Correlation between velocity measurements from Doppler echocardiography and from M-mode contrast echocardiography

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SUMMARY The slope of an individual contrast trajectory on M-mode contrast echocardiography represents a physiological variable similar to that measured by Doppler echocardiography: the projection of the intracardiac velocity vector in the direction of the sound beam. To test the hypothesis that M-mode contrast echocardiography slope measurement can yield information quantitatively similar to Doppler measurements, we performed both simultaneously in 11 normal volunteers. A pulsed Doppler unit capable of simultaneous M-mode and Doppler display was used. Contrast was obtained by intravenous injection of 5% dextrose. Two independent observers measured velocity simultaneously by both techniques at eight to 16 points per subject. One observer repeated the measurements a month later. All subjects had contrast, and 10 had sufficient quality tracings for simultaneous Doppler and contrast slope measurements. The correlation between velocity measurements by both techniques was good, though velocities by Doppler echocardiography were less than by M-mode contrast echocardiography. We conclude that the component of flow velocity towards or away from the transducer can be measured from M-mode contrast trajectory slopes as well as by Doppler echocardiography. M-mode contrast echocardiography may provide a practical method for verifying or calibrating Doppler measurements in vivo.

It has recently been shown that the slopes of individual contrast trajectories on M-mode echocardiography correlate with invasive measurements of velocity in humans.¹ A major problem with this sort of comparison is that both catheter recordings and M-mode contrast slopes examine only one projection of the blood flow velocity vector, and probably not the identical component.

Pulsed Doppler echocardiography is another way of examining one component of the intracardiac blood flow velocity vector. Instruments are available commercially that can display simultaneously the M-mode signal and the Doppler-derived velocity signal at a chosen depth. Using such an instrument to compare velocity derived from Doppler signals and M-mode contrast trajectory slopes would eliminate the problem alluded to above, since both M-mode contrast

slope derived velocities and Doppler derived velocities are examining exactly the same component of intracardiac flow velocity (that along the sound beam towards or away from the transducer). In this study we compare the velocities calculated simultaneously from the two echocardiographic techniques in a group of normal volunteers in order to validate the hypothesis that they give similar information.

Methods

EXPERIMENTAL SUBJECTS

Eleven normal volunteers comprise the study population (10 men and one woman). Ages ranged from 22 to 35 years (mean 29). No subject had cardiac disease by history and/or physical examination.

ECHOCARDIOGRAPHIC METHODS

Patients were examined supine or in the partial left lateral decubitus position. A short intravenous can-

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Fig. 1 Simultaneous M-mode echocardiogram (upper tracing) and Doppler tracing (D) in the right ventricular outflow tract direction during intravenous injection. The sign of the Doppler signal is inverted, so higher velocities away from the transducer are displayed as more positive values on this tracing. Note the contrast in the right ventricular outflow tract (RVOT) and pulmonary artery (PA), passing through the Doppler sample volume (SV). The curved arrow points to an individual contrast trajectory during systole, and the straight arrow at the right points to a contrast trajectory during diastole.

nula was introduced into an antecubital vein and hand injections of 5 to 10 ml 5% glucose solution were performed to obtain contrast.

A prototype range-gated pulsed Doppler instrument was used in this study. The instrument was developed by the Centre National des Recherches Scientifiques at Broussais Hospital, Paris, France. An improved version of this machine is now available commercially (Alvar Electronics, Paris, France). It has a range gate which is adjustable in depth and volume. The operating frequency is 4 MHz and the pulse repetition frequency is adjustable from 5 to 20 kHz. Maximal sample depth is 14 cm. Each acoustic pulse generated by the transducer is adjustable in duration from 2 to 4 μ s (adjustable size Doppler sample volume). A high band pass filter with a cutoff frequency of 500 Hz eliminates low frequency signals from cardiac and vascular structures. The analogue curve of velocity is derived from a zero crossing detector and transcribed on a black and white strip chart recorded with M-mode echocardiogram and electrocardiogram. A paper speed of 100 mm/s was used when contrast trajectory slopes were to be measured.

Two to five contrast injections and recordings were performed with the transducer in the parasternal position and the echocardiographic beam directed in each of two different directions: the right ventricular outflow tract—pulmonary artery (Fig. 1) and the right atrium—right ventricular inflow tract (Fig. 2).

DATA ANALYSIS

Velocity was obtained from M-mode contrast echocardiographic tracings by measuring the slope of an individual contrast trajectory using a method similar to that recently described by Shiina *et al.*¹ Individual contrast trajectories were chosen for analysis if they were at least 1 cm long (preferably 2 or 3 cm long) and could be followed separately from other trajectories through the sample volume. Trajectories were not analysed if they were curved—only linear trajectories were accepted. The velocity calculated from the slope was compared with the Doppler signal 40 ms after the trajectory passed the centre of the sample volume on the M-mode tracing. This was done to correct for the instrument delay in displaying the Doppler signal. The 40 ms delay was measured by comparing the M-mode and Doppler signals on the tracing resulting from a sudden perturbation (touching the transducer).

At least one injection with contrast across the tricuspid valve and one injection with contrast across the pulmonary valve were analysed in each subject. Eight to 10 different paired velocity measurements (contrast, Doppler) from two to six different cardiac cycles were measured in each study subject. In total, 120 points for paired measurements were analysed.

Inter- and intraobserver variability was studied by having two observers (RSM and NKV) independently measure both Doppler and M-mode contrast derived

Fig. 2 Simultaneous M-mode echocardiogram (upper tracing) and Doppler tracing (D) in the right ventricular inflow tract direction during intravenous injection. Positive D signal implies velocity towards the transducer (in contrast to Fig. 1). Arrow shows a single contrast trajectory passing through the Doppler sample volume (SV). Further abbreviations—RV, right ventricle; RA, right atrium; ECG, electrocardiogram; a, "a-wave" caused by atrial contraction; EF, early filling phase.

velocities at each point from duplicate Xerox^R copies of the original tracings. These measurements were repeated one month later by one of the two observers (NKV) on a third duplicated copy of the original tracings.

Standard linear regression methods were employed to analyse the results.

Results

Echocardiographic contrast was obtained in all subjects. No adverse effects were noted at any time during the study. The quality of the tracing was insufficient to measure the slopes of contrast trajectories in one subject; he was not included in further analysis.

Data on simultaneous M-mode contrast derived velocities and Doppler velocities are given in Fig. 3 for the remaining 10 subjects, as measured by observer 1. The correlation between the two techniques of velocity measurement was $r=0.96$ ($p<0.01$) for the $N=120$ paired velocity measurements. The regression equation for this correlation is:

$$V_{\text{Dop}} = 0.4 \text{ cm/s} + 0.7 (V_{\text{M-CE}}) \text{ cm/s.}$$

Where V_{Dop} is the Doppler derived velocity, on the y-axis, and $V_{\text{M-CE}}$ is the M-mode contrast echocardiography derived velocity, on the x-axis of Fig. 3.

Fig. 3 Comparison of velocity measurements (in cm/s) measured from M-mode contrast echo trajectories (M-CE, x-axis) and Doppler shifts (y axis) by observer 1. Pooled data from all 10 patients analysed. The 45° line is the line of identity.

The standard error of the estimate is 7 cm/s. For observer 2, the results were very similar, with a correlation coefficient also $r=0.96$ for his 119 paired veloc-

Fig. 4 Variability in velocity measurements from echocardiography. The 45° line is the line of identity in all panels. (a) Interobserver correlation in contrast echo slope measurements ($Y=0.94 X-1$, $SEE=7$ cm/s). (b) Interobserver correlation in Doppler measurements for the same points as measured in (a) ($Y=0.94 X+0.03$, $SEE=3$ cm/s). (c) Intraobserver correlation in M-mode contrast echo measurements repeated one month after the original measurements ($Y=1.04 X+0.4$, $SEE=9$ cm/s). (d) Intraobserver correlation in Doppler measurements repeated one month after the original measurement ($Y=1.01 X-0.3$, $SEE=3$ cm/s).

ity measurements (he left out one point that observer 1 included). The regression equation obtained by observer 2 was:

$$V_{\text{Dop}} = 0.6 \text{ cm/s} + 0.7 (V_{\text{M-CE}}) \text{ cm/s}.$$

The standard error of the estimate for observer 2 was 7 cm/s.

As can be seen from Fig. 3, Doppler velocity measurements are lower than simultaneous M-mode contrast echocardiography derived velocity measurements, an effect that is more apparent at higher velocities.

Variability for velocity measurements is shown in Fig. 4. Panels a and b show the interobserver correla-

tion in measuring velocity from M-mode contrast echo and Doppler, respectively. Panels c and d show the intraobserver correlation in repeat measurements from M-mode contrast echo and Doppler one month apart.

Discussion

This study has confirmed our hypothesis that velocity information similar to Doppler echocardiography can be obtained from the slopes of contrast trajectories on M-mode tracings. Several theoretical and clinical implications can be drawn from this conclusion.

There are some advantages of M-mode echocardiography over Doppler echocardiography as a technique for studying velocity. It uses standard echocardiographic equipment which is already available at most institutions and is considerably less expensive than pulsed Doppler equipment. It can sample velocity at multiple depths simultaneously (only multigate Doppler units can do this), and is not limited by a maximal depth/velocity tradeoff as all pulsed Doppler units are. On the other hand, Doppler echocardiography does not require intravenous injections and is able to study left heart flow velocities in the absence of right to left shunts. Experimental work currently in progress suggests, however, that transmission of echocardiographic contrast through the lungs after peripheral venous injection may be feasible,²⁻⁴ so that left heart velocity measurements using M-mode contrast trajectory slopes may be possible in the future after intravenous injections. Since range/velocity ambiguities for pulsed Doppler echocardiography are a serious limitation at the depths necessary to study the left heart in adults, this may be a useful advance.

Velocities calculated from the slopes of M-mode contrast trajectories may be used to help verify that the calibration and working range of a Doppler instrument are correctly set. Though echocardiographers performing Doppler studies generally recognise the gross distortions caused by the phenomenon known as "aliasing" (falsely low velocity readings if the Doppler shift exceeds 50% of the instrument's pulse repetition frequency), few are aware that the true velocity may also be underestimated when the Doppler shift is only in the range of 30 to 50% of the pulse repetition frequency.⁵ This may occur without gross distortions that are recognisable to an experienced operator. We believe that much of the explanation for the Doppler underestimation of contrast velocities in our study is the result of this phenomenon. Another possible explanation is that the Doppler-contrast relation is linear but the values estimated by Doppler are consistently lower, perhaps because of the mechanism of selection for the M-mode trajectories.

Clinically, certain patterns in flow velocity can be identified by either Doppler echocardiography or M-mode contrast trajectory analysis. For example, the same altered pattern of flow across the pulmonary valve in patients with pulmonary hypertension has been described by contrast echocardiography⁶⁻⁸ and independently described using Doppler echocardiography.⁹ Both observations have been confirmed invasively in an experimental model.¹⁰ Our M-mode contrast echocardiographic observations on flow in the inferior vena cava¹¹ agree with Doppler studies.¹²⁻¹⁴ Other M-mode contrast echocardiographic patterns have been described for tricuspid and pulmonary regurgitation^{6,8,15} which also fit well with Doppler observations.

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