Assessment of Aortic Insufficiency by Transcutaneous Doppler Ultrasound

By Derek R. Boughner, M.D., Ph.D., F.R.C.P. (C)

SUMMARY
Using a 2.2 MHz directional Doppler ultrasound unit, the instantaneous peak aortic velocity pattern was recorded transcutaneously in 15 normal persons and 15 patients with aortic insufficiency. The transducer was positioned in the suprasternal notch and aimed posteriorly to cross the descending aortic arch at an angle approximately parallel to blood flow. The electrocardiogram, phonocardiogram, and carotid pulse tracings were recorded simultaneously. In patients with aortic insufficiency there was significant diastolic flow that was not present in normal persons. The planimetered area under the systolic and diastolic velocity tracings represents the distance forward and backward that the stroke volume moves. The ratio was used to approximate the percent regurgitation, which ranged from 9% to 68%. From left ventricular angiograms in the patients with aortic regurgitation single plane ventricular volume measurements were used to calculate ventricular output and when compared with the Fick cardiac output gave an estimate of true percent regurgitation. A strong correlation was obtained with the Doppler estimate (r = 0.91), confirming that this simple ultrasound technique can accurately assess the degree of aortic insufficiency.

DESCENDING AORTIC ARCH blood velocity can be obtained from the chest surface using a directional Doppler ultrasound probe. This technique has been recommended for the assessment of aortic insufficiency but its accuracy has not been established.

In diastole there is normally very little reversed aortic blood flow (cm³/sec) and, consequently, little reversed aortic blood velocity (cm/sec). However, in the presence of aortic insufficiency the amount of reversed flow is increased and this increase can be used to calculate the amount of the stroke volume leaking back into the left ventricle. An electromagnetic flowmeter, with the cuff probe positioned around the ascending aorta, gives the best measure of the exact regurgitant volume but this is, of course, impractical clinically. Intraaortic blood velocity measurements, using a catheter tip electromagnetic velocity probe and a Doppler ultrasound velocity probe, have demonstrated the abnormal velocity pattern in aortic regurgitation. In dogs, a good correlation has been shown between estimates of the percent regurgitation (rather than volume regurgitation) calculated from such intraaortic velocity recordings and simultaneous cuff electromagnetic flowmeter recordings.

Since Doppler ultrasound can be used to record aortic blood velocity noninvasively it seemed possible that it could provide a simple and accurate measure of percent regurgitation.

Method
A 2.2 MHz directional Doppler ultrasound unit manufactured by Bach-Simpson Limited was used for this study. The transducer was of the "split D" configuration and was focused at a depth of 8 cm. The technique for obtaining aortic blood velocity was described by Light in 1969. The transducer was hand held in the suprasternal notch with the patient supine. The ultrasound beam, when aimed downwards and posteriorly towards the tip of the left scapula, crossed the descending arch such that the angle of incidence with the blood flow was approximately zero degrees (Fig. 1). In this area of the arch the transmural velocity profile was relatively flat, i.e., varied little across the lumen, so that the velocity reading obtained approximated the over-all velocity of the stroke volume. Also since the Doppler shift velocity recording obtained depends upon the cosine of the angle of incidence of the beam with the flowing blood, an angle of 20° from parallel will produce an error of only ±5% in the instantaneous peak velocity reading.

In each case the transducer was rotated in the suprasternal notch until a peak velocity away from the transducer was obtained. In many patients the carotid vessels lie in the path of the beam and, therefore, simultaneous flow toward the transducer was frequently recorded in systole.

The equipment provided three forms of display of the information: 1) The Doppler frequency shift produced by the flowing blood was made audible via stereophonic earphones, with velocities away from and toward the transducer on separate channels. 2) The instantaneous peak velocity away from and toward the transducer was indicated on two calibrated meters on the face of the equipment. 3) An output from the Doppler unit was connected directly to a Lit-
ton chart recorder with "away" velocity plotted upright and "toward" velocity inverted.

An oscillator contained within the equipment was used for calibration. When activated it produced a signal equivalent to a frequency shift representing 50 cm/sec. The electrocardiogram, phonocardiogram (recorded from the left sternal border, fourth interspace) and the carotid pulse tracing were recorded simultaneously with the velocity tracing at paper speeds of 50 mm/sec and 250 mm/sec.

To establish the normal aortic velocity tracing (fig. 2) recordings were performed in 15 individuals, ranging in age from 14-63 years, with no known cardiac disease. All showed an essentially parabolic wave form beginning ± 20 msec from the onset of the carotid pulse upstroke. The velocity tracings showed a rapid rise to peak velocity. The fall to zero velocity occurred rapidly near the end of systole with the baseline being reached at the dicrotic notch of the carotid pulse. The systolic flow in the carotid vessels was usually recorded simultaneously with the aortic arch blood velocity but was readily separated from that of the aortic arch by its opposite direction relative to the transducer. A small amount of reversed flow was often seen in early diastole. Blood velocity from the innominate vein could be recorded and was of considerable importance to this technique's assessment of aortic insufficiency. Flow in this vessel was toward the transducer, beginning in late systole and extending through to mid diastole. This velocity pattern therefore could obscure abnormal aortic arch reverse flow in early diastole and if not carefully excluded could invalidate the interpretation of the aortic velocity tracing. In most patients this vessel was avoided by careful aiming of the transducer, and the earphone display of the Doppler frequency shift aided in this technique as venous and arterial flow tended to sound different. Venous flow produced a more continuous rushing or rumbling sound without the rapid rise and fall in amplitude characteristic of the arterial flow.

Occasionally it was not possible to obtain a definite aortic arch velocity signal. In our experience this has been due most often to the presence of obstructive airways disease with air-containing tissue lying between the aortic arch and the transducer. The ultrasound beam is almost completely reflected at air-tissue interfaces and penetration to the aorta then becomes impossible. A separate difficulty can be encountered with the extremes of patient body size. Our transducer was focused at 8 cm which is too deep in small children and too shallow in some large adults. In this particular study problems with patient size and emphysema did not arise.

From the instantaneous aortic velocity tracing recorded on the Litton recorder additional information could be obtained. If we were using a cuff electromagnetic flow probe around the aorta our recording would be flow in cm/sec and the area under the systolic portion of that curve would yield an accurate measure of the stroke volume (cm³). However, our Doppler equipment provided a velocity recording in cm/sec. The area under the systolic portion was therefore in centimeters, i.e., the distance forward that the stroke volume moved or the amount of aorta occupied by the stroke volume. It follows that the area under any reversed velocity curve in diastole represented the distance backward that the stroke volume moved and the ratio represented the percent regurgitation. Since we were then dealing in ratios to obtain this pertinent information it became less important for the ultrasound beam to closely parallel the aortic arch blood flow, i.e., it was not absolutely essential to obtain the true peak velocity and the technique was therefore made simpler.

A group of 15 patients with clinical and/or echocardiographic findings of aortic insufficiency who were to undergo cardiac catheterization were studied prospectively using the Doppler ultrasound technique. In each patient the areas under the systolic and diastolic portions of the aortic velocity curve were measured with a planimeter. Ten beats

Figure 1

The ultrasound probe is positioned in the suprasternal notch and aimed such that the beam crosses the aortic arch approximately parallel to blood flow.

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Figure 2

Recordings from a normal individual. Blood velocity away from the transducer is plotted upright and toward the transducer is inverted. Forward aortic velocity is shaded area.
were analyzed from each patient and a mean ratio of the
distance forward and backward that the stroke volume moved,
i.e., percent regurgitation, was obtained.

Following cardiac catheterization the left ventricular cineangiograms for each patient, recorded in the right
anterior oblique projection, were analyzed. The end-systolic
and end-diastolic frames were selected by referring to a
simultaneously recorded electrocardiogram on which the
exposures of the angiograms had been marked automatically.
These two frames were then projected and traced, the areas
and long axis were measured manually with a planimeter
and ruler and finally the corrected ventricular volumes at
end systole and end diastole were calculated using the single
plane technique outlined by Dodge. Care was taken to
avoid extrasystolic and postextrasystolic beats. The stroke
volume was thus obtained as the difference between the two
volumes and when multiplied by the heart rate gave left
ventricular output. The Fick cardiac output was measured
by the rebreathing technique prior to the angiogram and the
difference between the two measurements of output
provided a close approximation of the percent aortic
regurgitation.

The estimates of the regurgitant fraction obtained from
the noninvasive Doppler ultrasound technique and the car-
diac catheterization technique were then compared. None
of the patients were found to have evidence of mitral in-
sufficiency.

Results
The aortic velocity patterns from normal persons
were similar to the invasive patterns obtained by
Benchimol et al. using a directional intraventricular
Doppler catheter. In addition, our recordings were
comparable to the noninvasive Doppler aortic velocity
tracings obtained by Light, whose equipment
differed from ours primarily in the recording system.

In our normals, the aortic velocity pattern did not
regularly demonstrate the small amount of low
velocity reverse flow normally present in early
diastole. This failure was due primarily to the pass
band of the Doppler instrument. The unit is sensitive
to velocities from 7–100 cm/sec; frequency shifts
representing velocities below or above these limits are
not detected. Thus very low velocity diastolic reversed
flow was not recorded. This characteristic of the unit
can introduce a small degree of error in the estimation
of the amount of reversed flow in aortic insufficiency
since the final low velocities will be lost.

The problem of innominate vein flow was more
significant. In that vessel, flow occurs toward the
transducer in late systole and early diastole and can
mask the presence of early diastolic reversed flow in
the aorta if both vessels fall simultaneously in the
ultrasound beam. If the velocity patterns from the two
vessels cannot be separated adequately by careful
aiming of the transducer this technique cannot be
applied reliably. Two patients were excluded from
this study for this reason (fig. 3).

In each of the 15 patients with aortic insufficiency
an abnormal diastolic aortic velocity pattern toward
the transducer (i.e., reversed flow), was recorded by
the Doppler technique. This pattern began at the
dicrotic notch and extended throughout varying por-
tions of diastole (figs. 4 and 5). It was not present in
normals (fig. 2) and was differentiated from in-
nominate vein flow by the methods outlined above.
The systolic portion of the velocity tracing showed no
features that would correspond to the aortic pressure
pulse abnormalities (such as the bifid aortic pulse)
seen in patients with aortic insufficiency. This was not
surprising since the interrelation between the two

![Figure 3](http://circ.ahajournals.org/content/vol32/issue5)

*Figure 3*

*Recordings from a patient with angiographically
mild aortic insufficiency. The reversed aortic
velocity pattern in diastole is obliterated by the
recording from the innominate vein of venous
blood velocity toward the transducer (shaded
area).*

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waveforms is complex. Pressure and velocity waveforms are propagated at different rates and even in normals they have quite different contours.7

By planimetry the areas under the systolic and diastolic portions of the aortic velocity curves were obtained and thus estimates of the percent regurgitation were calculated, varying from 9% to 68%. Each estimate was then compared to the percent regurgitation calculated from the left ventricular cineangiograms and Fick cardiac output (fig. 6). A strong correlation was demonstrated with an r value of 0.91.

An aortic valve gradient was present in nine of the patients indicating the presence of aortic stenosis in addition to the insufficiency. Although this abnormality could alter the aortic velocity pattern (fig. 7) it did not interfere appreciably with the estimation of the percent regurgitation by the Doppler technique. We observed that small valve gradients tended to produce a minor delay in the rise to peak aortic velocity while more severe aortic stenosis produced prolonged delays but this finding was not consistent. In our patients forward flow in the aorta still fell towards zero at the dicrotic notch and the regurgitant pattern could still be distinguished. It seems likely that such will not always be the case and that accurate differentiations of the pertinent forward and reversed velocity patterns in aortic stenosis might be disrupted by jet flow from the stenosed valve. If the jet were to extend around the arch the velocity profile would not be flat and the peak velocity indicated would not be representative of the mean velocity of the stroke.

![Figure 4](image-url)  
Recordings from patient with mild aortic insufficiency, regurgitant fraction 29%. Blood velocity away from the transducer is plotted upright and toward the transducer is inverted. Shaded area in systole is forward aortic velocity and in diastole is reversed aortic velocity in aortic arch. Unshaded area is velocity of blood in neck vessels toward transducer in systole.

![Figure 5](image-url)  
Recordings from patient with moderately severe aortic insufficiency, regurgitant fraction 54%. Shaded areas represent aortic arch velocity in systole and diastole. Planimetry of areas provided estimate of regurgitation.

![Figure 6](image-url)  
Correlation between percent regurgitation calculated from Doppler velocity recordings and regurgitant percentage calculated from angiographic left ventricular output (from left ventricular volume measurements) minus Fick cardiac output.
have only limited abilities to quantify the abnormality.\cite{12,13} Echocardiography provides little information regarding severity of the aortic lesion although it can indirectly indicate the presence of regurgitation by recording mitral valve anterior leaflet flutter during diastole. Transcutaneous directional Doppler ultrasound has been used to record peripheral arterial velocity patterns in patients with aortic valve disease.\cite{14} Although reversed velocity in diastole was normally present in radial and femoral artery tracings, it was of significantly increased magnitude and duration in aortic insufficiency. Correlation with the degree of regurgitation was not attempted.

Incorrect assessment of aortic insufficiency produces important difficulties in the management of patients with coincident aortic and mitral valve disease. Accurate information regarding the presence and degree of aortic regurgitation is necessary for the proper management of the mitral lesion since the aortic lesion can prove a serious technical handicap during open operative procedures on the mitral valve.\cite{15} The aortic Doppler technique can provide the information with greater ease and accuracy than other noninvasive methods.

In addition, patients with aortic prostheses may develop a degree of aortic regurgitation. The appearance of a diastolic murmur can be worrisome and may represent either a minor, small volume periprosthetic leak or a significant degree of regurgitation. The physical findings and noninvasive studies

Discussion

The need exists for simpler and more accurate means of assessing aortic insufficiency. This lesion is most commonly assessed invasively by cineangiography, a technique of limited accuracy. Originally that method was proposed by Lehman et al. as a procedure that could give only a rough estimate of the degree of insufficiency.\cite{11} Subsequent studies have borne this out.\cite{4,9,12} For example, Mennel et al.\cite{3} recently measured the amount of regurgitation with a cuff electromagnetic flowmeter probe around the ascending aorta at operation and compared the results with cineangiography. From that study it was apparent that cineangiography can distinguish mild from severe regurgitation but between those extremes it has little quantitative value. Similar results were obtained by Hunt et al.\cite{9} who used as their standard the technique that we have applied, i.e., Fick cardiac output versus left ventricular volume measurements. Their correlation coefficient was 0.56 between the cineangiographic estimate and true regurgitant fraction.

Noninvasive techniques presently employed have about the same degree of accuracy. The physical examination, the electrocardiogram and the chest X-ray

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure7}
\caption{Delay in rise to peak aortic velocity as recorded in some patients with aortic stenosis. The percent regurgitation can still be calculated.}
\end{figure}

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure8}
\caption{Leaking aortic prosthetic valve. The arrows indicate the opening and closing artifacts produced by the prosthesis.}
\end{figure}
are often not helpful. The Doppler technique which can detect and grade the regurgitation (fig. 8) may provide a suitable method for following these patients.

Thus the transcutaneous measurement of aortic arch blood velocity by directional Doppler ultrasound appears to have a useful place in patient management. It has the advantage of being noninvasive and can be done rapidly and safely. When a good tracing is obtained the results provide an accurate assessment of the degree of aortic regurgitation.

Acknowledgment

Appreciation is expressed for the excellent technical assistance of Mrs. Joan Persaud and the continued interest and assistance of Dr. S. P. Ahuja and Dr. W. J. Kostuk. We also wish to thank the Bach-Simpson Co. Ltd., London, Ontario for supplying the ultrasound unit and Mr. Victor Carriere for his technical advice.

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D R Boughner

Circulation. 1975;52:874-879
doi: 10.1161/01.CIR.52.5.874

Circulation is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
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Print ISSN: 0009-7322. Online ISSN: 1524-4539

The online version of this article, along with updated information and services, is located on the World Wide Web at:
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