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GUEST EDITORIAL

Quantifying Cardiac Flow with Freehand 3D Scan

Researchers are excited about exploring flow structures in three-dimensional (3D) space, discovering more insights and advantages over one-dimensional (1D) and two-dimensional (2D) Doppler techniques. Recent developments have evolved laminar flow quantification methods that are independent of Doppler angle, flow profile and vessel geometry[1]. Estimating the volume flow across the cardiac valves is an important clinical application. In the study presented in this issue[2], Haugen and co-workers have introduced an interesting idea that used a freehand approach for measuring the stroke volume with calibrated 3D position tracking. The method is promising for two practical reasons: the images were acquired with freehand scan, and the acquisition was quick – images were gathered in less than 20 s.

The use of position-tracking devices to improve the reconstruction accuracy has long been explored in 3D ultrasound. A magnetic sensing device, albeit with the apparent drawback of being prone to ferromagnetic interference, has gained some popularity due to its compact size and convenience in scanning. With sophisticated engineering efforts it repeatedly demonstrated adequate precision for echo intensity-based reconstruction and volume quantification. Its role in 3D Doppler imaging is less clear because the tendency of confounding probe motion may cause errors in constructing the 3D Doppler image and consequent velocity interpretation. Most investigators, including our group, have avoided these problems by: (i) spatially, using a rotational transducer where its scan geometry is known and its pivotal axis is fixed – the resulting 3D Doppler velocities all correspond to the centre of image origin; (ii) temporally, avoiding probe motion by advancing the image plane out of the phase of interest with calibrated and controlled probe motions. Haugen's group generated a 3D Doppler data set by tilting the probe in a careful manoeuvre, similar to rotational data acquisition.

It should be clarified that the principle for the angle-independent 3D flow quantification method allows the use of any shaped surface so long as the vector velocities that are normal to it are measurable. The geometry of this measuring surface is a combination of the beam orientation pattern and the scan excursion. The use of a spherical surface for flow calculation is a special case that is applicable only to situations when Doppler velocities were measured with a radial symmetrical scan geometry such as rotational acquistion. Even with a phased-array probe and a radial geometry, this surface can be spherical only when the probe's pivotal centre is fixed throughout the imaging. With freehand scans, such manoeuvres may be difficult to achieve. Any probe sweeping or translation along the skin surface inevitably results in an axial-asymmetrical geometry. In this case a non-spherical shaped surface is required for volume flow calculation, to ensure the Doppler velocities are normal to it.

One merit of this study was the novel use of a floating sample surface to correct the underestimation of stroke volume. They found improvement in accuracy of the flow measurement over a fixed sample surface. However, lack of a reliable reference in the patient study always poses a problem for stroke volume validation. The conclusion derived from the measurement against 2D Doppler reference is somewhat less convincing. It has been viewed as general opinion that 2D measurement that uses the central velocity tends to overestimate the average cross-sectional velocity due to the parabolic flow profile. Thus, the amount of underestimation due to placing the sample surface may be controversial, especially for the outflow tract. In pursuing the same objective, our group has conducted a series of *in vivo* validation studies with systematic data acquisition with sample surface at a fixed depth on 24 sheep for over 280 haemodynamic stages. Using an electromagnetic flow meter as a reference, Irvine and colleagues[3,4] demonstrated an excellent agreement between 3D-derived flow measurement and the references in the chronic animal model. These carefully conducted *in vivo* studies, however, were unable to show a significant underestimation in aortic data with our 3D method. Possibly the differences were due to variations in methodology or exam types (either closed or open-chest (like ours), where the transducer may move with the heart), but this will need further investigation.

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In summary, this promising study form the Trondheim group is important in applying the fundamentally sound and geometry-independent flow quantification approach with a more flexible imaging scheme. Some technical issues associated with the freehand Doppler acquisition method may need to be examined. For example, the sample surface should be adaptable to the probe excursion pattern. Probe handling may need to be monitored to eliminate motion errors in Doppler measurement. The placement of the sample plane phase by phase may impede its clinical application by making the method cumbersome, because for a clinical method to be applied widely the processing needs to be quick as well. Trade-offs between the good spatial coverage in the rotational method we have used versus fewer cardiac cycles in image acquisition needs to be addressed in large scan views such as mitral valve, because an ideal 3D scan method for computing flow requires both high temporal and spatial sampling, especially across the mitral or tricuspid valve. The relative accuracy and the trade-offs between these two methods should be explored in a side by side experimental study and compared to a gold standard for flow measurements.

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