Doppler-derived Aortic Maximal Acceleration*  
A Reliable Index of Left Ventricular Systolic Function

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We compared maximal acceleration of aortic blood flow (aortic Amax), calculated from maximal aortic velocity obtained with a conventional echo-Doppler machine with the invasive inotropic index left ventricular end-systolic pressure/left ventricular end-systolic volume (LVESP/LVESV) ratio and left ventricular ejection fraction (LVEF). Continuous wave (CW) and pulsed wave (PW) Doppler aortic blood flows were recorded from the apical view in 16 patients (age, 62.3 ± 6.4 years) within 24 h of left-sided catheterization. The theoretical exponential relationship between LVEF and LVESP/LVESV was confirmed in our study population (r = 0.92; p < 0.0001). The relationship between aortic Amax determined either by CW or PW and LVESP/LVESV was linear (r = 0.92 and 0.93, respectively, p < 0.001), whereas the relationship between aortic Amax and angiographic LVEF was exponential (PW: r = 54; CW: r = 0.85; both p < 0.001). We conclude that (1) aortic Amax, derived from maximal velocity obtained with a conventional machine, can be used as an index of left ventricular systolic function, and (2) PW as well as CW Doppler signals can be used for this calculation. (Chest 1993; 103:1064-67)

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left-sided catheterization is a reliable technique to assess left ventricular systolic function. However, when serial studies are required, repeated catheterizations might be dangerous and are therefore unethical. Noninvasive approaches, such as echocardiography, have been proposed to evaluate left ventricular (LV) performance, but owing to their inherent limitations and weak reproducibility, they are of limited clinical value.1

In a pioneering work published in 1964, Rushmer4 introduced a new concept: the initial ventricular impulse as an index of LV systolic function. Using electromagnetic probes to measure acceleration of blood flow in the ascending aorta, a number of authors have found close correlations with various indices of LV systolic function.3,4

The use of a noninvasive continuous wave (CW) Doppler velocimeter to measure peak aortic velocity and maximum or mean aortic acceleration represents a natural advancement of this concept. Recently, an automated Doppler system (Exerodop, Quinton Instrument Co, Seattle, Wash) that can measure peak modal velocity and maximum acceleration has been introduced.4,5 Measurements of these parameters have been applied clinically to the evaluation of patients with congestive heart failure,6,7 acute myocardial infarction,5.6 and during exercise testing.5,7,8 Maximum acceleration of aortic blood flow (aortic Amax) has been validated as a noninvasive inotropic index that can be useful to identify LV dysfunction6,8,9 or assess the effects of pharmacologic interventions such as the administration of β-blockers5,7 or positive inotropic agents.3,9

In routine echo-Doppler studies, peak velocity and mean acceleration are measured with pulsed wave (PW) or CW Doppler,10-18 whereas, up to now, determination of aortic Amax relies on the measurement of modal velocity with a specific CW Doppler machine. We report herein the use of a conventional echo-Doppler equipment to record PW and CW Doppler signals in the ascending aorta and the use of a homemade program to calculate aortic Amax from the maximal blood flow velocity. Doppler-derived aortic Amax was compared with hemodynamic gold standard invasive indices of LV systolic function.

METHODS

Population

Twenty patients with sinus rhythm, referred to our hospital for evaluation of chest pain by coronary angiography, were considered for the study. Two patients had to be excluded because of significant aortic regurgitation or aortic or subaortic stenosis and two had to be excluded because of poor Doppler recordings. None of the patients presented with advanced atriowentricular block or numerous premature ventricular contractions that are theoretical contraindications to the technique. Medications for ischemic heart disease, including nitrates, calcium antagonists, and β-blockers,

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Doppler-derived Aortic Maximal Acceleration (Dubourg et al)
This transformation was performed within 24 h of Doppler study. Hemodynamic measurements were obtained prior to coronary angiography and ventriculography. The LV volumes were computed using Simpson's rule from the ventriculogram obtained in the 30° right anterior oblique projection. The LV end-systolic pressure/end-systolic volume ratio (LVESP/LVESV ratio) was calculated in each patient. End-systolic volume was determined from the LV cineangiogram as the smallest calculated volume from serial frames. The LV end-systolic pressure was approximated by aortic diastolic pressure.

**Left-Sided Cardiac Catheterization**

Catheterization was performed within 24 h of Doppler study. All subjects were studied in the partial left lateral decubitus position using a 3.5-MHz imaging transducer. Two-dimensional echocardiographic LV volumes were calculated using the ellipsoid area-length method applied to cross-sections obtained from the four-chamber view.

Continuous wave and PW Doppler were recorded from the aortic arch window using a transducer (Pedol) (2.5-MHz carrier frequency). Both audible and spectral outputs were used to obtain the flow signal with the highest velocity and the most sharply defined spectral contour. The analog aortic velocity signal was recorded at 50 mm/s on a 1.25-cm inch VHS videotape for subsequent analysis.

The aortic Amax was digitized on the computer screen (Zenith 386) from the analog signal of ten consecutive beats. A personal program was used to measure aortic Amax on the aortic Doppler waveform, as previously reported. Briefly, the aortic flow envelope was divided into time intervals of 1 ms (dt). In each time interval, the change in velocity (dv) from the beginning to the end of this interval was measured and the acceleration (dv/dt) was computed. This value was then averaged with the two values measured during the preceding and the following interval (moving average method). Premature beats and postextrasystolic beats were rejected.

**Reproducibility of Doppler Data**

Intraobserver and interobserver variability were determined in a group of ten additional patients with congestive heart failure. The variability was expressed as percentage of error for each measurement and was calculated as the difference between two measures, divided by the mean value. Results are reported in Table 1.

**Statistical Analysis**

All data are expressed as mean ± 1 SD. Linear regression analysis was computed using the least square method, after logarithmic transformation when necessary. A p value <0.05 was considered as statistically significant.

**RESULTS**

Our study group consisted of 15 men and 1 woman with a mean age of 62.3 ± 6.4 years (range, 52 to 71 years). Mean angiographic ejection fraction (EF) was 54 ± 16 percent (range, 25 to 76 percent).

The aortic Amax obtained from both CW and PW Doppler correlated linearly with LVESP/LVESV ratio: r = 0.92 and r = 0.93, respectively (Fig 1). Angiographic LVEF correlated exponentially with LVESP/LVESV ratio (r = 0.92) (Fig 2), and so did LVEF with aortic Amax (Fig 3), whether it was derived from CW (r = 0.85; n = 16) or PW Doppler (r = 0.84; n = 16).

Echocardiographic LVEF was linearly related to angiographic LVEF (r = 0.74, p < 0.001). The exponential relationship between LVESP/LVESV ratio and echocardiographic LVEF (r = 0.70, p < 0.005) was weaker than that observed with angiographic LVEF. Similarly, the exponential relationship between aortic Amax derived from CW or PW Doppler and echocardiographic LVEF was also less close (r = 0.62, p < 0.02, and r = 0.65, p < 0.01, respectively).

**FIGURE 1. Relationship between maximum acceleration of aortic blood flow (aortic Amax) and left ventricular end-systolic pressure/volume ratio (LVESP/LVESV). Closed circles and thick regression line refer to continuous wave Doppler (y = 17.4 ± 3.9; r = 0.92; p < 0.0001) and open circles and thin correlation curve refer to pulsed wave Doppler (y = 17.7 ± 4.4; r = 0.93; p < 0.0001).**

**FIGURE 2. Correlation between angiographic left ventricular (LV) ejection fraction (EF) and LVESP/LVESV ratio (y = 0.19·10^{-0.77}; r = 0.92). Same abbreviations as in Figure 1.**

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**Table 1 — Reproducibility of Maximum Acceleration of Aortic Blood Flow**

<table>
<thead>
<tr>
<th>Doppler Technique</th>
<th>Reproducibility, %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Interobserver</td>
</tr>
<tr>
<td>Pulsed wave</td>
<td>11.1 ± 7.2</td>
</tr>
<tr>
<td>Continuous wave</td>
<td>8.6 ± 6.0</td>
</tr>
</tbody>
</table>

were unchanged for at least three weeks before the study. All patients gave informed consent to participate in the study.
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Sabbah et al\textsuperscript{23} reported a similar relationship using a power curve fit. However, in the studies from Sabbah et al\textsuperscript{23} and from others,\textsuperscript{4,5} aortic Amax was obtained with a special device using CW Doppler to measure aortic modal velocity, \textit{i.e.}, the velocity of the greatest number of red blood cells. In the present study and in a previous one from our group,\textsuperscript{9} a standard echo-Doppler machine was used and aortic Amax was derived from \textit{maximal} aortic velocity, \textit{i.e.}, the highest velocity of red blood cells.

Aortic Amax has the theoretical advantage over mean acceleration of being independent from time to peak and maximal velocity, two parameters that are used to calculate mean acceleration\textsuperscript{18} and are poorly reproducible. In the present study, mean acceleration was calculated and was neither related to aortic Amax nor to other indices of systolic function. However, mean acceleration, which does not require a special device for its determination, has been used by several authors to assess LV systolic function. Gardin et al\textsuperscript{10} determined mean acceleration using PW Doppler in patients with dilated cardiomyopathy, and Bedotto et al\textsuperscript{18} did so using CW Doppler in patients similar to ours. Calculation of maximal aortic acceleration is highly dependent on accurate identification of the onset of ejection. Continuous wave Doppler requires filtering of the signal because of background noise, whereas PW Doppler can be used without any filtering, so that accurate identification of the onset of ejection is easy. However, the correlation obtained in our study between invasive LV inotropic index was less close when it was obtained from PW Doppler than when it was derived from CW. Thus, identification of the Doppler signal does not appear to be a critical factor.

Doppler-derived aortic Amax has over two-dimensional echocardiography the advantage of being independent of LV shape. This may be of particular interest when studying patients with ischemic heart disease. Actually, the relationships between echocardiographic LVEF and aortic Amax derived from CW and PW Doppler signal were weaker ($r=0.62$ and $r=0.59$) than those observed between angiographic LVEF and aortic Amax ($r=0.78$, and $r=0.84$), probably because echocardiographic determination of LVEF was less reliable. This is also suggested by the weak exponential relation between echocardiographic LVEF and hemodynamic LVESP/LVESV ratio.

**Limitations of the Study**

Although several investigators have reported that aortic Amax is a reliable inotropic index,\textsuperscript{4,5,18} we did not address the load dependence of aortic Amax in this study. Wallmeyer et al\textsuperscript{3} studying mean aortic acceleration, reported that it was minimally load dependent, whereas Bedotto et al\textsuperscript{18} found it to be

No correlation could be found between mean acceleration of aortic blood flow whether it was determined by PW or CW Doppler on one hand and aortic Amax, LVESP/LVESV ratio, and LVEF on the other hand.

**DISCUSSION**

Our data show that aortic Amax derived from \textit{maximal} velocity, obtained with both CW and PW Doppler signals, fairly correlates with invasive indices of LV function. Specifically, a close linear correlation was found between aortic Amax and LVESP/LVESV ratio. The use in this study of LVESP/LVESV ratio as a reference inotropic index,\textsuperscript{15} \textit{i.e.}, a substitute for ESP/ESV slope,\textsuperscript{16} is supported by several observations. First, determination of dead volume, \textit{i.e.}, the volume of the LV at zero intraventricular pressure, is obtained from linear extrapolation, which is subject to errors.\textsuperscript{17} Second, dead volume is close to zero in normal ventricles,\textsuperscript{18} and small compared with LV end-systolic volume in dilated ventricles,\textsuperscript{18} so that the difference between the ESP/ESV slope and the LVESP/LVESV ratio may be disregarded, providing that LV afterload is maintained within the normal range.\textsuperscript{19} Such an approximation is supported in our study by the close exponential relationship found between LV ejection fraction and LVESP/LVESV ratio (Fig 2). This relation was identical to the one that was predicted on theoretical grounds\textsuperscript{20} and has been observed in human ventricles with both normal\textsuperscript{21} and depressed systolic function.\textsuperscript{22}

Since aortic Amax correlated linearly with LVESP/ LVESV ratio, and the latter correlated exponentially with LVEF, one would expect an exponential relationship between aortic Amax and angiographic LVEF. That actually was what we observed in this study.

**FIGURE 3.** Relationship between maximal aortic acceleration (aortic A\textsubscript{max}) and angiographic left ventricular ejection fraction (LVEF). Closed circles and thick correlation curve refer to continuous wave Doppler ($r=12.3-10^{4}a_{4}, r=0.85; p<0.0001$) and open circles and thin correlation refer curve to pulsed wave Doppler ($y=10.7-10^{4}a_{4}; p<0.0001$).

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strongly load dependent, increasing directly with preload and inversely with afterload. Harrison et al.,\textsuperscript{2,20} studying aortic Amax in normal subjects (with an ExerDop) found it to be heart rate dependend and afterload dependent. In this regard, as stressed by Cardin,\textsuperscript{21} Doppler indices are neither better nor worse than traditional indices of systolic function, such as LVEF or stroke volume, which are clearly load-dependent.

In conclusion, maximum acceleration of aortic blood flow derived from maximal velocity obtained with a conventional echo Doppler machine may be useful as an index of LV systolic function. Pulsed wave Doppler as well as CW Doppler signals can be used for this calculation.

REFERENCES

5 Metha N, Bennett D. Impaired left ventricular function in acute myocardial infarction assessed by Doppler measurement of ascending aortic blood velocity and maximum acceleration. Am J Cardiol 1986; 57:1092-58
19 Carabello BA. Ratio of end-systolic stress to end-systolic volume: is it a useful clinical tool? Am J Coll Cardiol 1989; 14:496-98
26 Harrison M, Clifton D, Berk M, DeMaria A. Effect of blood pressure and afterload on Doppler echocardiographic measurements of left ventricular systolic function in normal subjects. Am J Cardiol 1989; 64:905-98