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William J. Weadock and Thomas L. Chenevert

Technical Principles of MR Angiography Methods 1

Marko K. Ivancevic, Liesbeth Geerts, William J. Weadock, and Thomas L. Chenevert

Magnetic resonance provides a wide variety of possibilities for arterial and venous blood vessel imaging in all vascular territories. This article provides a brief review of the technical principles of MR angiography. The first section is dedicated to non–contrast-enhanced angiography techniques and includes several distinct approaches: time-of-flight, phase contrast, triggered angiography non–contrast-enhanced, and balanced steady-state free precession. The second section relates to the contrast-enhanced and time-resolved contrast-enhanced MR angiography methods. The latest technical developments in MR imaging hardware, sequences and software, coil technology, and reconstruction capability allow dynamic MR angiography performance similar to CT angiography, without risks of iodine contrast agent and ionizing radiation exposure.

Non–Contrast-Enhanced MR Imaging of Renal Artery Stenosis at 1.5 Tesla 13

Gregory J. Wilson and Jeffrey H. Maki

Balanced steady-state free precession (Bal-SSFP) techniques produce excellent anatomic images of renal arteries without the use of contrast agents and are relatively flow-insensitive. Electrocardiography (ECG)-triggered and non-ECG-triggered sequences have been shown to be quite sensitive for detection of regional arterial stenosis (RAS), and the already high specificity is likely to increase with further refinement of the techniques. Bal-SSFP sequences can be used as a screening tool or as an alternative to contrast-enhanced (CE) magnetic resonance angiography (MRA) when contrast agents are contraindicated. In addition to morphologic imaging of RAS, non-CE techniques can be used in functional assessment of hemodynamic significance. The complimentary tools can be used alone or in combination with CE-MRA for MR imaging of renal vascular hypertension.

Neurovascular Imaging at 1.5 Tesla Versus 3.0 Tesla 29

Benjamin Y. Huang and Mauricio Castillo

The primary advantage of high field strength MR imaging over imaging on modern 1.5 Tesla (T) systems is increased signal-to-noise ratio, which can be used to improve image quality or shorten scan acquisition time. In the years since 3.0T scanners were first approved for clinical use, one of the areas which has benefited greatly from its introduction is neurovascular MR angiography (MRA). Early experience has shown significant improvements in resolution and image quality. Whether high field strength MRA is robust or accurate enough to replace digital subtraction angiography in the foreseeable future remains to be seen. This article discusses the current state of neurovascular MRA at 3.0T, basic physical differences between MR imaging at 1.5T and 3.0T, and their effects on MRA sequences. The literature regarding the efficacy of 3.0T MRA techniques for diagnosing specific neurovascular pathologies and carotid steno occlusive disease is reviewed.

Susceptibility-Weighted Imaging: Clinical Angiographic Applications 47

Samuel R.S. Barnes and E. Mark Haacke

By combining filtered phase and magnitude information to create a novel and intrinsic source of contrast, susceptibility-weighted imaging (SWI) has shown great promise in clinical angiography and venography. SWI has contributed to new insights into traumatic brain injury, the role of calcification in atherosclerosis, and the possible relationship between blood settling and deep venous thrombosis. A further contribution from SWI to deep venous thrombosis research (and also stroke) involves its application to the noninvasive measurement of oxygen saturation in the brain and in other tissues. Altogether, SWI offers manifold and diverse avenues for further research using angiographic and venographic techniques.

Neuroradiologic Applications of Dynamic MR Angiography at 3 T 63

Hermant Parmar, Marko K. Ivancevic, Nancy Dudek, Dheeraj Gandhi, Liesbeth Geerts, R. Hoogeveen, S.K. Mukherji, and Thomas L. Chenevert

Four-dimensional time-resolved MR angiography (4D-MRA) using keyhole imaging techniques is a new method of performing contrastenhanced vascular imaging. Combining parallel imaging and keyhole imaging techniques, it is possible to obtain dynamic MRA scans up to 60 times faster, thereby achieving subsecond sampling of the contrast hemodynamics. Furthermore, imaging at 3 T gives higher signal, thus affording higher spatial resolution and allowing dynamic 3D MRA to approach the diagnostic performance of conventional digital subtraction angiography. This article presents the authors' clinical experience using 4D-MRA to evaluate various vascular abnormalities in the brain, spine, orbits, and neck at 3 T, demonstrates the imaging findings of this novel technique, and discusses its advantages and use in current neuroradiology practice.

Dynamic Four-Dimensional MR Angiography of the Chest and Abdomen 77

Michael Griffin, Thomas M. Grist, and Christopher J. François

Time-resolved (four-dimensional) contrast-enhanced MR angiography (CE-MRA) circumvents many of the adverse effects and limitations of conventional x-ray digital subtraction angiography. Four-dimensional CE-MRA uses improvements in gradient hardware, pulse sequences, or computational power to reduce scan times to seconds or less, allowing rapid sequential acquisitions within a single breath hold. These techniques eliminate the need for contrast bolus timing, ensure acquisition of the peak vascular phase of interest, and provide information on the dynamics of contrast arrival and hemodynamic consequences of complex vascular pathologies. This article reviews the techniques used to perform four-dimensional CE-MRA and provides an overview of how to use these techniques in CE-MRA of the chest and abdomen.

Peripheral MR Angiography 91

Harald Kramer, Konstantin Nikolaou, Wieland Sommer, Maximilian F. Reiser, and Karin A. Herrmann

Imaging of the arteries of the lower extremity is most often performed in patients who have known or suspected peripheral artery occlusive disease. Due to the recent advances in imaging modalities, the radiologic approach to the diagnosis of peripheral

artery occlusive disease has changed substantially in the last few years. Recent technical developments such as the introduction of new image reconstruction algorithms and dedicated contrast agents have pushed the limits of MR angiography toward higher spatial resolution and image quality and have enabled time-resolved imaging. This article discusses various techniques of peripheral MR angiography, including step-by-step, hybrid, continuous table movement, and non–contrast-enhanced MR angiography.

Pulmonary MR Angiography Techniques and Applications **101**

Elizabeth M. Hecht and Andrew Rosenkrantz

This article discusses the role of magnetic resonance angiography (MRA) in evaluating the pulmonary arterial system. For depiction of pulmonary arterial anatomy and morphology, MRA techniques are compared with CT angiography and digital subtraction x-ray angiography. Perfusion, flow, and function are emphasized, as the integrated MR examination offers a comprehensive assessment of vascular morphology and function. Advances in MR technology that improve spatial and temporal resolution and compensate for potential artifacts are reviewed as they pertain to pulmonary MRA. Current and emerging gadolinium contrast-enhanced and non–contrast-enhanced MRA techniques are discussed. The role of pulmonary MRA, clinical protocols, imaging findings, and interpretation pitfalls are reviewed for clinical indications.

Pediatric Body MR Angiography **133**

Rajesh Krishnamurthy, Raja Muthupillai, and Taylor Chung

Vascular pathology in children is commonplace and involves every organ system; however, the powerful, noninvasive, and rapid three-dimensional imaging capability offered by MR angiography is underutilized in children. The success of pediatric MR angiography depends on modifying the MR angiography on the basis of patient size, hemodynamic status, and clinical indications in children, and requires an adequate understanding of pediatric-specific hardware, software, and equipment requirements. This article provides an overview of general pediatric MR angiography techniques, common indications for body MR angiography in children, and the complementary role of MR angiography to other vascular imaging modalities in children, including CT angiography, Doppler ultrasound, and catheter angiography.

Coronary MR Imaging: Lumen and Wall **145**

Sebastian Kelle, Robert G. Weiss, and Matthias Stuber

Coronary MR imaging is a promising noninvasive technique for the combined assessment of coronary artery anatomy and function. Anomalous coronary arteries and aneurysms can reliably be assessed in clinical practice using coronary MR imaging and the presence of significant left main or proximal multivessel coronary artery disease detected. Technical challenges that need to be addressed are further improvements in motion suppression and abbreviated scanning times aimed at improving spatial resolution and patient comfort. The development of new and specific contrast agents, high-field MR imaging with improved spatial resolution, and continued progress in MR imaging methods development will undoubtedly lead to further

progress toward the noninvasive and comprehensive assessment of coronary atherosclerotic disease.

Nephrogenic Systemic Fibrosis 159

Jeffrey C. Weinreb and Phillip H. Kuo

There seems to be an association between exposure to intravenous gadolinium-based contrast agents (GBCAs) and nephrogenic systemic fibrosis (NSF), a debilitating and sometimes fatal disease. This article addresses the relationship between GBCAs and NSF and answers some common questions. The policy deployed at Yale-New Haven Hospital for prevention of NSF and screening for patients at risk is delineated and discussed along with recommendations by the Food and Drug Administration.

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