Non-invasive left ventricular volume determination by two-dimensional echocardiography

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Twenty patients undergoing routine left ventricular single-plane angiography have been investigated by an ultrasonic triggered B-scan technique to provide a two-dimensional cross-sectional image of the left ventricle in end-systole and end-diastole. An area-length method has been used to establish the correlation between the angiographic and the echocardiographic assessments of left ventricular chamber volume \( r=0.88 \) and ejection fraction \( r=0.81 \). Differences between the two techniques are discussed, and it is concluded that in approximately 80 per cent of patients triggered B-scanning may provide a safe, non-invasive, and convenient technique for the determination of volumes and certain functional parameters, especially in patients with dilated hearts and irregular left ventricular shape, where M-scanning is known to be less reliable.

Numerous authors have demonstrated a good correlation between the left ventricular (LV) volume calculated from the angiocardiogram and the cube of the left ventricular internal diameter obtained from a single linear ultrasonic measurement by M-scan (Feigenbaum et al., 1972; Fortuin et al., 1971; Gibson, 1973; Kreamer, Kerber, and Abbout, 1973; Ludbrook et al., 1973; Murray, Johnston, and Reid, 1972; Pombo, Troy, and Russell, 1971; Popp and Harrison, 1970). This does not hold for dilated ventricles (Fortuin et al., 1971; Kreamer et al., 1973; Ludbrook et al., 1973), and as we are often confronted with such cases it was felt that some improvement in method was called for. We were reluctant to depart from ultrasound techniques with their non-invasive character and safety and so looked to an obvious extension of the one-dimensional M-scan measurement, namely to cross-sectional cardiac ultrasonography by triggered B-scan (Gramiak and Waag, 1973; Kikuchi, 1968; King, 1973; Nimura et al., 1973; Tanaka et al., 1971). The pilot study of King et al. (1972) on 8 patients, while indicating that this method may be useful in assessing left ventricular volume, also showed a rather poor correlation with biplane angiocardiographic data for large volumes. However, we felt that this technique had so many advantages over angiocardiography for assessing cardiac performance, that further refinement of King's approach to this problem seemed worthwhile. In this paper we compare the results of measuring left ventricular volumes by a modified triggered B-scan technique with the findings at left ventriculography.

Methods

To achieve two-dimensional echograms, a Picker Echoview IV Laminograph was used. A conventional B-scan, as used in obstetrics, is not satisfactory for scanning the heart, because the cardiac motion results in blurred images, in which echoes obtained in systole are superimposed on those obtained in diastole. Therefore, it was necessary for the machine to be modified by the manufacturers to generate ultrasound pulses for only a short time (10 ms) within each cardiac cycle, the emission being actuated electronically, and triggered by the R wave of the electrocardiogram, which must be monitored simultaneously. A built-in delay control allows the emission burst, the gate, to be chosen at any preselected phase of the cardiac cycle. The timing of this short emission is shown as a time-marker line on a displayed electrocardiogram, as well as on a mitral valve echogram (M-scan) obtained as a preliminary to the triggered B-scan (Fig. 1).

Triggered B-scans produce a true cross-sectional
image of the heart, and it is of importance that the same plane through the heart is scanned in all cases. For consistent and reproducible results, a method of fixing the standard plane for cardiac B-scanning is required; it is necessary that the aortic root, aorto-mitral transition zone, the bases of both anterior and posterior mitral valve leaflets, and the left ventricular apex, are simultaneously imaged and recognizable within one plane, which in our experience is unambiguously fixed by these five landmarks. Initially, the apex beat is identified by palpation and marked on the chest wall. The position of the strongest echoes from the mitral valve is located by T/M-mode scanning and the gantry rotated so that the scanning plane passes through this point and the palpated apex. Minor adjustments of rotation allow all five landmarks to be recognized during a single sweep from aortic root to apex. After apparent correct positioning, a slow sweep in triggered B-mode from aortic root to left ventricular apex, over a period of 70-100 cycles, builds up a stored cross-sectional image of the left ventricular cavity, which is photographed on polaroid film from the B-scan storage tube. The examination is performed with triggering both in systole and diastole. In practice, the examination may have to be repeated as the ideal orientation of the scanning plane has to be found by trial and error, and this may be a time-consuming procedure. Fig. 2 illustrates a typical triggered B-scan. It is convenient to present the scans in the orientation shown, as it reflects the anatomical configuration in the scanning plane as seen by the observer (Fig. 3).

The timing of the trigger pulse within the cardiac cycle is determined by mechanical, rather than electrical, events within the heart. We assume that end-diastole, the largest volume the ventricle achieves, occurs immediately before the mitral valve closes, and end-systole, the smallest volume the ventricle achieves, occurs immediately before the mitral valve opens. The emission of the short burst of ultrasound can be electronically adjusted in relation to the R wave trigger, to occur at these moments, identified on a previously recorded M-scan (Fig. 1).

Left ventricular volumes were also calculated from single-plane cineangiograms performed in the right anterior oblique projection. The left ventricle was opacified, as a routine, with 50 ml of contrast medium injected at 10 ml/s by a rate-controlled electromechanical injector. Larger volumes were used with larger ventricles. The smallest and largest calculated volumes during the cardiac cycle were taken as end-systolic and end-diastolic volumes. Each cine film was projected by a Vanguard motion analyser onto a P.C.D. trace reader coupled in turn through digital voltmeters to an Olivetti P602 programmable calculator. The magnification factor was assessed as the ratio of the projected to the true catheter diameter. Ventricular volumes were calculated by the method of Kasser and Kennedy (1969). The long axis was first determined as the distance from the posterior aortic root to the apex of the left ventricle. Planimetry of the ventricular outline was performed automatically as the cursor travelled round the ventricular cavity. The ventricular volume was then automatically calculated from the previously supplied magnification factor (J. Darmon, 1974, personal communication). The same apparatus and programme were utilized for both B-scan and angiographic volume determinations. The significance of the aorto-mitral transition zone echo-landmark is clear from the above measurement procedure and the mitral valve landmarks are important for accurate delineation of the left ventricular chamber area, especially in end-diastole as shown in Fig. 4.

Subjects
The 20 adult patients in this study were all subjects undergoing left ventriculography for diagnostic purposes. The triggered B-scans (ultrasonograms) and the angiograms could not, of course, be recorded simultaneously, but were almost all performed within 24 hours of each other. Selection was solely on the basis of the patients having both a satisfactory B-scan and a ventriculogram suitable for volume measurements. A number of patients (about 20%) had to be rejected as either
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FIG. 2 Typical triggered B-scan in end-diastole showing the aorta (AO), the anterior root in continuity with the interventricular septum (IVS), and the posterior root with the anterior leaflet of the mitral valve (ALMV); the posterior leaflet of the mitral valve (PLMV), the left ventricular posterior wall (LVPW), the right ventricular anterior wall (RVAW), the right ventricle (RV), the left ventricle (LV), and the left atrium (LA) are clearly delineated.

FIG. 3 Orientation of the typical triggered B-scan of Fig. 2 in the standard longitudinal scanning plane.

Results

The left ventricular volumes derived from the ultrasonograms were plotted against the angiographic volumes at end-systole and end-diastole in Fig. 5. The correlation coefficient, $r$, is 0.88 ($P < 0.001$) and the regression equation is given by $y = 0.76x + 32$, with standard error of estimate, $s = 57$ ml. The correlation between the ejection fractions is shown in Fig. 6; $r = 0.81$ ($P < 0.001$) and the regression equation is given by $y = 0.66x + 13.2$, with $s = 11.5$ per cent.

Discussion

The comparison of our results with those of King et al. (1972) shows that similar accuracy is obtained for smaller volumes (< 250 ml). Though the scatter in our data becomes larger for larger volumes (up to 600 ml), the slope of the regression line is maintained quite close to unity (the theoretically expected value) in contrast to that of King et al.

Perfect correlation between angiographic and ultrasonic volumes is not to be expected. There is an essential difference between the angiographic and B-scan techniques; the former produces a projection image, whereas the latter gives a true cross-section. Clearly, the identical plane is not imaged in both cases but the oblique scanning plane gives a cross-sectional image similar to the chamber outline seen at right anterior oblique left ventriculography. The magnification factor for the angiograms was determined only by comparing the width of the catheter on the cine film with its known diameter, and the small scale of these measurements makes accuracy difficult. Ultrasound errors relate to an assumed velocity of ultrasound in tissue,
Outlining of the left ventricular cavity to calculate the corresponding volume by the area-length method. $L = \text{length}$.

<table>
<thead>
<tr>
<th>Diagnosis</th>
<th>No. of cases</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hypertrophic obstructive cardiomyopathy</td>
<td>5</td>
</tr>
<tr>
<td>Congestive cardiomyopathy</td>
<td>2</td>
</tr>
<tr>
<td>Mitral stenosis</td>
<td>2</td>
</tr>
<tr>
<td>Aortic stenosis</td>
<td>1</td>
</tr>
<tr>
<td>Subvalvular aortic stenosis</td>
<td>1</td>
</tr>
<tr>
<td>Mitral regurgitation + aortic regurgitation</td>
<td>1</td>
</tr>
<tr>
<td>Coronary artery disease</td>
<td>1</td>
</tr>
<tr>
<td>Coronary artery disease + mitral regurgitation</td>
<td>1</td>
</tr>
<tr>
<td>Atrial septal defect</td>
<td>1</td>
</tr>
<tr>
<td>Pericarditis with pericardial effusion</td>
<td>1</td>
</tr>
<tr>
<td>Constrictive pericarditis</td>
<td>1</td>
</tr>
<tr>
<td>Restrictive cardiomyopathy</td>
<td>1</td>
</tr>
<tr>
<td>Marfan's syndrome</td>
<td>1</td>
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<tr>
<td>Takayashu's syndrome</td>
<td>1</td>
</tr>
</tbody>
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which differs from that in blood by about 2 per cent, leading to a volume error of at least 6 per cent. Angiographic measurements generally include the volumes of the papillary muscles and trabeculae (Greene et al., 1967), whereas ultrasound reflections take place at blood-muscle interfaces excluding these structures, leading to an underestimate of cavity volume as compared to angiography. At small volumes, papillary muscles and trabeculae become so prominent at left ventriculography that they tend to be excluded from the cavity, and lead to smaller calculated volumes. This may explain the apparent overestimate of ultrasound at very small volumes, when angiography is known to be inaccurate. Finally, angiography produces an instantaneous picture of the left ventricle, whereas the triggered B-scan averages values of a large number of cycles.

Asymmetrical ventricles will lead to volume errors both by angiography and by triggered B-scans, particularly if the abnormal segments are not in the imaged plane. However, in abnormalities such as hypertrophic cardiomyopathy (Goodwin, 1967)
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References


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