMV without enhancement (the different flows are separated by the yellow dotted line on the image)

**Fig. 8** The SMV drains the right colon and the IMV drains the left and sigmoid colons (**a**). A sigmoid colon tumor may induce metastatic involvement preferentially in the left hepatic lobe (**b**). CT scan of a patient (C-D) with adenocarcinoma of the sigmoid colon with metastasis compromising mainly the left lobe (LL) and with relative sparing of the right lobe (RL)



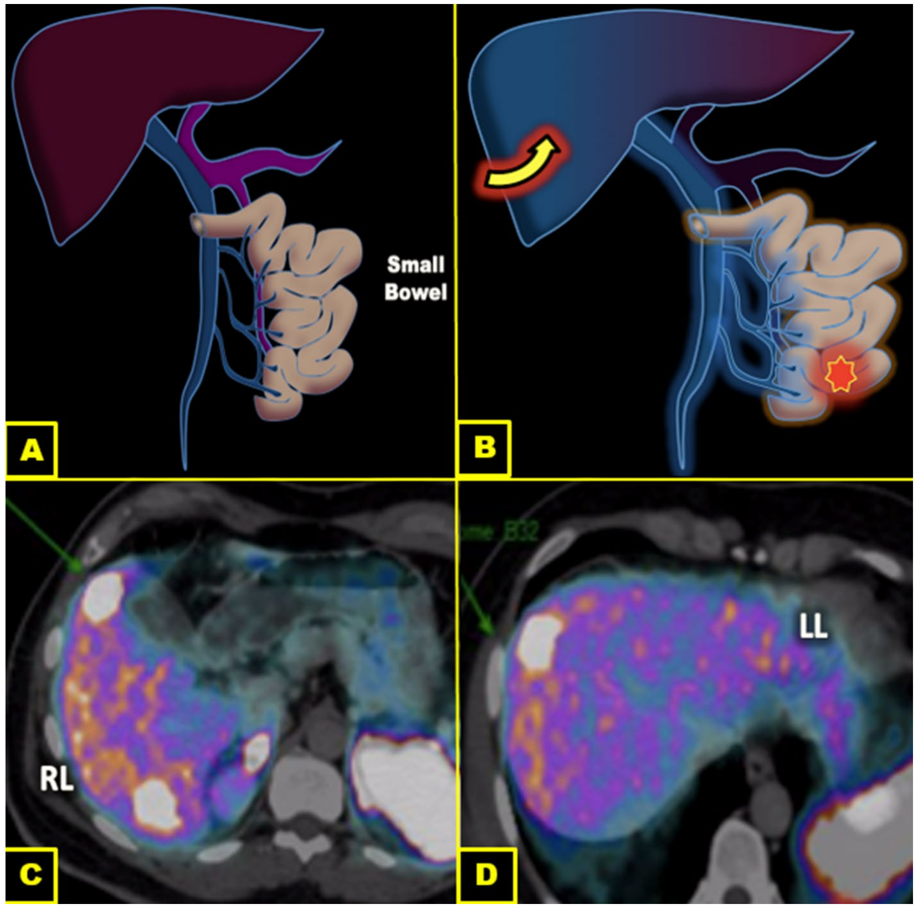



**Fig. 9** Small bowel drains to SMV (**a**), and tumors at this site may predominantly send metastases to the right hepatic lobe (**b**). PET/CT (with 68 Ga DOTATATE) from a patient with neuroendocrine tumor of the terminal ileus showing uptake lesions in the right hepatic lobe (**c**, **d**)

- Turbulent flow: in this pattern, the blood flows in all directions and it is in a continuous mixing process owing to the occurrence of whorls.

The normal blood flow in the portal vein follows a laminar and binary pattern [1, 2, 12], diverting blood from superior mesenteric vein (SMV) preferentially to the right hepatic lobe, and blood from splenic and inferior mesenteric veins preferentially to the left lobe (Fig. 4). Despite this binary pattern, there is a blood mixture in the PV, which may be attributable (to a greater or lesser extent) to morphological characteristics or anatomical variations of the vein [1, 2].

It is thought that SP occurs owing to the shortness of the PV trunk (impairing the mixture of flows at this level) and the larger caliber and smoother angle of the right portal branch (facilitating the entry of a greater blood volume from SMV straightly to the right lobe) [1, 2, 13] (Fig. 5).

## How can the phenomenon be demonstrated in imaging studies?

In the past, it has been demonstrated that the entrance of the hepatic blood flow through the portal system followed more or less a streamline pattern; studies with venography demonstrated that the blood coming from the SMV predominantly supplied the right lobe of the liver, while that coming from the SV/IMV supplied the left lobe [14] (Fig. 6). Nowadays invasive methods are not necessary to observe the binary pattern of portal flow. A simple careful attention to early arterial phases of cross-sectional imaging studies (such as CT or MRI) may demonstrate first the contrast enhancement of SV and, subsequently, of the

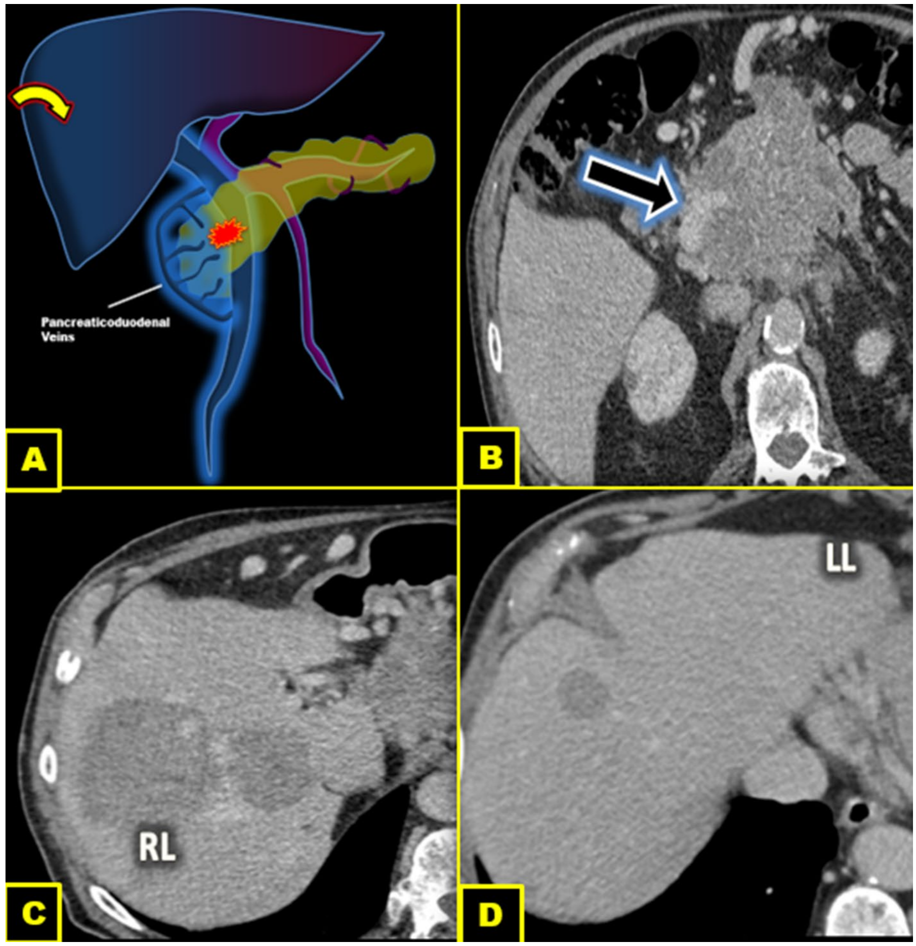



**Fig. 10** Pancreaticoduodenal veins drain into the SMV and PV (**a**). Patient with pancreatic head adenocarcinoma (arrow in **b**). The same patient with metastases only in the right hepatic lobe (**c**, **d**)

left portal branch, while SMV and the right portal branch are still unenhanced, because of the greater path to be yet covered by the contrast medium at that moment (Fig. 7).

### The influence of SP on the gastrointestinal system

The venous drainage of a specific organ of the gastrointestinal system is the starting point to study the influence of fluid dynamics phenomena. Following this theory, some organs and regions will drain predominantly to the right hepatic lobe, while others drain to the left. Representative cases under this approach will be used to discuss the occurrence and distribution of a variety of liver diseases that may be influenced by SP, such as metastases of gastrointestinal tumors; abscesses or secondary thromboses in the context of gastrointestinal tract infections; morphological changes in chronic liver disease (e.g., due to alcohol); and in hepatic steatosis [3, 4, 15, 16].

It should be preliminarily pointed out, however, that while SP can be demonstrated by invasive and noninvasive imaging techniques [17–19], not all studies support the clinical relevance of SP. Just to cite one example, there are studies showing no relationship between primary colon cancer location and the location of liver metastases [16, 20–22]. Although that does not imply that SP does not have clinical relevance, it emphasizes that not all investigations of this topic show a positive result and further research is needed.

## Imaging-based review

### Gastrointestinal tumors

#### Colon

The venous drainage of the right colon and part of the transverse section derives to the SMV, while the venous drainage of the left colon and upper rectum flows into the IMV. This drainage pattern may influence the distribution of liver

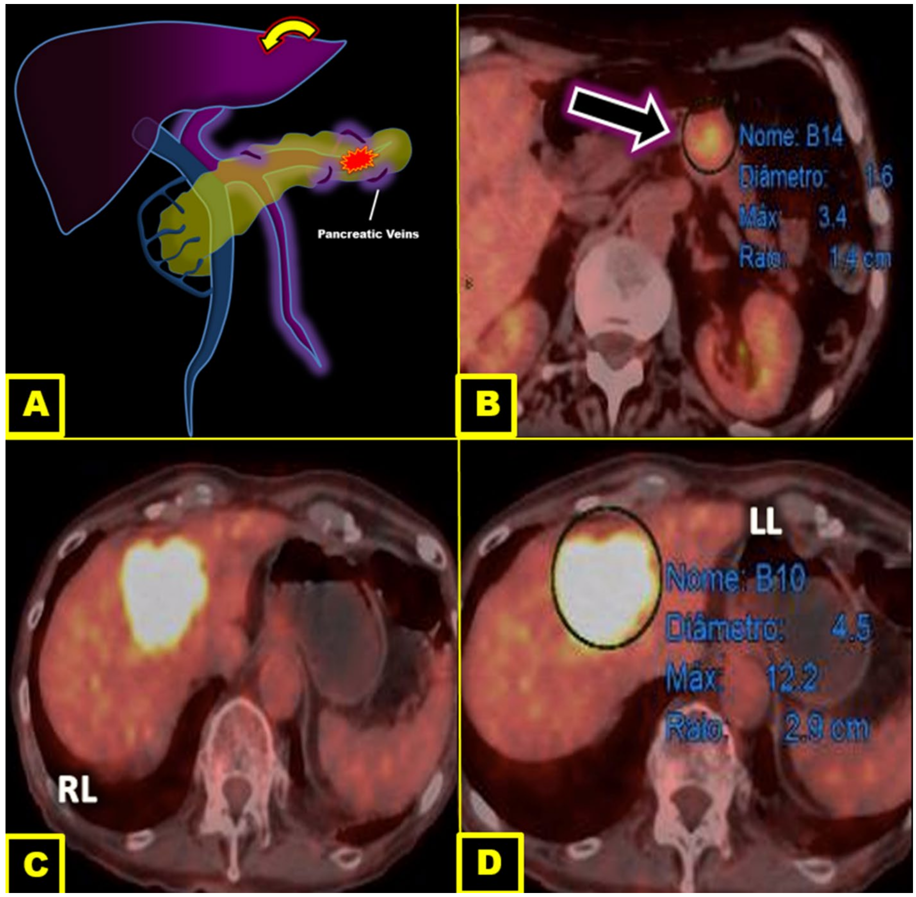



**Fig. 11** Pancreatic veins drain into SV (**a**). PET/CT (18F-FDG) from a patient with adenocarcinoma in the pancreatic body (arrow in **b**). The same patient with metastasis only in the left hepatic lobe (**c**, **d**)

metastases [23, 24]. A study of 410 patients with colorectal cancer (CRC) evaluated the right-to-left ratio distribution of hepatic metastases, finding a ratio of 2.20:1 when the primary site was on the right colon and 1.39:1 when the primary site was on the left ($p = 0.017$), demonstrating a significant difference in the lobar distribution of liver metastases between the right and the left colorectal cancer [23] (Fig. 8). It should be remembered, however, that colorectal tumors also may spread through the lymphatic route [25], a factor obviously not affected by the SP and that demands a careful evaluation of the whole liver and the appropriate lymph nodes stations by the radiologist.

## Small bowel

Jejunum and ileum constitute almost the entirety of the small bowel; the venous drainage of such segments occurs into the jejunal and ileal venous branches, which then divert to the SMV. To our knowledge, there are no studies demonstrating it with statistical significance, but in our oncological practice, liver metastases involve predominantly the right lobe when the primary tumor is situated in the small bowel [3, 4] (Fig. 9).

## Pancreas

There are studies showing that liver metastases of pancreatic tumors (adenocarcinomas and neuroendocrine ones) can be influenced by this portal system flow pattern; lesions of the pancreatic head (which is drained by the SMV) determine proportionally more metastases to the right lobe than to the left lobe, while in cases of lesions involving the body and tail of the pancreas (drained by the SV), this proportion is lower [13, 26, 27] (Figs. 10 and 11). Similarly, Ambrosetti et al. [13] demonstrated that liver metastases arising from adenocarcinomas of the pancreatic head have a preference for the right lobe in relation to the left lobe at a ratio of 7.4: 1, while in cases of lesions arising from the body and tail, this ratio is decreased to 3.3:1 ($p < 0.00001$).

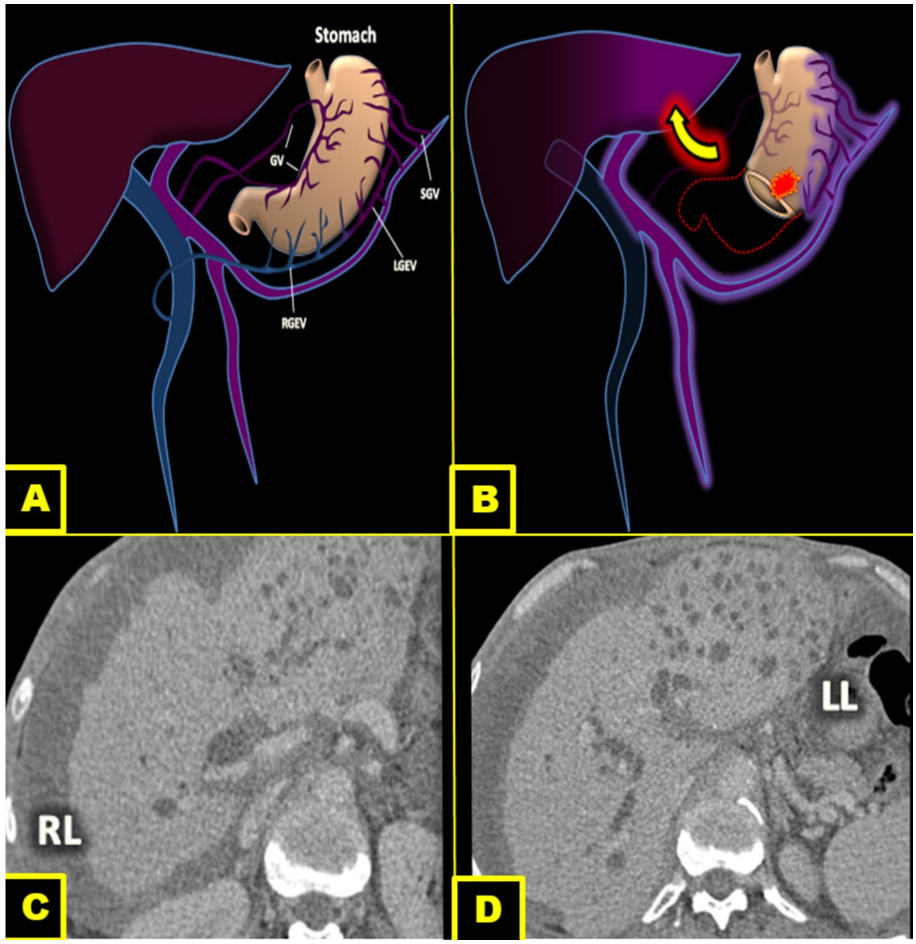



**Fig. 12** Gastric veins (GV) drain to portal vein; right gastroepiploic vein (RGEV) drains to SMV; left gastroepiploic vein (LGEV) and short gastric veins (SGV) drain to SV (**a**). Patient with gastric adenocarcinoma submitted to subtotal gastrectomy with recurrence in the gastric remnant (**b**). Metastases predominating in the left lobe (**c**, **d**)

## Stomach

Venous drainage of the stomach is performed by the gastric veins (right and left), which commonly drain into the portal vein; the right gastroepiploic vein drains into the pancreaticoduodenal arches that drain into SMV/PV and the left gastroepiploic vein and short gastric veins drain into the SV. It is not improbable that this pattern of drainage may influence the model of distribution of liver metastases depending on the location of the gastric tumor. In a study involving 172 patients with liver metastases of a range of gastrointestinal tumors, Hata et al. [4] found more frequent distributions of liver metastases in the lateral segment of the liver among patients with gastric cancer, and significantly less frequent distribution was found in the posterior segment. The authors concluded that the tumor distribution in liver metastases of gastrointestinal tumors differ depending upon the primary tumors, basically in accordance with SP [4]. Further studies are required to verify whether this observation can be confirmed (Fig. 12).

## Gastrointestinal infections

In order to obey the theory and respect the same logic on the distribution of hepatic metastases, the septic emboli released by inflammatory/infectious gastrointestinal processes can promote hepatic abscesses and thrombosis influenced by the binary flow pattern [1–4] (Figs. 13 and 14).

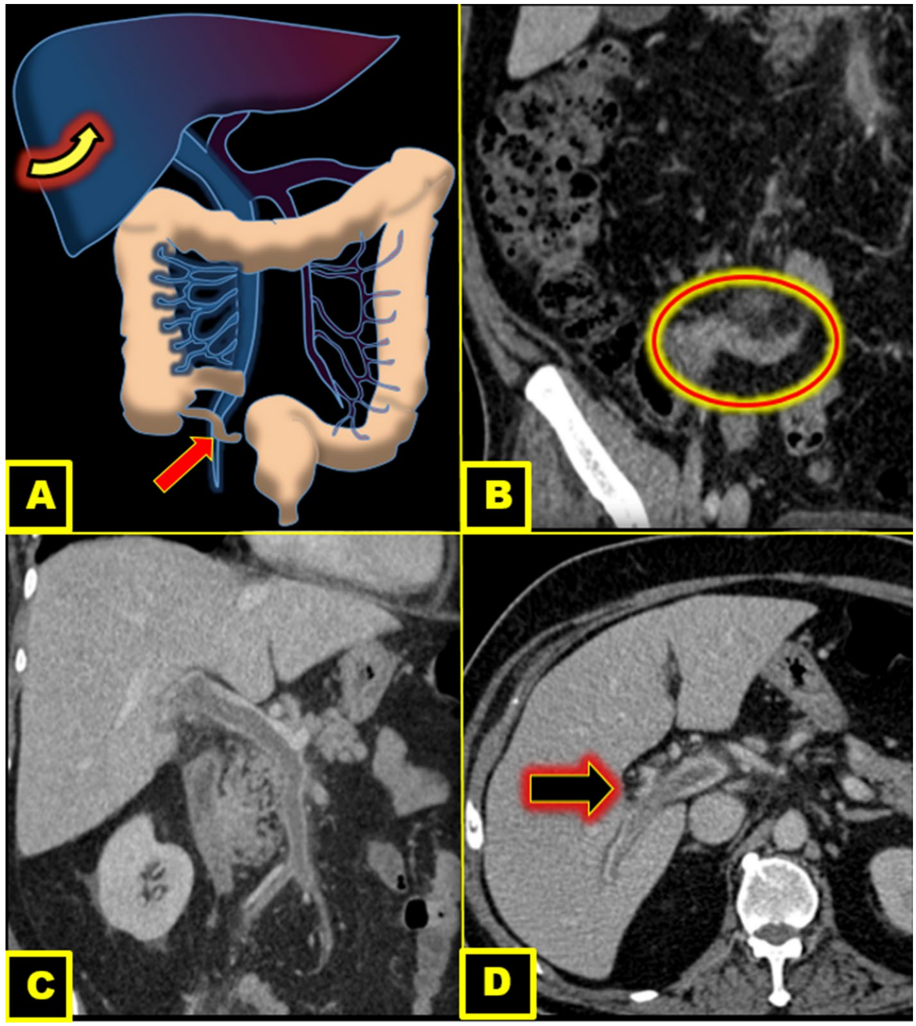



**Fig. 13** Appendix vermiformis (straight arrow) drains to SMV (**a**). Appendicitis (circle in **b**) with complication (pileflebitis and thrombosis) involving the SMV, partially the PV (lateral portion) and the right portal branch, and preserving the left portal branch (**c**, **d**)

## Alcoholic liver cirrhosis

When alcohol is ingested, it goes down the esophagus to the stomach and small bowel. It skips the normal digestive process and goes straight into the bloodstream. About 20% of the alcohol consumed is absorbed in the stomach and 80% in the small bowel, and then a part is subsequently metabolized in the liver [1, 16]. The cellular and molecular mechanisms of cirrhosis pathogenesis are still incompletely understood, but seem to be related to a complex interaction between behavioral, environmental, and genetic factors. The histological hallmarks of alcoholic liver disease (steatosis, inflammation, and fibrosis) are the result of interrelated and consecutive pathophysiological events in the context of continuous alcohol exposure [10, 28].

Morphologic changes of the liver vary with the stage of cirrhosis. More than 60% of patients with early cirrhosis have hepatomegaly. Additional early detectable morphologic changes of the liver include widening of the porta hepatis, enlargement of the interlobar fissure, and expansion of pericholecystic space [16, 28]. Although the morphological changes observed in the cirrhotic liver are common to different etiologies of cirrhosis, there is evidence in the literature suggesting that some specific morphological changes may be more associated to alcohol abuse. One study, for example, demonstrated that mean values of the volume index of the caudate lobe are significantly greater in patients with alcoholic cirrhosis in comparison to those with viral etiology, indicating that a large caudate lobe is highly suggestive of cirrhosis caused by alcohol abuse [29]; the same is thought

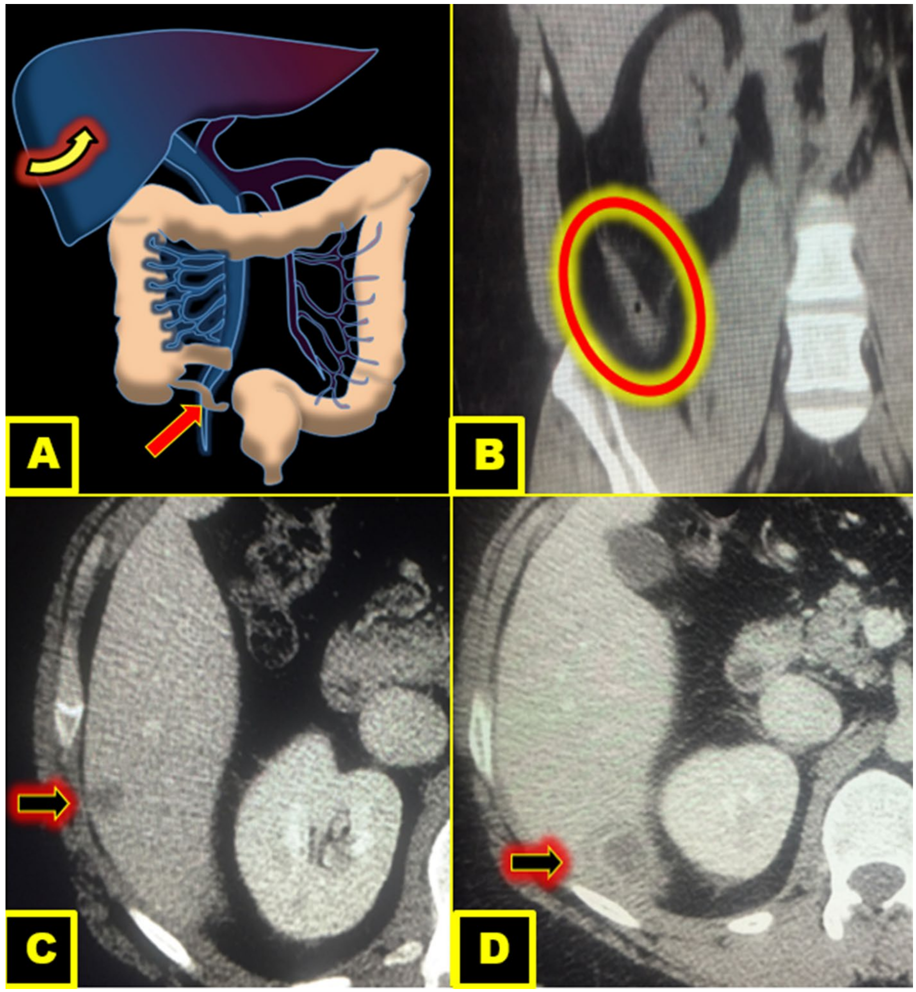



**Fig. 14** Appendix vermiformis (straight arrow) drains to SMV (A). Appendicitis (circle in **b**) complicating with liver abscesses in the right lobe (**c**, **d**)

regarding the presence of the right posterior hepatic notch, a sign resulting from atrophy of the posterior segments of right lobe of liver, hypertrophy of the caudate lobe of liver, due to hepatic fibrosis, and alteration in portal blood flow [29, 30]. Indeed, some authors argue that the preferential delivery of alcohol to the right lobe after digestive absorption might be the principal reason for the predominance of morphological changes in the right lobe in patients with alcohol abuse [17, 31, 32]. Moreover, there are studies using single photon emission CT indicating that heavy drinking causes both an increased total liver volume and a change in liver shape, with a relatively more enlarged left than right lobe, as well as a decreased capacity of the left lobe to concentrate radiocolloid in comparison to the right lobe [33], which also favors the streamline theory. All these facts together suggest that the higher presence of ethanol metabolites in the right lobe may cause more damages and consequently a hypotrophy in the chronic setting, while in the left lobe, less affected initially, a compensatory hypertrophy occurs (Fig. 15).

## Hepatic steatosis

Hepatic steatosis is defined as the presence of intrahepatic triglycerides in an amount of at least 5% of liver weight or 5% of hepatocytes containing lipid vacuoles, which are a metabolic complication due to a variety of toxic agents, ischemia, or infectious insult [15]. The pathogenesis of hepatic steatosis involves multiple pathways, including fatty acid uptake, de novo lipogenesis, oxidation of mitochondrial fatty acids, and lipoprotein secretion. Most chylomicrons (tiny particles of triglycerides) are removed from the

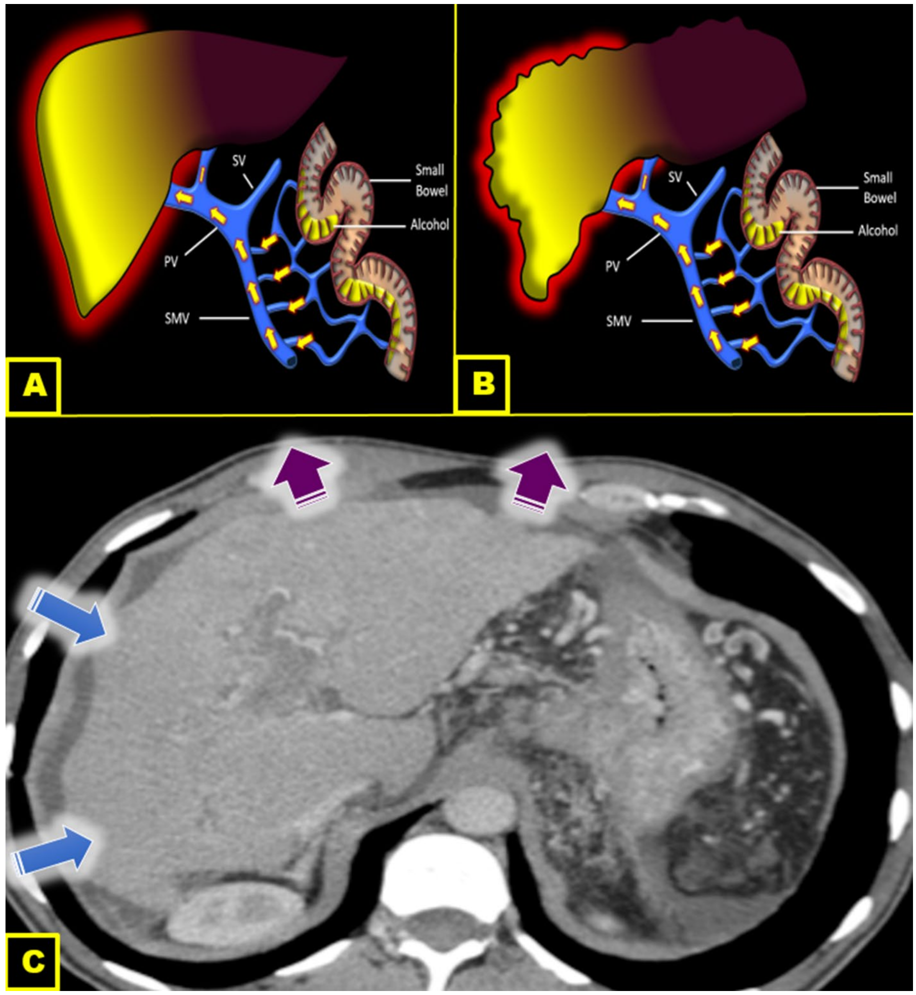



**Fig. 15** Most of the alcohol is absorbed in the small intestine and metabolized mainly in the right hepatic lobe (**a**). Alcohol abuse causes liver damage (cirrhosis), with morphological alterations—hypotrophic right lobe and hypertrophic segment II/III (**b**, **c**)

circulating blood as they pass through the capillaries of the liver [15].

Whenever an amount of carbohydrate ingested is greater than the amount that can be used immediately as a source of energy, the excess is converted into triglycerides and stored. Essentially, all of the fat digestion occurs in the small intestine, and only a small part is digested in the stomach by the lingual lipase (< 10%);perhaps, this may explain the reason for the observation, in the clinical practice, of many cases in which the right hepatic lobe is more severely affected by steatosis than the left one [34, 35]. In fact, studies encompassing patients with different causes of steatosis have observed that hepatic fatty infiltration in many patients is not uniform and that attenuation values in the right lobe of the liver are significantly lower than those in the left [34, 35]; a possible explanation to this phenomenon is the higher content of medium-chain fatty acids and glucose in the superior mesenteric venous blood directing predominantly to the right lobe owing to the SP [34, 35] (Fig. 16).

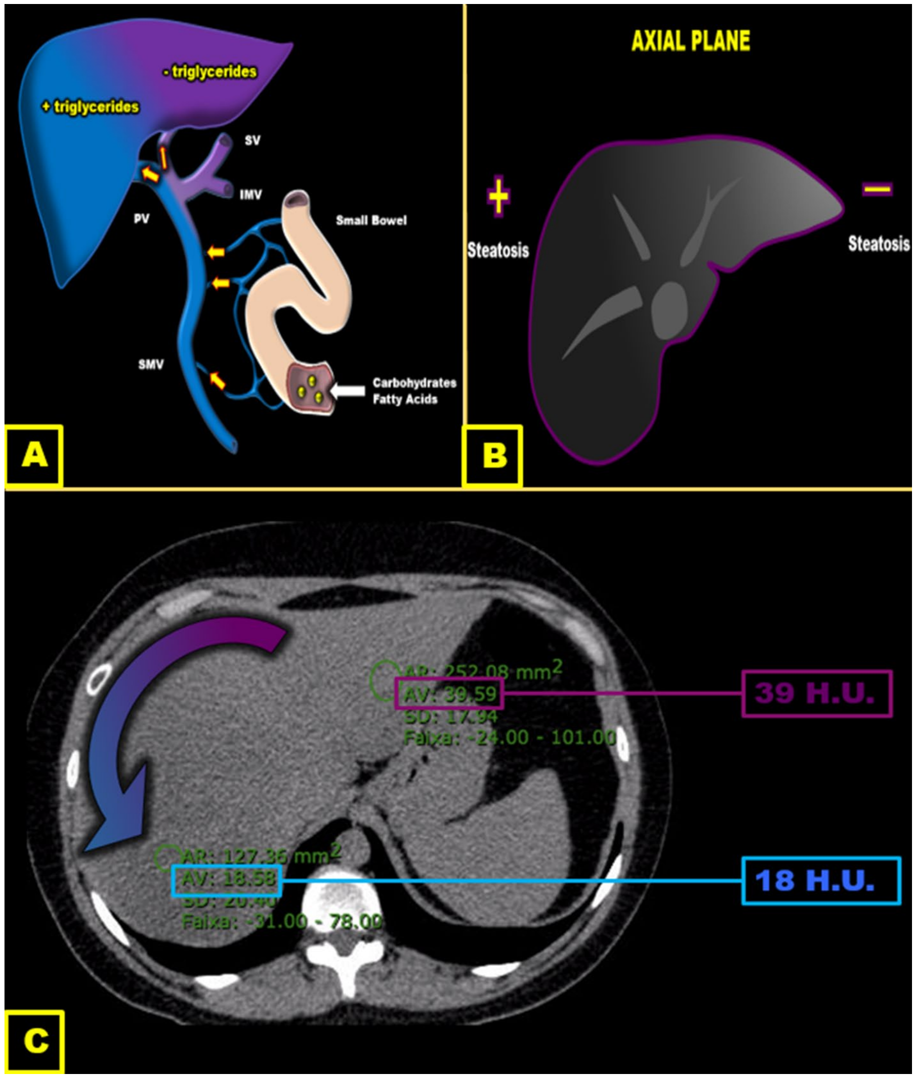



**Fig. 16** Particulates of fatty acids and carbohydrates are absorbed in the small bowel and transported by SMV, with accumulation of triglycerides in the liver (**a**) predominantly in the right lobe, thus leading to a higher degree of steatosis in the right lobe as compared to the left lobe (**b**, **c**)

## Conclusion

It is fundamental to understand that the anatomy of the portal system is interlinked with the physiology of the flow dynamics phenomena and that some morphological characteristics of the portal venous trunk and its branches may favor streamline flow. Understanding the patterns of liver disease under the light of SP may help the radiologist in carefully searching for even subtle signs of expected lobar involvement once a primary gastrointestinal disease is known.

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### Compliance with ethical standards

**Conflict of interest** There are no conflicts of interest to declare.

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