# Research Highlights

## Highlights from the latest articles in imaging

## Clinical applications of 4D contrast-enhanced MR angiography

By combining parallel imaging methods with temporal under-sampling techniques and partial Fourier acquisition, it is possible to obtain 3D contrast-enhanced MR angiography (CE-MRA) acquisitions that reduce the scan time by a net factor of 8–12 without compromising spatial resolution. Such rapid time-resolved acquisitions are often referred to as 4D CE-MRA techniques. The various MR vendors use slightly different approaches to under-sampling of k-space. However, the basic premise remains the same, in which the center and periphery of k-space are sampled at different rates, with relative undersampling of the periphery of k-space to achieve scan time reduction. The various algorithms employed by different vendors include keyhole imaging, time-resolved angiography with stochastic trajectories (TWIST) time-resolved imaging of contrast kinetics (TRICKS), and k-t broad-use linear acquisition speed-up technique (k-t BLAST), amongst others. We will review five recent papers that highlight clinical applications that benefit from the unique temporal information inherent in 4D CE-MRA, the ability to obtain high spatial resolution of small vessels, and the potential to reduce overall gadolinium dose administered for MR angiography.

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## Dural arteriovenous fistulae

**Evaluation of:** Nishimura S, Hirai T, Sasao A *et al.* Evaluation of dural arteriovenous fistulas with 4D contrast-enhanced MR angiography at 3T. *AJNR Am. J. Neuroradiol.* 31(1), 80–85 (2010).

In the setting of high-flow vascular malformations, such as arteriovenous malformations and arteriovenous fistulae, 4D contrast-enhanced MR angiography (CE-MRA) fulfills the clinical need for rapid CE-MRA technique with high spatial and temporal resolution that is capable of separating the arterial and early venous phases of contrast bolus passage through the circulation of interest, thereby providing discrete information on arterial feeders, nidus and the pattern of venous drainage. In this article, Nishimura *et al.* compare the diagnostic efficacy of 4D-CE-MRA with keyhole at 3T to digital subtraction angiography in 18 patients (mean age 64.8 years) with intracranial dural arteriovenous fistula. A total of 30 dynamic datasets were obtained at a temporal resolution of 1.9 s and a spatial resolution of $1 \times 1 \times 1.5$ mm. Two readers reviewed the 4D-CE-MRA for main arterial feeders, fistula site, venous drainage, overall diagnostic quality, level of confidence and intermodality agreement. The fistulae were located in the transverse and sigmoid sinus (8), cavernous sinus (8), and at the sinus adjacent to the foramen magnum (2). Interobserver agreement was fair for the main arterial feeders ($\kappa = 0.59$), excellent for the fistula site ($\kappa = 0.91$) and good for venous drainage ($\kappa = 0.86$). Intermodality agreement was moderate for the main arterial feeders ($\kappa = 0.68$), and excellent for the fistula site ($\kappa = 1.0$) and venous drainage ($\kappa = 1.0$). The authors concluded that the agreement between 4D-CE-MRA and digital subtraction angiography findings was good-to-excellent with respect to the fistula site and venous drainage. This article is one of several recent papers that highlight the

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critical importance of the 4D-CE-MRA technique as a noninvasive imaging option to conventional angiography for diagnosis as well as follow-up of vascular malformations. Apart from the ability to reliably separate high-flow from slow-flow lesions, it provides most of the findings relevant to treatment planning in the setting of high-flow lesions, thereby decreasing the need, contrast volume and radiation dose related to diagnostic angiography. It offers advantages over existing CE-MRA techniques in terms of improved spatial and temporal resolution, unique diagnostic features, significantly reduced scanning time and advanced postprocessing options.

# Limb ischemia

**Evaluation of:** Attenberger UI, Haneder S, Morelli JN, Diehl SJ, Schoenberg SO, Michaely HJ. Peripheral arterial occlusive disease: evaluation of a high spatial and temporal resolution 3-T MR protocol with a low total dose of gadolinium versus conventional angiography. *Radiology* 257(3), 879–887 (2010).

Conventional MR angiography (MRA) for the diagnosis of critical limb ischemia in the setting of peripheral arterial disease typically involves double-dose gadolinium injection, with static 3D imaging performed at discrete table positions (or stations) to cover the entire lower extremity arterial tree. In this study, the authors innovated in several ways, combining a continuous table movement (CTM) technique of the entire run-off vasculature using large-coverage phased array coils with high resolution dynamic time-resolved angiography of the calf vasculature using time-resolved angiography with stochastic trajectories (TWIST) to improve detail of the smaller vasculature, and a reduced total gadolinium dose of 0.1 mmol/kg body weight. In 30 patients with peripheral arterial occlusive disease (mean age 65 years), findings on MRA were compared with those on digital subtraction angiography. The accuracy of stenosis gradation and, specifically, the detection of high-grade stenoses (stenosis of 70–99%) with CTM MRA alone and with the combined protocol (CTM MRA + TWIST) were compared with digital subtraction angiography.

Image quality was good or excellent in both CTM MRA and TWIST. The combined protocol resulted in high overall diagnostic accuracy of more than 80% for detection of stenosis, and diagnostic accuracy of 93.5% for detection of high-grade vessel stenosis. They concluded that inclusion of TWIST MRA increased diagnostic value over that achieved with CTM MRA alone. The protocol also had the potential to reduce overall gadolinium dosage without sacrificing diagnostic efficacy for this indication. The temporal information from the TWIST sequence enabled assessment of the hemodynamic relevance of a stenosis, and helped to further characterize collateral flow, apart from obviating the need for a timing bolus. The ability to reliably discriminate arteries from veins may also be important in planning bypass surgery.

# Pelvic vein congestion syndrome

**Evaluation of:** Yang DM, Kim HC, Nam DH, Jahng G, Huh CY, Lim JW. Time-resolved MR angiography for detecting and grading ovarian venous reflux: comparison with conventional venography. *Br. J. Radiol.* doi: 10.1259/bjr/79155839 (2011) (Epub ahead of print).

The dynamic information inherent in time-resolved 4D acquisitions have been put to clinical use in the venous system as well. A good example is evaluation of central venous thrombosis, in which a combination of first-pass and equilibrium phase MR venography has been used to show venous patency of the subclavian, internal jugular and innominate veins and the SVC, along with patterns of collateral drainage. This article looks at the use of 4D contrast-enhanced MR angiography (CE-MRA) for another application in the venous system, namely to diagnose ovarian vein reflux as a marker of pelvic venous congestion syndrome. Yang *et al.* performed a retrospective analysis of 19 patients who underwent time-resolved MRA with keyhole, and compared the findings to conventional venography as the gold standard. They studied the accuracy of detection and grading of ovarian venous reflux. Ovarian reflux was graded as follows: grade 1 reflux was confined to the left ovarian vein and/or left parauterine veins; grade 2 reflux involved the right ovarian vein, the left internal iliac vein and the right internal iliac vein, and had varicosities of the vulva and thighs in addition to grade 1 reflux. The authors showed that there was no significant difference between time-resolved MRA and conventional venography for grading ovarian venous reflux (McNemar's test). The sensitivity, specificity and diagnostic accuracy of MRA were found to be 66.7, 100 and 78.9% for observer 1, and 75, 100 and

84.2% for observer 2. There was excellent agreement between the two observers for grading ovarian venous reflux on MRA. The study did have a referral bias to conventional venography, since only positive cases were referred for embolization. However, it provides a unique clinical application for the dynamic information inherent in a 4D contrast-enhanced MRA acquisition.

# Localization of the artery of Adamkiewicz

Evaluation of: Bley TA, Duffek CC, François CJ *et al.* Presurgical localization of the artery of Adamkiewicz with time-resolved 3.0-T MR angiography. *Radiology* 255(3), 873–881 (2010).

The temporal and spatial under-sampling techniques used in 4D-MR angiography (MRA) provide a flexible methodological currency that can be traded off to improve spatial resolution, temporal resolution, coverage, or all three, depending on the clinical need. This article illustrates the use of a time-resolved MRA technique with time-resolved imaging of contrast kinetics (TRICKS) on a 3T magnet to obtain high spatial and contrast resolution, with better delineation of higher order branches, to enable preoperative localization of the artery of Adamkiewicz prior to reimplantation of the feeding intercostal artery, lumbar artery, or both during aortic aneurysm repair. This retrospective study included 68 patients (mean age 67 years) who underwent time-resolved spinal MRA with high spatial resolution after being prepped with oral nitroglycerine. A 3D -MR volume that covered the levels between T7 and L2 neural foramina was prescribed. The acquired spatial resolution was 1.0 × 1.0 × 1.4–1.6 mm interpolated to 0.5 × 0.5 × 0.7–0.8 mm. 12–14 phases were acquired with an effective temporal resolution of 12.2 s. Depiction of the arteries was graded with a five-point scale on the basis of confidence of visualization. The artery of Adamkiewicz and the location of the feeding intercostal and/or lumbar artery were identified with high confidence in 60 (88%) of the 68 patients. An interesting finding in the study that highlighted the importance of the time-resolved technique was that the arrival of contrast material was highly variable in this patient population, which had substantial aortic disease. The highest signal intensity in the aorta, artery of Adamkiewicz and great anterior radiculomedullary vein occurred at a mean of 55, 72 and 95 s after contrast material administration, respectively. The time-resolved technique was able to capture the contrast bolus without the need for a timing bolus or contrast arrival monitoring method, and allowed confident differentiation of the arteries from the great anterior radiculomedullary vein even in patients with substantially altered hemodynamics.

# Noninvasive marker of mean pulmonary arterial pressure and pulmonary vascular resistance in pulmonary emphysema with fibrosis

Evaluation of: Sergiacomi G, Bolacchi F, Cadioli M *et al.* Combined pulmonary fibrosis and emphysema: 3D time-resolved MR angiographic evaluation of pulmonary arterial mean transit time and time to peak enhancement. *Radiology* 254(2), 601–608 (2010).

Enhanced dynamic information that can be extracted from the 4D contrast-enhanced MR angiography (CE-MRA) datasets include region of interest (ROI)-based wash-in/wash-out rates, time-to-peak signal maps and derived metrics, such as relative blood volume, blood flow and mean transit time. Such information can provide additional clinical information about regional and whole-organ perfusion and permeability, and specialized information for applications such as MR renography, stroke and tumor analysis. This article highlights one such quantitative biomarker, correlating conventional invasive pressure indices of pulmonary circulation with pulmonary first-order arterial mean transit time (MTT) and time to peak enhancement (TTP) obtained from 4D contrast-enhanced-MRA in patients with combined pulmonary fibrosis and emphysema (CPFE). A total of 18 patients with CPFE and 13 healthy controls matched for age and sex were enrolled (mean age 62 years). 4D CE-MRA was performed on a 3T magnet with a temporal resolution of 1.5 s. Three separate breath-held acquisitions were performed of 18 s each, separated by 2 s of breathing time. ROIs were drawn manually on first-order pulmonary arteries.

Within the ROIs, signal intensity versus time curves reflecting the first pass of the contrast agent bolus in the pulmonary vessels were obtained. MTT and TTP were calculated. The mean pulmonary arterial pressure (mPAP) and the pulmonary vascular resistance (PVR) were determined by cardiac catheterization. MTT and TTP values were prolonged significantly in patients with CPFE compared with those in the control subjects ($p < 0.001$). Mean TTP and mean MTT correlated directly with mPAP and PVR index ($p < 0.005$). At multiple linear regression analysis, MTT was the only factor independently associated with PVR index and mPAP. The ability to noninvasively monitor pulmonary artery pressures has significant implications in CPFE, as well as in other diseases that would benefit from a parameter to screen for small vessel disease in the lungs.