Detecting Left Main Coronary Artery Disease by Apical, Cross-sectional Echocardiography

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SUMMARY To test the feasibility of imaging the left main coronary artery (LMCA) noninvasively as a means of detecting left main coronary artery disease, we studied 73 patients who underwent cardiac catheterization and cross-sectional echocardiography. Fifty-two had a normal LMCA (controls) and 21 had significant obstruction (≥ 50% luminal reduction). The apical, tomographic, cross-sectional, phased-array, echocardiographic approach was used, and the LMCA was imaged in 52 of 73 patients (71%). In 34 of 36 controls (94%) the LMCA was correctly judged as having no luminal obstruction. In the other two, an asymmetric, high-intensity echo in one wall of the artery suggested atherosclerotic disease, but coronary angiography revealed no obstruction. In 12 of 16 patients (75%) in whom significant LMCA disease was imaged, obstruction was predicted by echocardiographic criteria of either luminal irregularity or an asymmetric, high-intensity echo in the arterial wall. This preliminary study suggests that cross-sectional echocardiography appears to be a feasible, noninvasive technique to image the LMCA and to detect hemodynamically significant luminal obstruction.

EVIDENCE that coronary artery bypass graft surgery for significant left main coronary artery stenosis prolongs life makes identification of left main disease in patients with ischemic cardiac symptoms a challenge to the cardiologist. Clinically, young patients with angina pectoris or markedly abnormal exercise stress tests often are subjected to coronary arteriography, with its attendant potential morbidity, mortality and cost, to detect obstruction of the left main coronary artery. Because there are no clinical features specific for its presence, the development of noninvasive techniques that can reliably identify and quantitate occlusive lesions of the left main coronary artery would be a major advance in reducing the frequency of invasive diagnostic coronary angiography. In addition, detecting left main coronary artery disease before cardiac catheterization may minimize exposure to the increased risk of angiography in such patients. Unfortunately, the results of high-quality, noninvasive exercise stress tests do not reliably differentiate left main coronary artery disease from multivessel involvement.

In 1976, Weyman and colleagues reported for the first time the feasibility of imaging the left main coronary artery by cross-sectional echocardiography. Using a mechanical sector scanner, the left main coronary artery was approached from the short-axis view at the cardiac base and verified by cardiogreen dye injections. Obstruction was defined using the criterion of luminal narrowing identified by a break in the continuous luminal space. An aneurysm of the left main coronary artery in one patient could be identified, and this finding was subsequently confirmed by Yoshikawa and colleagues in five patients with mucocutaneous lymph node syndrome. Prospective evaluation of the sensitivity and specificity of echocardiographic visualization of the left main coronary artery has not been reported in patients with coronary artery disease. Because a bend in the course of the left main coronary artery can simulate a break in the continuous luminal space and because the left main coronary artery moves with each heartbeat, markers other than disruption of the continuous echo-free luminal space should be found to identify left main coronary obstruction. For example, asymmetric, high-intensity echoes in the walls of the coronary artery may reflect the presence of atherosclerotic lesions. Increased echocardiographic densities reflecting collagen build-up in the left ventricle after myocardial infarction have been identified, and Rogers et al. presented preliminary data suggesting that high-density echoes from the wall of the left main coronary artery may be a manifestation of atherosclerotic plaque in the coronary artery. In this study, we evaluated the apical echocardiographic technique as well as criteria for identifying obstruction of the left main coronary artery.

Materials and Methods

The study population consisted of 73 patients who underwent cardiac catheterization for symptomatic ischemic heart disease, 60% of whom were referred to Lankenau Hospital for coronary arterial surgery. Twenty-one patients, with a mean age of 59 ± 8 years (± sd) had left main coronary arterial stenosis of at least 50% decrease in luminal diameter. There were 20
males and one female. Fifty-two patients (mean age 56 ± 9 years) had a normal left main coronary artery at cardiac catheterization and served as controls. Forty-three of these 52 patients (83%) were male. Echocardiography was performed and interpreted without knowledge of the results of coronary angiography. Image-intensification fluoroscopy to detect left main coronary artery calcification was not performed.

All cross-sectional echocardiograms were obtained using a commercially available, real-time, phased-array imaging system (Varian V3000 Ultrasonograph) and a transducer containing 32 piezoelectric crystals that operated at 2.25 MHz and measured 1.3 × 1.2 cm at the skin level. The ultrasonographic beam was electronically swept to an angle of 84° and produced a fan-shaped, cross-sectional image that was displayed in real time at a rate of 30 scans/sec, each containing 66 lines of information. The images were recorded on a ½-inch videotape cassette (Sanyo Corporation) that could be subsequently reviewed in real time, slow motion or frame by frame. Individual frames of the videotape recording were photographed using Polaroid film. There was significant degradation of the stop-frame image quality compared with dynamic displays because one field of a two-field video frame was displayed on each stop-frame photograph.

Figure 1 (left) shows the anatomic boundaries of the left main coronary artery: the pulmonary artery lies superiorly, the left ventricle inferiorly and the right ventricular outflow tract crosses the aorta inferiorly and the left atrium posteriorly. Figure 1 (right) shows the heart as it is usually projected by cross-sectional echocardiographic convention using the apical four-chamber view as described by Silverman and Schiller. The left ventricle is displayed at the top of the sector, because it is closest to the transducer, while the base of the heart is displayed at the bottom of the sector; the left atrium is imaged if a posterior angulation of the transducer is used, while the great vessels are imaged with an anterior angulation. In this projection, the left main coronary artery, after it originates from the aortic root, is bounded superiorly by the left ventricle and inferiorly by the pulmonary artery. The left anterior descending coronary artery arises at an acute angle from the left main coronary artery, and the left circumflex appears as a straight continuation.

The left main coronary artery was imaged using the apex view as described by Ogawa et al. With the patient in the left lateral decubitus position, the transducer was placed at the cardiac apex and oriented so that the left side of the cardiac structures would be on the left side of the television screen. The echocardiographic beam was directed toward the base of the heart perpendicular to the plane of the ventricular and atrial septa. Initially, the transducer was angled slightly posteriorly so that the beam passed through the plane of the mitral and tricuspid valves (fig. 2, S1). Next, the transducer was angled slightly anteriorly until the aorta and pulmonary artery were imaged and no mitral valve tissue could be identified (fig. 2, S2). The transducer position was then modified until the aorta and pulmonary arteries were clearly in focus, and the transducer was rotated slightly clockwise with increasing rejection of low-frequency echoes, which resulted in a dropout of some sections of the walls of the aorta and pulmonary artery. Clockwise rotation brought the ultrasonographic beam more closely parallel to the course of the left main coronary artery. Fine adjustments of the reject and gain controls were required to highlight the mass of echoes that appears between the left ventricle and pulmonary artery lateral to the aorta during this maneuver (fig. 2, S3). The left main coronary artery moves with each cardiac cycle, requiring frame-by-frame analysis of the videotape after the initial data are recorded. The left main coronary artery was identified as a constant set of parallel, echo-dense lines surrounding an echo-free lumen that was continuous with the lumen of the aorta. This pattern had to be identified for at least three consecutive frames. Analysis of the left main coronary artery was undertaken to determine whether there was any obliteration or alteration in the echo-free lumen along its length and whether there was symmetric or asymmetric density of echoes returning from the adjacent wall segments of the artery along its course. Stop-frame images were independently evaluated by two of the authors, with no interobserver variation in applying these criteria. Visualization of the left main coronary artery was documented by frame-by-frame analysis of the tip of a Judkins coronary artery catheter as it passed from the aortic lumen into the structure previously identified as the left main ostium (fig. 3). Detailed image-intensification fluoroscopy to analyze ectopic calcification in or near the left main coronary artery was not available. No attempt was made to compare the apical and the short-axis

**Figure 1.** (left) Sketch of the heart and great vessel relationships shows the aorta (Ao), left ventricle (LV) and pulmonary artery (PA). The arrow points to the left main coronary artery (LM), which was seen lying between the pulmonary artery and left ventricle. (right) The orientation of the heart in the apical, cross-sectional, echocardiographic view. The apex of the left ventricle is shown at the upper right; therefore, the left main coronary artery was bounded by the left ventricle above and the pulmonary artery below.
echocardiographic views of the left main coronary artery.

Results

Patients with Normal Left Main Coronary Arteriography

The normal left main coronary artery was imaged as it originated from the aorta with its widest diameter at the ostium and a gradual tapering toward its bifurcation. The length of the coronary artery varied. In only 36 of 52 subjects (69%) could the left main coronary artery be adequately defined for at least three consecutive frames as an echo-free lumen surrounded by echo-dense walls in which the lumen was contiguous with the aortic root. Failure to identify the left main coronary artery using these criteria was due primarily to interference from lung or abnormal chest wall configuration preventing the detection of an adequate apical view of the heart. In addition, aortic valvular calcification produced a confusing array of echo densities in the region of the left main coronary artery ostium, preventing adequate visualization. Thirty-three of 36 subjects adequately visualized had symmetric density of echoes arising from the walls of the left main coronary artery along the entire length. Three subjects had asymmetric, high-intensity echoes (false positives) and, in two of these subjects, echo-defined luminal irregularities were also present. Thus, 34 of the 36 patients (94%) with normal left main coronary arteriography had no luminal abnormalities (figs. 2 [S3] and 4).

Patients with Left Main Coronary Artery Disease By Angiography

Sixteen of the 21 patients (76%) with left main coronary arterial obstruction by angiography had adequate echocardiographic studies for detailed

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

**Figure 2.** (S1) A stop-frame, cross-sectional, echocardiographic image of the apical four-chamber view in which the left ventricle (LV) is on the right and the right atrium (RA) on the left, with faint visualization of the mitral and tricuspid valve tissue between the ventricles and the atria. (S2) A slight anterior angulation from S1 gives the apical four-chamber view in which the aorta (Ao), the interventricular septum (IVS) and the left ventricle were seen without evidence of mitral valve tissue in the field. (S3) A slight clockwise rotation of the transducer from S2 detected the left main coronary artery's walls and lumen, which were contiguous with the aorta. The left main coronary artery is shown between the two white markers lying between the superiorly situated left ventricle and the inferiorly situated pulmonary artery (PA). The interventricular septum is also shown.

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

**Figure 3.** A stop-frame, cross-sectional, echocardiographic image oriented as in figure 2 (S3), in which the tip of a Judkins catheter (large white arrow) is seen moving from midaorta (Ao) (panel A) toward the left main coronary artery (LM) (panel B) and finally merging with the ostium of the LM (panel C).
TABLE 1. Left Main Coronary Artery Disease by Coronary Angiography

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<th>Wall density</th>
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<td>Symmetric</td>
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<td>M</td>
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<td>Asymmetric</td>
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<td>M</td>
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<td>Asymmetric</td>
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analysis (table 1). Nine of these 16 patients had luminal irregularities suggestive of coronary obstruction (fig. 5). Five of these nine patients also had asymmetric echo densities (figs. 5 and 6). Three of the seven patients without luminal irregularities had only asymmetric, high-intensity echoes in the left main coronary arterial wall that suggested the presence of atherosclerotic coronary obstructions (fig. 6). Four patients had no echocardiographic abnormalities and were considered false negatives. In all four of these cases, the left main coronary artery was unusually long, and the lesion was located at the bifurcation and was out of the view of the left main artery as imaged by the echocardiogram (fig. 7). In patients with a shorter left main coronary artery, the obstruction can be seen echocardiographically (fig. 5). Thus, we detected left main coronary artery disease using echocardiographic criteria of asymmetric, high-intensity echo wall density or disruption of the arterial lumen in twelve of 16 patients (75%).

FIGURE 5. (left) A stop-frame, cross-sectional, echocardiographic image that shows the left main coronary artery arising from the aorta (AO) lying inferior to the left ventricle (LV) with a major luminal impingement and an asymmetric, high-density echo in the left main wall closest to the left ventricle (white arrow). (right) The left main coronary angiogram of this patient shows a subtotal obstruction in the distal segment of the short left main coronary artery. VS = interventricular septum; PA = pulmonary artery.
the short-axis view is not obtainable or is not of high quality. Because the left main coronary artery lies between the circular great vessels in an area where dense echoes are not highly prevalent, its identification is somewhat more certain, particularly when the artery can be visualized in at least three consecutive frames, and its lumen is contiguous with the lumen of the aorta. The left main coronary artery moves with each cardiac cycle, making a fixed image for prolonged viewing in real time unfeasible. Echocardiographic identification of left main luminal obstruction by demonstrating luminal obliteration or disruption is fraught with potential errors because the artery may bend in its course or there may be multiple echoes due to source artifact. We therefore evaluated the possibility of using, in addition to luminal irregularity, the presence of asymmetric, high-intensity echoes present in one wall compared with the opposite wall as a marker for obstructive coronary arterial disease. Increased collagen and calcification in atherosclerotic lesions have been suggested as criteria to identify obstructive left main coronary disease.7,8

We evaluated these two criteria in patients with angiographically proved left main coronary artery disease and in a control group without left main obstruction. Only three of 36 patients (8%) had false-positive echocardiographic results; two patients had irregular lumens and asymmetric wall echo densities and one patient had asymmetric wall echo density with a normal lumen. These false positives may be accounted for by a slight irregularity in the artery's course or redundant echoes due to artifact. Ectopic calcification in the region of the left main coronary arterial lumen rather than in an atherosclerotic plaque may produce the same asymmetric echo wall density not associated with obstructive luminal disease on angiography. Calcification of the left main coronary artery is uncommon, but it is usually accompanied by obstructive luminal disease.11 However, the asymmetric, high-intensity echoes in the left main luminal wall seen on the echocardiogram may, in fact, reflect the presence of atherosclerosis without intrinsic luminal narrowing.

Discussion

This study details the noninvasive technique of phased-array, cross-sectional echocardiography to detect the anatomic features of the left main coronary artery in man. The feasibility of echocardiography to image the left main coronary artery was shown2 using the short-axis approach, and its feasibility was predictable due to the left main coronary artery's fixed anatomic location and known boundaries that can be easily imaged. In this study, we evaluated an alternative method for imaging the left main coronary artery that may be useful in many patients in whom
EVALUATING THE CAUSE OF THE FALSE-NEGATIVE CASES IN THIS STUDY IS ESPECIALLY IMPORTANT. MANY OF THE 16 PATIENTS IMAGED WITH LEFT MAIN CORONARY ARTERY OCCLUSION HAD FALSE-NEGATIVE STUDIES DUE TO THE PRESENCE OF AN UNUSUALLY LONG LEFT MAIN CORONARY ARTERY WITH A DISTAL OBSTRUCTION OUT OF THE VIEW OF THE ECHOCARDIOGRAPHIC RECORDING.

FURTHER EXPERIENCE AND IMPROVEMENTS IN ECHOCARDIOGRAPHIC TECHNIQUE AND MORE SURE IDENTIFICATION OF THE BIFURCATION OF THE LEFT MAIN CORONARY ARTERY MAY ELIMINATE THIS CAUSE OF FALSE-NEGATIVE STUDIES. IN OUR EXPERIENCE, AN UNUSUALLY LONG LEFT MAIN CORONARY ARTERY WITH DISEASE AT THE BIFURCATION IS UNCOMMON; THEREFORE, THE FALSE-NEGATIVE RATE MAY BE LESS WHEN LARGER SERIES ARE CONSIDERED.

THE OVERALL SUCCESS RATE FOR IMAGING THE LEFT MAIN CORONARY ARTERY USING THE APICAL APPROACH WAS 71%. ADEQUATE ECHOCARDIOGRAPHIC EXAMINATIONS ARE DIFFICULT TO OBTAIN IN PATIENTS WITH LUNG DISEASE OR THORACIC DEFORMITIES. BECAUSE IT IS OFTEN EASIER TO IDENTIFY THE AORTA THAN DETAILS OF THE LEFT VENTRICLE IN SUCH PATIENTS, THIS TECHNIQUE OF IMAGING THE LEFT MAIN CORONARY ARTERY MAY BE FEASIBLE IN PATIENTS IN WHOM FULL ECHOCARDIOGRAPHIC STUDIES ARE NOT POSSIBLE. IN ADDITION, SEVERE AORTIC VALVULAR OR ROOT FIBROSIS OR CALCIFICATION OF PROSTHETIC AORTIC VALVES MAY PRODUCE A CONFUSING ARRAY OF ECHOS PREVENTING IDENTIFICATION OF THE LEFT MAIN CORONARY ARTERY.

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