Estimation of Pulmonary Windkessel Volume in Patients with Pulmonary Hypertension Using MR Phase Contrast Imaging

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Introduction

Pulmonary hypertension (PH) is a rare, progressive disease whose symptoms often become quite severe before a diagnosis is made. The invasive cardiac catheterization procedure is currently the clinical standard to determine the severity of the pressures in the pulmonary arteries. A noninvasive method that can provide a reliable index to differentiate patients with PH from healthy people would be helpful for clinical diagnosis. It has been demonstrated in animal experiments [1] and human studies [2] that the windkessel volume (Vwk), describing the reservoir and wave-transmitting properties of the blood vessels, and its derivative hemodynamic parameters are correlated with the properties of the thoracic aorta. In this study, we investigate the possible difference in Vwk of the pulmonary vessels between normal volunteers and PH patients.

Materials and Methods

Vwk is a hemodynamic index that describes the reservoir and wave-transmitting properties of the blood vessels, represented by the mean difference of volume between inflow and outflow during a cardiac cycle:

$$Vwk = \sum_t (Vin - Vout) \Big/ \text{RR interval} \qquad \text{[Eq.1]}$$

where Vin and Vout stand for the accumulated volume at each time point of inflow and outflow. RR interval means the period of cardiac cycle. For pulmonary circulation, Vin can be obtained from the main pulmonary artery (MPA) and Vout from a summation of the right and left pulmonay arteries (RPA and LPA). Our study population consisted of 3 patients with PH (female:1; male:2; age: 55 ± 16 years; pulmonary pressure with catheterization: 64 ± 31 mmHg) and 11 healthy volunteers without history of pulmonary disease (female: 7; male: 4; age: 39 ± 9 years). MR phase-contrast imaging was performed on a 1.5T clinical imager (Siemens Sonata, Erlangen, Germany) using the torso coil with ECG gating. A 2D FLASH sequence (TR/TE=22/4.8 ms, flip angle=15^0) with 150cm/sec velocity-encoding gradient was repeated two times with trigger delay of 0, 11 ms from the R wave, sampling 90% of the cardiac cycle. The inflow slice was selected at 2~3 cm above pulmonary valve and perpendicular to MPA. The outflow slices were obtained separately at about 2 cm from the bifurcation of MPA and perpendicular to RPA and LPA, respectively. Flows (Q) were derived for each cardiac phase (Fig.1a), with the cross-sectional area determined by manually outlining of the vessels. Vwk was calculated according to Eq.1, as graphically shown as the slashed area in Fig.1b.

Results

The mean stroke volume of healthy volunteers and patients with PH are 60 ± 10 cm^3 and 42 ± 6 cm^3, respectively. The value of Vwk from the PH patients is 340 ± 53 cm^3, significantly greater than the value of 176 ± 46 cm^3 obtained for 11 healthy volunteers (Student's t test, $p < 0.001$, Fig.2).

Conclusion

MR phase contrast imaging is an effective quantitative tool for noninvasive estimation of the Vwk for pulmonary circulation. Results from our preliminary investigation show that the Vwk is significantly increased in patients with PH ($p < 0.001$). The statistical significance suggests that MR-derived Vwk is a potentially useful index to diagnose PH and may be helpful in follow-up monitoring of hemodynamic changes associated with medical treatments.

References:

1. Wang et al. Am J Physiol Heart Circ Physiol 2003;284:H1358.
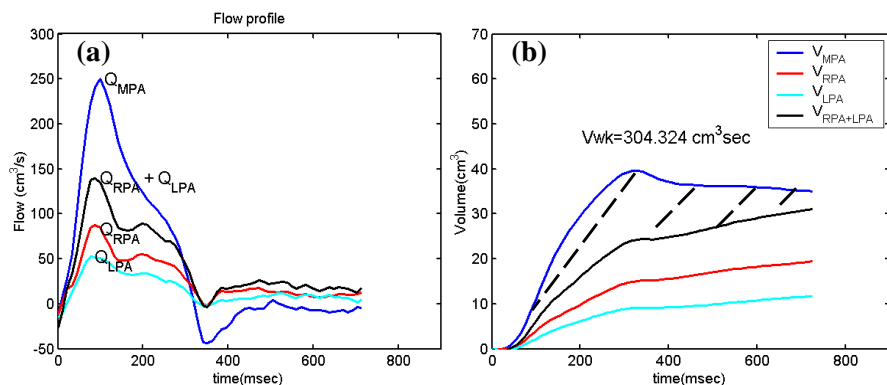2. Saba et al. Eur Respir J 2002;15:426.

Figure 1. (a) Flow profiles of MPA, RPA and LPA of a patient with PH. (b) Accumulated volume at each time point throughout the cardiac cycle. Vwk, the mean difference in volume between inflow and outflow, equals to the slashed area in (b) divided by the RR interval of this patient.
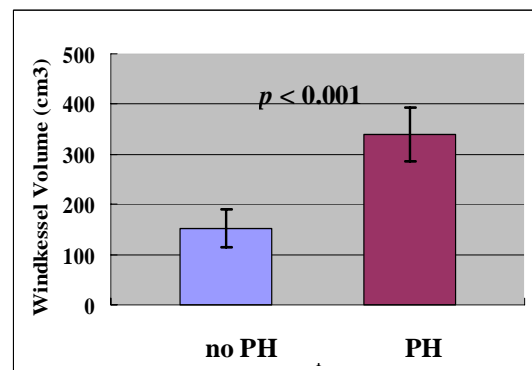
Figure 2. Vwk of healthy volunteers (no PH, 176 ± 46 cm^3) and patients with PH (340 ± 53 cm^3), showing significant difference between these two groups ($p < 0.001$).