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EDITORIAL

Pulmonary veins: an important side window into ventricular function

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Routine echocardiographic evaluation of left ventricular (LV) diastolic function includes measurement of mitral flow velocities, mitral annular velocities, and left atrial (LA) volume. Based on patterns of mitral filling, diastolic dysfunction is traditionally quantified as mild (Grade I), moderate (Grade II), and severe (Grade III).[1] A problem with defining Grade II is that this mitral filling pattern is similar to that in normal hearts (pseudonormal) and was considered 'the Achilles heel of diastology'. With the introduction of tissue Doppler, it became possible to measure mitral annular velocities, and peak early-diastolic LV lengthening velocity (e′), which reflects myocardial relaxation and restoring forces,[2] is now a key parameter when evaluating diastolic function. In patients with Grade II diastolic dysfunction, there is typically reduced peak early-diastolic velocity (e′) or signs of moderate elevation of LV filling pressure.[1] One problem when using e′ to differentiate between Grade II and normal filling, however, is the wide normal range for e′ which is between ~6 and16 cm/s in apparently healthy middle-aged individuals.[3,4] Therefore, additional measures such as abnormalities in pulmonary venous flow velocity are needed.[5] *Figure 1* shows a pulmonary venous flow velocity trace recorded by Doppler echocardiography.

In this study, Buffle *et al.*[6] present data on the additive prognostic value of pulmonary venous velocities when measured, in addition to mitral early (*E*) and atrial-induced (*A*) velocities, e′, the *E*/e′ ratio, and LA volume. The study population included patients with EF >50% who were admitted to the hospital for various cardiac and non-cardiac causes. In this group of patients, the best pulmonary vein predictor of the combined event rate was the ratio of pulmonary venous systolic to diastolic flow velocity-time integral, whereas the ratio between the peak systolic and diastolic velocities (S/D ratio) was the best predictor of heart failure readmissions. Increasing difference between the duration of Ar and mitral *A* velocity was also associated with heart failure readmissions. Furthermore, they showed that Grade II diastolic function with a peak S/D ratio of <1 had a markedly higher rate of admission for heart failure and a higher combined event rate than patients with Grade I, whereas there was no difference for Grade II with an S/D ratio of >1. The S/D ratio remained an independent predictor for survival when adjusted for LA volume index and *E*/e′. These results suggest that the pulmonary venous S/D ratio or the ratio between the velocity-time integrals may provide prognostic information beyond the traditional grading of diastolic function into mild, moderate, and severe.

The aetiology of the systolic pulmonary venous flow wave (S) has been debated. One theory has been that the S is caused by the early-systolic fall in LA pressure due to atrial relaxation and descent of the atrioventricular (AV) plane. *Figure 2* illustrates that onset of the S wave coincides with fall in LA pressure. Another theory has been that the S is due to transpulmonary propagation of the right ventricular (RV) pressure pulse. In the study which utilized wave intensity analysis (*Figure 3*), it was shown that the early-systolic flow wave

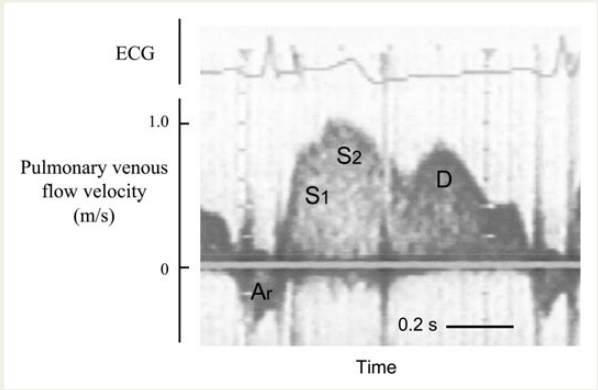

Figure 1 A typical pulmonary venous flow velocity trace with a systolic wave which has an early-systolic component (S1) and a larger mid- and late-systolic component (S2), followed by a diastolic component (D). During atrial contraction, there is slight flow reversal (Ar).

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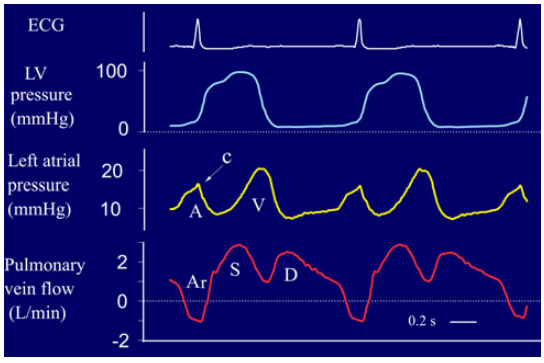

Figure 2 Recordings of LA and LV pressures along with pulmonary venous flow. Intraoperative measurements from a patient prior to coronary bypass surgery. The pulmonary flow trace resembles an inverted LA pressure trace. Reproduced with permission from Smiseth and Thompson.[7]

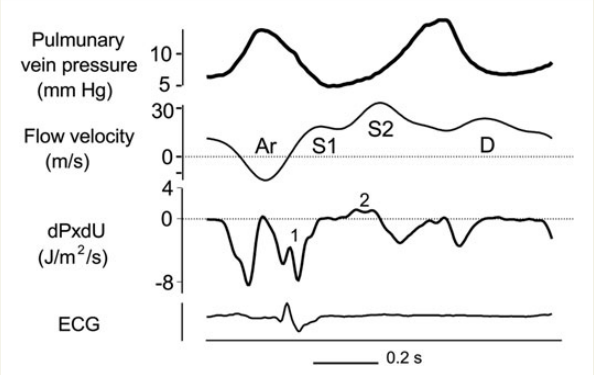

Figure 3 Wave intensity analysis of pulmonary venous flow: the two upper panels show pulmonary venous pressure by micromanometer and velocity by flowmeter. Wave intensity is calculated as the product of instantaneous change in pressure (*dP*) and change in velocity (*dU*), and a negative product means a net backward-going wave and *vice versa*. Negative $dP \times dU$ in early systole (1) is attributed to decline in pressure due to atrial relaxation and systolic descent of the AV plane that acts like a suction force which 'pulls' blood into the left atrium, causing S1. The subsequent positive $dP \times dU$ (2) reflects a net forward-going wave caused by the RV pressure pulse, which 'pushes' blood towards the left atrium and contributes to S2. Modified from Smiseth *et al.*[8]

(S1) is caused by atrial pressure decay, whereas the mid and late-systolic flow wave (S2) is caused predominantly by the RV pressure pulse and with an important contribution from systolic descent of the AV plane.[8] This implies that reduction in the pulmonary venous S wave may be due to reduced LV contractility since this reduces systolic descent of the AV plane. Furthermore, reduction in RV contractility is expected to reduce the RV pressure pulse, which pushes the blood forward in the pulmonary veins. Finally, atrial dysfunction may contribute due to reduced S wave due to a reduced rise in LA pressure during atrial contraction and therefore a smaller decline in pressure during atrial relaxation. Therefore, the observation that a reduced S/D ratio predicts cardiovascular events may be a reflection of reduction in left- or right-sided ventricular function and atrial function, and therefore is a relatively non-specific marker of cardiac dysfunction.

In the study of Buffle *et al.*,[6] pulmonary venous systolic and diastolic velocities could be measured in 73% of the patients and duration of reversed atrial-induced velocity in 65%. This implies that image quality is a problem in a significant fraction of the patients. Therefore, pulmonary vein indices should be considered only one of the several possible indices to identify 'true' Grade II diastolic dysfunction. Other important variables which are associated with elevated LV filling pressure include enlarged left atrium, LV hypertrophy, increased E/e' ratio, and elevated pulmonary artery systolic pressure estimated from the tricuspid regurgitation velocity. Possibly using two or three of the other non-invasive markers of elevated LV filling pressure may give similar information as pulmonary venous S/D ratio. The pulmonary S/D ratio is also used for assessing LV filling pressure,[9] but factors other than pressure modify the S/D relationship, and therefore is recommended just as a supplementary and not a stand-alone method in this context.[1] It is important to be aware that in young healthy subjects with normal diastolic function, the S/D ratio may be <1, but a noticeable Ar is absent. There is a need for more studies to determine how evaluation of pulmonary venous velocities can be better integrated into clinical decision-making.

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References

1. Nagueh SF, Appleton CP, Gillebert TC, Marino PN, Oh JK, Smiseth OA *et al.* Recommendations for the evaluation of left ventricular diastolic function by echocardiography. *Eur J Echocardiogr* 2009;**10**:165–93.
2. Opdahl A, Remme EW, Helle-Valle T, Lyseggen E, Vartdal T, Pettersen E *et al.* Determinants of left ventricular early-diastolic lengthening velocity: independent contributions from left ventricular relaxation, restoring forces, and lengthening load. *Circulation* 2009;**119**:2578–86.
3. Caballero L, Kou S, Dulgheru R, Gonjilashvili N, Athanassopoulos GD, Barone D *et al.* Echocardiographic reference ranges for normal cardiac Doppler data: results from the NORRE Study. *Eur Heart J Cardiovasc Imaging* 2015;**16**:1031–1041.
4. Dalen H, Thorstensen A, Vatten LJ, Aase SA, Stoylen A. Reference values and distribution of conventional echocardiographic Doppler measures and longitudinal tissue Doppler velocities in a population free from cardiovascular disease. *Circ Cardiovasc Imaging* 2010;**3**:614–22.
5. Redfield MM, Jacobsen SJ, Burnett JC Jr, Mahoney DW, Bailey KR, Rodeheffer RJ. Burden of systolic and diastolic ventricular dysfunction in the community: appreciating the scope of the heart failure epidemic. *JAMA* 2003;**289**:194–202.
6. Buffle E, Kramarz J, Elazar E, Aviram G, Ingbir M, Nesher N *et al.* Added value of pulmonary venous flow Doppler assessment in patients with preserved ejection fraction and its contribution to the diastolic grading paradigm. *Eur Heart J Cardiovasc Imaging* 2015;**16**:1191–1197.
7. Smiseth OA, Thompson CR. Atrioventricular filling dynamics, diastolic function and dysfunction. *Heart Fail Rev* 2000;**5**:291–9.
8. Smiseth OA, Thompson CR, Lohavanichbutr K, Ling H, Abel JG, Miyagishima RT *et al.* The pulmonary venous systolic flow pulse—its origin and relationship to left atrial pressure. *J Am Coll Cardiol* 1999;**34**:802–9.
9. Kuecherer HF, Muhiudeen IA, Kusumoto FM, Lee E, Moulinier LE, Cahalan MK *et al.* Estimation of mean left atrial pressure from transesophageal pulsed Doppler echocardiography of pulmonary venous flow. *Circulation* 1990;**82**:1127–39.