Flow Imaging: Technical foundations

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Phase-contrast MRI relies on the difference of phase of spins moving along the direction of a magnetic field gradient. It is commonly used to determine cardiac output volume of the ventricles and for shunt volumes.

Magnetic field gradients are responsible for phase shifts of spins according to their position in the magnet. In the case of motion, spins moving along a gradient are subject to an accumulated phase shift. The faster a spin is moving along a gradient, the stronger the phase shift. The phase-contrast technique is using this property to quantify velocities of moving spins (1,2). While the phase signal depends on the spin velocity, there are other contributions to the phase that prevent from quantifying velocity using a single phase measurement. However, it is possible to cancel these additional contributions to the phase by performing a second measurement with a different phase-encoding moment. Defining the phase of two measurements $\square^{(1)}$ and $\square^{(2)}$ corresponding to two velocity-encoding gradients with different first moments $M_1^{(1)}$ and $M_1^{(2)}$, it is possible to derive the velocity:

$$\vec{v}_0 = \frac{\phi^{(1)} - \phi^{(2)}}{\gamma\left(M_1^{(1)} - M_1^{(2)}\right)} = \frac{\phi^{(1)} - \phi^{(2)}}{\pi} venc$$

with the velocity sensitivity factor being defined as:

$$venc = \frac{\pi}{\gamma\left(M_1^{(1)} - M_1^{(2)}\right)}$$

The velocity sensitivity factor $venc$ is adjusted by the magnetic field moment (i.e., magnetic gradient strength and duration). It is defining the maximum absolute velocity that can be measured using phase-contrast MRI without observing phase wraps. Velocities higher than $venc$ result in velocity-induced phase shifts larger than $\pm\pi$ and phase wrapping occurs. This effect is described as velocity aliasing artifact.

Phase-contrast MRI is typically performed using a gradient-echo sequence with ECG synchronization (prospective or retrospective gating) to produce time-resolved CINE series.

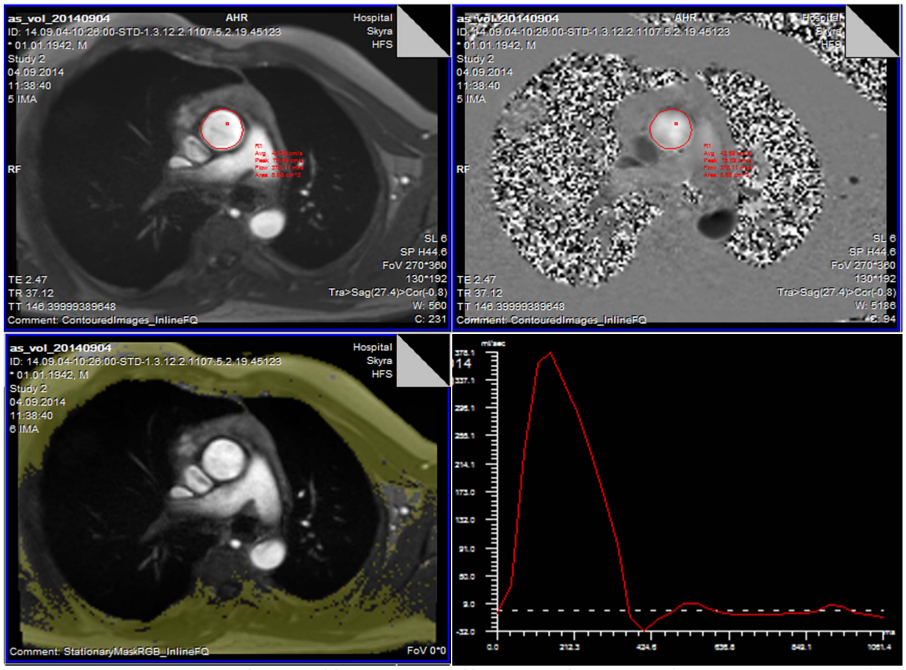

Figure 1 Magnitude (top left), phase-difference (top right), static tissues for background phase correction (bottom left) and flow-time curve (bottom right) in the ascending aorta.

In order to perform accurate phase-contrast MRI acquisitions, it is recommended to:

- **Avoid or correct velocity-induced phase warping (velocity aliasing):** Velocity aliasing can be avoided by setting the venc value according to the maximum expected velocities. This can be realized by performing a velocity scout prior to the acquisition. Alternatively, during post-processing, it is possible to correct velocity aliasing (venc anti-aliasing).
- **Minimize background phase errors:** Due to the rapid switching of magnetic field gradients during MR imaging, currents are induced in conducting surfaces. These so-called 'eddy currents' arise in RF coils, magnet components or the subject itself and result from the changing flux associated with the fields being generated from the gradient coils (i.e., they are related to $\partial B/\partial t$). These eddy currents generate in turn fields of their own that oppose the gradients. As a result, the magnetic field gradient seen by a sample in the scanner is reduced and delayed. In phase-contrast imaging, two measurements are performed with different first moments in the velocity-encoding direction. Consequently, the eddy currents from the velocity-encoding gradients are resulting in a phase drift in the velocity-encoding direction in the phase difference images. To reduce the effect of eddy currents, it is recommended to perform phase-contrast acquisitions at the isocenter of the magnet.
- **Correct for remaining background phase errors:** The effect of eddy currents is approximately linear and can be corrected with a linear fit on some static regions in the velocity images (background phase correction) (3)
- **Make imaging planes perpendicular to the flow direction:** When performing phase-contrast imaging with through-plane velocity encoding, only the axial component of the flow is being considered. In order to correctly measure the flow pattern, it is thus important to have an imaging plane perpendicular to the main flow direction.

While it is not yet clinically available, time-resolved 3D phase-contrast imaging with three-directional velocity encoding (4D Flow) is emerging as a new tool for comprehensive assessment of blood flow and flow-derived parameters in larger anatomical regions (4).

References:

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