Multiscan Echocardiography

II. Technique and Initial Clinical Results

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SUMMARY
A multiple element ultrasound system has been developed which provides moving cross-sectional images of the heart. Unique features are the capacity to display substantial segments of cardiac structures and to show them in continuous, real-time motion. Two standard transducer positions have been established of which one produces images of a sagittal cardiac cross-section in the plane of the septum and the other a horizontal section across the ventricles. Studies with satisfactory detail were possible in most children and in two-thirds of adults investigated. Clinical information may be obtained regarding anatomic relationships of major structures in congenital heart disease and about cardiac valve motion and thickening or calcification in valvular heart disease. Measurements of aortic root dimensions are accurate when compared with angiography. Ventricular dimensional measurements are not validated as yet. The Multiscan concept is still under development, but shows promise of significantly expanding the capabilities of clinical echocardiography.

Additional Indexing Words:
Ultrasound  Echograph  Noninvasive techniques

Despite rapid advances in clinical echocardiography over the past few years there remain some distinct limitations to the method. These are due in part to the use of single element transducers, with the resulting "flashlight beam" or "gunbarrel vision" image. In an effort to overcome this problem, a multiple element ultrasound system has been designed to provide noninvasive visualization of moving cross-sections of the heart. Technical descriptions of the instrument have been reported previously. The transducer consists of 20 adjacent piezo-electric elements in a linear array. Rapid electronic switching from one element to the next and appropriate display of resulting echoes produces a continuous two-dimensional image of cardiac structures. To date clinical studies have been carried out with this system in over 250 patients in all age groups and with a wide spectrum of heart disease. This paper reports the techniques which have been developed for using the instrument on human subjects and the initial clinical results.

Technique
Efforts have been made during studies of the first 150 patients with the new instrument to develop relatively standard techniques in positioning the transducer on the precordium. This was attempted for two purposes: to determine the most efficient and productive examination procedure and to establish standard views or anatomic projections. Two basic positions have evolved, one obliquely vertical and the other horizontal on the precordium. In the first position the probe is placed to the left of the sternum with the upper end at the costosternal border and the lower end angled outward from the midline about 30° (fig. 1). The long axis of the transducer is in the plane of the septum and along the pathway of the "sweep" motion used in single element echocardiography.

This produces a sagittal cross-sectional display of the heart similar to that seen on an angiocardiogram recorded with the patient in the right anterior oblique position (fig. 2). When the transducer is pointed straight posteriorly, the first structure identified is usually the aortic root. The left atrium is seen posterior to the aorta and the pulmonary outflow tract is anterior. The anterior mitral valve leaflet extends downward in direct continuity with the posterior aortic wall, and the ventricular septum is seen somewhat less clearly as a direct extension of the anterior aortic wall. Tilting the transducer so that it is directed slightly to the patient's left improves definition of the left atrial wall and cavity,
the posterior mitral leaflet and the posterior left ventricular wall. When the probe is directed more to the patient's right, the ventricular septum, right ventricular cavity and pulmonary outflow tract become better defined.

In the second standard position the transducer is placed horizontally to the left of the sternum along the third or fourth intercostal space (fig. 1). The upper end of the transducer (as displayed on the oscilloscope) is placed to the patient's right for uniformity and ease of orientation. The image produced is a horizontal cross-section through the ventricles roughly perpendicular to the long axis of the heart (fig. 3). The right ventricle is anterior and the left ventricle posterior, with the ventricular septum angling from the lower left to upper right on the display screen. Rocking the transducer inferiorly and superiorly establishes the position in which the cross-sectional diameters of the ventricles are greatest.

At this point the septum is usually well defined and the anterior mitral valve leaflet is seen moving within the left ventricular chamber. Directing the probe further superiorly demonstrates the ventricular septum merging into the anterior aortic wall and the anterior mitral leaflet continuous with the posterior aortic wall.

With both transducer positions the patient has usually been examined in the supine position with the upper trunk elevated about 30°. Attempts to enhance the image in difficult studies by recording with the patient sitting up, leaning forward or in the left lateral position have usually not improved the image appreciably. A striking difference from conventional single element echocardiography has been the ease with which cardiac structures can be identified from the Multiscan image. This is particularly true using the oblique probe position; those experienced in angiocardiography are immediately oriented and recognize familiar landmarks. As a consequence, learning to use the instrument has been more rapid and less demanding technically than with the single element method.

**Initial Results**

During the initial 150 patient studies with the Multiscan instrument, observations were recorded regarding the frequency and clarity with which important cardiac structures were recognized. Evaluations were subjective but semi-quantitative: for the aortic root, "excellent" indicates a very sharp image with the valve cusps visible in systole and diastole, "good" indicates that the cusps are visible in diastole only, "fair" denotes a clear image of the aorta without discrete valve cusps, and "poor"
Figure 2

Sagittal cardiac cross-section obtained with the oblique transducer position. The row of dots on the left indicates the transducer location on the anterior chest wall. The aortic root (AO) with closed valve cusps (C) is in the upper center, with the right ventricular outflow tract (RVO) anterior and the left atrium (LA) posterior to it. Other structures identified include the ventricular septum (VS), anterior mitral leaflet (AML), posterior left ventricular wall (PVW) and ventricular cavities (RV and LV). Polaroid photograph taken in late diastole (arrow) from the oscilloscope display.

implies a fuzzy, indistinct aortic outline. The results are shown in figure 4.

The aortic root is the structure recognized first and most frequently, even in technically difficult patients. It is seen with sufficient clarity to identify the valve leaflets (excellent or good) in 70% of patients. The anterior mitral leaflet is usually visible, but may be obscured in part of its length by overlying ribs in adults. However, it is seen well enough to evaluate mobility in about 60% of patients. The ventricular septum is seen with excellent definition less frequently, probably because the endocardial surfaces are at an unfavorable angle with the transducer beam, resulting in less distinct echoes. Posterior left ventricular wall motion is clearly visible in about three-fourths of the patients. With the current instrument the endocardial and epicardial surfaces are not suffi-
sufficiently well defined on the oscilloscope display to measure wall thickness. No structures are seen in less than 5% of all patients.

The Multiscan technique is subject to the same physical limitations of sound transmission as conventional single element techniques. Thus, intervening air spaces or dense tissues may prevent satisfactory transmission of echoes from the heart. The commonest cause of a difficult or unsatisfactory study is a small "pericardial window" due to pulmonary emphysema or a barrel chest. Heavily calcified ribs may obscure strips of the image, but considerable detail is usually visible between the obscured areas, enhanced by the fact that structures are moving. Calcification of the sternum is usually too dense by the age of five or six years to permit adequate transmission of echoes. However, it was found in infants and young children that the transducer can be placed directly over the sternum for visualization of right heart structures.

Occasionally chest deformities such as pectus excavatum or precordial bulging will prevent satisfactory contact of the transducer with the skin. Overall, satisfactory studies are possible in nearly all infants and children, and in about two-thirds of adults, with the poorest results in elderly people.

Cardiac Findings

The anterior leaflet of the mitral valve is seen as a direct continuation of the posterior aortic root, as

Figure 3

Horizontal cross-section through the ventricles. The patient's anterior chest is to the left. The ventricular cavities (RV and LV) and the septum (S) are labelled in the tracing. The upper four elements and right heart are obscured by the sternum and the anterior cardiac wall by air in interposed lung.

Figure 4

Multiscan image quality in 150 consecutive patient studies. The age distribution was: 1 to 10 years - 20%, 11 to 20 years - 34%, 21 years and older - 56%.
described previously with single element echocardiography. Anterior leaflet motion is best visualized with the transducer in the oblique position. The normal anterior leaflet is a thin structure with striking flexibility and mobility (fig. 5). At the onset of ventricular diastole it swings open briskly and often appears to slap the ventricular septum, then drifts slightly posteriorly. With atrial contraction at end-diastole the leaflet again swings anteriorly, then snaps shut at the onset of systole. The anterior leaflet thus describes the “M-shaped” pattern of motion observed in single element echocardiographic studies.4,5 The posterior mitral leaflet is a much shorter and thicker structure on the posterior wall against which the anterior leaflet closes. The apparent length and amplitude of motion of the posterior leaflet varies among individuals, but it always appears shorter and more limited in excursion than the anterior leaflet.

With mitral stenosis, alterations are seen primarily in anterior leaflet mobility and thickness. In mild stenosis the anterior leaflet opens in a jerky manner and usually the amplitude of opening is diminished. Bowing or bulging of the mid-portion of the leaflet is sometimes apparent. In severe stenosis, the anterior leaflet appears as a thickened, dense echo shadow with severely restricted motion (fig. 6).

The aortic root is visible as two parallel echoes at the base of the heart. In some cases the wider sinuses of Valsalva narrowing into the ascending aorta can be identified (fig. 7). The aortic valve cusps are visible during ventricular diastole as fine structures centered in the base of the aorta, and in optimal studies are also seen in the open position during systole. In aortic stenosis the valve cusps become dense and thickened, and mobility is impaired. Resolution of the aortic walls is sufficiently clear that the aortic root diameter can be measured accurately. A comparison of aortic root diameters measured from angiocardiograms and from Multiscan echocardiograms in 23 patients is

![Figure 5](http://example.com/figure5.jpg)

*Normal mitral valve motion. Cardiac orientation is as in figure 2. The anterior leaflet swings far anteriorly in early diastole, partially closes in mid-diastole, then reopens with atrial systole. The posterior leaflet is a short echo structure against the posterior ventricular wall. The mitral valve remains closed throughout systole.*
shown in figure 8. Mean values by the two methods are nearly identical.

A valuable attribute of the Multiscan instrument is the capability of displaying the ventricular septum and posterior left ventricular wall simultaneously as moving structures, thus permitting dimensional analysis and wall motion studies. With careful positioning of the transducer in the oblique position both the septum and posterior wall can often be seen from the aortic root and mitral ring to near the apex. The clarity with which the left ventricular apex can be seen varies depending on the length of the ventricle and the reflectivity for echoes from the apex. In the best studies it is possible to visualize the entire outline of the ventricular cavity as it is seen on angiocardiograms recorded in the right anterior oblique position. In such patients it may be possible to make left ventricular volume calculations using the standard formulas based on the ellipsoid of revolution concept (fig. 9).\textsuperscript{6} When the apex is not well seen it still may be possible to select a representative minor axis of the ventricle and calculate circumferential fiber shortening rate and/or volume data using previous echocardiographic formulas.\textsuperscript{4-6} Efforts to validate these approaches are currently underway.

With the transducer in the vertical position the right ventricular cavity and pulmonary outflow tract are usually seen in an oblique section not suitable for dimensional analysis. However, with the transducer in the horizontal position a cross-section across the right ventricular chamber is frequently apparent. By tilting the probe upward and downward one can establish the maximum cross-sectional dimensions of the right ventricle and assure that the appropriate segment is being evaluated. In infants and young children it is possible to obtain similar information about the right ventricle and pulmonary outflow tract by

Figure 6

\textit{Sagittal cross-section in severe mitral stenosis.} The calcified, thickened mitral valve is seen as a dense echo in the middle of the frame. The aortic root is directly above it and the large left atrium is to the right, with the left atrial wall visible at the far right. This is a forty line display currently produced by interlacing two consecutive Multiscan frames.
Figure 7

A single frame from a 16 mm cine film of a normal aortic root during diastole (A). The thin, closed valve cusps and narrowing of the sinuses of Valsalva into the ascending aorta are seen. In a patient with aortic stenosis the valve cusps appear as dense, thickened echoes in diastole (B) which open incompletely during systole (C).

positioning the transducer over the sternum horizontally at the level of the 3rd or 4th intercostal space.

Display Modes

A major advantage of Multiscan echocardiography is the capability of displaying simultaneously large segments of the heart rather than isolated points. Structures such as the anterior mitral leaflet and aortic root look like familiar anatomic cross-sections. This facilitates overall orientation and specific echo identification. A second advantage is the ability to display such structures as continuously moving echo images. As a result, dynamic characteristics such as mobility, flexibility and overall movement are better appreciated than with single element echo techniques. However, with these attractive features problems
AORTIC ROOT DIAMETER

![Graph showing comparison of aortic root diameter measured from cineangiograms and from video tape recordings of the Multiscan display in 23 patients.](image)

**Figure 8**

Comparison of aortic root diameter measured from cineangiograms and from video tape recordings of the Multiscan display in 23 patients. Five separate frames were measured and the average was used. There is a close agreement between the two methods (P < 0.001, chi square test).

are introduced in obtaining permanent records, particularly if records of the quality seen during the original study are expected. At present the best image is always seen on the oscilloscope displaying the primary signal from the Multiscan.

Storage on video tape will provide a permanent record for subsequent viewing or quantitative measurements and retains the unique capability of Multiscan to demonstrate anatomic relationships in motion. However, considerable degeneration of the image occurs. The same is true when the oscilloscope image is recorded on cine film. Although the image remains reasonably clear when viewed in motion, it deteriorates considerably with single frame projection. This phenomenon has been recognized for years in cineangiography and is related to the visual integration which occurs when sequential images are viewed with a sufficiently rapid repetition rate. For single frame records and analysis, Polaroid photographs taken from the oscilloscope image are an acceptable solution and avoid the added expense and processing required for cine filming. Triggering the camera from the electrocardiogram permits the recording of specific events such as end-systole and end-diastole.

In addition to the multiple element display recording modes, the Multiscan has the capability of displaying echo signals from any individual element in the standard time-motion mode. These can either be viewed on the oscilloscope or recorded on a line scan recorder. The resolution of important boundaries such as endocardium and epicardium is equivalent to that obtained with conventional single element time-motion recordings. The Multiscan has an advantage over single element studies in providing exact localization of the echo pathway and the structures through which it passes. One can select the element passing through a specific structure on the multi-element display, switch to time-motion mode for recording, and intermittently switch back to the multi-element mode to verify the position and image quality.

At present it appears likely that records from selected individual elements will be more useful for quantitative measurements such as ventricular wall and chamber dimensions, while the multi-element display will be of greater value in establishing anatomic relationships or evaluating gross structures, as in congenital heart lesions. However, the development of display and recording modes for the Multiscan is at an early stage and is still subject to considerable refinement.

**Clinical Applications**

Although clinical experience with the Multiscan is still limited, our initial observations give some indications of potential future uses of the instrument. A promising application is in the study of infants and children with congenital heart disease. They are especially favorable subjects for ultrasound studies because of their small size, cartilagenous rib cage and lack of retrosternal air. Very good visualization of cardiac structures is nearly always possible. Demonstration of anatomic relationships, which is an important requirement in evaluating congenital heart disease, is a particular capability of the Multiscan system. It has been possible to clearly show specific abnormalities such as septal-aortic discontinuity (overriding) in tetralogy of Fallot, absence of the septum in a child with a single ventricle and abnormal positions of the...
Figure 9

Sagittal cross-section demonstrating the potential for left ventricular dimensional studies. The outline of the ventricle is clearly visible and the apex can be included by sliding the transducer downward slightly.

great vessels in transposition. Right ventricular enlargement can be shown in patients with left-to-right intracardiac shunts, as well as abnormalities in magnitude and direction of septal motion. Multiscan echocardiography may be a particularly useful tool in the noninvasive evaluation of such patients and may avoid the need for catheterization studies in critically ill patients or in those who are not likely to be candidates for surgery.

The Multiscan image provides information about valve thickening or calcification and mobility or rigidity of leaflets in aortic and mitral valve disease, particularly stenosis. Observations thus far have been only qualitative but it may be possible to quantitate the range of motion and relate this to the severity of stenosis. In patients with mitral valve prolapse the anterior leaflet displays unusual mobility and sometimes can be seen to prolapse into the left atrium. Again, the diagnosis has been made thus far by inspection only, and quantitative measurements would be desirable. The Multiscan display should be ideal for detecting left atrial masses since the entire chamber can be displayed very clearly, but we have encountered none yet.

The possibility of dimensional studies utilizing long segments of structures from the multiple-element display has been most intriguing. The close agreement of aortic root diameters measured from Multiscan and angiographic images demonstrates that this is feasible. Considerable segments of the posterior left ventricular wall and septum are visible in many patients, and ventricular dimensions obtained in this manner would be most valuable for clinical purposes. However, validation of multi-element image dimensions by comparison with single element echograms and with angiographic dimensions must be completed before such data can be used for quantitative studies.

In summary, it must be emphasized that the Multiscan concept is still in an investigational stage and its real capabilities have yet to be completely defined.
Considerable caution must be exercised in speculating about the potential clinical usefulness of the method. Questions regarding the precise resolution of cardiac structures, particularly endocardial surfaces, must be resolved. Photographic and video tape records were initially of unsatisfactory quality, but display and recording techniques have been improved and considerable further improvement can be achieved. More extensive clinical experience is needed to establish criteria for normal and abnormal findings and to determine the specific contribution of Multiscan information to clinical diagnosis. However, these initial results have been encouraging and it is believed that this concept has a considerable potential in the noninvasive study of the heart.

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