Identification and Localization of Aneurysms of the Ascending Aorta by Cross-sectional Echocardiography

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SUMMARY Although the ascending aorta may be readily examined by cross-sectional echocardiography (2-D), no data are available regarding the ability of 2-D to detect and localize aneurysms of this structure. Therefore, we compared M-mode and 2-D echograms to cineangiograms of the aorta in 32 normal subjects and 12 patients with aortic aneurysms. Measurement of aortic width was performed in the longitudinal axis just above the sinus of Valsalva in normal subjects and at the point of maximal aortic width in aneurysm patients. A good correlation ($r = 0.88$) was observed between M-mode and angiographic measurements of aortic diameter for all subjects. However, M-mode and angiographic values of aortic diameter correlated less well ($r = 0.55$) in patients with aortic aneurysms. Values for aortic size by cineangiogram and 2-D were similar for both normal subjects (mean 34 and 33 mm, respectively) and aneurysm patients (62 and 65 mm, respectively). There was an excellent correlation ($r = 0.94$) between cineangiogram and 2-D for all patients evaluated, and for patients with aneurysms ($r = 0.91$). By 2-D we detected enlargement of the aorta in all 12 aneurysm patients, and mean aortic size by 2-D was greater (63 mm) than in normal subjects (33 mm) ($p < 0.001$). The site and nature of aneurysm was accurately identified by 2-D in all patients. Thus, 2-D provides an accurate noninvasive modality for the detection and localization of aneurysms of ascending aorta.

ANEURYSMS OF THE ASCENDING AORTA, once established, characteristically exhibit progressive enlargement,¹ and may result in compression of adjacent structures or, more important, the sudden appearance of catastrophic complications such as rupture or severe aortic regurgitation. The potential consequences of these aneurysms can frequently be prevented by surgical intervention.¹ Accordingly, early identification is of major importance in the management of aortic aneurysms.

Cross-sectional or two-dimensional (2-D) echocardiography affords noninvasive visualization of the entire aortic root.²³⁴ However, no data are available regarding the accuracy of cross-sectional echocardiography in identifying aortic aneurysms. Therefore, we undertook the present study to assess the value of 2-D echocardiography in the detection and localization of aneurysms involving the ascending aorta.

Methods

Forty-four patients undergoing complete cardiovascular evaluation at the University of California, Davis-Sacramento Medical Center were selected for this study. The study group comprised 27 males and 17 females, ages 36–78 years (mean age 51 years). All patients underwent right and left heart catheterization and coronary arteriography. Thirty-two subjects had normal findings, while 12 patients had aneurysms of the ascending aorta, all confirmed by supravalvular aortography. Aneurysms were defined both angiographically and on echogram as a localized dilatation of the aortic wall. In all patients the aneurysms were either saccular — eccentric, involving only part of the circumference of the aorta — or fusiform — spindle-shaped, involving the entire aortic circumference. Various aneurysms were present in these 12 patients, including sinus of Valsalva aneurysms in three patients, massive aortic root aneurysms secondary to Marfan’s syndrome in two patients, a localized out-pouching after surgical drainage of a perivalvular abscess caused by infectious endocarditis in one patient, and fusiform aortic dilation in four patients. Two patients had dissection of the aortic wall, which was also present with massive root dilation in one of the patients with Marfan’s syndrome.

All patients in this study underwent M-mode and 2-D echocardiography and left ventricular cineangiography. In addition, supravalvular aortography was performed in all 12 patients with abnormalities of the aortic root. M-mode echocardiography was performed in the standard fashion with a commercially available ultrasonograph (Eko Sector I, Smith-Kline Instruments, Sunnyvale, California) interfaced to a fiberoptic strip-chart recorder (Model 1856, Honeywell Corporation). Cross-sectional echocardiography was performed with either a focused phased array wide angle echograph (RT400, Gruman Health Systems, Woodbury, New York) or a single-element mechanical ultrasonic sector scanner with a visualized sector arc of 30° or 80° (Eko Sector I, Smith-Kline Instruments). In each subject echograms were per-
formed in the long axis of the aorta as well as in the short axis of the aorta perpendicular to the longitudinal plane with as superior a transducer position on the chest wall as possible. Accordingly, the ultrasound transducer was positioned in progressively more superior intercostal spaces until an interpretable echogram was no longer obtainable. During echographic examination all patients were placed in a 15–30° left lateral decubitus position. Biplane cineangiography was performed in 30° right anterior and 60° left anterior oblique projections on 30 mm film taken at 64 frames/sec using an image-intensifier system with a 9-inch field. With a catheter positioned either in the left ventricle or just above the aortic valve leaflets, the respective chamber was opacified with 0.75–1 ml/kg of Hypaque 75% (Winthrop) at 300 lb/in.²

Angiographic measurements of the aorta in normal subjects were obtained by opacification from the left ventricular cineangiogram, and by supravalvular aortagram in aneurysm patients. In normal subjects, measurement of aortic diameter by angiogram was performed at the level of the midpoint of the coronary sinuses in both right and left anterior oblique projections. Since no differences existed between aortic measurements made in right or left oblique views, we report only right anterior oblique measurements, since they most closely approximate the dimension obtained by echocardiography. Values were obtained at end-diastole, just before the first opening movement of the aortic valve leaflets, and included the outer edges of the dye silhouette of both aortic walls. In patients with aortic aneurysms, cineangiographic measurements were obtained at the point of maximal aortic width in either the right or left anterior oblique projection.

Aortic dimension on M-mode echo was recorded in end-diastole from the leading edge of the anterior wall to the leading edge of the posterior wall at the level of the aortic leaflets. Measurements by 2-D echocardiography of the aorta in normal subjects were made at the level of the midpoint of the coronary sinuses in long axis, and at a level just above the aortic leaflets in the short axis view. Since aortic measurements made in long or short axis views in normals did not differ, only values obtained in the long axis view are given (fig. 1). As with angiography, ultrasound measurements in patients with aortic aneurysms were obtained at the point of the maximal width imaged in any projection. Cross-sectional echograms were examined in a blind fashion, the examiners having no prior knowledge of the etiologic and angiographic diagnosis. Measurements of aortic size obtained by

**Figure 1.** Representative normal two-dimensional echograms of the aorta in the long axis (left) and short axis (right) views with schematic diagrams of the structures visualized. A marker is drawn in the long axis view to delineate the aortic sinuses, the area where measurements were obtained in normal subjects. The short axis view was obtained with the leaflets in the closed position during diastole. Abbreviations: AO = aorta; LA = left atrium; LV = left ventricle; RA = right atrium; IVS = interventricular septum.
echocardiography and cineangiography were then subjected to linear regression analysis.

Results

M-mode echograms of adequate technical quality for interpretation were obtained in all subjects examined. Enlargement of the aortic diameter ≥ 44 mm was observed in 11 of 12 aneurysm patients; the remaining patient had an aortic diameter of 38 mm. Aortic enlargement on M-mode echograms appeared symmetrical in all patients, but the precise configuration of the aneurysm could not be discerned in any pa-

Figure 2. Right anterior oblique projection of the supravalvular aortogram (left panel) and the short axis view of the two-dimensional echogram (middle panel) from a patient with a postoperative perivalvular aneurysm. The schematic diagram shows the structures on the echogram. Quadrant markers for orientation are superimposed on the echogram. A line depicting the plane of the ultrasound tomogram is superimposed on the aortogram. The aneurysmal prominence is easily visualized as an out-pouching anterior to the aorta on both angiogram and two-dimensional echogram. The three stents of the aortic prosthesis can be seen within the true lumen of the aorta. Abbreviations: AN = aneurysm; A = anterior; Ao = aorta; P = posterior; RA = right atrium; LA = left atrium; PA = pulmonary artery.

Figure 3. Supravalvular aortogram and two-dimensional echogram of the aorta recorded in the long axis view from a patient with an aortic dissection. A schematic diagram of the cardiac structures adjacent to those on the echogram is provided for orientation. The area of the spiral aortic tear (arrow) separates the true lumen of the aorta from the false lumen (FL). LA = left atrium; AO = aorta; IS = interventricular septum; AML = anterior mitral leaflet; LVPW = left ventricular posterior wall.
FIGURE 4. Supravalvular aortogram and long-axis two-dimensional echogram with schematic diagram of adjacent structures in another patient with an aortic dissection. The intimal tear (arrow) is at the point of separation from the aortic wall. IS = interventricular septum; LVPW = left ventricular posterior wall; AO = aorta; AML = anterior mitral leaflet.

Patient. Linear regression analysis indicated that M-mode measurements of aortic dimension correlated well with angiographic measurements for all patients (y = 0.81x + 1.4; r = 0.88; SEE = 1.4). However, when M-mode values of maximal aortic diameter were compared with values obtained by angiography, there was a diminution in the correlation (r = 0.55, SEE = 1.9).

Images of the aortic root and ascending aorta of adequate technical quality for analysis of contour and size were obtained by cross-sectional echocardiography in all subjects. Initially, qualitative visual examination of the ascending aorta by 2-D echocardiography was carried out for abnormalities of structure and contour. In normal subjects the contour of the aorta in short axis recorded by 2-D echocardiography consisted of a narrow circle at the level of the fibrous skeleton with subsequent bulging in the area of the aortic sinuses and a gradual uniform round

FIGURE 5. Left anterior oblique aortogram and short-axis echogram from a patient with Marfan's syndrome and an aneurysm of the aortic root. A schematic diagram of the structures on the echogram is shown. The circular outline of the aortic wall (arrows) can barely be accommodated by the 70° sector arc afforded by the echograph. Multiple echoes from a valvular prosthesis may be seen in the center of the aorta (AO).
enlargement occurring superiorly. On the long axis 2-D echogram, the curvature of the coronary sinuses was followed by the gradual assumption of two parallel echoes representing the aortic walls (fig. 1).

In all 12 subjects with aneurysms of the ascending aorta, excessive bulging and enlargement was observed by cross-sectional echocardiography (figs. 2–7). Measurements of aortic diameter in normal subjects were similar by both echocardiography and cineangiography (34 and 33 mm, respectively). In addition, values for aortic size in aneurysm patients were comparable by both methods (63 and 67 mm, respectively). Significantly, 2-D echocardiography and cineangiography provided identical separation of normal subjects from patients with abnormally large aortas, and aneurysms of the ascending aorta were not only detected as discrete lesions, but were correctly localized by cross-sectional echocardiography in the five patients with either sinus of Valsalva aneurysms or localized aortic out-pouching after surgical drainage of a perivalvular abscess. In addition, massive symmetrical dilatation beginning in the aortic sinuses was observed in the two patients with Marfan's syndrome and was distinguished ultrasonically from diffuse fusiform aortic enlargement and saccular distortion of other etiologies. Finally, portions of the spiral aortic tear were observed on echogram in all patients with aortic dissection.

Examples of cross-sectional echograms and angiograms obtained in this study are given in figures 2–6. An aneurysm is easily visualized anterior to the aorta both by supravalvular aortogram and 2-D echogram in the patient with the postoperative perivalvular aneurysm (fig. 2). In addition, the area of the spiral aortic tear separating the true lumen and false lumen as well as aortic enlargement is shown in two patients with aortic dissection (figs. 3 and 4). Supravalvular aortograms and 2-D echograms in short axis (fig. 5) and long axis views (fig. 6) depicting massive dilation of the aortic root are shown for the two patients with Marfan's syndrome. Finally, the cross-sectional echogram of a patient with an aneurysm involving the noncoronary sinus is shown in figure 7.

The results of the comparison of measurements of aortic dimensions obtained by 2-D echocardiography with those provided by contrast cineangiography are seen in figure 8. Ultrasound provided an accurate method for predicting actual aortic size. Accordingly, there was an excellent linear relationship between cineangiographic and 2-D echographic measurements.

![Figure 6](http://circ.ahajournals.org//content/759/2/759)

**Figure 6.** Left anterior oblique projection of a supravalvular aortogram and the two-dimensional echogram of the aorta in the long-axis view from a 30° sector scanner from another patient with massive aortic root dilation secondary to Marfan's syndrome. Although the area of the aortic annulus remains relatively normal in dimension, both the anterior and posterior aortic walls are immediately displaced by severe bulging. A schematic diagram of cardiac structures contiguous to the aorta is provided for orientation. Arrow indicates direction of the ultrasound beam. RV = right ventricle; AO = aorta; LA = left atrium; AM = anterior mitral leaflet; PM = posterior mitral leaflet; LVW = left ventricular wall.
of aortic size for all patients \( (r = 0.94, \text{ SEE } = 3.7) \), and between angiographic and ultrasonic data. In addition, measurements of maximal aortic dimension by 2-D echogram also correlated well with measurements obtained by cineangiography in the 12 aneurysm patients \( (r = 0.91, \text{ SEE } = 1.25) \).

**Discussion**

Cross-sectional echocardiography provides an accurate, noninvasive modality for diagnosing aneurysms of the ascending aorta. The 30–80° sector arc provided by the 2-D echograms used in the present study enabled the simultaneous examination of a substantial portion of the ascending aorta and the aortic root in both long and short axes. Cross-sectional echocardiography not only allowed us to detect enlargement of the aorta, but also provided definitive data regarding the nature and location of the aneurysm involving the ascending aorta in all 10 patients evaluated (figs. 2–6). The ability to accurately delineate the perimeter of an aortic aneurysm by ultrasound is a major advance in the noninvasive evaluation of diseases of the aorta.

Previous studies have indicated that M-mode echocardiography in normal subjects provides measurements of aortic diameter which correlate well with those obtained by cineangiography.\(^6\)\(^8\) However, there has been disparity between the ultrasound values for aortic size in normal subjects reported by various authors, and no systematic study has been performed regarding the accuracy of such measurements in patients with aortic aneurysms. The correlation of M-mode measurements of aortic dimension with those obtained by cineangiography in the present study was not as good as that observed by Lundstrom and associates,\(^8\) who reported an excellent correlation between values of aortic size performed by these two techniques \( (r = 0.98) \). However, this study evaluated only normal children, in whom echograms may be more easily recorded than adults. The correlation between techniques in our investigation was least in the patients with aortic aneurysm.

In the present study, 2-D echocardiography provided a measurement of aortic diameter that correlated very closely with cineangiographic measurements of the aorta in both normal subjects and patients with enlargement of the aorta. Furthermore, cross-sectional echocardiography provided an insight into the disparities in measurements of aortic dimension obtained by M-mode echocardiography. Thus, on 2-D echograms the aortic walls exhibited a definite bulge in the midportion of the coronary sinuses at the level of the tips of the aortic leaflets in systole. Although a recording of the aorta containing aortic

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**Figure 7.** Long axis and schematic representation of the two-dimensional echogram obtained in a patient with a sinus of Valsalva aneurysm. Aneurysmal protrusion of the posterior aortic wall may be seen in the area of the posterior coronary sinus (AN). \( AO = \) aorta.

**Figure 8.** Correlation between cineangiographic and two-dimensional echographic measurements of aortic size for normal subjects and patients with aortic aneurysms.
leaflet echoes might be recorded from either area, measurements of aortic diameter by M-mode echocardiography at the level of the annulus would be substantially less than those obtained from the midportion of the coronary sinuses. Finally, aortic size and contour at the level of the annulus remained normal in all patients, even those with the massive dilation of the aortic root. Observations made on the basis of 2-D echograms serve to emphasize the necessity of examining the aorta as superiorly as possible to avoid errors in recognizing aortic abnormalities.

How do cross-sectional and M-mode echocardiography compare in the diagnosis of aortic aneurysms? Although we did not intend to resolve this question in the present investigation, M-mode echocardiograms were performed in all patients and certain conclusions seemed apparent. Although M-mode echocardiography yielded evidence of aortic enlargement in all but one patient with aortic aneurysm, no decision could be made regarding the precise nature, location or extent of these lesions. Furthermore, measurements of aortic diameter obtained by M-mode echocardiography correlated less well with cineangiographic values than those recorded by 2-D echocardiography in patients with aneurysms. Cross-sectional ultrasound records were superior primarily because substantial uncertainty existed regarding the precise identification of the echoes obtained by M-mode recording in several patients with aortic aneurysms, whereas the orientation provided by 2-D echocardiography enabled us to interpret these echoes properly and confidently.

The echographic findings in the three patients with aortic dissection evaluated in this study should be considered. Although reports have indicated the value of M-mode echocardiography in the diagnosis of dissecting aneurysms of the aorta,6–8 other studies have emphasized the potential pitfalls which could result in the false positive or false negative diagnosis of this entity by the M-mode technique.9,11 Thus, beam width problems inherent in M-mode echocardiography may result in multiple echoes in the area of the aortic walls and therefore a false positive diagnosis of dissection, while eccentric location of an aortic tear could result in a normal aortic echogram and a false negative study. Although beam width and lateral resolution problems also exist with 2-D techniques, the ability to image the aorta in a variety of projections afforded by spatial orientation may enhance the sensitivity and specificity of 2-D echocardiography in the diagnosis of aortic dissection. Indeed, aortic dissection was clearly observed by 2-D echocardiography in all patients with this disorder, while aortic dissection was diagnosed by M-mode echo in only one patient in whom this lesion was present. However, the spiral nature of the aortic tears resulted in the appearance of the aortic intima as merely short lines within the true wall of the aorta. Furthermore, due to the tomographic nature of the images obtained by cross-sectional echocardiography, the false lumen of the aorta was not recorded with all transducer angulations, and ultrasonic scanning was still necessary to record this specific lesion. Accordingly, although the diagnosis of aortic dissection was evident in both patients in this study, the exact sensitivity and specificity of 2-D echocardiographic findings in the detection of the abnormality remains to be established.

The illustrations in this manuscript are not entirely representative of the quality of the echographic images obtained by real-time 2-D techniques. For example, the motion of ultrasonic targets displayed by real-time examination aids substantially in the interpretation of the echograms, and this cannot be conveyed by a single photograph. Furthermore, stop-frame illustrations result in significant degradation of the ultrasonic images due to the ability to present only one-half of the echographic scan lines visualized in real-time, and to photographic limitations in reproduction. Finally, we emphasize that the ascending aorta is a difficult structure to record by ultrasound because the lung and sternum interpose between the transducer and the great vessel, and that echographic images of aneurysms are often obtained at the expense of poor visualization of adjacent cardiac structures.

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