Diagnostic Accuracy of Continuous Wave Doppler Echocardiography in Severe Aortic Stenosis in the Elderly

MASAO NITTA, M.D., TOSHIHIKO TAKAMOTO, M.D., KOICHI TANIGUCHI, M.D., AND HERBERT N. HULTGREN, M.D.*

SUMMARY

Forty-four male patients (mean age 63.6 years) with aortic stenosis (AS) were evaluated by conventional hemodynamic methods and continuous wave (CW) Doppler echocardiography. The relationship between Doppler mean gradients and direct mean pressure gradients in all patients was significant, with an r value of 0.88. Sixteen of 17 patients with a mean Doppler gradient ≥40 mmHg had severe AS (AVA ≤1.0 cm²). Twenty-seven patients had a Doppler gradient <40 mmHg, and 8 of these patients had severe AS (AVA ≤1.0 cm²). The sensitivity and specificity of a Doppler gradient ≥40 mmHg in detecting severe AS were, therefore, 67% and 95%, respectively. Thirty-three percent (8/24) of patients with severe AS and low Doppler gradients (<40 mmHg) had evidence of poor left ventricular function, evidenced by a lower cardiac output, a higher heart rate and an abnormal PEP/LVET ratio compared to the other patients. Thus, the presence of a low stroke volume ≤60 ml/beat and PEP/LVET × HR >26 is of value in identifying patients where the Doppler is likely to significantly underestimate the degree of aortic stenosis.

Additional Indexing Words:
Aortic stenosis Noninvasive methods Doppler echocardiography Diagnostic accuracy

MANY studies have demonstrated a close correlation between transvalvular hemodynamically determined gradients in aortic stenosis (AS) and gradients estimated by Doppler echocardiography.1)–8) Less information is available regarding the relationship between Doppler echo gradients and the aortic valve area (AVA), as calculated from hemodynamic data.9) The purpose of this study was to examine this relationship and to evaluate the reasons for the inaccuracies of Doppler echocardiography.

From the Second Department of Internal Medicine, Tokyo Medical and Dental University, Tokyo.

* Cardiology Division, Stanford University School of Medicine, Stanford, California, U.S.A.

Address for reprint: Masao Nitta, M.D., Second Department of Internal Medicine, Tokyo Medical and Dental University, 1-5-45 Yushima, Bunkyo-ku, Tokyo 113, Japan.

Received for publication March 24, 1987.

169
Methods

Patients: Forty-four consecutive male patients (mean age of 63.6 years, range 29 to 85 years) with aortic stenosis were evaluated by continuous wave (CW) Doppler echocardiography and conventional hemodynamic methods. One patient was excluded because an adequate CW Doppler signal of the transaortic velocity could not be obtained. Mild aortic regurgitation was present in 17 patients. Significant coronary artery disease, defined by at least one major vessel with more than 50% stenosis, occurred in 24 patients (53%). The patients were divided into 3 groups according to the aortic valve area and Doppler echo pressure gradients (DEG). Patients in group A (n=8) had an AVA \leq 1.0 \text{ cm}^2 and a DEG < 40 \text{ mmHg}, group B (n=16) had an AVA \leq 1.0 \text{ cm}^2 and a DEG \geq 40 \text{ mmHg}. Group C consisted of patients with mild AS (n=20) (AVA > 1.0 \text{ cm}^2).

Cardiac catheterization: Right and left heart cardiac catheterization and coronary arteriography were performed by the retrograde femoral artery technique with a standard fluid-filled transducer system. The mean aortic valve pressure gradient was obtained by planimetry of the area between the two pressure curves of left ventricular and aortic pressure, either on pullback across the aortic valve or when recorded simultaneously. The Gorlin equation was used to obtain the aortic valve area. Cardiac output was measured by the Fick method.

Doppler examination: An Irex CW Doppler ultrasound instrument was used for the noninvasive recording of the transaortic flow velocity signals with the use of a 2.0 MHz nonimaging transducer. Occasionally a 2.5 MHz two-dimensional imaging Doppler transducer was used for orientation. Doppler recordings from the ascending aorta were made using standard interrogation planes (apical five-chamber, supra sternal notch and right parasternal area). The Doppler measurement of maximum flow velocity was estimated by the simplified Bernoulli equation. A mean aortic valve pressure gradient was derived using the Irex Meridian TM Measurement & Analysis Package Computer System. The CW Doppler echo study was performed within one day of cardiac catheterization.

Phonocardiograms: Phonocardiograms and mechanocardiograms were recorded simultaneously using an Irex System 11 Instrument. Impulse tracings, heart sounds and murmurs were recorded at a paper speed of 100 mm/sec. The pre-ejection period (PEP) was calculated as Q-S2 minus left
ventricular ejection time (LVET) from carotid pulse tracing.

**M-mode echocardiogram:** Stroke volume was calculated by using Teichholz's method.¹²)

**Statistical analysis:** Comparisons between invasive and noninvasive measurements were made by linear regression analysis using the least squares methods. All data are presented as mean±1 standard deviation. Multiple comparisons between groups were determined by the one way analysis of variance. A difference of p<0.05 was considered statistically significant.

**RESULTS**

Figure 1 compares the mean aortic valve pressure gradient obtained by Doppler ultrasound with the mean pressure gradient obtained by cardiac catheterization. The aortic valve mean pressure gradients at catheterization ranged from 0 to 80 mmHg. The linear regression analysis (r value) between Doppler echo and catheterization derived mean gradient resulted in an r value of 0.88 (y=1.4x−12, p<0.01).

![Mean AV gradient graph](image)

Fig. 1. Mean AV pressure gradient by Doppler echocardiography compared to mean AV pressure gradient at catheterization in 44 patients with AS.
Fig. 2. The difference between the mean AV pressure gradient (Doppler determined AV gradient minus the catheter measured gradient) in relation to the aortic valve area. A negative value indicates that the Doppler gradient is less than the catheter gradient. A positive value indicates that the Doppler gradient is higher than the catheter gradient. In severe AS, echo-Doppler gradients are rarely overestimated, but frequently underestimated when compared with catheter data.

Fig. 3. The aortic valve area determined by catheterization compared to the mean pressure gradient estimated by Doppler echocardiography. Horizontal lines indicate 40 mmHg and 20 mmHg. The vertical line is drawn at 1.0 cm².
Figure 2 compares the mean AV gradient obtained by Doppler echo and catheterization. With severe AS, most gradients were underestimated by the Doppler echo method and none were significantly overestimated. With mild AS the Doppler estimate of the gradient was usually higher than the hemodynamic gradient.

Figure 3 compares calculations of the aortic valve area by catheterization and the aortic valve gradient by CW Doppler echo. In 17 patients with a mean ED gradient $\geq 40$ mmHg, 16 had severe AS (range 0.3 to 0.9 cm$^2$). Twenty-seven patients had ED gradients $< 40$ mmHg and 8 of these patients had an AVA $\leq 1.0$ cm$^2$. The sensitivity and specificity of Doppler echo gradient $\geq 40$ mmHg in detecting severe AS were, therefore, 67% and 95% respectively. However, 8 patients (33%) with severe AS had low Doppler echo gradients ($< 40$ mmHg). A Doppler echo gradient $< 20$ mmHg was present in 13 patients; only 2 had severe AS (sensitivity: 55%, specificity: 92%).

Figures 4 and 5 compare the cardiac output and stroke volume determined by both catheterization and M-mode echocardiography using Teichholz's method. Group A showed a significantly lower stroke volume and

![Cardiac Output](image-url)

Fig. 4. Group A patients (AVA $\leq 1.0$ cm$^2$ and DEG $< 40$ mmHg) had a lower cardiac output by cardiac catheterization (left panel) and by M-mode echo (right panel) compared to groups B and C.
Fig. 5. Group A patients had the lower stroke volume by cardiac catheterization (left panel) and M-mode echo (right panel) compared to groups B and C patients.

Fig. 6. Group A patients exhibit a higher resting heart rate than groups B and C patients. This higher heart rate was present during the hemodynamic study (left panel) and during the Doppler study (right panel).
lower cardiac output than groups B and C.

Figure 6 shows the resting heart rate during cardiac catheterization and during the Doppler echo examination. Group A showed a significantly higher heart rate compared to groups B and C. Finally, Fig. 7 shows the ratio of PEP/LVET, using the carotid pulse tracing. There was a significant difference between group A and group B, but not between group A and group C. Group A patients had a significantly higher value of the PEP/LVET × HR (during the recording of the phonocardiogram) than the other groups. These results were independent of the presence of coronary artery disease.

**Discussion**

Several recent studies have reported an excellent correlation between
Doppler echo velocities and the transvalvular pressure gradients, calculated by a simplified Bernoulli equation. The Doppler echo method would clearly be valuable in the diagnosis and follow up of patients with aortic stenosis, especially elderly patients. In elderly patients with aortic stenosis, the Doppler technique used initially showed a significant underestimation of the pressure difference in some subjects. However, more recent studies showed that the Doppler technique was more accurate in predicting the pressure gradient and was independent of age, sex and the presence of other valvular abnormalities. These findings were also true in elderly patients. The improved accuracy is probably due to improvement in equipment and the modification of currently applied techniques. The apical transducer position has a higher yield of good quality spectral tracings than suprasternal and right sternal border positions. However, the simple prediction of the pressure gradient is not as useful to the clinician as the valve area, since the pressure gradient may vary substantially in relation to the cardiac output and heart rate. The distinction between severe and mild aortic stenosis requires calculation of the aortic valve area, which is dependent upon the measurement of the cardiac output.

In this study, 35 of 45 patients were correctly identified noninvasively as having either severe or mild aortic stenosis. As illustrated in Fig. 3, the Doppler echo-derived pressure gradient information alone is often sufficient to determine the severity of aortic stenosis. When patients have a mean estimated pressure gradient above 40 mmHg, they are likely to have severe aortic stenosis and a gradient of less than 20 mmHg usually indicates mild AS. However, 8 patients (group A) had a mean transaortic pressure gradient of less than 40 mmHg and significant AS (valve area ≤ 1.0 cm²), which could not be identified by the pressure gradient alone. Yeager and his colleagues have pointed out that when echo Doppler mean gradients exceed 50 mmHg, severe aortic stenosis is nearly always present and that when gradients are less than 30 mmHg, mild aortic stenosis is usually present; with estimated gradients between 30 and 50 mmHg the diagnosis is uncertain. Our results confirm these observations.

Some workers have investigated methods to obviate left sided heart catheterization and avoid the underestimation of severity of stenosis in patients with small gradients and a reduced cardiac output. Mean pressure gradients and systolic ejection times, combined with thermodilution stroke volume, have been shown to be useful adjuncts to Doppler studies in predicting valve areas without cardiac catheterization. Recent reports indicate that accurate estimation of the cardiac output is possible using a combination of Doppler and two-dimensional echocardiographic techniques.
The continuity equation has been reported to increase the accuracy of non-invasive estimation of the aortic valve.\(^{23}\)

The present study indicates that simple noninvasive variables will enhance the accuracy of the echo Doppler estimation of the severity of aortic stenosis in elderly patients. Patients with an estimated echo Doppler gradient of <40 mmHg who have an estimated cardiac output of <4.0 liters/minute, a resting heart rate of >70 beats/minute and a product of PEP/LVET x resting heart rate of ≥26 are likely to have severe aortic stenosis.

**References**

7. Smith MD, Kwan OL, DeMaria AN: Value and limitations of continuous wave Doppler echocardiography in estimating severity of valvular stenosis. JAMA **255**: 3145, 1986
9. Gorlin R, Gorlin SG: Hydraulic formula for calculation of the area of the stenotic mitral valve, other cardiac valves, and central circulatory shunts. Am Heart J **41**: 1, 1951
views in the evaluation in aortic stenosis in adults by continuous-wave Doppler. Am J Cardiol 55: 445, 1985


