Assessment of Heart Valve Function by Magnetic Resonance Velocity Mapping

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Introduction
Valvular diseases cause an increased hemodynamic load on the heart. Chronic valvular incompetence may lead to impaired myocardial function and eventual progression toward heart failure. Accordingly, current diagnostic modalities aim at the detection of progressing valvular lesions before irreversible changes of the myocardium have developed. Symptomatic patients with severe valvular lesions are referred for valve replacement or valve repair surgery. In asymptomatic and mildly symptomatic patients, however, there is ongoing controversy about the optimal timing for intervention. Thus, a quantitative diagnostic modality providing indices for prediction of optimal post-operative results is a premise for improved patient care.

In clinical practice, methods of echocardiography are routinely involved for evaluation of heart valve disease and heart valve function. While these modalities provide sufficient morphological information, the assessment of hemodynamic characteristics is often hampered by the inadequacy to resolve spatial distributions of velocities, limitation due to the restricted echo window, and the inability to register multiple velocity components.

Magnetic resonance imaging has evolved to an accurate diagnostic complement for evaluating ventricular geometry and function. The ability to encode blood velocity in arbitrary spatial directions holds potential for accurate quantification of transvalvular blood flow and thus for quantification of valvular incompetence.

However, several limitations apply to current methods used for magnetic resonance velocity mapping near or within the heart. Accurate positioning of an imaging slice is hampered by the excursion of the valvular plane during the cardiac cycle. Myocardial contraction and relaxation are referred to as the active motion of the heart. The active motion is a potential source for misregistration of low blood velocities. Acquired images represent velocity magnitudes resulting from blood velocities superimposed by the velocity of through-plane motion of the heart. Accordingly, leakage flow through heart valves may be considerably underestimated if the active motion of the heart is not taken into account.

Aim of the present work was to develop improved acquisition and post-processing methods allowing for accurate quantification of blood velocities around heart valves and in the coronary vessels. Dedicated techniques for compensation of the active motion of the heart are presented in combination with improved respiratory gating strategies for image artifact reduction. The accuracy and feasibility of the methods proposed are shown in healthy volunteers and in studies including patients with valvular heart disease.

Methods
A new data acquisition scheme providing adaptation of the imaging slice according to cardiac motion was developed to account for the considerable excursion of the valvular plane of the heart. The procedure for velocity mapping with slice adaptation involves the following steps (Figure 1).

**Labeling**: A cine imaging sequence with a labeling prepulse is performed within a single breath-hold to mark points of the basal plane. Basal plane motion is then automatically quantified based on segmented basal markers.

**Velocity mapping**: Adaptation of the imaging slice position according to the basal plane motion is used to map blood velocities in the vicinity of the aortic valve.

In a clinical study, the moving slice imaging technique was applied to quantify valvular regurgitation in patients. Using the same technique, a second study aimed at the description of axial blood velocity distributions downstream of prosthetic valves in humans.
Results

Anatomic and velocity profiles of a representative subject with mild aortic regurgitation are shown in Figure 2. Correction for cardiac motion through the imaging slice was demonstrated to be relevant for the quantitation of valvular leakage. Mild-to-moderate regurgitation was underestimated by as much as 60%, if correction for cardiac motion was not performed.

In the study of flow patterns downstream from prosthetic heart valves, the moving slice imaging technique facilitated velocity mapping in the immediate vicinity of the valve (Figure 3). It could be shown that only measurements very close to the valve provide a correlation between the valve design and alterations in blood velocities. Further downstream, velocity patterns varied among subjects depending on individual anatomic differences.

Figure 2: Anatomic frames and corresponding velocity profiles acquired during late systole and early diastole in a patient with a bicuspid aortic valve showing mild regurgitation.
Discussion and Conclusion

Moving slice imaging allows to obtain motion corrected velocity data closer to native and prosthetic heart valves than it has hitherto been possible. Adaptation of the imaging slice to heart motion in conjunction with prospective phase re-ordering techniques for respiratory artifact reduction enables visualization of valvular leaflets over the entire heart cycle and accurate quantification of forward and reverse blood flows across heart valves. Correction of velocity data has been shown to be of particular relevance in patients with mild-to-moderate valvular incompetence.

Maintenance of an imaging slice position at a constant distance with regard to prosthetic heart valves has proven to be important for quantitative assessment of valve induced changes of blood flow. Variations of velocity distributions due to varying aortic geometry and curvature among patients indicated the importance of a measurement site located as close as possible to valve prostheses. Competing conditions from individual anatomy are minimized by imaging in the immediate vicinity of the valve and thus allow assessment of effects due to specific valve designs.

In summary, improved acquisition strategies for quantification of blood flow through heart valves and for the description of flow patterns around heart valve prostheses were developed. Dedicated, motion adaptive acquisition schemes were proposed to account for the active motion of the heart and the passive motion due to respiration. Application of the techniques in patients with valvular heart disease demonstrated the feasibility and the clinical relevance of the methods.