Comparison of multiple views for the evaluation of pulmonary arterial blood flow by Doppler echocardiography

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ABSTRACT Forty adult patients underwent Doppler and two-dimensional echocardiographic examination of the pulmonary artery from multiple views to determine the variability in the magnitude of Doppler-determined flow velocity and pulmonary arterial diameter from various echocardiographic windows. Flows were recorded from two or more views in 32 patients (80%). Twelve of these patients (38%) had flow velocities recorded from two or more views that were within 6% of each other. Twenty of these patients (62%) had view-dependent differences in measured flow velocity ranging from 7% to 48%. The commonly used parasternal short-axis view yielded the highest pulmonary arterial flow velocity in only 35% of the patients studied. Determinations of pulmonary arterial blood flow can vary markedly when measured from different sites, and this is presumably due to varying ability to approximate a zero-degree Doppler angle from different views. Measurement of pulmonary arterial flow velocity should be attempted from multiple views, and the highest flow velocity should be selected as that obtained with the best zero-degree Doppler angle approximation.

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THE MEASUREMENT of pulmonary arterial blood flow velocity by Doppler echocardiography can be useful in the assessment of pulmonic valvar disease,1,2 pulmonary hypertension,3 cardiac output,4 and intracardiac shunt magnitude.5 For quantitative measurements of blood flow velocity, the Doppler equation requires the precise determination of the Doppler angle or orientation of the ultrasound beam parallel to blood flow. It has been shown that multiple ultrasound views are often needed to obtain a reliable measure of aortic flow velocity.6 Since similar anatomic constraints are present for measurement of pulmonary arterial blood flow velocity, we evaluated and compared images from three two-dimensional echocardiographic views that potentially permit visualization of the pulmonary artery while simultaneously allowing near-parallel orientation of the ultrasound beam to the direction of blood flow, thus minimizing Doppler angle-dependent errors in measurement of flow velocity.

Methods

Forty patients representing all consecutive patients referred to our laboratory on randomly selected days were chosen for study. They ranged in age from 16 to 84 years (mean 59 ± 16 years); sixteen (40%) were female patients. Two-dimensional images and Doppler flow signals from the parasternal short-axis and the parasternal right ventricular outflow tract views with patients in the left lateral decubitus position, and from the subcostal short-axis view with patients in the supine position, were recorded with an ATL Mark 600 Duplex ultrasound instrument (Advanced Technology Laboratories, Inc., Bellevue, WA) (figures 1 and 2).

In the commonly used parasternal short-axis view, the coaptation point of the pulmonic valve leaflets and the greater curvature of the pulmonary artery are rarely visualized. The parasternal right ventricular outflow tract view provides better visualization of the pulmonic valve and the greater curvature of the pulmonary artery; it is obtained by angulating the transducer anteriorly and superiorly toward the right shoulder in a plane approximately midway between the parasternal long- and short-axis views. In the subcostal short-axis view the pulmonic valve plane is seen as a horizontal structure with the vessel walls clearly visualized. The parasternal right ventricular outflow tract and subcostal short-axis views appear to provide more optimal imaging of the pulmonary artery for measurement of its diameter at a known distance beyond the plane of the pulmonic valve. By use of the cross-sectional area (CSA) of the pulmonary artery calculated from the diameter measurement and the flow velocity integral (FVI) obtained from the Doppler recording of flow velocity, stroke volume (SV) may be calculated with the equation SV = CSA × FVI.

A 9 mm Doppler sample volume was positioned at approxi-
mately the midline of the pulmonary artery, 1 cm distal to the coaptation point of the pulmonic valve leaflets in each view. Scan planes and Doppler sample volume position were adjusted in each view until the highest velocity flow signal was obtained. Peak Doppler flow velocities and pulmonary arterial diameters were measured with the Cardiologic Analysis System (SONY Medical Systems, Park Ridge, New Jersey). Pulmonary arterial diameters were measured as inside-to-inside distance at peak systole, 1 cm distal to the coaptation point of the pulmonic valve leaflets.

**Results**

Doppler recordings of good quality were obtained in 31 patients from the parasternal short-axis view, in 33 patients from the parasternal right ventricular outflow tract view, and in 21 patients from the subcostal short-axis view (table 1). Doppler recordings could not be

**FIGURE 1.** Two-dimensional echocardiograms demonstrating visualization and pulsed wave Doppler interrogation of the pulmonary artery from the parasternal short-axis (*top*), parasternal right ventricular outflow tract (*middle*), and subcostal short-axis (*bottom*) views. Ao = aorta; LA = left atrium; LV = left ventricle; PA = pulmonary artery; PV = pulmonic valve; PW = left ventricular posterior wall; RA = right atrium; RV = right ventricle; S = interventricular septum; TV = tricuspid valve.

**FIGURE 2.** Pulsed Doppler waveforms of pulmonary arterial blood flow velocity from a single patient recorded from the parasternal short-axis (*A*), parasternal right ventricular outflow tract (*B*), and subcostal short-axis (*C*) views. Horizontal scale: 1 sec between lines. Vertical scale: 0.2 m/sec between lines; 0 m/sec line is in boldface.
obtained from more than one view in seven patients; recordings from a single view only were obtained in one patient from the parasternal short-axis view, in two patients from the parasternal right ventricular outflow tract view, and in four patients from the subcostal short-axis view. No single view consistently provided the highest peak flow velocity. The highest flow velocity was recorded from the parasternal short-axis view in 14 of 31 patients in whom flow recordings from this view could be obtained, from the parasternal right ventricular outflow tract view in 24 of 33 patients, and from the subcostal short-axis view in 14 of 21 patients.

Based on the cosine function in the Doppler equation, an error of up to ±20 degrees in the assumed zero-degree Doppler angle results in only a 6% error in measured flow velocity. Due to the nonlinearity of the cosine function, an error in the assumed zero-degree Doppler angle of greater than 20 degrees results in proportionately much greater error in measured flow velocity. We therefore considered flow velocities within 6% of each other measured from different views in the same patient to represent equivalent flow velocities and those with a greater than 6% difference to represent view-dependent—and therefore Doppler angle-dependent—differences in measured flow velocity. Thirteen patients had flow velocities recorded from two or more views that were within 6% of each other; this was achieved from two views in 12 patients and from all three views in one patient (table 1). Peak flow velocity ranged from 49 to 159 cm/sec, with a mean peak flow velocity of 94 ± 26 cm/sec. Twenty patients had view-dependent differences in measured flow velocity ranging from 7% to 48%. It is thus likely that in these patients, the actual Doppler angle was greater than 20 degrees from the assumed zero-degree angle in the view providing the lower flow velocity. Satisfactory Doppler recordings could not be obtained in one patient.

Of the 40 patients studied, clinically satisfactory pulmonary arterial images were obtained in 29 patients from the parasternal short-axis view, in 32 patients from the parasternal right ventricular outflow tract view, and in 22 patients from the subcostal short-axis view (table 2). Of these images, pulmonary arterial diameters were measurable on none of those from the parasternal short-axis view, on 30 of those from the parasternal right ventricular outflow tract view, and on 20 of those from the subcostal short-axis view. Pulmonary arterial diameters were measurable from both the parasternal right ventricular outflow tract and subcostal short-axis views in 15 patients; for these 15 patients, excellent correlation was found between diameter measurements from these two views, with a correlation coefficient of .92 (figure 3). In 15 patients, pulmonary arterial diameters could be measured only from the parasternal right ventricular outflow tract view and in five patients they could be measured only from the subcostal short-axis view. The pulmonary arterial diameter could not be measured in five patients from any view. Pulmonary arterial diameters in the study group ranged from 1.8 to 4.5 cm, with a mean diameter of 3.1 ± 0.4 cm. Both pulmonary arterial diameter and satisfactory Doppler recordings of flow velocity were obtained for 35 of the 40 patients (88%), thus permitting the calculation of volume blood flow.

**Discussion**

Combined two-dimensional imaging and pulsed Doppler echocardiography allows rapid positioning of the Doppler sample volume in the proximal pulmonary artery from multiple views; this is particularly helpful in the measurement of pulmonic flow velocity from the subcostal short-axis approach. The commonly used
parasternal short-axis view yielded the highest pulmonic flow velocity in only 35% of our patient population. The parasternal right ventricular outflow tract view provided a higher recorded pulmonic flow velocity than the parasternal short-axis view in 38% of the patients studied. In an additional nine patients (23%), the highest flow velocities could be obtained only by the subcostal approach. Our findings are very similar to those reported by Vijayaraghavan et al. \(^6\) on the use of multiple views to obtain the highest Doppler aortic flow velocity. Thus the need to measure Doppler flow velocity from multiple views to obtain an adequate quantitative assessment of flow cannot be overemphasized.

Although the highest obtained flow velocity in each view was attributed to the closest approximation of a zero-degree Doppler angle, it is acknowledged that some variation in measured blood flow velocity within the pulmonary artery may be due to a nonlinear velocity profile.

Since our Doppler measurements of pulmonic flow velocity were not compared with measurements of pulmonic flow by alternative methods, the accuracy of the data may be questioned. However, the maximum flow velocities we obtained compare favorably with those reported by other investigators. \(^7,8\) Other investigators have suggested that continuous-wave Doppler measurements of aortic blood flow may be superior to those obtained by pulsed Doppler techniques. \(^9\) These arguments are largely based on the ability to either better approximate a zero Doppler angle with the use of the Doppler flow signal for guidance of transducer positioning (such as the right parasternal border view for aortic stenosis), or the elimination of flow-signal aliasing that occurs when high-velocity blood flow is measured with the pulsed Doppler recording technique. In adults, pulmonic stenosis is a rarity, and even in patients with significant pulmonic insufficiency, it is unusual to obtain flow velocities of sufficient magnitude that they cannot be resolved with use of either standard or high pulse-repetition frequency pulsed Doppler echocardiography. However, smaller non-imaging Doppler transducers using either continuous or pulsed mode might well permit alternative transthoracic ultrasound windows with more optimum Doppler flow signals than can be obtained with an imaging scanhead in some patients. This aspect deserves further investigation.

We were able to measure pulmonary arterial diameters in 35 of the 40 patients studied using either the parasternal right ventricular outflow tract or the subcostal short-axis views. Thus the diameter measurement was the major limiting factor in our ability to estimate volume blood flow in the pulmonary artery, reducing our theoretical volume flow measurement group from 39 to 35 patients (39 patients had satisfac-

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Y = 0.895X + 0.3
\]

\[R = 0.92\]

FIGURE 3. Correlation of pulmonary arterial diameters measured from the parasternal right ventricular outflow tract view and from the subcostal short-axis view in the 15 patients in whom both views yielded a measurable diameter. PRVOT = parasternal right ventricular outflow tract; SCSAX = subcostal short axis.
tory Doppler recordings). In both views, the vessel walls are relatively parallel to the ultrasound beam, thus reducing measurement resolution, which becomes dependent upon geometry of the lateral and azimuthal beams. In our experience, the subcostal two-dimensional view of the pulmonary artery, when obtainable, provided the best images of the vessel. However, there was a high correlation between blinded measurements of vessel diameter from the two views. While not used in the present study, additional images of the pulmonary artery for diameter measurements might be obtained from the suprasternal approach. However, it is frequently difficult to obtain high-quality images from this view in adult patients.

The data from this study lead us to conclude that determinations of pulmonary arterial blood flow velocity can vary markedly when it is measured from different sites, due presumably to varying ability to approximate a zero-degree Doppler angle from multiple views. Therefore, measurements of pulmonary arterial flow velocity should be attempted from all three (parasternal short-axis, parasternal right ventricular outflow tract, and subcostal short-axis) views, and the highest flow velocity should be selected.

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