Pulmonary Venous Flow Assessed by Doppler Echocardiography in the Management of Atrial Fibrillation

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Introduction
Pulmonary venous blood flow (PVF) exhibits a pulsatile behaviour, which is related to left atrial pressure and function, mitral valve function and left ventricular compliance. The use of transthoracic (TTE), transesophageal (TEE) and more recently intracardiac (ICE) Doppler echocardiography have helped to define characteristic flow patterns in normals and various heart diseases. The normal PVF has been found to contain both a systolic and diastolic forward phase and a reverse phase during atrial contraction. By using TEE, the systolic phase can be further subdivided into an early and a late systolic forward flow. A systematic overview of imaging techniques as well as PVF in normals and various heart diseases such as dilated and restricted cardiomyopathy, constrictive pericarditis or mitral valve disease has been provided earlier. [1]

More recently the influence of atrial fibrillation (AF), the most common arrhythmia in clinical practice, [2] on PVF has been systematically studied. This article reviews the current literature on PVF in AF and summarizes potential clinical applications.

PVF Pattern in AF
There are several descriptive studies showing the influence of AF on PVF. [3-7] Characteristic findings were the disappearance of atrial reverse flow, a decrease in systolic flow with a greater diastolic than systolic flow, a prolonged onset of systolic flow and the appearance of an early systolic reverse flow.

A loss of the end-diastolic atrial reverse wave is observed in the majority of AF patients. This typical finding can be explained by the loss of global active left atrial contractions. It is interesting to note, however, that in some patients with short-lasting AF multiple small reverse waves may be observed (Figure 1). [8] Those waves seem to represent atrial "contractions". This is supported by the fact that they correspond to larger fibrillatory waves recorded on the ECG. One might speculate that left atrial contractions may still be present immediately after AF onset and diminish over time because of the loss of contractile filaments.
In the majority of AF patients an early systolic reverse wave can be detected. Paraskevaidis et al. [6] described this wave in all of their 20 patients studied. The authors explained this finding as an abnormal motion of the mitral annulus toward the left atrium starting with the onset of ventricular contraction. By applying transesophageal pulsed Doppler echocardiography and measuring pulmonary capillary wedge pressure in 27 patients with AF which was associated with mitral stenosis or no underlying organic heart disease, it has been postulated that early systolic reversal waves reflect left atrial pressure, and the second systolic forward waves reflect left atrial filling. Both velocities varied, however, with preceding RR intervals. [9]

A reduction in systolic PVF expressed by reduced peak velocity, reduced velocity-time integral (VTI) of systolic flow, and reduced systolic fraction of PVF were noted in previous studies and attributed to the existence of AF. [5] The reduction of systolic PVF fraction has been found, however, to correspond closely to left atrial appendage (LAA) dysfunction (Figure 2) [8, 10] and spontaneous echo contrast (SEC) formation. [11] Thus, PVF modification seems to reflect a change in left atrial function, mainly atrial relaxation, compliance and reservoir function, [12] caused by the sustained arrhythmia rather than just a change in heart rhythm. This finding is supported by experimental studies [13] in which an increase in atrial stiffness after rapid atrial pacing in dogs resulting in a reduction in systolic PVF has been noted. The observation that frequent AF episodes significantly diminished systolic PVF among patients with paroxysmal AF is additional support for systolic PVF being a marker for mechanical remodeling of the atrium. [14]

Figure 1: PVF in a patient with multiple small reverse waves (arrow) corresponding with atrial contractions. Note a normal PVF pattern with similar systolic and diastolic flow (modified from [8]).
In contrast to systolic PVF, the diastolic PVF shows no relation to LAA dysfunction or SEC formation. [11]
This observation is supported by findings from others [5, 7] who have shown similar diastolic PVF parameters for patients in sinus rhythm and AF.

**PVF Changes After Restoration of Sinus Rhythm**
AF is associated with electrical, structural and contractile remodeling. [15] It is a common observation that following cardioversion atrial contractility is reduced which is associated with an increased risk of atrial thrombus formation for several days to weeks after restoration of sinus rhythm. [16, 18]

There are several studies that have analyzed the possible recovery of mechanical atrial function including normalization of PVF pattern and its time course by serial echocardiographic examinations. Common findings were small early systolic forward and atrial reverse waves after restoration of sinus rhythm which increase over time indicating a gradual restoration of atrial filling and contraction. [19, 20] Interestingly, in patients with nonvalvular AF of prolonged duration, recovery from atrial electrical dysfunction after conversion to sinus rhythm took much longer than that from either atrial hormonal or mechanical dysfunction, the latter being normalized after 1 month after cardioversion. [20]

The possible clinical importance of systolic PVF is Furthermore evidenced by the link with recovery of left atrial pump function, which was observed in 39 of 45 patients with chronic AF (86.6%) undergoing pulmonary vein (PV) isolation (see also below). Systolic PVF wave before and after ablation correlated with the degree of left atrial pump function after PV isolation. In more detail, an early systolic PV flow peak velocity >57 cm/s predicted good pump function recovery with 96% specificity indicating that preserved reservoir function during AF is predictive of satisfactory recovery of pump function after PV isolation. [21]

In addition, this study is noteworthy for the finding that good left atrial contractility returned in most patients immediately after PV isolation, which is in contrast to the time course of recovery reported in the aforementioned studies on electrical cardioversion.

**PVF in the AF Management**

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Figure 2: Pulsed-wave Doppler recordings from the left atrial appendage (top panel) and upper left pulmonary vein (bottom panel) from two patients with AF. Note the high LAA flow profile corresponding with normal PVF (a). In contrast, the low LAA flow profile corresponds with a decreased systolic PVF (b). The superimposed table shows the correlation between left atrial appendage emptying flow velocity and systolic PVF variables in 33 patients with persistent AF (modified from [8]).
Current AF management guidelines [2] suggest that "there are fundamentally two ways to manage the dysrhythmia: to restore and maintain sinus rhythm or to allow AF to continue and ensure that the ventricular rate is controlled". Both strategies seem to carry the same mortality risk if adequate anticoagulation is performed. [22, 23] However, patients’ selection and management remains substantially empirical and often is not based on recommendations that "take the various mechanisms and patterns of AF into account". [2] Thus, it seems desirable to develop and apply tests that quantify AF disease state and guide AF management. [24]

In that sense, PVF variables appear promising since they have been found to be related with AF recidivism (Figure 3). Low systolic PVF obtained during AF (before cardioversion) [25] as well as obtained during sinus rhythm (immediately after cardioversion) [26] was associated with AF recurrence at 6 and 12 months after electrical cardioversion, respectively. So far, one study has assessed if PVF variables could predict AF recurrence after PV antrum isolation. As with the two cardioversion studies, patients with a 6-month recurrence had, aside from lower LA appendage peak emptying velocity, lower peak PV systolic wave velocity compared with those who remained in sinus rhythm. [27]
One of the major drawbacks of PV ablation is the potential risk for PV stenosis. Subsequently, techniques and tools are needed to minimize the risk of this complication. While the application of ICE has been previously proposed as a tool for positioning of ablation catheters and bubble monitoring for energy adjustments during radiofrequency ablation of AF, [28] the acquisition and analysis of PVF seems well suited for the purpose of preventing and diagnosing PV stenosis in conjunction with PV isolation. By monitoring PV peak flow velocities during PV ostial ablation in 93 AF patients, a mild-to-moderate increase could be detected. [29] Of special note is the finding that of 13 patients with repeat ablation, two had PV velocities >100 cm/sec before repeat ablation, and three PVs in two patients had flow velocity >158 cm/sec (estimated pressure gradient 10 mm Hg) after repeat ablation. Subsequently, a more cautious approach may be warranted for patients undergoing repeat PV isolation. Moreover, lesion distribution rather than total number of lesions may have an impact on flow velocity increase. Results from the same group showed that in the majority of PVs (72%), electrical isolation could be achieved by partial (targeting <=3 segments/PV) rather than complete circumferential ablation with lower acute increase in ostial peak flow velocity while still obtaining good AF control. [30] Taken together these findings point to the possibility of monitoring the PVF response to and adjusting of ablation procedures accordingly on an individual basis.

Once PV stenosis is suspected it can be assessed by angiography, Doppler echocardiography, computed tomography, magnetic resonance imaging (MRI), and/or Doppler echocardiography, the latter being suspected to overestimate the rate of PV stenosis. [31] Subsequently, new Doppler criteria have very recently been defined which were validated by comparison with signal enhanced MRI. TEE Doppler PVF measurements detected or excluded significant PV stenosis following PV isolation if the diagnosis was restricted to a combination of elevated peak velocity (= 110 cm/s) with turbulence and little flow variation (Figure 4). [32] With the establishment of these diagnostic criteria and the more widespread use of ablation procedures, PVF analysis may gain an even greater importance in the care of AF patients.

**Figure 3:** Prediction of AF recurrence using PVF variables (adapted from [25-27]). Note the lower systolic flow expressed as flow velocity (top and bottom) or systolic fraction (middle) in patients with recurrent AF (p<.05 in all studies).
Conclusions
Assessment of PVF variables and patterns by Doppler echocardiography seems useful in the management of AF patients. Especially the reduction in systolic PVF may be used as marker for left atrial dysfunction, which favours thrombus formation and AF reinitation. Finally, PVF monitoring has the potential to an increasing role in AF ablation procedures.

Bibliography


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Publication: September 2005

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Webmaster  Actualización: 12-sep-05