Beyond 4D MRA
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Highlight
New 4D MRA acquisition and reconstruction techniques reduce imaging time and provide whole brain serial imaging with good spatial and temporal resolution. 4D Flow MRI improves the characterization of brain aneurysms, AVMs and slow flow states by displaying pathologic flow conditions in addition to the morphology of the lesion.
Target audience: Clinicians and scientists interested in advanced vascular imaging of the brain.
Outcome: The objective of this presentation is to promote the use of advanced MRA techniques in clinical practice.
Purpose: The goal of this presentation is to demonstrate how to use 4D MRA and 4D Flow MRI to identify pathological conditions such as arterial stenosis, aneurysms, vascular malformations and venous outflow obstruction.
Methods: MRA applications continue to expand following the introduction fast, whole brain time-resolved techniques (4D MRA) and methods to accurately measure velocity and flow (4D Flow MRI). Parallel imaging, undersampling strategies, compressed sensing and constrained reconstruction are used to accelerate the acquisition and improve image quality. One method to achieve fast imaging is based on a 3D radial readout (VIPR) that does not require phase encoding and vastly undersamples k-space relative to conventional Cartesian methods. VIPR is used for the serial imaging in time-resolved contrast enhanced MRA and is also used for phase contrast 4D Flow imaging. Recently, a non contrast MRA technique using pseudo-continuous arterial spin labeling has been developed using VIPR.

The image quality of the time-resolved contrast enhanced 4D MRA can be dramatically improved by using highly constrained reconstruction (HYPR). The basic idea in constrained reconstruction is that a time series has temporally correlated information. A composite image can be formed by combining all the information from the time series into one dataset. Basically, each time frame is multiplied by the composite image to improve SNR. An alternate approach is to use a separate acquisition with higher spatial resolution to serve as the composite image. After HYPR reconstruction the resulting images have improved SNR and maintain the spatial resolution present in the composite image. In one implementation called HYPRFlow, a phase contrast MRA using a VIPR readout (PC VIPR) is used as the constraining/composite image. This approach provides not only a time series of images during the first passage of a contrast bolus but also velocity and flow information.

Non contrast dynamic MRA exams can be acquired using pseudo-continuous arterial spin labeling. In this approach images are obtained using increasing labeling times thus creating a series of images displaying inflowing at multiple time points.
Results: The time resolved/velocity encoded MRA (HYPRFLow) images provide excellent characterization of brain AVMs, dural AV fistulas, slow flow conditions in arteries or veins and collateral flow patterns in patients with arterial occlusive disease. The image data can be further analyzed to provide color coded time of arrival maps of the arterial system. The time of arrive maps highlight small differences in flow thus improving the detection of pathologic flow conditions. A virtual bolus can also be generated by weighting each time frame by a Gaussian distribution in the time domain.

The velocity data are used to calculate volume flow rates, generate flow streamlines/pathlines and provide estimates of wall shear stress and pressure gradients. Wall shear stress is considered an important component in the risk stratification of intracranial aneurysms.
Discussion: Emerging MRA techniques such as HYPRFlow can now provide a comprehensive evaluation of the cerebrovascular system in reasonable imaging times and with a high level of safety. The temporal and spatial resolution is adequate to clearly define the morphology of brain vascular malformations with the brain and dura. Streamlines and velocity vector plots are used to identify the dominant feeding

arteries and reveal multiple compartments within the AVM nidus. Aneurysm morphology and flow patterns can be defined assisting in treatment planning.

Conclusion: The MRA exam is expanding to include important physiologic information such as time of arrival maps, velocity measurements, flow streamlines and estimates of wall shear stress. These observations improve our understanding of pathologic flow conditions in the brain.

Reference: Time resolved angiography: Past, Present and Future. Grist T, Mistretta C. Strother C Turski P. J Magn Reson Imaging. 2012 May 7. doi: 10.1002/jmri.23646