IN 1969 Hirata et al. demonstrated that the left atrial dimension on the echocardiogram correlated well with the maximum left atrial angiographic dimension. Since then others have confirmed these findings and the maximum left atrial echo dimension has become a routine part of the echocardiographic report. In fact the aorta and left atrium may be the only recordable echocardiographic structures in some difficult patients such as those with chronic lung disease.

The left atrial dimension is normally measured at the point of maximum separation of the posterior aortic wall from the posterior left atrial wall corresponding to the maximum distension of the left atrium with pulmonary venous blood. The similarity between the cyclic change in this measurement and the left heart volume curve has intrigued us. However, the diagnostic value of the cyclic change in left atrial echocardiographic dimension and factors affecting it are unclear from previous work. Since most of the change in the left atrial echocardiographic dimension is due to posterior aortic wall motion, this study was designed to explore the factors influencing the posterior aortic wall motion and to assess the importance of the cyclic change in left atrial volume on this motion.

Methods
Echocardiographic Studies
All echocardiograms were performed using a Smith Kline Ekoline 20A ultrasonoscope, utilizing a 0.50 inch, 2.25 MHz transducer with a 5 cm collimation and either an Irex 101 or Cambridge strip chart recorder. All examinations were conducted with the patients rotated 30° into a left lateral decubitus position. The transducer was placed along the left sternal border at the interspace where the mitral valve echo was best seen with the transducer perpendicular to the chest wall. To record the left atrial echocardiogram, the transducer was then rotated cephalad and medially until both the aorta (at the level of the valve) and the left atrium were visualized.

Aortic and left atrial echocardiograms were recorded from 20 normal subjects (4-60 yrs). In one 30-year-old patient with congenital heart block and no associated congenital heart disease, a simultaneous recording of the mitral and aortic-left atrial areas was performed using two ultrasonoscopes and recorders.

Angiographic Studies
After obtaining informed consent, six patients undergoing cardiac catheterization for coronary artery disease were placed in the 30° RAO projection and contrast material was injected into the pulmonary artery with filming of the left atrial area over several beats at 32 frames per second. The magnification factor was determined for each patient as previously described. The left atrial echocardiogram was recorded simultaneously with the angiogram so the cardiac cycles and dimensions could be matched using both methods. Frame by frame analysis of the left atrial angiogram was performed for a minimum of one complete cardiac cycle and plotted against time. The posterior aortic wall motion was plotted against time for the cycles corresponding to those analyzed on the angiogram.

Hemodynamic Studies
Manometer tip catheters (Millar #5 F) were placed into the left ventricle retrograde and left atrium transseptal in four patients with secundum atrial septal defects with pulmonic to systemic flow ratios ranging from 1.5 to 2.5. Either the left atrial catheter was manipulated into the left ventricle or vice versa for exact equalization of zero level and sensitivities. Then one catheter was pulled back into the appropriate chamber to record simultaneously left atrial and left ventricular pressures. These pressures were printed on a strip chart recorder with the aortic-left atrial and mitral valve echocardiograms allowing us to correlate hemodynamic and echocardiographic events.
Results

Echocardiographic Studies

A typical normal left atrial echocardiogram is shown in figure 1 with a schematic illustration in figure 2. The posterior aortic wall is at its most anterior position at point O. It moves rapidly posteriorly until point R where the motion slows and becomes more horizontal. This O-R segment corresponds to the rapid emptying of the left atrial blood into the left ventricle after the opening of the mitral valve. From point R to point A the wall motion is relatively flat corresponding to the portion of diastole when the left atrium acts as a conduit for blood flowing from the pulmonary veins through the left atrium and open mitral valve into the left ventricle. At point A the posterior aortic wall moves rapidly posteriorly following the P wave of the ECG. This A wave corresponds to forceful emptying of left atrial blood into the left ventricle with atrial systole. Beginning at point V, the posterior aortic wall moves anteriorly corresponding to left atrial filling after mitral closure and during ventricular systole. Note the posterior aortic wall motion continues anteriorly after aortic valve closure until the following point O when the mitral valve once again opens allowing the left atrium to empty.

IC is an anterior deflection of the posterior aortic wall occurring immediately after point V and is temporally related to isovolumic contraction. IR is a posterior deflection of the posterior aortic wall occurring immediately after aortic valve closure and is related temporally to isovolumic relaxation. Evidence for the etiology of these deflections will be presented in the hemodynamic section of our results.

Figure 3 shows the echocardiograms from our patient with congenital heart block. Using two different systems, the aortic-left atrium and mitral valve areas were recorded simultaneously, although paper drives of the recorders ran at slightly different speeds. The P waves march through the independent regular ventricular rhythm. The first P wave occurs during ventricular systole when the mitral valve is closed, yet there is a posterior deflection of the posterior aortic wall (first short vertical arrow) corresponding to left atrial emptying. Since the mitral valve is closed, we presume that left atrial blood is forced retrograde into the pulmonary veins. The same sequence of events is repeated with the third P wave. The second and fourth P waves occur during ventricular diastole and open the mitral valve allowing left atrial blood to leave the left atrium and the posterior aortic wall to move posteriorly. The fifth P wave occurs at the end of a long ventricular diastole when the left atrium has had considerable time to empty and just after ventricular systole has closed the mitral valve. As a result, there is no left atrial emptying and no perceptible posterior aortic wall motion. However, the seventh and ninth P waves occur before ventricular systole closes the mitral valve and allows the left atrium to empty and the posterior aortic wall to fall posteriorly. The sixth P wave occurs early in ventricular diastole when the left atrium normally is rapidly passively emptying and the posterior aortic wall is moving rapidly posteriorly. Because active left atrial systolic emptying is superimposed on the rapid passive emptying phase, the posterior aortic wall moves more rapidly posteriorly (first oblique arrow). The eighth and tenth P waves occur even earlier in ventricular diastole resulting in steeper posterior aortic wall motion (second and third oblique arrows).

Angiographic Studies

Figure 4 shows a tracing of a typical left heart angiogram in the RAO view at end ventricular systole (solid line) and at end ventricular diastole (dotted line). The reference system used here includes an external grid and notation of an im-

![Figure 1](http://circ.ahajournals.org/)

**Figure 1.** Typical aortic-left atrial echocardiogram. O = beginning of rapid left atrial emptying after the mitral valve opens; R = end of rapid left atrial emptying and beginning of the left atrial conduit phase; A = beginning of left atrial systolic emptying; V = end of left atrial emptying with the onset of ventricular systole; IC = anterior deflection of the posterior aortic wall occurring during isovolumic contraction; IR = posterior deflection of the posterior aortic wall occurring during isovolumic relaxation; AAW = anterior aortic wall; AV = aortic valve; PAW = posterior aortic wall; PLAW = posterior left atrial wall.

![Figure 2](http://circ.ahajournals.org/)

**Figure 2.** Schematic drawing illustrating the posterior aortic wall motion relative to the mitral valve motion. AML = anterior mitral leaflet; PML = posterior mitral leaflet.
mobile diaphragm. As the left atrium empties during diastole, its superior margin remains fixed by the pulmonary veins while its anterior wall and the posterior aortic wall move posteriorly and its inferior border and the mitral valve anulus move superiorly. During ventricular systole the left atrium fills and increases in size with its anterior wall and the posterior aortic wall moving anteriorly and its inferior border and mitral valve anulus moving inferiorly.

There was excellent correlation between the change in the left atrial angiographic area and posterior aortic wall motion in all six patients. Figure 5 shows the plots of posterior aortic wall motion and left atrial angiographic area versus time from two of the six patients. With the opening of the mitral valve, the left atrial angiographic area rapidly decreases in size, then remains relatively constant during the conduit phase of left atrial emptying, and again decreases in size with the left atrial systolic contraction. These three phases of left atrial emptying are seen well on the simultaneous plot of echocardiographic diastolic posterior aortic wall motion. Figure 5 also illustrates how an increase in heart rate eliminates the conduit phase as diastole becomes shorter.

With the onset of ventricular systole and mitral valve closure, the angiographic atrial area increases until the mitral valve reopens. The echocardiographic posterior aortic wall anterior motion during systole matches this angiographic change.

Hemodynamic Studies

Figures 6 and 7 show typical recordings of left atrial and left ventricular pressures with echocardiograms of the aortic-left atrial and mitral valve areas from one of our patients with an atrial septal defect. Here we only observe the echocardiographic pressure relationships and tentatively extrapolate these relationships of the left atrium to normals. None of our patients had equalization of right and left atrial pressures.

Following the electromechanical delay from onset of the P
wave (fig. 6, interval 1–2), the left atrial a wave is apparent in the left atrial pressure tracing. The delay (fig. 6, interval 2–3) between the onset of the left atrial a wave and the beginning of the rise in the left ventricular pressure is presumably due to the time necessary for the pressure generated in the left atrium to cause flow from the left atrium into the left ventricle. The A wave of the posterior aortic wall is coincident with flow from the atrium into the ventricle and the rise in left ventricular pressure at end diastole (fig. 6, line 3). When the left ventricular end-diastolic pressure exceeds the left atrial systolic pressure, the anterior mitral leaflet begins to close and move posteriorly back toward the left atrium producing a second hump in the left atrial a wave pressure tracing (fig. 7, line 4).

Left atrial emptying ceases when the mitral valve is closed at the onset of ventricular systole (fig. 7, line 5). This corresponds to point V on the posterior aortic wall (fig. 6, line 5). As systole begins, the mitral valve is pushed posteriorly into the left atrium during isovolumic contraction (fig. 7, interval 5–6) and the c wave is seen in the left atrial pressure. This seating of the mitral valve with isovolumic contraction and the left atrial c wave coincide with the posterior aortic wall IC notch (fig. 6, interval 5–6). There next follows a period (fig. 6, following line 6) during which the left atrial pressure continues to fall, while the posterior aortic wall moves anteriorly (increase in left atrial volume). This may either be due to left atrial relaxation or secondary to the ventricle pulling the mitral valve anulus inferiorly resulting in a suction component to left atrial filling. The left atrial pressure next gradually increases and then accelerates its rate of rise (v wave) as the left atrium becomes more distended and less compliant.

The posterior aortic wall continues to move anteriorly throughout ventricular systole and after the ventricular pressure falls below the aortic pressure until point O (fig. 6, line 7) when the left atrial pressure exceeds the left ventricular pressure and the mitral valve begins to open (fig. 7, line 7). The left atrium then rapidly empties with a rapid decrease in left atrial pressure (fig. 6, lines 7–8). During the following conduit phase of left atrial emptying (fig. 6, R–A) the atrial and ventricular pressures are equal and increasing. This increase in left ventricular and left atrial pressures may explain why the posterior aortic wall moves slightly anteriorly during the conduit phase in some patients. As the left ventricular diastolic pressure increases, left atrial volume may increase due to the left atrial compliance characteristics.

### Discussion

While others have correlated maximum left atrial echocardiographic dimensions with maximum left atrial angiographic dimensions,1–2 we present data investigating the echocardiogram’s potential for describing the left atrial volume curve throughout the cardiac cycle. This paper attempts to show that posterior aortic wall motion is largely governed by left atrial volume change and this echo describes the left atrial volume curve throughout the cardiac cycle.

In order to understand how the posterior aortic wall motion could describe the left atrial volume curve, it is useful to review the anatomy of the left atrium. Posteriorly the left atrium is bound by the pulmonary veins and mediastinum. In the supine position the weight of the heart compresses the posterior left atrial wall against mediastinal structures supported by the immobile thoracic spine. Therefore the echocardiogram of the supine patient shows little motion of the posterior left atrial wall, and most of the left atrial volume change is reflected in the motion of the anterior left atrial wall. However, anteriorly the left atrium and posterior aorta share a common wall at the aortic root level and produce the posterior aortic wall echo.7 These series of observations suggest that the posterior aortic wall motion reflects left atrial volume change despite lateral atrial motion not seen on the echocardiogram. In fact, the left atrium moves the whole aorta at the level of the aortic valve and explains the nearly parallel anterior and posterior aortic wall motion. The anterior aortic wall motion often does not exactly parallel the posterior aortic wall motion since the aorta is also distended laterally by the ejection volume.

Hawley et al.,8 Burn and Brode,9 Gribbe et al.10 and Murray et al.,11 all previously have described the left atrial angiographic dimensions throughout the cardiac cycle. Our
left atrial angiogram curves agree with theirs and closely correspond to simultaneously recorded posterior aortic wall echocardiograms.

We hypothesize the following mechanism to explain the motion of the posterior aortic wall. During ventricular systole, posterior aortic wall motion is due to a combination
of left atrial volume increase, ballistic forces during ejection, distension of the aorta during ejection, and forces generated by the ventricular muscle contraction sequence. The left atrial-left ventricular angiograms (fig. 4) show this motion, as well as the inferior motion of the interior atrial wall-mitral valve anulus structure. Whether this inferior motion is secondary to the left atrial filling pushing the mitral valve anulus inferiorly or due to the left ventricle contracting and pulling the mitral valve anulus inferiorly is unclear from our observations. The fact that the left atrial pressure decreases between the c and v waves could be regarded as due to left ventricular contraction pulling the mitral valve anulus inferiorly, increasing the left atrial size and decreasing the left atrial pressure; or this drop in left atrial pressure could be secondary to left atrial relaxation following left atrial systole.

During ventricular diastole, following the opening of the mitral valve, the posterior aortic wall moves rapidly posteriorly until R because of rapid passive left atrial emptying, allowing the posterior aortic wall to fall posteriorly (fig. 2). Following R and until A (R–A), the posterior aortic wall motion may be flat or move slightly anteriorly. The R–A segment corresponds to the conduit phase of the left atrium as blood flows from the pulmonary veins into the left ventricle. In their studies, Hawley et al. and Murray et al. calculated that this left atrial conduit phase accounted for a widely varying percentage (averaging 60%) of the left ventricular stroke volume. We suggest that the posterior aortic wall R–A segment often moves slightly anteriorly because as left ventricular pressure increases during mid-diastole, atrioventricular flow is reduced and atrial volume and pressure increase according to the left atrial compliance characteristics. Following the P wave of the ECG, the posterior aortic wall moves abruptly posteriorly (A–V) reflecting left atrial systole and a further active decrease in left atrial size. The data from the patient with congenital heart block show the variable timing of the A wave coincident with the ECG P waves (fig. 3). Thus, the motion of the aortic root during ventricular diastole appears to be affected mainly by changes in left atrial volume.

There are other segments of posterior aortic wall motion that we have noted on the posterior aortic wall echogram. After the first heart sound and during isovolumic contraction there is a small anterior deflection of the posterior aortic wall that we have labeled IC (fig. 2). There is also a small posterior deflection of the posterior aortic wall that occurs after the second heart sound during isovolumic relaxation that we have labeled IR. Our hemodynamic data suggest the IC wave is the result of the mitral valve bulging into the left atrium during isovolumic contraction producing the left atrial pressure c wave which briefly pushes the posterior aortic wall anteriorly (fig. 6). The exact mechanism of the IR wave is still unclear from our observations.

While we have postulated that posterior aortic wall motion reflects the left atrial volume curve, Zaky et al. have postulated that a continuous structure, the mitral valve anulus, describes a left ventricular volume curve. In fact these authors might have been describing the posterior aortic wall echo. We propose that posterior aortic wall motion mainly is produced by left atrial volume change with some contribution from the motion of the heart particularly during systole and with little effect from left ventricular volume change or aortic flow. There are several pieces of evidence that favor this hypothesis. 1) The anterior motion of the posterior aortic wall (V–O) continues anteriorly even after the aortic valve has closed and before the mitral valve has opened, when left ventricular volume remains constant. Since the left ventricle is no longer ejecting blood (and has already begun to relax), this continued anterior motion of the posterior aortic wall during isovolumic relaxation cannot

![Figure 8. Aortic and left atrial pressures recorded simultaneously with the aortic-left atrial echocardiogram. Note that while the ectopic beat generates only a small aortic pulse pressure (long vertical arrow), the posterior aortic wall continues to move in a normal fashion (small vertical arrow) suggesting a pulsatile aorta is not the major determinant of posterior aortic wall motion. In addition, note that the beat following the PVC is a nodal escape beat not preceded by a p wave. The failure of the posterior aortic wall to move posteriorly prior to this ventricular systole contrasts with the posterior aortic wall motion preceding the first two sinus beats.](http://circ.ahajournals.org/doi/abs/10.1161/01.CIR.41.1.749)
be explained by the left ventricle alone. However, the left atrial hypothesis explains this observation since the left atrium continues to fill during isovolumic relaxation and push the posterior aortic wall anteriorly until the mitral valve opens. 2) When left atrial systole occurs during ventricular systole when the mitral valve is closed, in complete heart block, the posterior aortic wall still moves posteriorly because of left atrial ejection of blood presumably into the pulmonary veins (fig. 3, first p wave. 3) We know that ventricular filling continues throughout diastole, yet the posterior aortic wall may move both posteriorly (O–R and A–V segments) and anteriorly (R–A segment) during diastole. However, our atrial hypothesis explains this observation because while the left atrial volume decreases during the early diastolic and atrial systolic phases, it may increase during the mid-diastolic conduit phase. During mid-diastole, the left ventricular pressure increases, reducing atrioventricular flow, and there may be a net increase in the atrial volume. 4) In the patient in figure 8, a premature ventricular contraction resulted in only a small aortic pulse pressure (long vertical arrow), yet the posterior aortic wall continued to move in a way identical to the previous beat (short vertical arrow) when there was a normal volume of blood flowing through the aorta. This observation suggests that the volume of blood flowing through the aorta is not responsible for the posterior aortic wall motion. While posterior aortic wall motion may be the result of several factors, the work presented in our paper supports the hypothesis that posterior aortic wall motion during ventricular diastole is governed principally by left atrial events and describes left atrial emptying. Aortic wall motion during ventricular systole is complex but seems to reflect in part left atrial filling. Since left atrial volume changes are important to the understanding of various cardiac disease states, such as mitral stenosis, mitral regurgitation, and increased ventricular stiffness, posterior aortic wall motion should be helpful in quantitating these conditions. Our preliminary data support this concept and further investigation in this area is continuing.

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