Techniques For Right Heart Cardiac Function

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The assessment of right ventricular (RV) function using magnetic resonance imaging (MRI) presents unique challenges and opportunities. The complex semilunar geometry, thin wall-thickness relative to the left ventricle (LV), and large base-to-apex shortening combine to make the quantitative assessment of right heart function more difficult.

State-of-the-art
The structure and function of the right ventricle is measured well by the same stack of parallel, contiguous imaging planes that are used for assessment of the LV. These image planes are prescribed from a horizontal long-axis view to contain parallel planes extending from the tricuspid-mitral valve plane to the LV apex. Additional RV specific scan planes include: 1) a three-chamber view that intersects the tricuspid and pulmonary valves and the RV apex for imaging the RV inflow-outflow tract; 2) an RV outflow plane, which is prescribed from the RV three-chamber view as a plane parallel to the conus arteriosus and the pulmonary trunk; and 3) a short-axis slice through the pulmonary valve, prescribed perpendicular to the RV outflow plane.

RV masses, RV volumes, wall thickness, and dynamic changes in wall thickness (wall thickening) are all readily measured from cine (movies), usually as a result of manual contouring of RV “epicardial” and endocardial contours and integration of volumes using Simpson’s rule, geometric models, or advanced image processing methods. The currently preferred MRI pulse sequence for this type of imaging is cine balanced steady-state free precession (i.e. FIESTA, TrueFISP, or Balanced FFE on various platforms) due to the high contrast between blood and myocardium and the acquisition efficiency (excellent image resolution and SNR in a short breath hold) that is accorded by the ability to use short repetition times (TR) of less than 3.0ms per k-line.

RV Specific Challenges
Selection of the correct imaging slices and contouring of consistent regions of the RV in end-diastolic and end-systolic images is especially important in the RV. In particular, care must be taken to only include the conus arteriosus (infundibulum) and not part of the pulmonary trunk when quantifying RV function as visualization of the thin pulmonary valve may be challenging on short-axis images. In order to confirm that the same amount of RV is included in ED and ES segmentations, it is judicious to compare the calculated RV mass at ED and ES. If they closely match then there is better confidence that the RV cavity volumes calculated from the same contours can be more fairly used for calculating SV and EF. Careful tracking of the basal myocardium by cross-referencing short-axis images to the corresponding four-chamber view is important due to the large amount of through-plane motion of the RV free wall. Lastly, controversy exists over whether to include the conus arteriosus or not because it does not change volume during the cardiac cycle and therefore results in lower estimates of ejection fraction when included.

The RV typically has more trabecular myocardium than the LV in addition to the septomarginal trabecula (or moderator band) and these pose a special problem. Trabecular tissue
should be included in estimates of RV mass and excluded from the blood pool lest the RV mass and EF be under-reported and RV volume over-reported. Manual contour typically facilitates this better than model-based segmentation that does not specifically account for these tissues, but is typically more time consuming owing to the complexity of trabeculation present in the RV. Without good myocardium-lung contrast or discernable epicardial fat the RV epicardial border can be difficult to delineate especially because of the thin wall.

The use of imaging slices that are not parallel may afford better coverage of the RV for qualitative clinical assessment, but care must be used to calculate volumes, as Simpson’s rule does not straightforwardly apply. The use of model based methods of image segmentation may have an advantage if this functionality were incorporated.

The challenge of accurately assessing RV function is highlighted, in part, by a study that demonstrates lower inter-study reproducibility for RV function compared to LV function in the same patients

Phase Contrast and Tagging
Phase contrast techniques are available for quantifying flow velocities and flow rates in the great vessels. The pulmonary artery exhibits less through plane motion than the aorta and therefore makes quantification of RV cardiac output easier, but the RV outflow tract is also more arched which necessitates the careful selection of a plane parallel to the pulmonary valve. Quantification of flow through the tricuspid valve is complicated by the relatively large amount of through-plane motion.

Myocardial tagging techniques are useful for qualitative or quantitative assessment of regional myocardial function and have been widely applied to the left ventricular myocardium. The relatively thin wall of the RV free wall and the comparatively widely-spaced applied tags currently makes impossible the assessment of wall thickening, but circumferential and longitudinal shortening strains are reported.

Three-dimensional Imaging
There exist numerous recent reports of breath held 3D cine sequences for the assessment of cardiac function. A comparison of 2D breath held and 3D free-breathing imaging techniques for RV assessment has shown a good correlation, but further improvements can be expected. It should be noted that the gains of 3D imaging compared to 2D imaging may not be substantial due to the decreased in-flow contrast of 3D imaging of large slabs which reduces the blood-myocardium contrast.

Alternatives Imaging Techniques
Echocardiography is frequently used in a clinical setting to assess right heart function, but it is limited in its ability to accurately quantify RV EF. Assumptions about LV geometry can provide accurate assessments of LV function from limited echo measurements, but geometric assumptions for the RV have proven more difficult to generalize. The advent of 3D echo may result in an improved ability to quantify RV function.

The increased availability of computed tomography (CT) for functional cardiac imaging has resulted in more widespread use. Typically, cardiac functional analysis is derived from the same images that result from a clinically necessary coronary CT angiography (CTA) exam. Under these circumstances a saline bolus is usually injected into the RV to enhance visibility of the right coronary artery (RCA), but this has the consequence of limiting the accurate assessment of
RV function due to inadequate contrast opacification of the RV\textsuperscript{8}. The result is poor myocardium-blood contrast that limits the accurate assessment of EF, wall thickness, wall thickening, etc. In general, the lower temporal resolution, frequent need for beta-blockers to lower the patient’s heart rate and extant concerns of radiation exposure may limit the use of CT solely for the quantification of RV and LV cardiac function if CTA is not otherwise warranted.

Cardiac MRI is still the gold standard to which other imaging modalities are compared.

References