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EDITORIAL

On the accuracy of intracardiac flow velocimetry methods

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"Begin challenging your own assumptions. Your assumptions are your windows on the world. Scrub them off every once in a while, or the light will not come in."—Alan Alda [1].

The topic of the flow pattern inside the heart and vortex imaging has been a main stream of research in echocardiography during the past decade. Progress has been made to incorporate quantitative fluid dynamics into echocardiography using particle tracking algorithms [2, 3, 39] that are based mostly on the well-known optical imaging techniques of particle image velocimetry (PIV) [4–6] or color Doppler imaging [7–10]. Recent advances in understanding left ventricular (LV) fluid dynamics based on experimental methods [11–14] and numerical simulations [15–17] have shed light on many aspects of ventricular flow, such as the development of intraventricular vortices. These vortices are shown to significantly influence transmitral momentum transfer and help redirect the flow from the left atrium toward the left ventricular outflow tract (LVOT) [18, 19]. Alternatively, formation of unnatural vortices can be a sign of adverse blood flow, which may indicate progressive LV dysfunction [18–21]. The knowledge gained about LV fluid dynamics, and in particular the associated vortical flow motion, has introduced novel clinical indicators for LV function based on vortex dynamics [18, 19, 21–25].

PIV is an optical method for flow visualization used to obtain instantaneous velocity measurements and related properties in the fluids. In this technique, the fluid is seeded with tracer particles, which are assumed to faithfully follow the dynamics of flow. The motion of these seeding particles is used to compute the flow velocity. In its current form, 2D ultrasound-based PIV or 2D echocardiographic PIV (Echo-PIV) was introduced by Kim et al. [2], through capturing digital B-mode images of contrast agent particles, and further used for vortex imaging by Kheradvar et al. [21]. This technique computes the velocities of the ultrasound-imaged particles based on the PIV technique, with the Δt being equal to scanning time. The number of beams and the samples along each beam define the number of pixels for each image after scan conversion. Particles used as the flow tracers are microbubbles filled with octafluoropropane encapsulated in either a lipid (DEFINITY®, Lantheus Medical Imaging, Inc.) or protein (Optison™, GE Healthcare) outer shell [3, 26], which are both FDA-approved for clinical use. This technique allows the velocity directions and streamlines, principal blood flow patterns, recirculation regions, and vortices to be drawn with reasonable confidence in a reproducible scheme [18, 21, 22, 27–32].

Alternatively, vector flow mapping (VFM) measures blood flow velocity by considering color Doppler imaging and ventricular wall velocity [7–10]. This method works based on combining measured axial velocities with estimated radial velocities according to the physical principles [33]. VFM ignores the three-dimensional component of the flow by assuming the flow is two-dimensional, solves the 2D continuity equation, and use ventricular wall velocity acquired by tissue tracking to improve the results [34].

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In reality, any physical flow is three-dimensional. However, some flow regimens can be considered 2D if the out-of-plane velocity component does not (or at least minimally) exist. A good example for such a flow regime is laminar flow in an axisymmetric tube. In laminar flow, there is no lateral mixing, and the nearby layers pass each other in a totally parallel scheme. Laminar flow requires no cross-currents perpendicular to the flow direction or eddies/swirls in the fluid [35]. Non-uniform geometries, such as in the heart chambers, increase flow three-dimensionally. Furthermore, time-dependency and the rotational nature of the flow minimize the application and accuracy of the methods developed for potential flow. Principles of fluid dynamics should be properly considered and applied for each particular flow regimen to avoid fundamental oversights in solving cardiovascular problems [36].

In prospect, intracardiac flow velocimetry is an emerging field in cardiac imaging. It should be considered that intracardiac flow is principally three-dimensional, time-dependent, and non-laminar. Modern echocardiography systems use ultrasound probes that can capture three-dimensional brightness fields associated with the blood flow. Generally, the ultrasound-based velocimetry methods are all bounded by the limitations and constraints of echocardiographic acquisitions, such as inter and intra-operator variabilities and acoustic shadowing. Furthermore, limited frame rate of echocardiographic acquisitions—particularly in 3D—is currently a major obstacle for accurate assessment of high-velocity values and advancement of 3D ultrasound-based velocimetry modalities for intracardiac flow [21, 33, 37]. More recent efforts may overcome these limitations and pave the way for routine clinical applications [33, 37–39].

Compliance with ethical standards

Conflict of interest Prof. Kheradvar holds multiple pending patents on velocimetry methods.

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