Application of a three-dimensional phase-contrast MR sequence to determine blood flow pattern within brain aneurysms

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Introduction:

The flow patterns in brain aneurysms are complex and three-dimensional (3D) in shape. The impact of flow on the aneurysm wall may be an important factor in pathogenesis and in assessment of rupture risk. The flow pattern can be directly visualized in large aneurysms using catheter digital subtraction angiography (DSA) or indirectly by computational fluid dynamics simulations (CFD) [1]. 3D PC VIPR, previously applied in canine models of aneurysms [2], is a non-invasive imaging approach that provides dynamic 3D velocity measurements, enabling the in vivo study of blood flow pattern in aneurysms with high spatial and temporal resolution. 4D Flow MRI techniques have already been tested on a few human brain aneurysms. Here we present the first application of the 3D PC VIPR MR sequence [3] for the study of 14 human brain aneurysms. This technique offers a significant improvement in spatial resolution compared to similar Flow MR pulse sequences [4, 5]. In the present study, we compare the blood flow patterns obtained with 3DPC-VIPR to the DSA findings, considered as the reference.

Methods:

Patients: After Institutional Review Board approval, we prospectively imaged 14 patients with aneurysms diameters ranging from 4 to 24 mm (n=7 [4-7 mm]; n=7 [>7-mm]). All patients had a 3D PC VIPR MR acquisition and DSA within 24 hours of each other.

MR acquisition: Velocity-encoded MR data were acquired using the 3D PC VIPR pulse sequence with retrospective cardiac gating [3] on a 3T MR scanner (GE Healthcare) after injection of 15 mL of contrast agent (Gd-DTPA). Two encoding speeds were used to obtain flow information on parent arteries (80cm/s) and in slow flow aneurysms (30cm/s). The imaging parameters were: FOV=22×22×22 cm^3, TR/TE=6,6/2,8 ms, BW=83.3 kHz, 16000 radial projections with 256 readout points, leading to an isotropic spatial resolution of 0.86×0.86×0.86 mm^3. The total scan time was 9 minutes.

MR reconstruction and post-processing: 3D PC VIPR raw data were reconstructed as previously described [3]. All radial projections were pooled to compute a single time-averaged 3D velocity vector field for each encoding speed. Blood-flow tracking was performed, resulting in 3D streamline visualizations of the time-averaged flow patterns (Ensight, CEI, Apex, NC).

DSA acquisition: All patients underwent DSA while under local anesthesia, prior to endovascular treatment (Philips, the Netherland). A serie of 2 to 6 images per second, depending on the size of the aneurysm, was acquired to analyze the inflow, the global pattern of the flow and morphology.

Results and discussion:

3D PC VIPR velocity maps were informative for all patients, allowing blood flow tracking within all aneurysms, even in the 4mm ones. For each aneurysm, we could visualize the location of flow impact, the inflow jet and 3 already known flow pattern types: a recirculation pattern (n=8) (Fig 1), a direct inflow jet (n=1), and a lateral slow pattern (n=5). For the seven patients presenting an aneurysm of a diameter > 7mm, DSA allowed to analyze the flow pattern, which was consistent with that seen on 3D PC VIPR streamlines reconstructions. For the others, DSA lacked sensitivity to depict the blood flow.

Figure 1 displays a comparison between DSA and Velocity streamlines from PC VIPR in a large (1cm) anterior communicating artery aneurysm. PC VIPR streamlines show a rapid inflow with a left sided entering zone, followed by a vertical pattern in the inferior to superior direction (image E showing ascending flow vectors at the anterior part of the aneurysm) as confirmed by DSA (A). The flow pattern is a recirculation pattern, the blood entering the aneurysm with a circulatory trajectory before ending in the two daughter branches (a, b).

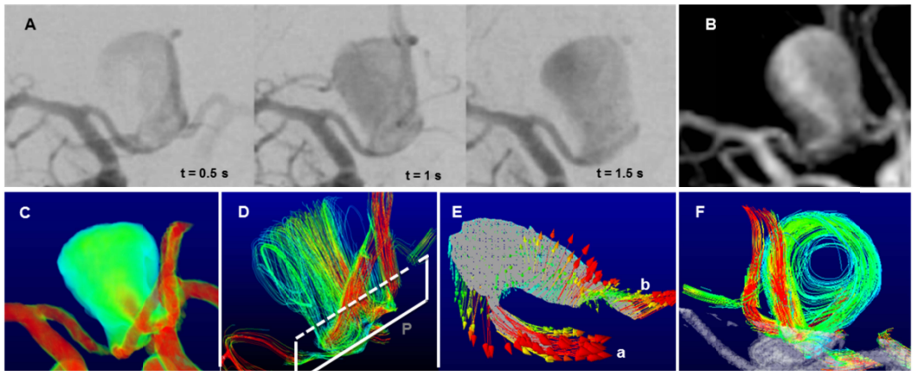

Figure 1. A: Anterior views of DSA. B: 3D PC VIPR Complex-difference MIP image. C-F: Ensight visualisations of blood flow pattern from 3D PC VIPR velocity maps. C: Volume rendering; D: Streamlines and selected plane P; E: Velocity vectors on plane P; F: Streamlines sagittal view.

In brain aneurysms, where non laminar flow conditions are present, the application of streamline reconstructions from 3D PC VIPR MR data could characterize the flow circulation pattern with an isotropic spatial resolution of 0.9 mm. This new insight in flow tracking allowed us to distinguish in-vivo and non-invasively three flow patterns. It has also in our study been validated by the comparison to DSA, for which flow pattern could be visualized in the subpopulation of aneurysms > 7mm. The main current limitation of this method is the long reconstruction and post-processing time (≈4 hours) since the process is not fully automated and depends on the location and size of each aneurysm. This methodology shed some new light in the quantitative description of complex blood flow patterns. It provides high spatial resolution 3D velocity maps, which can further be used to compute pressure maps and wall shear stress estimations. During PC VIPR acquisitions, physiological data (pulse oximeter gating) are recorded, which can be used to retrospectively reconstruct time-resolved velocity maps at different phases of the cardiac cycle (data not shown) [2].

Conclusion:

Non-invasive in-vivo determination of flow patterns in aneurisms may help to assess the risk of aneurysmal rupture. Determining which flow pattern is associated with clinical progression or rupture could help us determine the relative influence of these mechanisms. Improving our understanding of hemodynamics in ruptured and unruptured aneurysms may help in developing further improvements in our treatment paradigms for cerebral aneurysms.

References:

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