Evaluation of Flow
Technical Foundations: How is it Done?

Frank R. Korosec, PhD, University of Wisconsin-Madison

Phase contrast MR methods are used routinely in clinics world-wide to quantitatively assess the velocity and flow of blood. Phase contrast methods employ additional gradients to sensitize MR imaging sequences (typically fast gradient echo sequences) to motion (1-5). The gradients (a positive and negative amplitude pair, together forming what is referred to as a bipolar gradient set) are applied after the magnetization is tipped into the transverse plane, and the result is that stationary spins are imparted zero net phase, whereas moving spins are imparted a phase that is linearly proportional to their velocity.

During a phase contrast scan prescription, the operator specifies a velocity encoding (Venc) value, just greater than the maximum expected velocity of blood to be imaged. Magnetization from blood flowing at a velocity equal to +Venc will receive a phase shift of +180°, magnetization from blood flowing at a velocity equal to -Venc will receive a phase shift of -180°, and magnetization from blood flowing at velocities in between will receive a linearly proportional phase shift. It is important not to specify a Venc that is too low, otherwise encoding errors will occur (referred to as velocity aliasing).

When phase difference reconstruction is applied, the result is that each pixel in the image contains a phase value that can be interrogated to directly reveal the velocity of the blood in that pixel. If the cross-section of a vessel is imaged, the area can be determined, and the flow (in ml/min, for example) can be calculated. If multiple images are acquired throughout the cardiac cycle, the flow from each image can be calculated to obtain time-resolved flow information as shown in Figure 1.

![Figure 1: A magnitude image from one phase of the cardiac cycle. In this image, the signal in each pixel is proportional to the magnitude of the magnetization in each pixel. b) A phase difference image from one phase of the cardiac cycle, showing a region-of-interest (ROI) drawn around a cross-section of the aorta. In this image, the signal in each pixel is proportional to the phase of the magnetization in each pixel. c) A plot of the flow in the aorta measured from a series of phase difference images acquired at different points in the cardiac cycle. Integrating the flow over the cardiac cycle yields stoke volume.](image)

With phase contrast methods, flow is only encoded along the axis containing a bipolar gradient (slice selection, phase-encoding, or frequency-encoding axis). If flow is to be encoded in all three Cartesian directions, a bipolar flow-sensitizing gradient must be applied on each axis in separate TR intervals, to form three flow-sensitized data sets. Furthermore, to eliminate unwanted phase accumulations from
sources other than flow (main magnetic field non-uniformities, susceptibility effects, etc.), it is necessary to acquire a reference data set as well that is subtracted from each of the flow-sensitized data sets (6). The result is that the scan times are relatively long for phase contrast methods (two data sets are required for assessing flow in one direction, and four data sets are required for assessing flow in all three Cartesian directions). Acquiring data throughout the cardiac cycle further increases the scan time. For these reasons, current clinical applications typically are limited to acquiring data from a single slice oriented perpendicular to a vessel of interest, as shown in Figure 1b. This method is used for a number of useful clinical applications.

Recent advances have made it possible to acquire time-resolved, three-dimensional data sets, with good temporal and spatial resolution, in reasonable scan times (7-8). These methods allow complex flow patterns to be observed throughout the cardiac cycle allowing for a host of applications (9-13). Although these acquisition and processing methods currently are not available for routine clinical use, it seems reasonable that they will gain widespread clinical use in the near future.

References