ELSEVIER

General Review

A Practical Guide to Magnetic Resonance Vascular Imaging: Techniques and Applications

Ellen L. Vessie,[1] David M. Liu,[2] Bruce Forster,[1] Sebastian Kos,[3] Keith Baxter,[4] Joel Gagnon,[4] and Darren Klass,[2] Vancouver, Canada, Basel, Switzerland

Magnetic resonance angiography is a technique used to image both central and peripheral arteries using contrast and noncontrast techniques. These techniques are similar in that a bright signal, which appears white within blood vessels, is generated and the background tissues, veins, and stationary tissues are dark. This allows for assessment of anatomy and vascular disease. Extracellular gadolinium-based contrast agents allow for excellent visualization of both central and peripheral arteries. Acquiring images during first pass is required for high-contrast images within arteries, thereby limiting contamination with contrast enhancement of veins and soft tissue. Contrast-enhanced techniques using time-resolved angiography and blood pool contrast agents minimize this temporal limitation. Noncontrast techniques eliminate the uncommon but potentially fatal complications associated with gadolinium contrast agents, such as nephrogenic systemic fibrosis. These techniques including phase contrast and time-of-flight sequences have inferior contrast resolution compared with contrast-enhanced techniques and are susceptible to artifacts, which can limit interpretation. The advantage, however, is the ability to assess vascular disease in patients with severe renal failure without the added risks of gadolinium contrast media. The aim of this review is to outline the different techniques available for imaging both the arterial and venous systems, their advantages and disadvantages, and the indications in vascular disease.

INTRODUCTION

The study of blood vessels with the use of magnetic resonance imaging (MRI) to perform magnetic resonance angiography (MRA) has evolved significantly over the last 2 decades, revolutionizing the field of noninvasive vascular imaging. The lack of ionizing radiation as compared with computed tomographic angiography (CTA), in addition to the introduction of noncontrast magnetic resonance angiography (NC MRA), confers advantages to patients of lower radiation risk, expanded ability to image patients with poor renal function, and quantitative assessment of flow.

Given the significant advances in imaging and acquisition techniques, the amount of data generated has increased, as has the complexity of both magnetic resonance (MR) protocols and image interpretation. Accordingly, this article reviews the more recent contrast and noncontrast image acquisition techniques as they relate to contemporary practice and has been divided into sections that will provide the reader a review of current and

[1]*Department of Radiology, University of British Columbia, Vancouver, Canada.*

[2]*Division of Interventional Radiology, Department of Radiology, University of British Columbia, Vancouver, Canada.*

[3]*Division of Interventional Radiology, Institute of Radiology, University Hospital Basel, Basel, Switzerland.*

[4]*Division of Vascular Surgery, Department of Surgery, University of British Columbia, Vancouver, Canada.*

Correspondence to: Ellen L Vessie, MD, MSc, FRCPC, 3350 - 950 West 10th Avenue, Vancouver, British Columbia V5Z 4E3, Canada; E-mail: ellenvessie@gmail.com

Ann Vasc Surg 2014; 28: 1052–1061
http://dx.doi.org/10.1016/j.avsg.2014.02.001

Manuscript received: May 15, 2013; manuscript accepted: February 3, 2014.

Table I. Biophysical profile of selected contrast media used in magnetic resonance angiography

Contrast media	Type	Dose	Excretion profile
Gadodiamide	Paramagnetic, ECF (extracellular fluid), nonionic, linear.	0.1 mmol/kg iv (intravenous); can give an additional 0.2 mmol/kg 20 min later.	Renal
Gadopentetate dimeglumine	Paramagnetic, ECF, ionic, linear.	0.1 mmol/kg iv; not to exceed >10 cc/min	Passive renal filtration
Gadoversetamide	Paramagnetic, ECF, nonionic, linear.	0.1 mmol/kg; iv injection of 1−2 mL/sec.	Renal
Gadoteridol	Paramagnetic ECF, nonionic, macrocyclic.	0.1 mmol/kg iv; can give an additional 0.2 mmol/kg 30 min later. Rapid bolus iv injection.	Renal excretion
Gadofosveset trisodium	Paramagnetic, blood pool, >85% protein binding, ionic, linear.	0.03 mmol/kg iv bolus injection over 30 sec followed by a 30 cc saline flush.	(9%) Biliary and (91%) renal excretion
Gadobenate dimeglumine	Paramagnetic, ECF, weak albumin binding, ionic, linear.	0.1 mmol/kg rapid iv bolus injection.	(5%) Biliary and (95%) renal excretion
Gadoxedic acid	Paramagnetic, Hepatobiliary specific, ionic, linear.	0.1 mmol/kg; iv injection at 1−2 mL/for optimal arterial enhancement.	(50%) Biliary and (50%) renal excretion

The contrast agents are listed in the far left column (generic name). The type, dose, and excretion profile of the contrast agents are described. A saline flush is given after intravenous administration of all the gadolinium contrast agents listed, except where otherwise specified.

future contrast agents and contrast-enhanced protocols, a review of noncontrast protocols and acquisition sequences, and a discussion on nephrogenic systemic fibrosis (NSF).

CONTRAST-ENHANCED MRA

Gadolinium-based Contrast Enhancement: T1-weighted Imaging

The primary objectives of contrast agents are to minimize a specific parameter termed T1 relaxation (or in short form, T1). Commercially available gadolinium contrast agents can be classified into 5 groups including extracellular, hepatocyte-specific, blood pool, combined, and reticuloendothelial agents.[1] Hepatocyte-specific and reticuloendothelial agents have no currently defined role in vascular imaging and therefore will not be included in the discussion; however a brief summary is provided in Table I. Contrast-enhanced MRA techniques are summarized in Table II.

Most of the commercially available gadolinium contrast agents fall in the extracellular (EC) category. The rapid diffusion to the extravascular extracellular space (EES) is related in part to the small size of the EC agents (<1000 Da) and because of the fact that they do not bind with plasma proteins, such as albumin. EC agents, therefore, diffuse easily through the vascular endothelium into the EES,[2,3] resulting in rapid tissue distribution and potential for ''missed bolus''. The equilibration of rapid tissue distribution occurs quickly and for optimal imaging, acquisition of the data must be acquired during the ''first pass'' as demonstrated in (Fig. 1), which demonstrates good opacification of the calf arteries. Otherwise, contamination of contrast in nontargeted extracellular compartments, including veins, results in uniform distribution of contrast thereby rendering the advantages of gadolinium useless when imaging contrast medium through a selected slice of the artery as seen in (Fig. 2).

Although not specifically approved by Food and Drug Administration (FDA) for MRA, ''off-label'' use of EC gadolinium agents in imaging the arterial system is common.[4−9] Because of their extracellular properties, the concentration of EC agents is high in the arteries and low in veins and stationary tissues shortly after the initial intravenous bolus (Fig. 1). Improved visualization of the arterial system can be achieved by the use of techniques to isolate the agent within the vessel lumen, such as cuff compression where a blood pressure cuff is inflated to a subsystolic pressure before injection of the contrast agent.[8−10]

Blood pool contrast agents represent the newest class of commercially available chelates that reversibly bind to serum albumin and represent the most