

# HyperDoppler

## Intracardiac flow dynamics

## Background

Blood flow is closely linked to the morphology and function of the cardiovascular system. In recent years, experts have increasingly come to a consensus on the central role of cardiac fluid dynamics in several pathologic states<sup>[1,3,6]</sup> such as:

- LV Function (Systolic Function, Diastolic Function, Apical thrombus, LV dyssynchrony);
- LA Function (Treatment strategy, LA thrombus);
- RV Function (RV systolic function);
- Valve disease (Valvular function, Prosthetic Valve, LV remodeling after valve surgery);

Following this new concept, maladaptive fluid mechanisms can potentially highlight early signs of cardiac **damage** and, as a result, provide predictive information on possible future cardiac **remodeling**<sup>[1,2,3,4,5,6]</sup>.

Currently there are three imaging techniques that are used to evaluate intraventricular blood flow: phase-contrast magnetic resonance imaging (PC-MRI), echocardiography particle image velocimetry (echo-PIV), and Color Doppler flow mapping (CDFM)<sup>[3,6]</sup>.

Table 1 provides a handy comparison of the techniques currently available, with their associated pros & cons.

Table 1 - Comparison of techniques for visualization and assessment of intracardiac flows

	PC-MRI	Echo-PIV	CDFM
Signal source	Velocity encoded PC-MRI	Tracking of contrast microbubbles	Mean velocity of CDFM
Spatial resolution	Good spatial 2D and 3D resolution	Good spatial 2D resolution, limited or no 3D resolution	Good spatial 2D resolution, limited or no 3D resolution
Time resolution	Moderate time resolution	Good time resolution	Good time resolution
Accuracy	Accurate for high and low flow velocity	Accurate in low flow velocity, limited in high flow velocity	Accurate in high flow velocity, low flow velocity underestimated
Advantages	Full 3D capability, contrast medium not required	Bedside, lower cost, short processing time, validated parameters vs MRI	Bedside, lower cost, short processing time, contrast medium not required
Limitations	Restricted access, average of many cardiac cycles, longer examination time, high cost	Contrast required, longer examination time (contrast preparation and infusion), high frame rate required, acoustic window	Nonvalidated vs MRI, lower temporal resolution, acoustic window, reconstructed transversal velocities

## Intracardiac Flow Dynamics: what's that?

The flow of blood within the left ventricle is characterized by the presence of vortices.

At the beginning of diastole, when blood enters the LV from the atrium, vortices are created when the boundary layer of a fluid detaches from a sharp edge. Inside the LV, the early trans-mitral flow forms vortices that start from the distal tips of the mitral valve leaflets (Figure 1). As a matter of fact, the unbalanced shape of the mitral valve, whose anterior leaflet is larger than the posterior one, generates an asymmetric vortex that propagates away from the mitral valve.

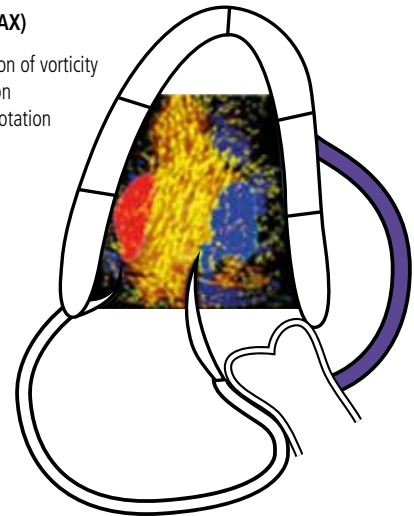
Figure 1 - Vortex formation at mitral in-flow. ALAX (A3CH) view illustrating the asymmetric vortex detaching from the distal tips of the mitral valve

### Apical Long Axis (ALAX)

**VORTEX:** compact region of vorticity

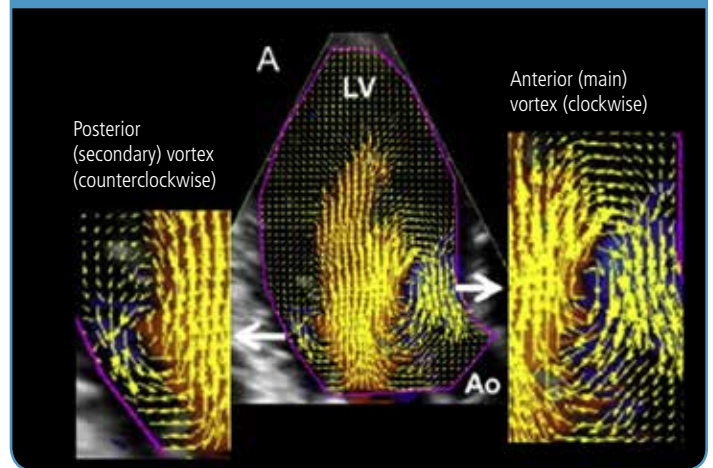
**BLUE:** clockwise rotation

**RED:** counterclockwise rotation



Normally the main anterior vortex rotates clockwise, and the secondary posterior vortex rotates counterclockwise (Figure 2). During the cardiac cycle, the vortex flow changes. As vortices propagate towards the LV apex, their rings deform. This deformation is due both to the inhomogeneous pressure gradient within the LV and to the interaction with LV walls.

Figure 2 - HyperDoppler Flow Velocity Vector mapping, highlighting the different rotational behavior between the anterior and posterior vortex - Modified from Mele et al., JASE. 2019 Mar;32(3):319-332



During diastasis, the vortex maintains its rotary motion. Subsequently, at the moment of atrial contraction (late filling), a second vortex ring occurs, and the late filling jet combines with the residual early vortex ring. During the isovolumic contraction (IC) period, the vortex redirects blood toward the LV outflow tract (LVOT), with formation of a large anterior vortex across the in-flow-outflow region (Figure 3).

Blood is then ejected.

Figure 3 - Modification of the vortex occurring during the cardiac cycle as depicted by the different ultrasound technologies in comparison with the Doppler trace at mitral inflow

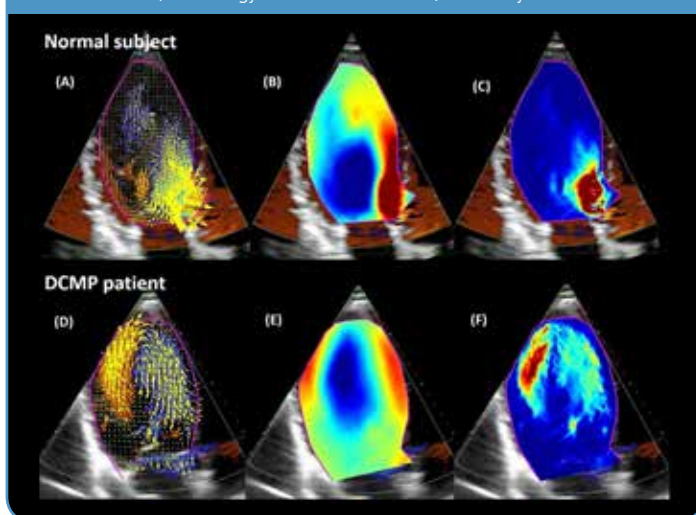
	Early filling	Diastasis	Late filling	
Pressure gradients				Echo-PIV
Streamlines				VFM
Circulation				Hyperflow adapted to CDFM
Transmitral flow velocity	E wave		A wave	Conventional PW Doppler

## HyperDoppler

HyperDoppler\* is Esaote's advanced imaging tool for the investigation of the intracardiac flows, intended to provide, in addition to the conventional echocardiographic parameters, a better understanding of cardiac physiological or pathological state. HyperDoppler is based on Color Doppler flow mapping (CDFM) technology.

It provides different map representations to highlight the intracardial flow properties, thanks to which the qualitative differences between the intracardiac flow dynamics in a normal subject and in a patient with dilated cardiomyopathy (DCMP) can be easily identified as documented by images in Figure 4, obtained at the end of the isovolumic contraction period.

Figure 4 - Findings in Normal versus a DCMP patient - Picture courtesy of Dr. Donato Mele, Cardiology Unit and LTITA Center, University of Ferrara



- Panels A and D of Figure 4 provide an example of Flow Velocity Vector data map representation, in which a 2D velocity vector field is represented as vectors superimposed on the traditional CFM.
- Panels B and E of Figure 4 show a circulation parametric map, in which the vortices are represented as compact regions colored in either blue (vortex rotation is clockwise) or red (vortex rotation is counterclockwise).
- Panels C and F of Figure 4 provide kinetic energy map representations.

The images in Figure 4 were acquired with an Esaote MyLab™X8 echo-scanner equipped with a IQ wide band phased array P1-5 probe for adult cardiology (Figure 5).

Figure 5



The Flow Velocity Vector map registered in the healthy subject shows a blood flow that circulates in the direction of the left ventricular outflow tract (panel A).

The circulation parametric map brings to light the formation of a pair of vortices immediately below the aortic valve (panel B).

Finally, the analysis of kinetic energy makes evident that the highest levels of kinetic energy, depicted with red color, are located in the left ventricular outflow tract (panel C).

In contrast, in the patient with DCMP, the Flow Velocity Vector map shows that the flow circulates along the posterolateral wall and rotates anteriorly at the level of the left ventricular apex (panel D).

In the circulation parametric map this translates into the formation of a single large vortex that rotates clockwise (blue color) at the apex of the left ventricle (panel E).

In this patient the analysis of the kinetic energy shows that the highest energy levels (shown with the red color) are found far from the left ventricular outflow tract, at the level of the ventricular apex (panel F).

\* HyperDoppler is an Esaote advanced research tool

## Conclusions

Intracardiac flow analysis is a **different way** to look at cardiac function **providing incremental and additive information** to conventional approaches based on cardiac mechanics.

The HyperDoppler is easy to use, intuitive in terms of data provided, and complete in terms of parameters offered.

The study of intracardiac flows is very complex: today, thanks to the dedicated software HyperDoppler, you can quickly and easily estimate blood vortices, allowing qualitative assessments of intracardiac vortex flows.

Potential application areas for the study of intracardiac flows include left ventricular remodeling and heart failure: the research field is broad, which is why this application is dedicated also to supporting research clinical trials.

## Bibliography

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