4D FLOW MRI TO MONITOR MEAN PULMONARY ARTERIAL PRESSURE IN PATIENTS WITH CHRONIC THROMBOEMBOLIC PULMONARY HYPERTENSION TREATED BY PERCUTANEOUS TRANSLUMINAL PULMONARY ANGIOPLASTY

Hideki Ota[1], Koichiro Sugimura[2], Haruka Sato[2], Kotaro Nochioka[2], Shunsuke Tatebe[2], Saori Yamamoto[2], Masanobu Miura[2], Kimio Satoh[2], Yuta Urushibata[3], Yoshiaki Komori[3], Aurelien F. Stalder[4], Andreas Greiser[4], Hiroaki Shimokawa[2], and Kei Takase[1]

[1]Diagnostic Radiology, Tohoku University Hospital, Sendai, Miyagi, Japan, [2]Cardiology, Tohoku University Hospital, Sendai, Miyagi, Japan, [3]Siemens Japan K.K, Tokyo, Japan, [4]Siemens Healthcare, Erlangen, Germany

Target audience: Researchers, radiologists, and clinicians imaging or treating patients with pulmonary hypertension.

Introduction: Chronic thromboembolic pulmonary hypertension (CTEPH) is a distinct disease entity of pulmonary hypertension with a mean pulmonary arterial pressure (mPAP) greater than 25mmHg lasting for more than 6 months and is classified into central- and distal-types (1). Central-type CTEPH with persistent thrombotic obstruction in the large pulmonary arteries can be treated by pulmonary thromboendarterectomy as an established method, whereas, distal-type CTEPH, which is not indicative for thromboendarterectomy, has had a poor prognosis with the lack of effective treatment. Feinstein et al. first proposed percutaneous transluminal pulmonary angioplasty (PTPA) for distal-type CTEPH (2). Although interventional procedures sometimes cause significant complications such as pulmonary hemorrhage and edema, advances in the interventional treatment strategy reduced complications significantly; it markedly improved pulmonary hemodynamics and long-term prognosis in patients with distal-type CTEPH (1). With the improvement of patients' prognosis, there is a need to monitor conditions of CTEPH. Mean pulmonary arterial pressure is one of the most important parameters to monitor for patients who undergo any intervention to pulmonary hypertension. However, a non-invasive tool to estimate mPAP has not been established. Past studies indicated that cardiac MR imaging and 4D flow imaging parameters are correlated with mPAP (3,4). However, longitudinal studies to evaluate treatment effects on MR imaging are sparse.

Purpose: The purpose of this study was to examine whether the change of PA flow patterns imaged with 4D flow and parameters obtained with standard cardiac MR imaging are correlated with the change of mPAP in patients with CTEPH treated by PTPA.

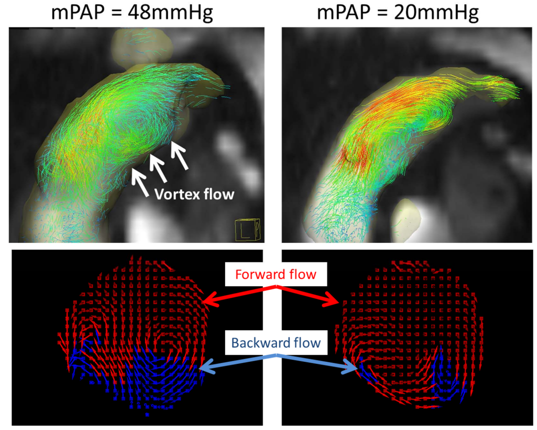
Materials and Methods: This study included 16 patients with CTEPH who were scheduled for PTPA. PTPA procedure was limited to 1 lobe in 1 procedure to minimize critical complication such as reperfusion pulmonary edema. Angioplasty was repeated at an interval of 2-8 weeks and 4-8 procedures per patient were performed.

All patients underwent serial MR imaging examinations using a 3.0T whole-body scanner (Magnetom Trio A Tim System, Siemens Healthcare, Erlangen, Germany) before and after PTPA (mean interval of MR scans, 49.4 ± 5.7 weeks, range, 12-85 weeks). Scan protocols included cardiac cine MR imaging and prototype 4D flow MR imaging of the pulmonary trunk. Cine MR imaging was acquired in a balanced steady-state free-precession-based standard protocol with 20 phases per beat. 4D flow MR imaging was acquired using the following parameters: 3 dimensional phase-contrast MR imaging with 3-directional velocity encoding in transverse slab orientation; ECG gating; respiratory gating using a navigator; TR/TE, 52.4ms/3.43ms; flip angle, 15 degrees; VENC, 50-110cm/sec; voxel size, 2.4mm x 1.8mm x 3.5mm; the number of slices, 30.

Using cine MR images, we measured left-ventricular (LV) ejection fraction, LV stroke volume, LV cardiac index, right-ventricular ejection fraction (RVEF), RV stroke volume, RV cardiac index, RV end-diastolic and end-systolic volume index (RVEDVI and RVESVI) and pulmonary trunk diameter to ascending aortic diameter ratio (PA/AA ratio). 4D flow images were analyzed with a standalone prototype software (4D Flow Demonstrator ver. 2.3, Siemens Healthcare, Erlangen, Germany). On 4D flow, the degree of vortex flow in the pulmonary trunk in the end-systolic phase was evaluated in diameter and area measurement. In diameter measurement, a perpendicular line to the course of pulmonary trunk that included the largest vortex flow was selected; a ratio of vortex flow diameter to the pulmonary trunk diameter (vortex diameter ratio) on the line was calculated. In the area measurement, a cross-section that contained the largest vortex flow was extracted; a ratio of area with backward flow to total cross-sectional area in the end-systolic phase was calculated (backward flow area ratio). Each MR imaging parameter was compared with catheter-driven mPAP. Multivariate linear regression analysis was used to evaluate significant association of MR findings with mPAP. $P < 0.05$ was used to designate statistical significance.

Results: Vortex flow in the pulmonary trunk was observed in all patients prior to PTPA. The mean of mPAP was significantly decreased after PTPA procedures in all patients (37.5 ± 10.7 mmHg vs 26.9 ± 10.6 mmHg, $p < 0.01$). Significant correlations with pre-treatment mPAP were observed in PA/AA ratio ($r = 0.510$, p = 0.037), vortex diameter ratio ($r = 0.515$, $p = 0.034$) and backward flow area ratio ($r = 0.678$, $p = 0.003$). RVEF ($r = -0.370$, $p = 0.174$), RVEDVI ($r = 0.392$, $p = 0.149$) and RVESVI ($r = 0.430$, $p = 0.109$) tended to be correlated. None of the other cine MR imaging parameters were correlated with mPAP. On multivariate linear regression analysis, only backward flow area ratio demonstrated significant correlation with mPAP (coefficients of 0.1 increase, 5.94, 95% CI, 0.82, 11.07, $p = 0.027$). The difference of backward flow area ratio ($r = 0.797$, $p < 0.001$), difference of vortex diameter ratio ($r = 0.496$, $p = 0.043$) and difference of RVESVI ($r = 0.487$, p = 0.047) were significantly correlated with difference of mPAP before and after PTPA procedures (Figure). The difference of RVEF ($r = -0.442$, $p = 0.099$) and RVEDVI ($r = 0.445$, $p = 0.096$) tended to be correlated. On multivariate linear regression analysis, only difference of backward flow area ratio demonstrated significant correlation with difference of mPAP (coefficients of 0.1 increase, 11.17, 95% CI, 6.49, 15.84, $p < 0.01$).

4D Flow MRI before and after balloon angioplasty



Discussion: Vortex flow in the pulmonary trunk may be a characteristic finding of pulmonary hypertension. Among various parameters derived by cardiac MR imaging, backward flow area ratio was the strongest estimator for mPAP. This is probably because 4D flow directly reflects hemodynamics of pulmonary artery. Standard 2D phase contrast imaging may give a similar result regarding demonstration of backward flow in the pulmonary trunk. However, the cross-section with the largest vortex flow could be extracted only by post-processing, which was the advantage of 4D flow MR imaging. While previous reports showing the correlation between flow vortex and mPAP were semi-quantitative with observer-based grading (4), the backward-flow area ratio provides a simple and objective quantitative value to estimate mPAP.

Conclusions: 4D flow MR imaging can visualize vortex flow in the main PA. Backward flow area ratio by 4D flow MR imaging has a potential to monitor mPAP in patients with CTEPH who undergo PTPA.

References:

1. Sugimura K, et al. Circulation Journal. 2012;76:485–8.
2. Feinstein JA, et al. Circulation. 2001;103:10–3.
3. Swift AJ, et al. J Am Coll Cardiol Img. 2013;6:1036–47.
4. Reiter G, et al. Circ Cardiovasc Imaging. 2008;1:23–30.