Evaluation of cardiac function: Technical requirements

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Cardiac function parameters are of utmost importance in the detection, characterization, and prognosis of acquired and congenital heart diseases. Cine and phase-contrast imaging are the basic imaging techniques for assessment of cardiac function. Beside a field strength of at least 1T or more, basic requirement for sufficient signal detection are the use of multi-element surface coils as they not only significantly improve signal-to-noise-ratios but also are a prerequisite for the use of parallel imaging techniques.

In most applications, Cine and phase-contrast imaging are performed with use of ECG-triggering: it helps to reduce motion artifacts and enables acquisition of images in different cardiac phases. This ECG synchronization may be prospective or retrospective. In prospective triggering, data acquisition is initiated by the detection of the R-wave of the QRS-complex, the last 10% of the RR-interval are excluded from the data acquisition window to avoid artifacts due to the variable physiological length of the RR-interval. In retrospective gating, untriggered MR data and ECG signals are acquired continuously throughout the RR-interval. The phase-encoding gradient is incremented each time an R wave is detected. Prior to Fourier transformation, the k-space lines are assigned to the correct phases in the cardiac cycle, thus covering the entire RR-interval. If an adequate trigger signal is not recorded with the chest wall lead, peripheral pulse oximetry using a photopletysmograph delivers information about the cardiac cycle. The delay between the R wave and maximum peripheral pulse wave ranges from 150 to 500 ms, depending on the heart rate. Images acquired immediately after the peak in the peripheral pulse wave are assigned to diastole. Systole is located at the end of the trigger period. Systolic images can be acquired only when retrospective gating is used.

Cine-Imaging

The basic sequences for Cine imaging of the heart are gradient-echo images with segmented data acquisition. The latter was the basic requirement for Cine imaging using breath-hold technique. However, these gradient-echo techniques suffered from different disadvantages e.g. the relatively long TR allowing unsaturated blood to enter the imaging plane. Moreover, the contrast between blood and myocardium is further diminished if blood flow is reduced owing to

global or regional impairment of cardiac function. This can make it difficult to quantify wall-motion abnormalities.

These problems were eliminated by the introduction of steady state free precession (SSFP) sequences. The hallmark of these sequences is that the residual magnetization still present from the previous excitation is refocused and superimposed over the magnetization excited in the next phase-encoding step. If all the gradients are balanced (nulled) at the time the RF pulse is applied and the repetition time is equal to twice the echo time, the echoes will overlap in time. Contrast in SSFP sequences is determined by the ratio of T2 to T1 at flip angles > 45º and therefore does not depend on unsaturated spins flowing into the slice. The echo time and repetition time in SSFP sequences can be greatly shortened compared with FLASH gradient echo sequences, depending on the gradient system. This reduces the acquisition time and results in higher contrast-to-noise and signal-to-noise ratios. This also permits the more accurate quantification of wall-motion abnormalities compared with FLASH gradient echo sequences. ECG-triggered sequences do not provide acceptable image quality in patients with arrhythmias. One solution in these cases is real-time imaging. Real-time images can be acquired without ECG triggering and can be produced at a frame rate of 20 or more per second with the latest techniques. Real-time MRI can accurately detect wall-motion abnormalities owing to its high temporal resolution and the high contrast between blood and myocardium, even in areas with abnormal wall motion.

SSFP imaging permits the accurate, reproducible quantification of left ventricular volumes and ejection fraction. Determination of the right ventricular ejection fraction is subject to a relatively high standard deviation due to the anatomic configuration of that chamber. For this reason, some authors prefer the analysis of right ventricular function on axial images taken through the entire heart. Real-time SSFP techniques may lead to significant underestimation of the EDV and SV in case of insufficient temporal resolution (TR > 50 msec).

Phase-contrast Imaging

Flow measurement techniques have been used routinely since the 1980s for the quantification of blood flow in MRI. Unlike stationary spins, moving spins induce a phase shift in the transverse magnetization within a magnetic field gradient. This phase shift, designated φ (phi), is roughly proportional to the velocity of the spins, assuming the spins are moving at a constant velocity. The phase shifts are measured in degrees and must lie within a range of ± 180°. This means that the user must preset the correct velocity range. The encoding velocity (V_{enc}) is entered in cm/s on most systems. Phase-contrast imaging with a 2D GE sequence is most commonly used for flow measurement in MRI. In this method, two data sets are acquired for each voxel. The first

data set contains information on signal intensity (magnitude image) and the second contains phase information (velocity image).

The better the encoding velocity matches the true velocity, the more accurate the resulting velocity information will be. Noise in the phase-contrast image increases with greater values of V_{enc}. This may cause random noise voxels to appear in the vessel lumen, leading to overestimation of velocity. Blood flow, on the other hand, is relatively insensitive to noise voxels because flow represents the sum of all intravascular voxels, and individual voxels have less impact on this averaged quantity. If the encoding velocity is set too low, aliasing will occur. This is a phase inversion in which the aliased voxels display a color opposite to that of the other voxels. Computer algorithms can correct for these errors, provided the true velocity is no more than twice the encoding velocity. In principle, however, it is better to repeat the measurement with a higher V_{enc} setting.

Ideally, the slice position for phase-contrast flow measurement should be orthogonal to the vessel of interest, and this requires a double-oblique slice orientation. The true velocity is reduced by the cos α of the deviation from a true orthogonal slice (measured velocity = true velocity x cos α). Deviations up to 15° are acceptable, as they do not cause a significant deviation from the true velocity or flow. A slice thickness of 6 mm is considered an optimum trade-off between partial-volume effects and signal-to-noise ratio. The guidelines of the German Radiology Society require a minimum temporal resolution of 50 ms and at least 4 pixels per vessel cross section.

Flow measurements in large vessels such as the aorta and pulmonary trunk show very good interobserver reproducibility (difference of 3-6%).

In healthy subjects, the volume flow determined in the ascending aorta is equal to the volume flow in the pulmonary artery (approximately 70 mL/heart beat; r = 0.92). A slight discrepancy between the two measurements results from coronary arterial flow, which comprises about 5% of the cardiac output. It has also been found that the stroke volume of the right and left ventricles is predicted significantly better by flow measurements than by cine volumetry based on intra- and interobserver variability.

Clinical Applications

Cine studies are an essential part of each cardiac MR examination. They allow for assessment of global and regional myocardial function as well as intra- and interventricular dyssynchronia, respectiviely. They help detect valvular pathologies (incompetences and stenoses), und finally, they are used in stress testing for detection of stress induced myocardial ischemia (high-dose

dobutamine stress testing). Phase-contrast imaging is a basic imaging technique for quantification of intra- and extracardiac shunts and for quantification of valvular insufficiences and stenoses as well as stenoses of the great vessels.

References:

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