

# IMPAIRED VENOUS RETURN DUE TO RIGHT VENTRICULAR DIASTOLIC STIFFNESS IN PULMONARY ARTERIAL HYPERTENSION

J. Tim Marcus<sup>1</sup>, Marielle van de Veerdonk<sup>2</sup>, Frank Oosterveer<sup>3</sup>, Rudolf Verdaasdonk<sup>1</sup>, and Anton Vonk Noordegraaf<sup>2</sup>

<sup>1</sup>Physics & Medical Technology, VU University Medical Center, Amsterdam, Netherlands, <sup>2</sup>Pulmonology, VU University Medical Center, Netherlands, <sup>3</sup>VU University Medical Center, Netherlands

## Introduction

In pulmonary arterial hypertension (PAH), the overloaded right ventricle (RV) becomes stiffer, leading to increased RV end-diastolic pressure (RVEDP) and right atrium pressure (RAP). As a consequence, venous return might be impaired which may become manifest by backward flow in the vena cava (VC). The aim of this study was to quantify the RV diastolic stiffness in PAH, and to explore the effect of this stiffness on the vena cava flow.

## Methods

In 35 patients, CMR was performed on a Siemens 1.5T 'Avanto' whole body scanner (Siemens Healthcare, Erlangen, Germany) equipped with a 6-element phased-array body coil. The volumetric flows in both the VC superior and VC inferior were measured using MRI phase-contrast velocity quantification. The fraction of backward flow was calculated by dividing the total reverse volume, by the total forward volume in the VC per heartbeat. By short-axis cine MRI, the RV begin-diastolic (BDV) and end-diastolic (EDV) volumes were measured. Using right heart catheterisation, the mean pulmonary artery pressure (PAP), the RV begin-diastolic pressure (RVBDP), RVEDP and the right atrial maximum pressure (RAP\_max) were recorded.

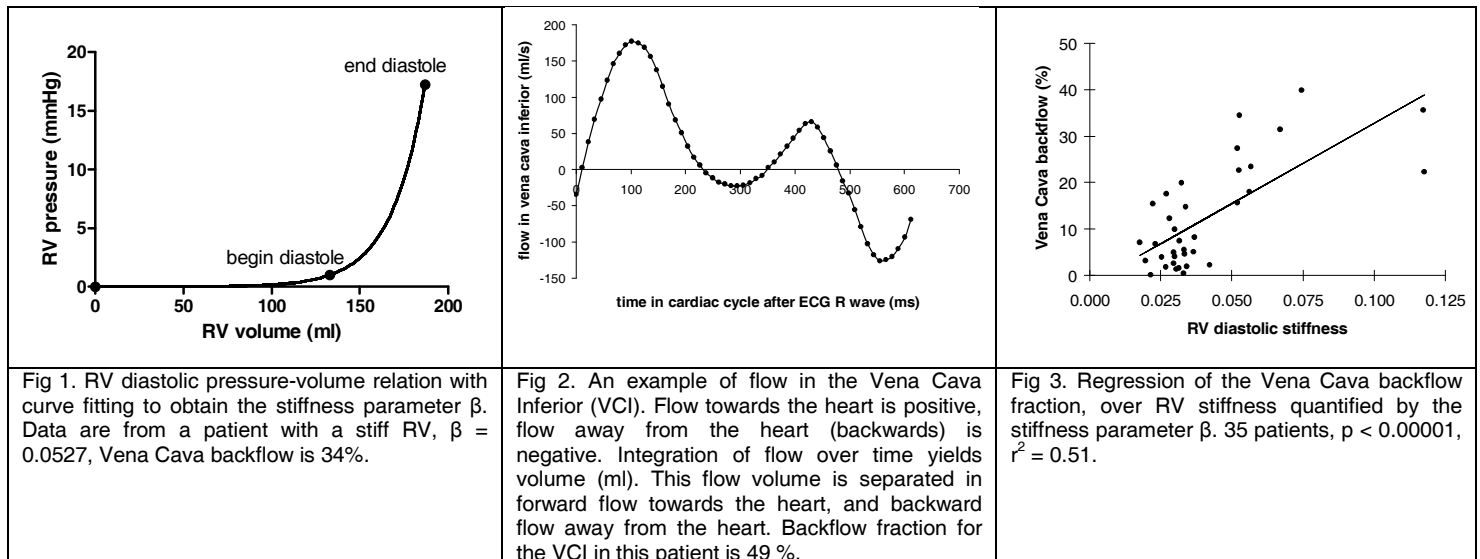
The RV diastolic pressure-volume (PV) relation was constructed by fitting a non-linear exponential curve through (P=0, V=0), and the begin- and end-diastolic PV points using the following formula:

$$P = \alpha (e^{V\beta} - 1)$$

(Rain et al., 2013). P: pressure in mmHg;  $\alpha$ : curve-fitting constant;  $\beta$ : diastolic stiffness constant; V: volume in ml (fig 1). The steepness of the curve presented the RV pressure increase during filling. It was characterized by the exponential term  $\beta$ , which quantified RV diastolic stiffness. With multiple regression analysis, the effect of RV stiffness was controlled for the effect of mean PAP.

## Results

Fig 2 shows an example of VC flow in a PAH patient. For the whole patient group, the fraction of VC backward flow, given as mean  $\pm$  SD, was  $12 \pm 11$  %. For 8 patients, the VC backflow fraction was above 20%. The RV stiffness parameter  $\beta$  was  $0.041 \pm 0.023$ . The VC backflow fraction was associated with the RV stiffness ( $p < 0.00001$ ,  $r^2 = 0.51$ ), RVEDP ( $p < 0.00001$ ,  $r^2 = 0.53$ ), and RAP\_max ( $p < 0.00001$ ,  $r^2 = 0.53$ ). See fig 3. The effect of RV stiffness on VC backflow remained significant ( $p < 0.0001$ ) after controlling for the effect of mean PAP. In addition, RV stroke volume was negatively associated with the VC backflow fraction ( $p < 0.0001$ ,  $r^2 = 0.43$ ).



## Discussion

The pressure in a stiff RV increases during filling, resulting in increased RVEDP. Presumably the RA pressure is then not able to overcome this increased RVEDP at end-diastole, resulting in partial atrial backward ejection into the low-pressure VC. This backflow volume can become so large, because there are no effective valves between RA and VC. Thereby this backflow phenomenon is hemodynamically very disadvantageous, and may well be the explanation for the prognostic value of RA pressure in PAH, as assessed by Benza et al. (2010). In clinical practice, VC flow measurement by MRI is easy to apply, and useful as a non-invasive indicator of the RV diastolic function in PAH patients.

## Conclusion

In PAH, the RV diastolic stiffness is associated with backward flow in the VC, and thereby plays an important role in impairment of venous return to the right heart.

## References

Rain S, Handoko ML, Trip P, et al. Right Ventricular Diastolic Impairment in Patients with PAH. *Circulation*. 2013 Oct 29;128(18):2016-25.  
Benza RL et al., Predicting survival in pulmonary arterial hypertension. *Circulation*. 2010 Jul 13; 122(2):164-72.