Noninvasive Visualization of the Left Main Coronary Artery by Cross-sectional Echocardiography

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SUMMARY  Real time cross-sectional echocardiographic studies of the left main coronary artery (LMCA) were performed in 15 normal patients, 15 patients with angiographically proven coronary artery disease but normal left main coronary segments, three patients with greater than 75% obstruction of the left main coronary artery, and one patient with a large aneurysm of the left main coronary artery. In normal subjects the LMCA evaginates from the inferolateral wall of the aorta. The artery appears as two dominant parallel linear echoes separated by a clear space representing the lumen of the vessel. The LMCA courses beneath the right ventricular outflow tract and can generally be followed to its expected point of bifurcation.

THE LEFT MAIN CORONARY ARTERY is that short segment of the left coronary artery which extends from its aortic origin to its bifurcation into the anterior descending and circumflex branches. Since the branches of the left main coronary artery supply the major portion of the left ventricular muscle mass, significant obstruction of this artery places the patient at risk for extensive myocardial infarction and death. The three year cardiac mortality following angiographic demonstration of significant left main coronary obstruction has been reported to approximate 50%. 1, 2

There are no historical or clinical features which are specific for left main coronary artery obstruction. 1, 3, 4, 6 A markedly positive treadmill exercise test should alert the physician to the possibility of a left main coronary artery lesion but it is in no way diagnostic. 1, 4, 6

At present an obstructive lesion of the left main coronary artery can be demonstrated conclusively only by coronary arteriography. Although the mortality and morbidity of coronary cineangiography, in general, is low, the patient group with left main coronary artery lesions appears to be at a greater risk, with angiographic mortalities as high as 10 and 15% being reported. 5, 4 The ability to visualize the left main coronary artery noninvasively would therefore be of clinical value. This study describes the results of our initial attempts to visualize the left main coronary artery using a cross-sectional echocardiographic technique.

Materials and Methods

Cross-sectional echocardiograms of the left main coronary artery were recorded in 15 normal subjects, 15 patients with cineangiographically proven coronary artery disease but no obstruction of the left main coronary artery, three patients with greater than 75% obstruction of the left main coronary artery, and one patient with a large aneurysm of the distal left main coronary artery. Normals consisted of young adults with no evidence of ischemic heart disease. There were eleven males and four females. Ages ranged from 16 to 29 (mean 26). Cardiac catheterization was not performed in the normal group.

Cross-sectional echograms were performed using a high resolution mechanical sector scanner developed in conjunction with the Fortune-Fry Research Laboratories at Indiana University. This system consisted of a modified Ekoline 20 echograph with a pulse repetition rate of 4.5 kc/sec. The cross-sectional probe contained a 2.25 MHz transducer which was mechanically driven through a 30° sector at a variable frame rate of from 0 to 60 frames/sec (0-30 cycles/sec). This system was routinely operated at a frame rate of approximately 40 frames (20 cycles) per second which yielded a line density of approximately 112 lines per frame. The images thus derived were recorded on 1/2 inch videotape cassettes using a standard portable television camera (GBC-VTC 6000) and a Sanyo VTC 7100 videotape recorder. With this system the cross-sectional images could be viewed in real time during the course of the study, or following the study in a slow motion or single frame format. Individual frames were converted to hard copy using a video scan converter and a modified Honeywell 1856 strip chart recorder. Further details of this system have been previously reported. 6, 9

For the purpose of this discussion the chest wall will be considered to be anterior and the thoracic spine posterior; the head of the patient superior and the feet inferior; right and left will refer to the patient's right and left.

The left main coronary artery normally lies in a relatively fixed anatomic position with relation to the left ventricle and great arteries. It is bordered anteriorly by the right ventricular outflow tract as it crosses the root of the aorta, superiorly by the descending portion of the pulmonary artery (the pulmonic valve as a rule lies slightly superior to the left main coronary artery), inferiorly by the superior margin of the left ventricle, and posteriorly by a portion of the left atrium. The left main coronary artery itself is a relatively short segment arising from the root of the aorta in the area of the aortic valve leaflets and extending leftward.
for a short distance to its point of bifurcation. The relationship of the structures in this area to each other and to the plane of the cross-sectional scan has recently been described in detail.10

When attempting to visualize the left main coronary artery, the patients were placed in either supine or slightly left lateral position. The cross-sectional probe was initially placed in the standard echocardiographic window along the left sternal border in either the third or fourth intercostal space. The probe was aligned with the transducer sweep parallel to the assumed long axis of the aorta. Having located the aorta and aortic root, the transducer was then rotated 90° to a position parallel to the short axis of the aorta. A short axis scan of the aortic root at the aortic valve level was then the starting point for locating the left main coronary artery.

The probe, with the plane of the sweep maintained perpendicular to the short axis of the aorta, was then swept in a superior-inferior arc to locate the superior margin of the left ventricle and the descending portion of the pulmonary artery. These reference points represent the upper and lower limits of the area in which the left main coronary artery should lie. During the course of this sweep a relatively dense mass of echoes originating along the left, inferior border of the aorta and extending leftward beneath the right ventricular outflow tract could be visualized. This mass of echoes corresponds to those dense echoes normally seen behind the pulmonary artery on the routine M-mode echocardiographic examination of the pulmonary artery and pulmonic valve and has been termed the atrio-pulmonic sulcus by Gramiak et al.11 The left main coronary artery lies within this mass of echoes. Having located the area in which the left main coronary artery lies, the transducer was then rotated parallel to the short axis or horizontal cross-section of the body rather than the short axis of the aorta in an attempt to align the plane of the ultrasonic scan more closely to the course of the left main coronary segment. The probe was then swept back and forth within the previously described boundaries maintaining the aorta in the left-hand margin of the scan until the coronary ostium or left main coronary artery was located. Fine changes in the plane of the cross-sectional scan were required to align the transducer sweep parallel to the long axis of the left main coronary artery. Although this process is somewhat painstaking to describe, the area of the left main coronary artery is relatively easy to locate and with experience the entire process can be accomplished in a matter of a few minutes.

During the cardiac cycle the left main coronary artery was observed to move in both an anterior-posterior and inferior-superior direction; as a result it was generally not possible to visualize it throughout the cardiac cycle. Once the artery was located, therefore, the probe was generally held steady and the artery allowed to move in and out of the field of vision. To record it during different portions of the cardiac cycle, it was necessary to make slight changes in the position of the probe. To confirm that the structure we were visualizing was indeed the left main coronary artery, indocyanine green dye was injected directly into the left main coronary artery during cardiac catheterization in two cases and into the aortic root in the area of the left coronary ostium in one case. This was a somewhat difficult procedure since it required that the left main coronary artery be in the field of the cross-sectional scan at the instant that the dye was injected. However, in each of these cases we were successful in visualizing the dye within the left main coronary artery during at least one injection.

Results

The Normal Left Main Coronary Artery

During cross-sectional echocardiographic study the left main coronary artery appeared as an elongated, funnel-
shaped structure arising from the inferolateral margin of the aortic root at about the 4 o'clock position. The coronary ostium formed the conical portion of the funnel while the left main coronary artery formed the stem. The relative depth of the ostium and length of the left main coronary segment varied from individual to individual. The presence of a large coronary ostium which results in a prominent interruption of the lateral aortic wall facilitated localization of the left main coronary artery. Figure 1 is a cross-sectional echogram from a normal subject illustrating the left half of the aortic root, left coronary ostium and proximal portion of the left main coronary artery. During the cardiac cycle there is both superior-inferior and anterior-posterior motion of the aortic root. Since the left main coronary segment is attached to the aorta, it follows this motion. At end diastole the aorta is in its most posterior position. At this point in the cardiac cycle the left main coronary artery generally followed a lateral and slightly anterior course after leaving the aorta. During systole the aorta moves anteriorly, reaching its most anterior position at approximately end systole. From this aortic position the left main coronary segment generally pursued an almost directly lateral course.

Figure 2A is a left main coronary segment from a second normal subject. In normal subjects the artery appeared as

![Figure 2A](image)

**Figure 2.** A) Cross-sectional recording of a normal left main coronary artery. The artery appears as two parallel dominant linear echoes (indicated at the tips of the vertical arrows) which seem to arise from the inferolateral border of the aorta and extend in a slightly anterior and leftward direction. The relatively echo-free space between these linear echoes appears to represent the lumen of the vessel. B) Recording from the same patient made during injection of indocyanine green dye directly into the left main coronary artery. The dye produces a cloud of echoes which appears to completely fill the space between the two parallel linear echoes. The near field echoes seen in this and subsequent recordings are frequently recorded over the pulmonary artery; their precise cause is unclear.

![Figure 3](image)

**Figure 3.** Cross-sectional echogram from a patient with obstruction of the proximal left main coronary artery. A fairly extensive area of luminal narrowing beginning just distal to the coronary ostium and producing almost complete obliteration of the artery was visualized (large vertical arrow). Distal to the area of obstruction a relatively normal arterial lumen was recorded (small vertical arrow).
two parallel dominant linear echoes which were felt to be produced by its anterior and posterior walls. There was an echo-free space between these two linear echoes representing the lumen. To confirm the fact that this structure was indeed the left main coronary artery, indocyanine green dye was injected directly into the left main coronary during continuous recording in two patients and near the coronary ostium in a third. Figure 2B is a recording of the left main coronary segment during such an intracoronary injection of dye. The dye produced a cloud of echoes within the left main coronary segment. This cloud of echoes filled the entire echo-free space between the two parallel echoes (arrows) produced by the vessel walls.

**Left Main Coronary Obstruction**

In each of the three patients examined with significant (greater than 75%) obstruction of the left main coronary artery an area of localized echo production with almost complete obliteration of the otherwise echo-free arterial lumen was observed. In each case the lumen returned to normal size distal to the area of narrowing. Figure 3 is a cross-sectional echogram from a patient with a fairly extensive obstructive lesion of the left main coronary artery. An extensive area of luminal narrowing beginning just distal to the coronary ostium and producing almost complete obliteration of the left main coronary artery was visualized (larger vertical arrow) in this recording. Distal to the area of obstruction a relatively normal arterial lumen appeared (small arrows). This pattern of obstruction corresponded to an extensive area of left main coronary artery obstruction extending from the coronary ostium to the area of bifurcation demonstrated angiographically (fig. 4).

**Coronary Artery Aneurysm**

In addition to obstructive lesions of the coronary artery it was possible also to visualize other abnormalities in this area. Figure 5 is a cross-sectional echogram of a patient with a large aneurysm of the left main coronary artery. Angiographically this aneurysm was located just proximal to the bifurcation of the left main coronary segment with both the anterior descending and circumflex branches arising from the aneurysm itself (fig. 6). By cross-sectional study it was possible to visualize the left main coronary artery and its communication with this large aneurysm which appeared as an echo-free space in direct continuity with the left main coronary segment.

**Discussion**

This study demonstrates the potential ability of cross-sectional echocardiography to visualize the left main coronary artery. Visualization of this structure is facilitated by its relatively large size, consistent anatomic location, and position within clearly definable echocardiographic boundaries.

The major role of the left main coronary artery in supplying blood to the left ventricular myocardium, the frequent involvement of this vessel in the atherosclerotic process, the high mortality rate associated with lesions in this area, and the increased angiographic risks associated with these lesions should make the noninvasive visualization of this structure clinically useful.

Although this technique visualizes only a small area of the coronary tree and may prove applicable in a limited group of patients, there are areas in which these limited applications could be helpful. The ability to demonstrate obstructive lesions in this area prior to angiography would alert the angiographer to the potential risk involved. In addition, since atherosclerotic obstruction of the left main coronary artery is an area where coronary artery bypass surgery is felt by many to increase patient survival, a significant group of patients undergo coronary cineangiography only for evaluation of a possibly correctible left main stem lesion. Cross-sectional echocardiographic demonstration of a normal left main coronary artery in these patients might therefore eliminate the need for coronary cineangiography.

There are a number of technical considerations involved in recording the left main coronary artery. First, there are several structures in the area of the LMCA which produce horizontal linear echoes. To be sure one is visualizing the LMCA it is necessary to record its origin from the aorta and the continuity between the lumens of the two vessels. Secondly, since the artery does not remain in the field of vision throughout the cardiac cycle but rather moves in and out of the plane of the cross-sectional scan, analysis of a number of still frames is required to clearly visualize the left main coronary structures. Thus high quality still frames are an obvious requirement of the cross-sectional system. In addition, the left main coronary artery, although extending only a short distance, is not perfectly straight in each case. Frequently slight changes in transducer angulation are required to record the coronary ostium and body of the left main coronary artery and in these cases these two areas must be evaluated individually. In order to determine convincingly the presence of an area of coronary artery obstruction, it is necessary to visualize the lumen of the vessel both distal and proximal to the lesion. This is because a bend in the artery might appear on a cross-sectional scan as total obstruction if the lumen were not visible again distal to the area of obstruc-
tion. Finally no intracardiac structure is ever completely echo-free. Fine transient echoes are frequently seen in the left ventricle, left atrium, aorta, etc. Transient echoes may also be seen in the left main coronary artery. To indicate a lesion echoes must be fixed in position and consistent from cycle to cycle.

It should be clearly noted that this study demonstrates the ability of cross-sectional echocardiography to visualize the left main coronary artery in a selected group of patients. It provides no information concerning the sensitivity and reliability of this technique in routine clinical practice. A large prospective study is under way to evaluate these questions. During the course of the present study several points did become apparent. First the left main coronary artery is a relatively small structure arising from the larger aorta. In general in patients in whom the aorta and aortic root can be clearly recorded it appears that the left main coronary artery can be recorded also. In patients in whom it is not possible to record the aorta or aortic root it is equally not possible to record the left main coronary artery. As a result the left main coronary artery is relatively easier to evaluate in normal patients in whom the echocardiographic examination is simpler than in patients with coronary artery disease in whom the echocardiographic examination is characteristically more difficult. The fact that we have been able to demonstrate obstructive lesions in three patients does suggest the feasibility of this approach even in patients with coronary artery disease. Another area of apparent difficulty is in patients with prosthetic aortic valves. We have attempted to examine one patient with a prosthetic aortic valve and an ostial lesion of the left coronary artery. In this case the intense echo production by the prosthetic valve prevented any visualization of the left coronary ostium or left main coronary artery.

This study therefore demonstrates the potential ability of cross-sectional echocardiography to visualize the left main coronary artery, confirms by the injection of cardiogreen dye that the structure visualized is indeed the left main coronary artery, and indicates the ability of this high resolution system to detect the presence of obstructive lesions in the left main coronary system. Further studies are required to determine the sensitivity and reliability of this technique in a larger group of patients with coronary artery disease.
An Echocardiographic Study of Interventricular Septal Motion in the Wolff-Parkinson-White Syndrome

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SUMMARY Echocardiographic studies of interventricular septal motion were performed in 26 consecutive patients with the Wolff-Parkinson-White (WPW) syndrome and in ten normal subjects. All patients with types A or B pre-excitation were subclassified into groups I to IV on the basis of their electrocardiogram utilizing the method of Boineau and associates. In all 14 patients with type A (Group III or IV) pre-excitation, the motion of the interventricular septum and posterior left ventricular wall motion were normal. However, in 11 patients with type B (Group I) WPW an abnormal septal motion was noted. This was characterized in ten patients by an early systolic posterior motion, a subsequent anterior movement in mid systole, and the usual posterior septal motion beginning in late systole. In eight patients, including the one without early systolic posterior movement of the septum, the late systolic posterior movement was interrupted by a prominent septal notch. One patient with type B (Group II) WPW was studied and exhibited normal septal and posterior wall motion.

In one patient with a spontaneous change in the QRS complex from normal to type B (Group I) WPW, the septal motion was initially normal and abruptly changed following the first WPW beat. The onset of abnormal interventricular septal motion with type B pre-excitation QRS complexes strongly suggests that abnormal septal movement may be related to an altered sequence of ventricular depolarization during right ventricular pre-excitation.

THE ANOMALOUS CONDUCTION and ventricular depolarization occurring in the Wolff-Parkinson-White syndrome has been studied electrophysiologically, but no good correlation has been established between the electrophysiological abnormalities and a mechanical disturbance of contraction. Demonstration of such an electro-mechanical association would be useful in understanding the effects of various types of pre-excitation on ventricular contraction, and could be useful in identifying the site of pre-excitation. Echocardiography provides a reliable noninvasive method for characterizing interventricular septal and posterior left ventricular wall motion.\(^1\) Abnormal septal motion has been demonstrated echocardiographically in patients with right ventricular volume overload,\(^2\) coronary artery disease,\(^3\) and in association with conduction abnormalities such as left bundle branch block.\(^4\) It was the purpose of the present study to characterize interventricular septal motion and left ventricular posterior wall motion in patients with the Wolff-Parkinson-White syndrome.

Methods

Ten normal subjects and 26 patients with typical electrocardiographic and vectorcardiographic patterns of the WPW syndrome were studied. All of the patients were clinically free of cardiac disease and were referred for study solely on the basis of the conduction abnormality. One patient had a history of atypical chest pain, but selective coronary cineangiograms were normal. All patients were subclassified on the basis of their twelve-lead electrocardiogram according to the method of Boineau and associates\(^5\) as follows:

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