21 The Splenoportal Venous System

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CONTENTS

21.1 Introduction 419
21.2 Technical Considerations 419
21.2.1 TOF MRA 419
21.2.2 PC MRA 420
21.2.3 Contrast-Enhanced 3D MRA 420
21.2.4 Flow Quantification 421
21.3 Applications of MRA to the Splenoportal Venous System 421
21.3.1 Normal Anatomy 421
21.3.2 Anomalies of the Portal Venous System 423
21.3.3 Portal Venous Collateral Circulation 423
21.3.4 Portal Hypertension 425
21.3.5 Transjugular Intrahepatic Portal-Systemic Shunt and Surgical Shunts 426
21.3.6 Liver Transplantation 428
21.3.7 Portal and Mesenteric Vein Thrombosis 432
21.3.8 Tumor Encasement 433
21.3.9 Budd-Chiari Syndrome 433
21.3.10 Liver Tumors 435
21.4 Conclusions 438
References 439

21.1 Introduction

Reliable and precise delineation of the splenoportal venous system is essential before liver transplantation, tumor resection, and transjugular portosystemic shunting (TIPS). In addition, adequate visualization of the splenoportal venous system is useful in the evaluation of patients with liver cirrhosis, portal hypertension, ascites of unknown etiology, and before portosystemic shunt surgery.

Since its introduction in the early 1950s, conventional catheter angiography has been the primary method of evaluating the splenoportal venous anatomy and portal hemodynamics. Since the mid-1970s, ultrasound (US) and computed tomography (CT) have been of considerable value in the evaluation of the abdominal vasculature. Currently, noninvasive evaluation is usually performed by US including duplex Doppler imaging and color Doppler flow imaging. These techniques allow for the visualization of the splenoportal venous system and provide important information about hepatic arterial and hepatic portal venous hemodynamics, such as velocity and flow direction.

In the past, magnetic resonance angiography (MRA), including time-of-flight (TOF) and phase-contrast (PC) techniques, was successfully applied as a noninvasive modality for the evaluation of vascular pathologies in the head and neck. In contrast, MRA of the abdominal vasculature has been of limited value due to technical challenges such as respiratory motion artifacts and the saturation effects of flowing spins. Recently, a new MRA technique – contrast-enhanced (CE) MRA – has been developed which overcomes many of the problems that have degraded conventional MR angiograms. When used in conjunction with high power gradient MR systems, images similar in appearance to conventional catheter angiography can be obtained.

21.2 Technical Considerations

MR angiographic techniques make use of flow effects to highlight the blood signal. “Bright-blood” imaging is divided into TOF and PC methods, depending on whether the predominant contrast mechanism is flow enhancement or flow-induced phase shifts. Both TOF and PC angiograms are produced using gradient echo sequences.

21.2.1 TOF MRA

TOF MRA relies on unsaturated flowing blood to generate a signal which appears bright in relation to
the adjacent saturated, relatively dark stationary tissues. TOF techniques employ flow-refocussing gradient pulses to rephase flow. On short repetition time (TR) sequences, regular bursts of radiofrequency energy saturate stationary spins, whereas blood flowing into the slice between phase-encoding steps is fully relaxed. The inflow of this relaxed blood results in reliable signal enhancement on gradient echo images (AXEL 1980; EDELMAN et al. 1993).

The degree of flow enhancement is influenced by many factors, including the slice thickness, flow velocity, repetition time, flip angle, and T1 of stationary tissue. Enhancement is increased with thinner slices, higher flow velocity, longer repetition times, larger flip angles, and flow that is perpendicular to the image ("through-plane flow"). If the vessel runs a long course in the plane of the image ("in-plane flow"), the inflow effect becomes less effective and reduces the intravascular signal. Thus, potential difficulties in TOF MRA may arise in situations where larger sections of vessels lie within a section, and in situations where turbulent flow is present, as this suppresses bright intravascular signal.

TOF MR angiograms can be acquired as single slices (2D) or as a volume (3D). Although TOF MRA in the abdomen has most commonly been performed using 2D acquisitions, volume acquisition has also been successfully used (LEWIN et al. 1991). While 2D techniques offer a high vessel-background contrast, the vessel-background contrast in 3D techniques is typically lower, and it progressively decreases when spins penetrate through the imaging volume. The slab thickness or vessel coverage in 3D techniques is therefore limited to a distance at which blood signal approaches a steady state signal. Typically, 3D TOF techniques are applicable in combination of fast flow situations, while 2D TOF techniques may be applied for the visualization of slower flow.

Flowing blood appears bright on TOF MRA regardless of the direction of flow. Hence, arteries and veins cannot be differentiated. Additional radiofrequency pulses, termed presaturation pulses, must be used to obtain selective TOF arteriograms or venograms.

**21.2.2 PC MRA**

Phase-contrast (PC) MRA techniques use velocity-induced phase shifts to distinguish flowing blood from stationary tissue. Although several pulse sequence variations are possible, nearly all are gradient echo techniques that use bipolar (flow-encoding) gradients along one or more axes. The fundamental flow principle underlying this strategy is that stationary spins experience no net phase shift by this combination of positive and negative gradients, whereas spins moving with constant velocity experience a phase shift proportional to flow velocity, amplitude of the bipolar gradient, and the time interval between the gradient lobes. The amplitude of the bipolar gradient determines the degree of velocity encoding (VENC). By adjusting VENC, it is possible to sensitize the sequence to slow or fast flows.

To generate optimal images, some a priori knowledge of the velocities to be encountered within the imaging volume must be used to set up appropriate flow sensitivity. Since each data set acquisition is considerably longer than TOF data sets, considerable time involvement may be necessary before optimal images are obtained in any particular clinical setting. In addition, PC techniques require high levels of machine performance, and are sensitive to errors from several non-flow-related sources such as eddy currents, gradient instabilities and magnetic field inhomogeneity. Like TOF techniques, phase-contrast can generate images as volume (3D) or as single-slice images (2D). In either case, the composite information can be post-processed to generate 3D angiograms.

**21.2.3 Contrast-Enhanced 3D MRA**

Contrast-enhanced 3D MRA (CE MRA) significantly differs from TOF and PC techniques in that it is not dependent on flow. In CE MRA, the use of a paramagnetic extracellular contrast agent (such as gadolinium-DTPA) increases the blood signal. This is due to shortening of the T1 relaxation time of blood after contrast injection. Depending on the actual concentration of gadolinium-DTPA, the arterial blood T1 can be as short as 50–100 ms and thus substantially shorter than T1 of fat. Therefore, blood produces the largest signal, and thus the vessel lumen will be picked up with the maximum intensity projection (MIP) to create an MR angiogram (PRINCE et al. 1999; GAA et al. 2000). The timing of the contrast medium injection must be chosen to ensure the presence of a high concentration of contrast material within the vessels of interest during the acquisition of the central portions of k-space that are responsible for image contrast. Bolus timing is most critical for the arterial phase images. The bolus timing can be done empirically