Quantitative assessment of portal vein flow in subjects with liver cirrhosis: comparison of phase-contrast magnetic resonance angiography with color Doppler ultrasonography

Essay
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By
Ahmed Farouk Abd El Aleem

Under supervision of
Dr. **Hatem Hosny Sallam**
Assistant Professor of Diagnostic Radiology
Faculty of medicine
Cairo University

Dr**. Hatem Elazizy**
Assistant Professor of Diagnostic Radiology
Faculty of medicine
Cairo University

Faculty of medicine
Cairo University
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List of abbreviations

- 2D: Two-dimensional
- 3D: Three-dimensional
- CE-MRA: Contrast-Enhanced MRA
- CHF: Congestive heart failure
- CLD: Chronic liver disease
- CT: Computed tomography
- HCS: Hyperdynamic circulatory state
- HCV: Hepatitis C virus
- HVPG: Hepatic venous pressure gradient
- HVPG: Hepatic venous pressure gradient
- MIP: Maximum intensity projection
- MPR: Multiplanar re-formation
- MRA: Magnetic Resonance Angiography
- NO: Nitric oxide
- PC-MRA: Phase-contrast Magnetic Resonance Angiography
- PI: Pulsatility index
- PVF: Portal vein flow
- PVV: Portal vein velocity
- RF: Radiofrequency pulses
- RI: Resistance index
- SAAG: Serum ascitic albumin gradient
- SENSE: Sensitivity encoding
- SMV: Superior mesenteric vein
- SNR: Signal-to-noise ratio
- SSD: Shaded surface display
- TE: Echo time
- TIPS: Transjugular intrahepatic portosystemic shunt
- TOF: Time of flight
- TR: Repetition time
- US: Ultrasound
- V_{enc} : Velocity encoding
- V_{max} Peak systolic velocity
- V_{min} : Minimum diastolic velocity
- VPS: Views per segment
- WHVP: Wedged hepatic venous pressure

Anatomy

Anatomy of the portal venous system

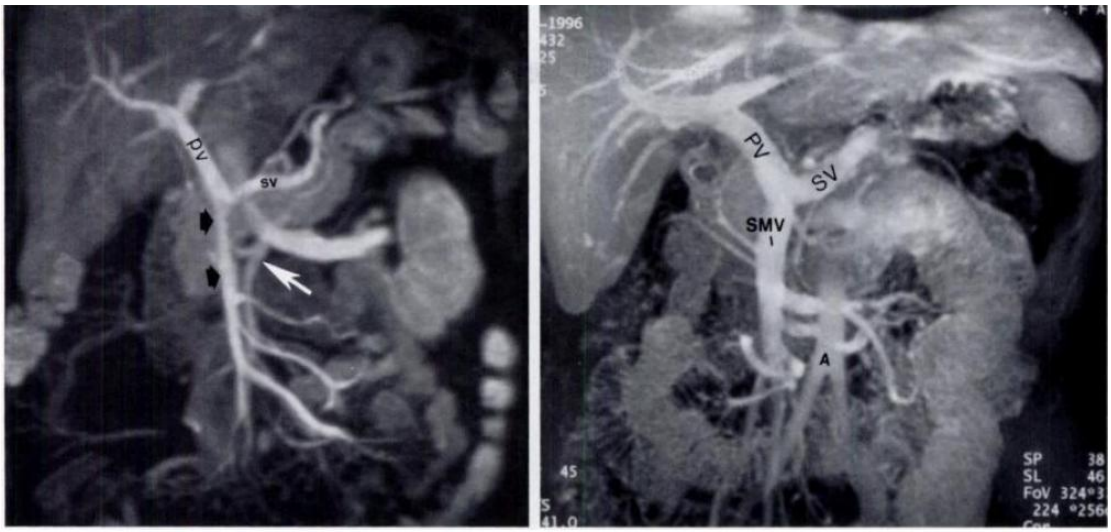
The main blood supply of the liver comes from the portal vein. The portal vein drains the spleen and the gastrointestinal tract, apart from the distal half of the colon. In the liver, this vein ramifies like an artery and ends in capillary-like vessels termed sinusoids, from which the blood is conveyed to the inferior vena cava by the hepatic veins***. (Iain et al., 2006)***

Total hepatic blood flow at rest is about 1500 ml/min (i.e. 25–30% of cardiac output). Of this, 70% comes from the portal vein, the remainder from the hepatic artery. Blood flow to the stomach and small intestine (and thus to the liver) doubles after a meal and the increase lasts up to 3 hours. ***(Iain et al., 2006)***

The portal vein is about 8 cm in length, and is formed at the level of the second lumbar vertebra by the junction of the superior mesenteric and splenic veins (Fig. 1), the union of these veins taking place in front of the inferior vena cava and behind the neck of the pancreas. It passes upward behind the superior part of the duodenum and then ascends in the right border of the lesser omentum to the right extremity of the porta hepatis, where it divides into right and left branches, which accompany the corresponding branches of the hepatic artery into the substance of the liver**.** In the lesser omentum, it is placed behind the common bile duct and the hepatic artery, the former lying to the right of the latter. ***(Gray et al., 2000)***

The right branch of the portal vein enters the right lobe of the liver, but before doing so, it receives the cystic vein. The left branch, longer but of smaller caliber than the right, gives branches to the caudate lobe, and then enters the left lobe of the liver. It is joined in front by a fibrous cord, the ligamentum teres *(obliterated umbilical vein),* and united to the inferior

Vena cava by a second fibrous cord, thee ligamentum venosum *(obliterated ductus venosus).* ***(Gray et al., 2000)***



a. b.

Fig. 1 venous phase of mesenteric circulation. **(a)MIP** image from the second data acquisition shows the mesenteric venous return as well as the arterial supply the SMA (white arrow), SMV (black arrow, splenic vein(*SV*) and portal vein (*PV*) are seen. **(b) MIP** image from third data acquisition ***(Watanabe et al., 2000)***.

Perhaps a more correct way of thinking about the anatomy of the liver is in terms of the acinus as the anatomical unit. There are about 100,000 acini, each composed of hepatocytes, endothelial cells and Küpffer cells arranged like grapes on a vascular stalk containing terminal branches of portal veins via hepatic arteries and bile ducts. The 'central' vein of the lobule is on the periphery of the acinus. ***(Iain et al., 2006)***

• Portal Vein Tributaries:

A) **The splenic vein:** commences by five or six large branches which return the blood from the spleen. These unite to form a single vessel, which passes from left to right, grooving the upper and back part of the pancreas, below the splenic artery, and ends behind the neck of the pancreas by uniting at a right angle with the superior mesenteric vein to form the portal vein. ***(Gray et al., 2000)***

- ***Tributaries:***

1) **The short gastric veins:** four or five in number, drain the fundus and

left part of the greater curvature of the stomach.

2) **The left gastroepiploic vein:** receives branches from the antero-superior and postero-inferior surfaces of the stomach and from the greater omentum.

3) **The pancreatic veins:** consist of several small vessels which drain the body and tail of the pancreas, and open into the trunk of the splenic vein.

4) The inferior mesenteric vein: returns blood from the rectum, the sigmoid and descending parts of the colon. It begins in the rectum as the **superior hemorrhoidal vein,** which has its origin in the hemorrhoidal plexus, and through this plexus communicates with the middle and inferior hemorrhoidal veins. The superior hemorrhoidal vein leaves the lesser pelvis and crosses the left common iliac vessels with the superior hemorrhoidal artery, and is continued upward as the inferior mesenteric vein. Sometimes it ends in the angle of union of the splenic and superior mesenteric veins. ***(Gray et al., 2000)*** ***(Boyer et al., 1982)***

B) **The Superior Mesenteric Vein:** returns the blood from the small intestine, from the cecum, and from the ascending and transverse portions of the colon. It begins in the right iliac fossa by the union of the veins which drain the terminal part of the ileum, the cecum, and appendix. The superior mesenteric vein is joined by the **right gastroepiploic** and **pancreaticoduodenal** veins. The right gastroepiploic vein receives branches from the greater omentum and from the lower parts of the antero-superior and postero-inferior surfaces of the stomach. ***(Williams et al., 1995)*** ***(Watanabe et al., 2000)***

C) **The Coronary Vein *(Left* gastric vein):** derives tributaries from both surfaces of the stomach, it runs from right to left along the lesser curvature of the stomach, between the two layers of the lesser omentum, to the esophageal opening of the stomach, where it receives some esophageal veins. It then turns backward and passes from left to right behind the omental bursa and ends in the portal vein. ***(Sacerdoti et al., 1995)***

D) The Pyloric Vein: is of small size, and runs from left to right along the pyloric portion of the lesser curvature of the stomach, between the two layers of

the lesser omentum, to end in the portal vein. ***(Boyer et al., 1982)***

E) **The Cystic Vein:** drains the blood from the gall-bladder, and accompanying the cystic duct, usually ends in the right branch of the portal vein.

F) **Para-umbilical Veins:** In the course of the ligamentum teres of the liver and of the middle umbilical ligament, small veins (para-umbilical) are found which establish an anastomosis between the veins of the anterior abdominal wall and the portal, hypogastric, and iliac veins. The best marked of these small veins is one which commences at the umbilicus and runs backward and upward in, or on the surface of, the ligamentum teres between the layers of the falciform ligament to end in the left portal vein. ***(Gray et al., 2000)***

Portosystemic Collateral Vessels

The most common cause of portosystemic collateral vessels is portal hypertension. Other causes of portosystemic collateral vessels are splenic or splenomesenteric venous stenosis and obstruction due to neoplasms, pancreatitis, or surgery ***(Gallego et al., 2002)***.

More than 20 pathways have been described, with the most common being gastroesophageal, paraumbilical, splenorenal, and inferior mesenteric collateral vessels. Pleuropericardial-peritoneal, pancreatico-duodenal, splenoazygos, and mesocaval collateral vessels are unusual pathways for decompression of the portal vein (Fig. 2).

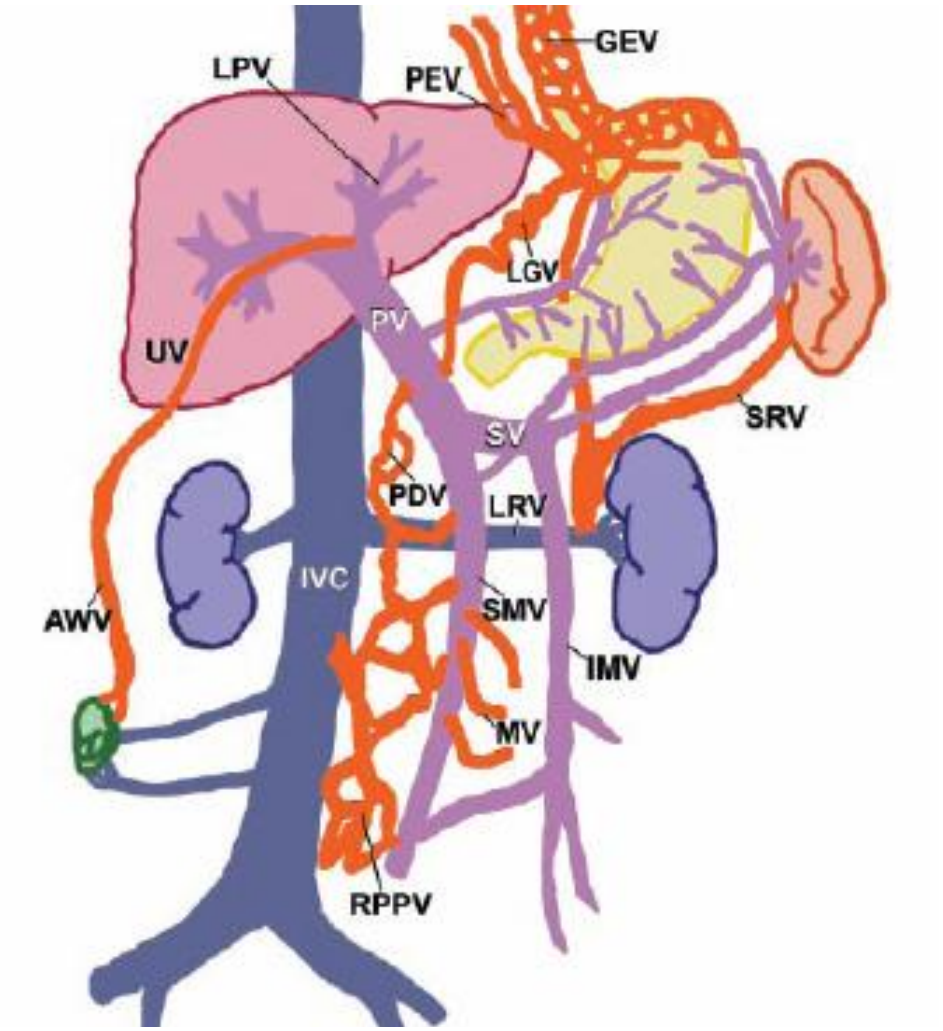


Fig. 2 Drawing illustrates the collateral vessels in portal hypertension. AWV=abdominal wall vein, GEV=gastroesophageal vein, IMV=inferior mesenteric vein, IVC = inferior vena cava, LGV=left gastric vein, LPV=left portal vein, LRV=left renal vein, MV=mesenteric vein, PDV=pancreaticoduodenal vein, PEV=paraesophageal vein, PV=portal vein, RPPV=retoperitoneal-paravertebral vein, SMV=superior mesenteric vein, SRV=splenorenal vein, SV=splenic vein, UV=umbilical vein ***(Jain et al., 2006)***

Coronary, Esophageal, Paraesophageal, and Gastric Collateral Vessels:

Coronary collateral veins at the lesser omentum are the most frequently depicted varices at cross sectional imaging (in approximately 80% of patients with portal hypertension) ***(Cho et al., 1995)***. They are usually accompanied by esophageal and paraesophageal varices and less commonly by retrogastric varices.

Esophageal varices are of major clinical importance because they are a frequent source of gastrointestinal bleeding ***(Ito et al.,1997)***. They are

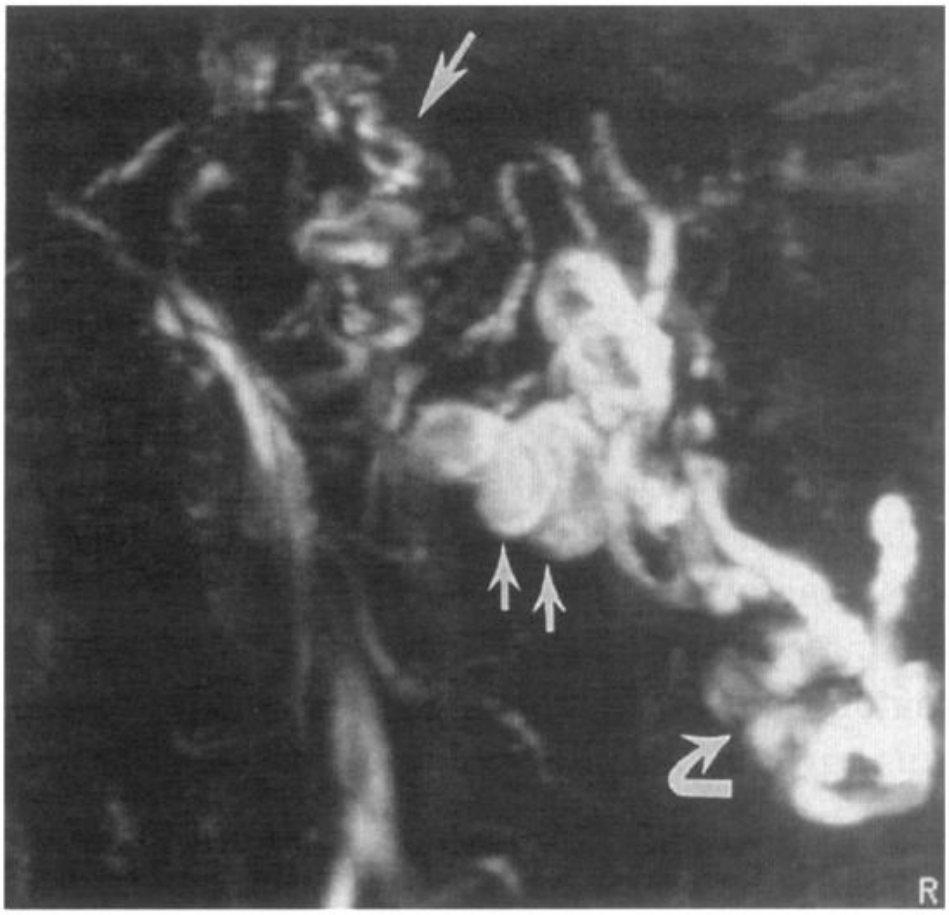


Fig. 3. Coexistent coronary, paraesophageal, splenorenal, and splenoretroperitoneal collaterals in a patient with cryptogenic cirrhosis. Coronal phase contrast **MR** portogram shows massive collaterals from the splenic hilum passing both medially toward the left renal vein (splenorenal collaterals, short straight arrows) and laterally and inferiorly (splenoretroperitoneal collaterals, curved arrow). Additionally, note the extensive coronary and paraesophageal varices (long straight arrow). ***(Ito et al.,1997)***

embedded in the wall of the esophagus and are sometimes difficult to see at cross-sectional imaging because of the lack of adipose tissue surrounding them ***(Cho et al., 1995)***. They are so bulky that they may simulate a posterior mediastinal mass at chest radiography.

Gastric varices are located at the posterosuperior aspect of the gastric fundus.

Most gastric varices drain into the esophageal or paraesophageal veins, but occasionally they drain into the left renal vein ***(Ito et al.,1997)***. When a gastrorenal shunt develops, the chances of hepatic encephalopathy increase. (Fig.3)

Paraumbilical Collateral Vessels

Paraumbilical collateral vessels are next in frequency ***(Leyendecker et al., 1997)***. Numerous paraumbilical vessels can arise from the left portal vein in patients with cirrhosis. Patent paraumbilical vessels are a good predictor of portal hypertension. They are not associated with gastrointestinal bleeding ***(Ito et al.,1997)***. The most common pattern of drainage of paraumbilical veins is through the epigastric veins into the external iliac veins ***(Williams et al., 1999).***

Paraumbilical veins can also connect with subcutaneous vessels of the anterior abdominal wall, creating the caput medusae: a varicose dilatation of subcutaneous veins around the umbilicus ***(Cho et al., 1995)***.

Splenorenal Collateral Vessels

Collateral vessels from the splenic hilum to the left renal vein are fairly common. They are desirable spontaneous shunts in portal hypertension because they are not associated with gastrointestinal bleeding ***(Ito et al.,1997)***. However, enlarged shunts are significantly associated with hepatic encephalopathy. (Fig. 4).

A common feature depicted at cross-sectional imaging is an enlarged left renal vein and dilatation of the inferior vena cava at the level of the left renal vein in the presence of a splenorenal shunt. ***(Gallego et al., 2002)***

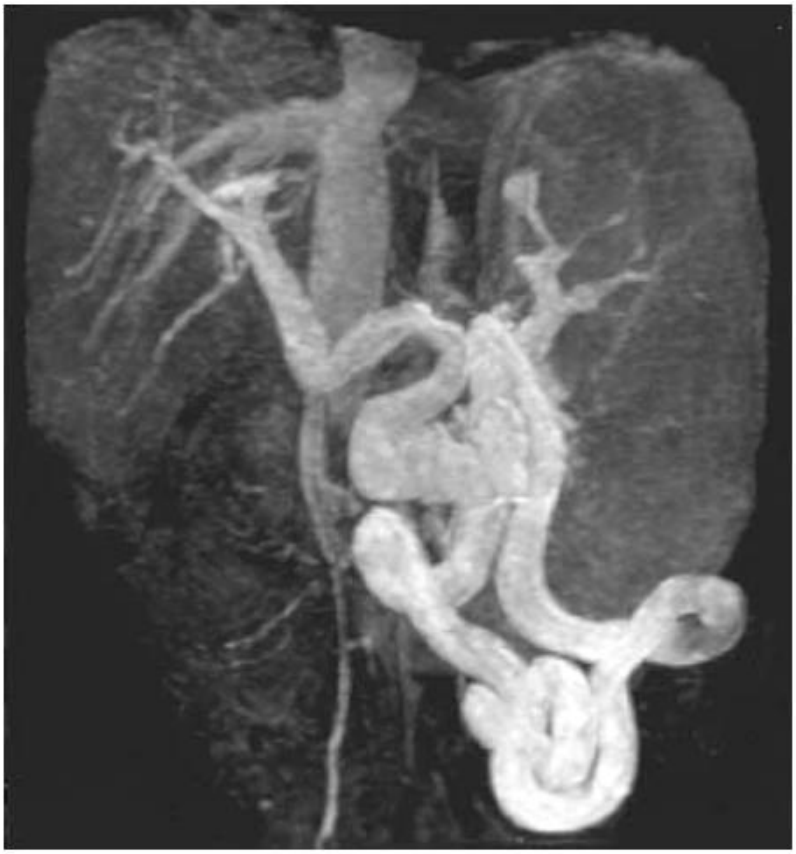


Fig. 4. portal hypertension and varices in a patient with cirrhosis. Coronal venous-phase reformatted image from a **3D** gadolinium-enhanced **MR** angiographic examination (arterial-phase data subtracted from venous –phase data) reveals marked splenomegaly and extensive varices ***(Ito et al.,1997)***

Mesenteric Collateral Vessels

Inferior mesenteric collateral vessels are less frequent than the collateral vessels mentioned earlier but are of great importance because of their association with rectal bleeding. The portal venous system (superior hemorrhoidal vein) and the systemic venous circulation (middle and inferior hemorrhoidal veins) connect via the hemorrhoidal plexus. ***(Ito et al.,1997)*** ***(Cho et al., 1995)***

Mesocaval shunts are portosystemic collateral vessels between the inferior mesenteric vein and inferior vena cava that are established through lumbar and retroperitoneal veins ***(Leyendecker et al., 1997)***. These collateral vessels are not associated with an increased risk of rectal bleeding.

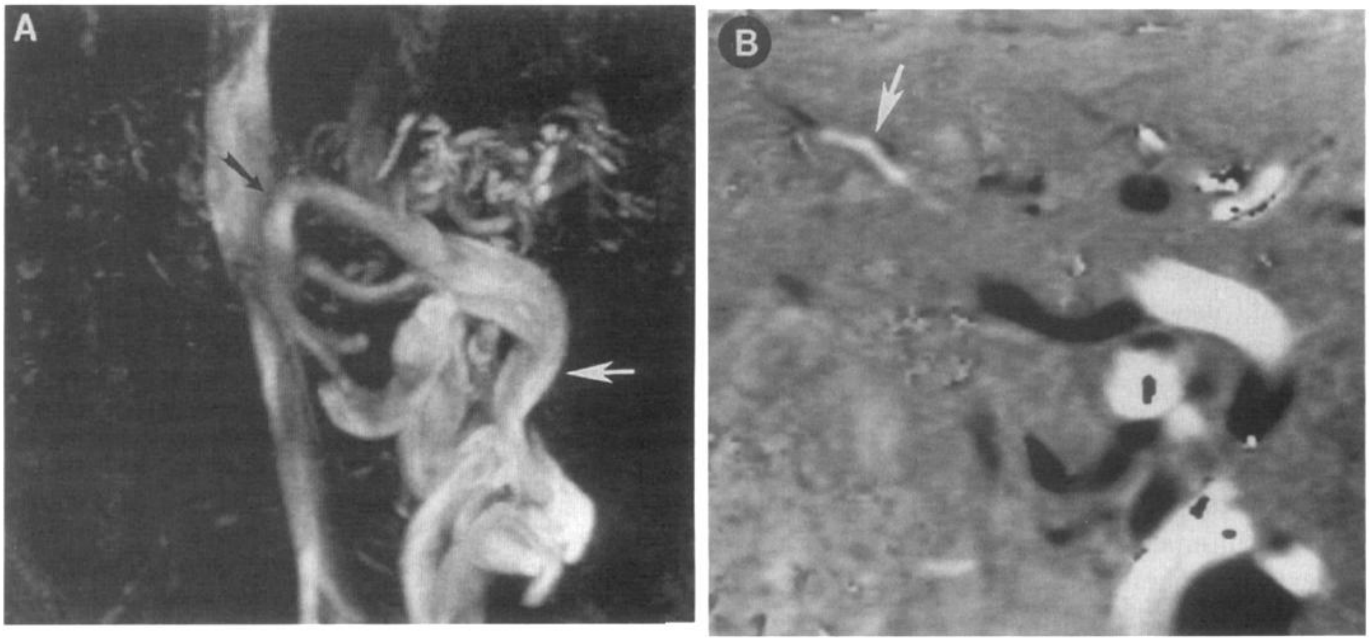


Fig. 5. Mesenteric collaterals in a patient with portal hypertension. **(A)** Coronal phase contrast MR portogram shows massive retroperitoneal and mesenteric venous collaterals (white arrow). The portal vein Is not apparent on this image because of its small size and its overlap with the inferior vena cava. Black arrow, superior mesenteric vein. **(B)** Phase image with flow encoding from right to left shows a small but patent main portal vein (arrow). Flow in the main portal vein, which is displayed in white, is hepatofugal. ***(Nghiem et al., 1996)***

Mesentericorenal collateral vessels between the superior mesenteric vein and the right and left renal veins are the least frequent mesenteric shunts(Fig. 5) ***(Nghiem et al., 1996)***.

Other Collateral Pathways

Rare collateral pathways have been reported, including pleuropericardial-peritoneal, splenoazygos, intrahepatic, and from the coronary or splenic veins to the inferior pulmonary vein or to diaphragmatic veins. Portoportal and portosystemic collateral vessels also develop if there is occlusion of the splenic vein. If obstruction occurs near the splenic hilum, collateral vessels develop at the gastric fundus and the greater and lesser omentum, resulting in gastric fundal varices and an enlarged vein of Barkow (omental vein). When splenic vein occlusion is near the splenomesenteric confluence, mesocaval (via the inferior mesenteric vein), hemorrhoidal, splenorenal, or splenoretroperitoneal collateral vessels are the usual portosystemic pathways of decompression

(Leyendecker et al., 1997). In occlusion of the superior mesenteric vein, mesenteric varices and mesentericorenal collateral vessels develop. ***(Gallego et al., 2002)***