Breathhold time-resolved three-directional MR velocity mapping of aortic flow in patient follow-up after aortic valve-sparing surgery

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Introduction: Aortic valve-sparing surgery has evolved recently as a more efficacious method for repairing aortic aneurysm by preserving the native aortic valve anatomy and function. Echocardiography is the most useful method to follow up the success of the valve-sparing operation by assessing aortic valve directly and intraoperatively. Cardiac functional MRI has become an excellent alternative modality for noninvasive assessment of patients with aortic root disease due to its accurate anatomic characterization and aortic flow quantification. However, conventional phase-contrast MRI only produces a uni-directional map of velocity, it is unable to visualize the aortic flow patterns which are highly associated with aortic valve function. Although previous studies have demonstrated the feasibility of three-directional MR velocity mapping in the visualization of aortic flow patterns [1,2], only few analysis of the technique in patients with aortic valve-sparing surgery have been published [3,4]. In addition, these techniques have less clinical utilities due to their relative long acquisition time. It is now feasible to acquire three-directional MR velocity mapping in a given plane with one breathhold. The purpose of this study was to evaluate the potential of breathhold time-resolved three-directional MR velocity mapping for the follow-up in patients after aortic valve-sparing surgery.

Methods: 13 patients (11 men and 2 women aged 23-64 years, mean age, 43 years) underwent valve-sparing surgery were evaluated by using cardiac functional MRI and time-resolved three-directional MR velocity mapping at 6 to 12 months (mean 8.3 months) after their operation. For comparison, 10 healthy volunteers (7 men and 3 women aged 24-62 years, mean age, 41 years) with no history of cardiovascular disease and 12 patients (9 men and 3 women aged 24-67 years, mean age, 45 years) with ascending aortic aneurysm were assessed by the same method. Follow-up information was obtained at 24 months after operation. The outcome events analyzed were presence of death, need for re-operation, recurrence of > grade 2 aortic regurgitation, and heart failure [5].

Cardiac MRI examinations were performed with a 1.5 T scanner (Avanto, Siemens Medical Solutions). MR velocity mapping was performed using a two-dimensional cine phase-contrast sequence with three-directional velocity encoding in breathhold. Three Contiguous slices oriented along the axis of the aortic valve image and one along the left ventricular outflow tract image was obtained. TR = 8.0 msec, TE = 4.0 msec, flip angle = 15º, FOV = 250×340 mm, matrix = 86×192, slice thickness = 6 mm, acquisition time = 24 sec per slice, velocity-encoding value = 150, 120, 120 cm/s x, y, z directions respectively.

A 4D flow analysis software (Siemens Medical Solutions) was used to create a dynamic color-encoded velocity vectors map of aortic flow. The flow vectors maps were assessed by two experienced radiologists independently who are unaware of information of the subjects. Laminar flow was defined as parallel or near parallel vector lines and was scored on scale of 1 - 4 (1=poor, 2=fair, 3 = good, 4 = excellent). Turbulent flow, indicated by circular, semi-circular or demisemi-circular vector lines, was scored on a scale of 0 - 3 (0 = none, 1 = mild, 2 = moderate, 3 = severe). The presence or absence of vertical flow in the sinuses of Valsalva after the peak systole was also determined. The scores of laminar and turbulent flow as well as the presence of vertical flow in the sinuses of Valsalva were statistically analyzed and compared.

Results: All patients with aortic valve-sparing operation were alive and no patient had heart failure at 24 months follow-up. There were 2 re-operations within 3 months after primary operation. Four of 13 patients presented with mild aortic regurgitation and no patient had > grade 2 aortic regurgitation assessed using echocardiography. Functional MRI demonstrated stable dimensions of graft (mean aortic annulus, 3.00±0.15; sinus of Valsalva, 3.60±0.40; sinotubular junction 2.85±0.32) and normal left ventricular function (left ventricular stroke volume, 80.7±18.7; eject fraction, 0.59±0.09) in the 13 patients.

Breathhold time-resolved three-directional MR velocity mapping was performed successfully in all volunteers and patients. The average score of laminar flow in the ascending aorta for patients with valve-sparing surgery was similar to that for volunteers (3.38±0.74 versus 3.8±0.4, $p = 0.14$), but was significantly greater than that for patients with aneurysm (3.38±0.74 versus 1.25±0.43, $p < 0.01$). The average score of turbulent flow for patients with aneurysm was significantly greater than that for patients with valve-sparing surgery (2.25±0.72 versus 0.23±0.42, $p < 0.01$). No turbulent flow was visualized in any volunteer. The presence of systolic vertical flow in the Valsalva sinuses for patients with valve-sparing surgery was similar to that for volunteers (8/13 versus 8/10, $p = 0.26$), but was significantly greater than that for patients with aneurysm (8/13 versus 4/12, $p < 0.05$).

Conclusions: Breathhold time-resolved three-directional MR velocity mapping allows for the detection of flow patterns in aortic root and ascending aorta. Normal laminar flow in the ascending aorta and vertical flow in the sinuses of Valsalva can be restored in patients after aortic valve-sparing surgery. Evaluation of aortic flow patterns using MR velocity mapping may be a useful indicator for outcome of patients with aortic valve-sparing surgery.

References: 1. Kilner PJ, et al. Circulation 1993. 2. Bogren HG, et al. J Magn Reson Imaging 1999. 3. Kvitting JE, et al. J Thorac Cardiovasc Surg 2004. 4. Markl M, et al. J Thorac Cardiovasc Surg 2005. 5. de Waroux JB, et al. Circulation 2007

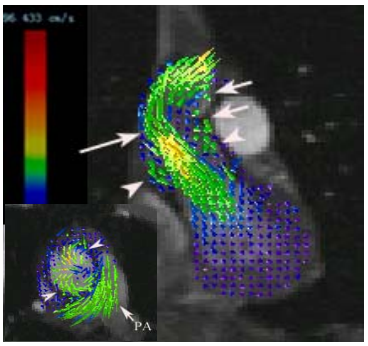

Figure 1. A late systolic color-coded vector map of left ventricular outflow shows helical laminar flow in the ascending aorta (long arrow), vortical flow in the sinuses of Valsalva (arrowhead), and retrograde flow along the inner wall of the distal ascending aorta (short arrow) in a patient after valve-sparing operation. The inserted image is an axial view above aortic valve demonstrating the vortical flow in the sinuses of Valsalva (arrowhead).

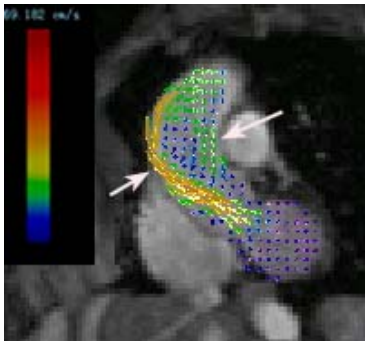

Figure 2. A systolic color-coded vector map of left ventricular outflow shows disrupted laminar flow (short arrow) and a circular turbulent flow (long arrow) in the ascending aorta in a 67-year-old patient with aortic aneurysm.