White Paper

HYPERDOPPLER
Intracardiac Flow Dynamics at the Patient Bedside

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"Vortex and energy metrics reveal how cardiac chambers work—not only how they look."

Background

In recent years, there has been growing interest in the assessment of intracardiac flow dynamics for the evaluation of ventricular, atrial, valvular, and aortic function (Figure 1). Several technologies are available for this purpose, including 4D-flow MRI, 4D-flow CT, and both contrast and non-contrast echocardiography [1].

Among non-contrast echocardiographic techniques, methods based on color Doppler flow mapping are of particular relevance, as they enable the evaluation of intracardiac flow dynamics in routine clinical practice. These techniques are relatively easy to use and can be applied directly at the patient's bedside. HyperDoppler represents the latest advancement in color Doppler technology specifically designed for the assessment of intracardiac flow dynamics.

Basis of the HyperDoppler Technique

HyperDoppler generates a two-dimensional velocity map of blood flow within the cardiac chambers by combining conventional color Doppler data with principles of fluid dynamics. Because Doppler ultrasound measures only the velocity component aligned with the ultrasound beam, HyperDoppler estimates the missing transverse velocity component using the continuity equation, under the assumption of incompressible blood flow.

HyperDoppler Image Acquisition and Analysis

The workflows for HyperDoppler image acquisition and analysis have been standardized for use during transthoracic echocardiography. For left ventricular (LV) assessment, a standard apical long-axis color Doppler view encompassing both LV inflow and outflow tracts is acquired [2]. For left atrial (LA) evaluation, a modified apical four-chamber view is used to visualize one left pulmonary vein and the right upper pulmonary vein [3].

Image acquisition is performed at end-expiration in cine-loop format, capturing a complete cardiac cycle (R–R interval). Imaging depth and sector width should be optimized to achieve a color Doppler frame rate of ⩾21 frames per second while maximizing inclusion of the chamber of interest within the color Doppler sector.

For image analysis, the region of interest is traced along the LV or LA endocardial borders at end-diastole and end-systole, respectively. The mitral annular plane is automatically identified by the software and does not require manual tracing. HyperDoppler analysis results are generated within a few seconds.

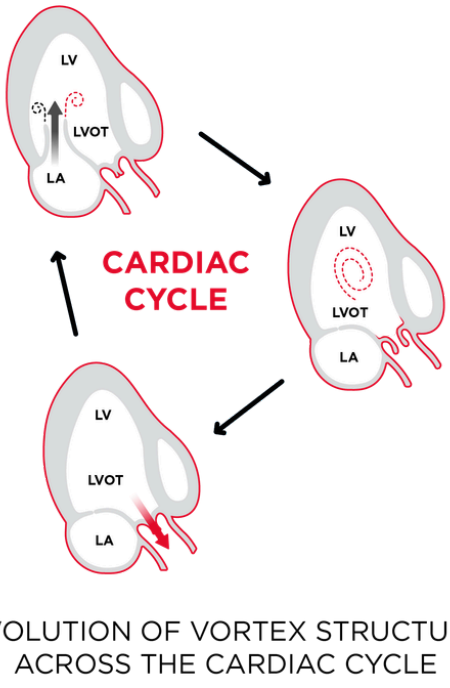

Figure 1: LV: left ventricle, LA: left atrium, LVOT: left ventricle outflow tract

HyperDoppler Image Presentation

HyperDoppler allows visualization of multiple flow dynamics maps (Figure 2). The velocity vector map is the primary display of the HyperDoppler technique and depicts reconstructed intracardiac velocity vectors throughout the cardiac cycle. The circulation, or intensity, map is generated by calculating vorticity within a defined blood area inside the cardiac chambers, providing information on rotational flow patterns. In the LV, assessed in apical long-axis view, blood with clockwise rotation is represented in blue, and blood with counterclockwise rotation is shown in red. Intracardiac pressure gradient maps represent the hemodynamic forces that drive blood flow within the cardiac chambers. These gradients are displayed using a color scale ranging from blue (lower pressure) to red (higher pressure).

All maps can be reviewed frame by frame, enabling detailed assessment of the spatial and temporal characteristics of intracardiac flow across the cardiac cycle.

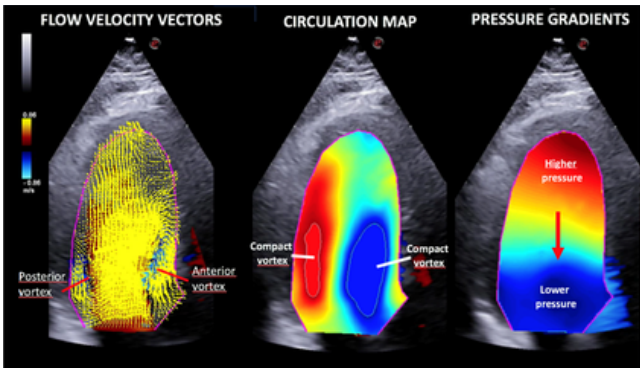

Figure 2. HyperDoppler flow dynamics maps

Quantitative Measurement of Vortex Properties

The quantification of vortex properties is derived from the steady-streaming flow field map, which visually represents the net circulatory flow over a single cardiac cycle (Figure 2).

Several scalar indices have been developed to describe the characteristics of the main LV vortex [4]. These indices are automatically calculated by HyperDoppler (Table 1).

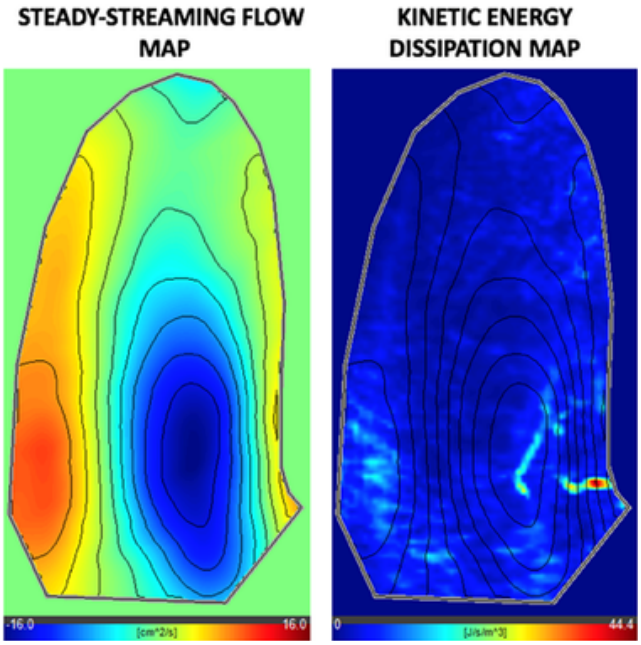

Figure 3. Steady-streaming flow map and kinetic energy dissipation map, used to obtain the quantitative HyperDoppler measures

LEFT VENTRICULAR (LV) VORTEX PROPERTIES BY HYPERDOPPLER			
Vortex Property	**Definition**	**Normalization**	**Normal value**
Area	Area of the compacted main vortex	LV area	24.4 ± 4.8%
Length	Length along the base-to-apex direction	LV length	57.4 ± 7.4%
Depth	Distance of vortex center from the LV base	LV length	34.4 ± 5.6%
Intensity	Integral of vorticity within the vortex	Total LV vorticity	-31.5 ± -5.8%

Table 1: Reference ranges from the multicenter NORVORTEX study Supplementary Material, expressed as mean ± SD; in the original publication, results were presented as median (25th - 75th percentile) [4]

Energy Dissipation and Fluctuation

HyperDoppler automatically calculates kinetic energy dissipation (KED) and fluctuation (KEF) within the cardiac chambers [4]. Physiologically, KED represents the viscous energy loss. In the presence of cardiac pathologies, KED may become more influenced by turbulence. LV KED is computed as the integral over the entire LV using the KED map (Figure 2 and Table 2). KEF quantifies the intra-beat variability of kinetic energy. Physiologically, KEF reflects the temporal irregularity or instability in blood flow (Table 2).

LEFT VENTRICULAR (LV) ENERGETIC PROPERTIES BY HYPERDOPPLER

Property	Definition	Normalization	Normal value
KED	Integral over the entire LV	Mean KE	0.58 ± 0.19
KEF	Integral over the entire LV	Mean KE	0.91 ± 0.12

Table 2: Reference ranges supported by the multicenter NORVORTEX study [4]

The Norvortex Study

Quantitative measures of LV flow dynamics provided by HyperDoppler are supported by the NORVORTEX (NORmal VORTEX) study, a multicenter, international investigation involving 13 echocardiographic laboratories and an independent core laboratory [4]. In NORVORTEX, 467 normal subjects were enrolled; 317 were analyzed at the core laboratory to establish reference values, while 419 were evaluated on-site. The study demonstrated excellent reproducibility of key HyperDoppler LV flow dynamics parameters -including vortex area, length, depth, intensity, and global kinetic energy dissipation-, confirming that HyperDoppler captures physiologically coherent intraventricular flow dynamics in normal hearts.

Clinical Applications

HyperDoppler measures have been proposed as a complementary tool for assessing morphological remodeling in the athlete's heart [5,6]. These measures can also distinguish between physiological and pathological conditions [5,7]. In patients with dilated cardiomyopathy and reduced LV ejection fraction, the main vortex typically appears wider and more rounded, with a displacement toward the apex compared with normal subjects (Figure 3). In patients with aortic stenosis, HyperDoppler can identify different patterns of LV concentric remodeling [8], while in those with atrial fibrillation it can detect abnormal flow dynamics in the left atrium [3]. HyperDoppler has also been proposed for the evaluation of blood flow in the ascending aorta in patients with a bicuspid aortic valve [9].

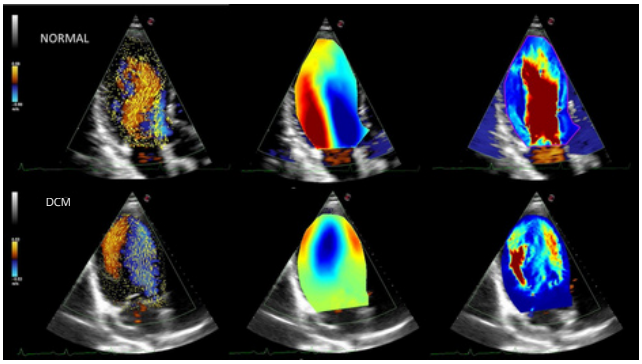

Figure 4. Vector velocity, steady streaming and kinetic energy maps in a normal subject and a patient with dilated cardiomyopathy (DCM).

Additional proposed applications of intracardiac flow dynamics analysis include the early detection of systolic and diastolic dysfunction, assessment of thrombotic risk in patients with myocardial infarction and atrial fibrillation, and evaluation of restored physiological flow in patients with obstructive hypertrophic cardiomyopathy following treatment. The HyperDoppler technique is currently under evaluation for these applications.

Conclusions

HyperDoppler has been introduced as a practical tool for characterizing intracardiac flow dynamics at the patient bedside. It enables both qualitative and quantitative assessments, offering quick and easy measures of vortex flow within the cardiac chambers, along with energetic parameters of flow dynamics.

References

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