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review

Magnetic resonance angiography of the portal venous system

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Background. *Imaging of the portal venous system is necessary in different clinical conditions. Three-dimensional (3D) contrast-enhanced magnetic resonance angiography (MRA) is useful in obtaining high quality portal vein images. A fast gradient-echo MR imaging sequence with minimum repetition time and echo time is used. Up to 40 ml of paramagnetic contrast is injected into peripheral vein as a bolus. The Arrival of contrast medium in the aorta is preferably detected with an automated system, when breath-hold sequence is started, and repeated two times, to depict arterial and venous phase. Maximum-intensity-projection (MIP) imaging is the usual postprocessing method.*

Conclusions. *In patients with portal hypertension, MRA can present collateral pathway and patency of the portal vein or portosystemic shunt. In portal vein thrombosis MRA provides information about the location and length of portal vein obstruction and helps in therapeutic strategy decision. MRA is a proper technique in Budd-Chiari syndrome, where it is important to determine the location and length of hepatic outflow obstruction. MRA is a very good modality before liver transplantation to depict vascular anatomy and portal vein patency, and after liver transplantation to image possible liver complications. Its limitations include inappropriate positioning of the 3D acquisition slab, respiratory motion artefacts, and metal implants (e.g. pacemaker).*

Key words: portal vein; magnetic resonance angiography; vascular patency

Introduction

The portal venous system must be evaluated before planning the treatment of patients with portal hypertension, portal vein thrombosis, hepatic veins occlusion or a tumour of the liver, pancreas, or bile duct.

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Colour Doppler ultrasonography (US), catheter angiography, computed tomographic angiography (CTA) and magnetic resonance angiography (MRA) can be used for portal venous system imaging. Colour Doppler US is non-invasive, relatively inexpensive and can provide information on portal blood flow, but it is operator and patient dependent (acoustic window, uncooperative patient).[1] Catheter angiography (indirect portography, percutaneous transhepatic portography, and direct splenoportography) are invasive and limited by flow dynamics.[2] CTA can demonstrate the portal venous system in a short time, but this

technique uses ionizing radiation and requires a large amount of iodinated contrast material.[3]

Three-dimensional (3D) contrast-enhanced magnetic resonance angiography (MRA) was initially used manly in arteriography of the aorta and renal arteries.[4,5] Respiratory motion had previously been a major source of artefact in abdominal imaging. With faster sequences it has become evident that this technique has greater capability in abdominal and liver imaging. MRA has the ability to cover large regions of interest within a single breath hold. Superb images of the portal, mesenteric and systemic veins can be obtained routinely. Source images can be obtained to help evaluate parenchymal lesions. The combination of parenchymal and vascular information allows accurate staging of liver neoplasm. In addition, vascular complications of hepatic transplantation can be clearly demonstrated with MRA.[6] Its advantages over digital subtraction angiography (DSA) include its large field of view, its short imaging time, and its non-invasive nature and low risk of complications, which permit repeated studies.

In this article, we briefly discuss some technical aspects of 3D contrast enhanced MRA, reformatting methods and limitations. We present the advantages of MRA in different clinical conditions - portal hypertension, portal vein thrombosis, Budd-Chiari syndrome and liver transplantation.

Technique

A fast 3D spoiled gradient-echo MR imaging sequence with minimum repetition time and echo time is used, with low flip angles ranging from 20° to 30°. Tissue contrast is low; vascular contrast is achieved with high intravascular concentrations of gadolinium, which is injected intravenously as a bolus. By the time extra cellular contrast agent reaches the portal vein, it is rather diluted. That is why a dose of 0.2 to 0.3 mmol/kg body weight and flow rates from 2.5 to 4 ml/sec are recommended.[7]

The best images are obtained when the acquisition of the central portion of k-space corresponds with the maximum concentration of contrast material in the vessels of interest.[6] The range of contrast travel times is broad and depends on patient age, cardiovascular status and hydration state; it is advisable to perform timing with a test bolus,[8] or preferably, with an automated triggering, in which the vessel of interest is continuously scanned until the signal intensity reaches a specified level - at that time the 3D sequence is started.[9] Centric phase encoding is used in conjunction with these techniques; central k space, which is responsible for image contrast, is acquired at the beginning of the scan, when vascular contrast is maximal.[10]

These timing strategies are generally used to optimize the arterial-phase imaging. Acquiring two additional 3D volumes after the optimized arterial-phase imaging almost always yields good visualization of the portal and systemic veins with one or both of the later sequences.[6]

Our typical portal MRA examination consists of axial fast spin-echo MR imaging through the region of interest. This is useful for the evaluation of liver and spleen and helps determine landmarks for the 3D volume. A contrast bolus - 40 ml of Magnevist with flow-rate 2.5 ml/s is then injected. Smartprep (GE Medical Systems) is used to automatically detect arrival of contrast medium in the aorta. The arterial-phase breath-hold sequence in coronal plane is acquired 5 seconds after the arrival of contrast medium in the abdominal aorta. The first-phase sequence is followed immediately by two additional acquisitions with 10 seconds intersequence delay. One sequence takes 14 to 20 seconds, depending on volume of interest. Before the examination, patients were instructed in breath-holding in the same posi-

tion. A final post-MR angiography axial fat-saturated spoiled gradient-echo sequence is performed to help visualize parenchymal lesions.

Data processing

Data processing is an important aspect of 3D contrast-enhanced MRA. A variety of reformatting techniques are now available to the radiologist, and each technique has its own strengths and weaknesses, which can lead to pitfalls and artefacts in inexperienced hands. It is important to be well versed in different reformatting techniques.

Maximum-intensity-projection (MIP) imaging is the most common method. It is well suited to contrast-enhanced MRA, particularly arterial-phase imaging, in which background signal is low and arterial contrast is high. MIP images obtained from the entire data set are almost always contaminated by artefacts, which can limit the visibility of vessels. Image quality can be improved by obtaining sub volume MIP images or by manually editing the entire data set.[6] Subtraction of a precontrast data set from the arterial- phase data to eliminate background noise is problematic in the abdomen, where any discrepancy in breath holding between acquisitions can result in misregistration artefact. Arterial-phase images of the abdomen are almost always diagnostic without subtraction (Figure 1a) as long as good bolus timing has been achieved. Subtraction is much more useful in the venous phase.[11] Even in imperfect subtraction conditions due to different breath-hold positions between each acquisition, excellent suppression of arterial signal and enhancement of adjacent organs can be obtained after post-processing by using a partial volume MIP technique (Figure 1b).[12] We routinely use subvolume MIP in three orthogonal and oblique projections if necessary (depending on patient anatomy). We improve portal venous images by subtracting the arterial phase from the portal venous phase image using available software.

However, source images should be examined too, because nonocclusive thrombus can easily be missed on MIP images and subtraction is an artificial technique. Volume rendering, surface rendering, and virtual endoscopy may be useful in certain applications.[13]

Clinical applications

Contrast-enhanced 3D MRA can demonstrate the intrahepatic and extrahepatic portal venous system as well as hepatic veins. Clinical

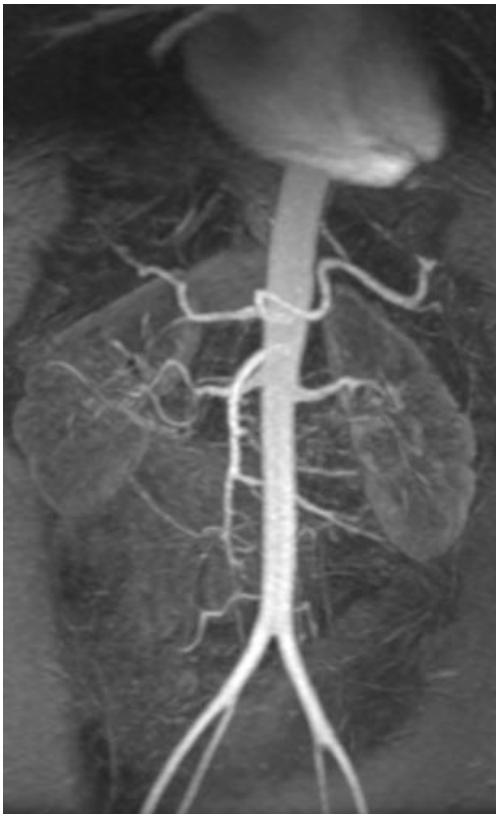

Figure 1a. 3D contrast-enhanced MRA in patient with suspected portal occlusion, arterial phase, subvolume MIP. Superb visualization of the abdominal aorta and visceral arteries.

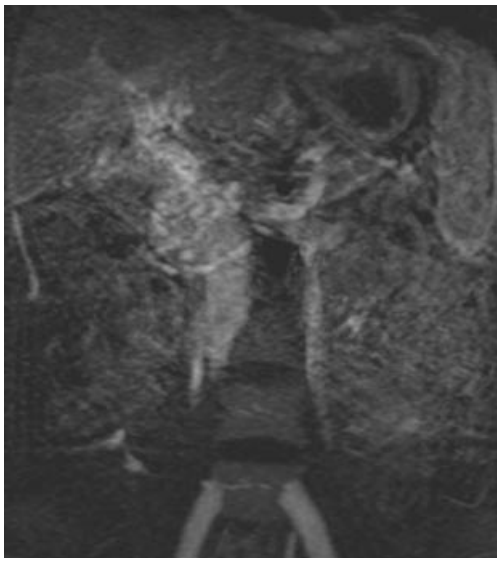

Figure 1b. The same patient, portal phase, arterial phase is subtracted. A network of small collateral vessels despite normal portal vein is seen in hepatic hilus - cavernous transformation of the portal vein.

applications of this method include portal hypertension (portosystemic shunt, portal vein obstruction, and hepatic vein obstruction), hepatic encephalopathy, hepatocellular carcinoma and pancreatobiliary tumours and liver transplantation (pre-and posttransplantation evaluation).[14] In patients with portal hypertension, MRA can be used to evaluate portosystemic shunt, hepatopetal collateral pathways, and obstruction of the portal or hepatic veins. In planning treatment for hepatic encephalopathy, it is important to identify the causative portosystemic shunt. In patients with hepatocellular carcinoma or pancreatobiliary tumours, one must determine the presence or absence of portal vein invasion when planning treatment.

Portal hypertension

Different pathologic conditions like liver cirrhosis, chronic hepatitis, and Budd-Chiari syndrome can lead to portal hypertension and hepatic encephalopathy. It is important to evaluate portosystemic collateral pathways because such patients are at high risk of hepatic coma and massive haemorrhage from oesophagogastric varix. Portosystemic shunts can be formed anywhere in the abdomen and include oesophagogastric varix, paraumbilical vein, mesenteric-gonadal, mesenteric-retroperitoneal, intrahepatic portosystemic, and splenorenal shunts. Therefore, it is necessary to examine the whole abdomen.[14]

Hepatic encephalopathy is caused by a massive portosystemic shunt, which can be easily detected with MRA, as well as oesophagogastric varices, especially when MRA is performed with arterial-phase subtraction (Figures 2a, 2b).

Artificial portosystemic shuts (surgical or percutaneous transhepatic-TIPS) are used to reduce flow and pressure in varix and diminish the risk of variceal bleeding. 3D contrast MRA can be a useful guide for shunt planning and it can present shunt patency. MRA assesses patency of any kind of shunt, as long as metallic clips do not obscure portal venous anatomy. TIPS shunts are more difficult to assess due to metallic stents. If the stainless steel stent is used to bridge the portal and

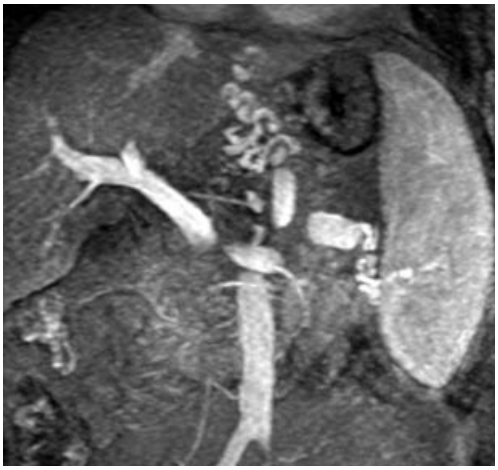

Figure 2a. 3D contrast-enhanced MRA in patient with portal hypertension, subvolume MIP. Portal vein is clearly shown, as well as oesophagogastric varix. Enlarged spleen and distal abdominal aorta is visible.

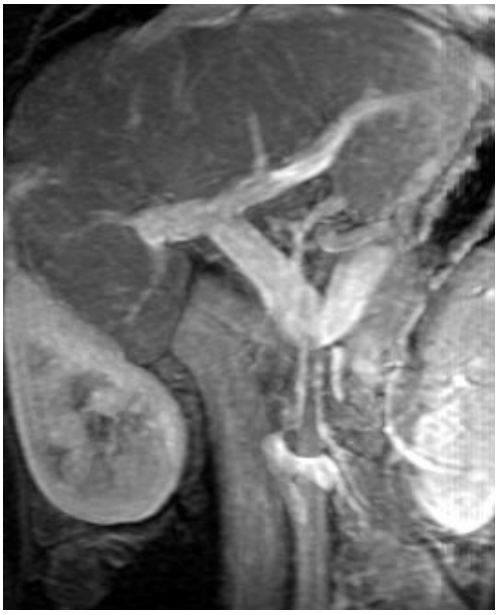

Figure 2b. The same patient with portal hypertension, oblique view. Major intrahepatic branches of portal vein are shown to better extent.

systemic venous systems, the lumen cannot be evaluated by MRA.[7] In conjunction with phase contrast techniques, shunt flow volume can be determined non-invasively.[15]

Portal vein thrombosis

Different pathologic conditions can cause portal vein thrombosis, like pancreatitis, portal hypertension, trauma, malignancy and coagulopathy.[16] The acutely thrombosed portal vein is expanded with thrombus and contains no flow. Over time portal venous collateral pathways develop in both hepatopetal and hepatofugal directions. Hepatopetal collateral pathways include the cavernous transformation of the portal vein that develops in main portal vein obstruction, the dilated pancreaticoduodenal venous arcades that develop in superior mesenteric vein obstruction and the dilated gastroepiploic, short gastric, and coronary veins that develop in splenic vein obstruction. Cavernous transformation of the portal vein represents a network of small collateral vessels (Figure 1b). It is identified by characteristic enhancement pattern in the hepatic hilum during portal venous phase of MRA.[17]

It is important to assess portal venous patency in these diseases. MRA provides information about the location and length of portal vein obstruction and also about portal collateral pathways.[18] In potential candidates for liver transplantation, it is necessary to evaluate portal venous patency.[19]

Budd Chiari

Budd-Chiari syndrome is a rare disorder characterized by hepatic outflow occlusion and is difficult to diagnose by any method.[7] It is caused by various conditions including congenital or idiopathic obstruction, hepatic vein thrombosis, hepatic veno-occlusive disease after liver transplantation, and hepatic tumours. The major symptoms are ascites, hepatomegaly, and abdominal pain. It is classified into three types according to the location of the occlusion. Type 1 is defined as occlusion of the inferior vena cava, type 2 as occlusion of major hepatic veins and type 3 as obstruction of the small centrilobular venules. Imaging methods should help in decision, whether it can be treated with anticoagulants, surgery, or interventional procedures. In planning treatment, it is important to determine the location and length of hepatic outflow obstruction.[14] MRA is an appropriate technique to diagnose hepatic vein occlusion. Budd-Chiari can be confirmed by observing absence of hepatic veins and more heterogeneous enhancement of peripheral liver.[7]

Liver transplantation

Patent portal vein is required for liver transplantation. When ultrasound fails to adequately visualize the portal vein, MRA offers a safe and accurate imaging of portal venous

anatomy and anatomy of others important veins - inferior vena cava, superior and inferior mesenteric vein, splenic vein and varices.[7]

Following liver transplantation, MRA is a very good modality to image possible liver complications. In suspicion of allograft ischemia, portal vein is the first to evaluate, since blood supply to the liver is primarily via this vessel. The most common site of stenosis is at the anastomosis. Hepatic artery is much smaller in calibre and eventual stenosis of this vessel is difficult to assess.[20] Thrombosed artery results in ischemia of the common bile duct which can lead to biliary strictures and leaks. Inferior vena cava (IVC) anastomoses may also become flow limiting - IVC is generally well depicted on portal phase of MRA.

Before MRA, T1- and T2-weighted images should be performed to look for possible other postoperative complications - abscesses, fluid collections, hepatic masses. With fast breath-hold sequences even biliary obstruction may be evaluated.

Limitations

General contraindications to MR imaging (pacemakers, aneurysm clips, or claustrophobia) also apply to contrast-enhanced 3D MRA, which has several other limitations.

This technique is unable to demonstrate the flow direction of the portal venous system, unlike phase-contrast or time-of-flight MRA.[15] Metallic clips, stents, and embolization coils can cause considerable artefact and obscure important structures. Artefacts from respiratory motion and peristaltic bowel movement degrade image quality, especially in debilitated patients who are unable to hold their breath. When subtraction techniques are used, respiratory misregistration also degrades image quality.[14] Even when the study is optimal, the resolution of gadolinium-enhanced MR angiography is relatively low compared with that of conventional angiography, and visualization of small peripheral arteries is very limited.[6] There is a risk of allergic reactions to contrast media, although the incidence is low. Gadolinium-enhanced MR angiography, although less expensive than conventional angiography, is still an expensive examination.

Conclusion

A precise assessment of the portal vein and collateral pathways is potentially helpful for treatment and planning purposes. Three-dimensional gadolinium-enhanced MRA is helpful in evaluating the anatomy of the portal venous system and its pathologic conditions, such as portosystemic shunt, portal vein thrombosis, portal vein invasion by hepatic and pancreatobiliary tumours, and hepatic vein obstruction.[21] It is frequently useful in both pre- and postoperative imaging of artificial portosystemic shunts and liver transplant recipients.

A variety of methods to increase the speed of 3D acquisition are under investigation.[22,23] Time-resolved MR angiographic techniques allow repeated acquisition of a volume of interest during the passage of the contrast material bolus. Novel imaging and reformatting techniques may allow faster acquisition or improved resolution. Echoplanar imaging may become a viable alternative to the standard gradient-echo acquisition.[6]

Several intravascular contrast agents are currently undergoing clinical trials. These agents have much longer vascular half-lives and may allow high-resolution imaging of the arterial and venous system with appropriate respiratory gating.[24,25]

MRA combines speed, excellent contrast, and relative simplicity and has been applied to virtually all regions of the body from the brain to the extremities.

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