Evaluation of Left Coronary Artery Anatomy In Vitro by Cross-sectional Echocardiography

EDWIN W. ROGERS, M.D., HARVEY FEIGENBAUM, M.D., ARTHUR E. WEYMAN, M.D., ROBERT W. GODLEY, M.D., AND SÄEED T. VAKILI, M.D.

SUMMARY This study was undertaken to provide a better anatomic description of the location and course of the left coronary artery within a commonly used ultrasonic tomographic plane. Twenty-three hearts were excised at autopsy and scanned in vitro. The locations of the left main (LMCA), left anterior descending (LAD), and left circumflex (LCCA) coronary arteries were confirmed by direct cannulation, by Cardio-Green injection, and by subsequent dissection. While the proximal LMCA was recorded in all specimens, the entire LMCA was visible in only 70%. Proximal portions of the LAD and LCCA were also identifiable in 70% of examinations, and their spatial positions were defined. In most recordings, the first branch of the LAD or LCCA arose distal to the segment seen echocardiographically. The spatial orientation of the ultrasonic beam relative to the LAD and LCCA and the presence of other overlying cardiac structures limit the imaging of these vessels by cross-sectional echocardiography to only their most proximal portions.

IN AN EARLY REPORT Weyman et al. demonstrated that the left main coronary artery (LMCA) could be visualized noninvasively using cross-sectional echocardiography. In addition to the normal anatomy and orientation of this vessel, examples of both atherosclerotic narrowing and saccular dilatation of the lumen were presented. Other reports have confirmed the capability of examining the proximal LMCA using cross-sectional echocardiography and of recording obstructions and aneurysms. In addition, the ability to view this area from the cardiac apex, as well as the original parasternal position, provided the potential for orthogonal, or biplane, imaging.

Because of the high incidence of atherosclerotic disease in the region immediately distal to the LMCA, it is appropriate to expand our ability to examine the left coronary system. Cases have been reported in which the bifurcation of the left coronary artery was felt to be well visualized on a clinical examination and the most proximal portions of the left anterior descend-
The probe was swept caudad and cephalad in the left selected transducer. The transducer was oriented so that it ran parallel to the aorta for a short distance, requiring a greater degree of clockwise rotation. A preformed catheter designed for percutaneous angiography was used to cannulate the LMCA under simultaneous direct external observation and ultrasonic visualization to confirm accurate identification of this vessel.

The transducer was then angled laterally and slightly cephalad and rotated slightly clockwise. This resulted in a tomographic plane that was felt in vivo to demonstrate best the bifurcation of the LMCA, proximal LAD and proximal LCCA (fig. 1B). The course of both the LAD and LCCA were followed as far distally as possible. The left atrial appendage remained in its normal anatomic location during this study. The preformed catheter was advanced alternately down the LAD and LCCA. Simultaneous echocardiographic visualization and gross visualization of the exterior of the heart confirmed proper identification of the LAD or LCCA. At the completion of the study, several milliliters of saline, shaken to achieve aeration, were injected through the catheter. The appearance of a dense cloud of echoes from the “Cardio-Green effect” of this injection further confirmed the visualization of the left coronary arteries. A similar technique has been used in vivo for chamber identification for identification of the LMCA. This was done at the completion of the recording because the persistence of the Cardio-Green effect in the in vitro model made further visualization of the coronary artery difficult.

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**Figure 1.** Two cross-sectional echocardiograms in vivo using 82° mechanical scanner. (A) Long axis of left main coronary artery (LMCA). The aorta (Ao) is seen as a circle in short axis. The pulmonary artery (PA) lies above the LMCA and the right ventricular outflow tract lies over the aorta. The left atrium (LA) lies below. (B) Transducer rotation demonstrates bifurcation of LMCA into left anterior descending (LAD) and left circumflex (LCA) coronary arteries.

atrium. The superior vena cava was severed as far superiorly as possible, and the inferior vena cava was cut near the diaphragm. The hearts were then removed and grossly inspected. Each specimen was then copiously lavaged to remove intracavitary thrombi and the aorta was vigorously injected with water under pressure to flush the coronary arteries. All specimens were examined before formalin fixation.

Cross-sectional echocardiograms were performed using a commercially available mechanical sector scanner (Smith-Kline Instruments Ekosector I) equipped with both 2.25- and 3.5-MHz transducers. The selected transducer was oscillated through a 30° arc at a scan rate of 60 frames/sec. The pulse repetition rate was 3200 Hz, yielding a line density of 54 lines/30° field. Cross-sectional images could be recorded by direct ultrasonic recording on a Sanyo VTC 7100 videotape recorder and were available for analysis on an oscilloscope in real-time, slow motion or single-frame format.

Hearts were pinned to a dissecting board at the venae cavae, pulmonary veins, and cardiac apex. This board was secured into the bottom of a beaker, which was then filled with warm water previously degassed by boiling. The pulmonary artery was located anteriorly and the atria were posterior. The origin of the left coronary artery lay posterior to the pulmonary artery and the LMCA initially coursed parallel to the surface of the water. This positioning thus simulated the in vivo intrathoracic orientation, and the surface of the water simulated the location of the sternum. An insulated cross-sectional probe was clamped to a ring stand with the transducer 4–5 cm from the aorta, a depth known to correspond to the point of maximum resolution of the ultrasonic beam for these transducers. The echocardiographic plane was oriented so that it transected the aorta in its short axis. The probe was swept caudal and cephalad to locate the ostium of the LMCA. The transducer was then rotated clockwise to demonstrate the length of this vessel. This resulted in a relationship between the echocardiographic plane and the left coronary artery identical to that used in the initial clinical echocardiographic study of the LMCA. This similarity can be seen when comparing an in vivo 82° scan in figure 1 and the results of one of the present in vitro 30° studies in figure 2. In most cases, changing the tomographic plane from the short axis of the aorta to the long axis of the LMCA required only slight clockwise rotation. In two cases, the proximal LMCA ran parallel to the aorta for a short distance, requiring a greater degree of clockwise rotation. A preformed catheter was advanced alternately down the LAD and LCCA. Simultaneous echocardiographic visualization and gross visualization of the exterior of the heart confirmed proper identification of the LAD or LCCA. At the completion of the study, several milliliters of saline, shaken to achieve aeration, were injected through the catheter. The appearance of a dense cloud of echoes from the “Cardio-Green effect” of this injection further confirmed the visualization of the left coronary arteries. A similar technique has been used in vivo for chamber identification and for identification of the LMCA. This was done at the completion of the recording because the persistence of the Cardio-Green effect in the in vitro model made further visualization of the coronary artery difficult.

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Figure 2. Cross-sectional echocardiogram in vitro using 30° mechanical scanner. The pulmonary artery (PA) is anterior. Posterior to the PA lies the left main coronary artery (LMCA) and its branches (LAD and Circ). To the right is an artist's sketch of the long axis of the left coronary artery with the circular aorta (Ao) in short axis and the left atrium (LA) below the LMCA. RA = right atrium.

its long axis. We noted whether the division of the LMCA had been recorded and, if so, the number of vessels that arose from the LMCA. The position and course of the LAD relative to the LMCA were noted and the length of the segment of the LAD that could be visualized echocardiographically (L_{LAD}) was measured. Similarly, the position of the LCCA and the length that was visible echocardiographically (L_{LCCA}) were recorded.

The heart specimen was then removed from the water bath for dissection. The pulmonary outflow tract and left atrial appendage were dissected free and retracted to expose the proximal left coronary artery. The ostium of the LMCA was identified. A dissecting probe was passed through the LMCA to the proximal LAD and LCCA to rule out a separate origin of the LCCA. The proximal left coronary artery was then serially sectioned beginning at the aorta, producing multiple short-axis LMCA, LAD, and LCCA slices approximately 5 mm thick. The accuracy of determination of the course of each of these vessels, the number of arteries present at the bifurcation of the LMCA, and the length of the LMCA were confirmed by this direct visualization.

Results

Left Main Coronary Artery

The LMCA was visualized in all 23 autopsies. In 21 cases it arose from the superior portion of the left coronary sinus and coursed nearly perpendicular to the long axis of the aorta. In two cases, the proximal LMCA ran parallel to the long axis of the aorta for a short distance, requiring a greater degree of clockwise transducer rotation in order to visualize the long axis of the coronary artery. In each case, the LMCA appeared as two distinct parallel lines on the echocardiogram. The LMCA was bounded anteriorly by the pulmonary artery and posteriorly by the atrioventricular groove or left atrium (fig. 2). In each of these cases, the preformed catheter could be seen entering the ostium of the LMCA, thus confirming accurate identification (fig. 3).

The actual length of the LMCA in this group was found by dissection to range from 0.5–3.0 cm (mean 1.6 cm). The LMCA was straight or showed a slight anterior curve around the posterior wall of the pulmonary artery in each case. No patient had a significant LMCA atherosclerotic lesion. The entire length of the LMCA and the “bifurcation” were visible echocardiographically in 16 of the 23 cases (70%). In 14 of these hearts, two branches were present (fig. 2). In two studies, there was a trifurcation of the LMCA into the LAD, a diagonal branch, and the LCCA (fig. 4). The number of vessels present at the division of the LMCA was determined correctly echocardiographically in all 16 patients in whom this region could be recorded. In seven of the 23 patients only a segment of the LMCA was recorded. The length visible echocardiographically (L_{LMCA}) was 0.8–1.5 cm (mean 1.0 cm).

Left Anterior Descending Coronary Artery

The lumen of the LAD coronary artery was visualized in 16 of 23 cases (70%). This vessel was seen to represent a continuation of the LMCA, with the LAD forming a smooth curve as it coursed anteriorly, beneath the pulmonary artery, and toward the interventricular groove (fig. 2). The anterior curve of the LAD formed an angle with the more horizontal LMCA, which ranged from 10–75° (mean 41°). The length of the segment of the LAD visible echocardiographically (L_{LAD}) ranged from 0.7–2.0 cm (mean 1.1 cm). The preformed angiographic catheter could
be seen on selective cannulation of the LAD in each case.

By gross pathologic inspection, the LAD, lying beneath the pulmonary artery, was frequently embedded within deposits of epicardial fat. This epicardial fat also involved the posterior pulmonary artery and left atrial appendage. Serial sectioning revealed that the origin of the first septal perforating branch arose distal to that region of the LAD that was visible echocardiographically in each case. The first diagonal branch of the LAD arose distal to the visualized segment in 14 of 16 cases, while in two cases, the first diagonal branch arose at the trifurcation of the LMCA. Mild-to-moderate atherosclerotic changes were noted in the proximal LAD before the first septal perforator in three of the 23 studies. This portion of the LAD was visible echocardiographically in two of these cases, though no change in luminal size was detected echocardiographically. In the third case, the bifurcation of the LMCA, the LAD, and the LCCA were not visualized. In none of these three specimens was the degree of arterial narrowing estimated pathologically to be greater than 50%.

Left Circumflex Coronary Artery

The lumen of the proximal portion of the LCCA (fig. 2) was also recorded in 16 of the 23 studies (70%). Because the proximal portion of the LCCA often lay parallel to the echocardiographic beam, shorter segments of this vessel were visible echocardiographically in most cases. The length of the LCCA that could be recorded (L\(_{LCCA}\)) ranged from 0.4-2.0 cm (mean 0.8 cm). The angle formed between the anteriorly directed LAD and the more posterior LCCA ranged from 45-180° (mean 77°).

On gross pathologic inspection, the LCCA, as it coursed toward the atrioventricular groove, was seen to lie beneath the left atrial appendage and within deposits of epicardial fat. The left atrial appendage frequently covered the entire LCCA up to the bifurcation of the LMCA. The LCCA did not give off its first major obtuse marginal branch within the echocardiographically visible segment in any case. Pathologic examination revealed mild-to-moderate atherosclerotic changes in the LCCA in three of 23 patients, though in none of the studies did these lesions lie within the segment visualized on the cross-sectional scan.

Discussion

The purpose of this study was to obtain anatomic confirmation of clinical observations of the position of LAD and LCCA as visualized echocardiographically. We hope that this will provide insight into the feasibility of and lend direction to further attempts at imaging these structures. To obtain reliable reference data, a model was required that optimized the ability to record the proximal left coronary artery. We used human hearts excised at autopsy because such a model had several advantages. First, the removal of the intervening structures of subcutaneous tissue and lung from the path of the ultrasonic beam improved the signal-to-noise ratio of reflected ultrasound and greatly enhanced visualization of cardiac structures. Second, gross inspection of the external surface of the heart was possible throughout the echocardiographic study, providing optimal spatial orientation for the operator, and cardiac dissection was available immediately after the ultrasonic study, supplying important feedback. Third, the in vivo examination of the LMCA is hampered by the motion of the base of the heart, which prevents maintaining this vessel within the viewing plane throughout the cardiac cycle. Although many structures require recognition of characteristic motion patterns for echocardiographic identification, the coronary arteries were more easily studied in a stationary specimen.

Despite the advantages of such an in vitro model, the use of unfixed autopsy specimens may not be an ideal method for evaluating the coronary arteries, as one cannot insure that the proximal coronaries are not partially collapsed during the echocardiographic examination. In this series, the aorta was vigorously flushed with saline; however, no effort was made to maintain filling pressure on the LMCA. Thus, constant perfusion pressure or prior fixation could improve the ability to visualize the coronary arteries.

With the advantages of improved spatial orientation and a better ultrasonic signal-to-noise ratio, the bifurcation of the LMCA and the proximal LAD and LCCA were visualized in many of these excised hearts, demonstrating that portions of these vessels clearly lie within the resolving power of crystal transducers. In addition, specific anatomic details were noted of each of these vessels that are pertinent as further clinical studies are considered. In this study, in which the ability to visualize the LMCA using cross-sectional echocardiography was confirmed, the
length of the LMCA was 3 cm or less in all of the autopsy specimens. The echocardiographically visible segment averaged only 1 cm, however, and the entire LMCA was recorded in only 70%. Of those seven cases in which the entire LMCA was not visible, the nonvisualized segment was 0.4–1.8 cm long and was over 1 cm in six of them. Considering these data and the fact that the LMCA may be up to 4 cm long, clinical cases will remain in which the entire length of the LMCA can not be visualized echocardiographically. Too few hearts were studied to determine how often this significant problem may arise, however. Furthermore, this study does not determine the intraobserver or interobserver error in measuring the length of the LMCA.

Two important variations in LMCA anatomy were noted. First, the relationship between the course of the LMCA and the proximal aorta was variable. In the vast majority of cases, the LMCA arose nearly perpendicular to the long axis of the aorta. In two cases, however, the LMCA coursed parallel to the long axis of aorta for a short distance. Thus, as the long axis of the LMCA is sought for during in vivo examinations, in a minority of cases more clockwise rotation of the transducer will be required. The second variation in LMCA anatomy lay at the bifurcation. James reported that the LMCA often gives rise to more than two branches. In this study, a trifurcation of the LMCA was present in two specimens and was correctly identified echocardiographically in both. The number of vessels at the division of the LMCA should be specifically searched for during future in vivo echocardiographic imaging.

While confirming our ability to record the LMCA, demonstrating its common anatomic variations, and recognizing some potential limitations of imaging, this report provides new data on the spatial orientation of the branches of the LMCA relative to the echocardiographic plane. The smooth curving relationship of the LAD to the LMCA could be well demonstrated, with the LAD turning approximately 40° anteriorly. In addition, there was found to be a uniform close approximation of the posterior wall of the pulmonary artery and the LAD as it approached the interventricular groove. While imaging the LAD, two important technical considerations were noted. First, only a very short segment of this vessel was visible echocardiographically, even when using an in vitro model. In the average case, only slightly over 1 cm could be identified. This portion of the LAD lies entirely proximal to the first septal perforator. Thus, as cross-sectional echocardiography is applied clinically, a significant portion of the pathology affecting the LAD probably will not lie within this conventional ultrasonic viewing plane.

Second, large deposits of epicardial fat were found to lie posterior to the pulmonary artery and to overlie the region of the LAD. The adipose tissue was a strong reflector of ultrasound and appeared as a dense granular echocardiographic structure. In some patients it could be seen over the entire anterior surface of the heart. The strong energy reflection was presumed to be due to the presence of lobulations. This has not been well recognized in previous attempts to identify the proximal left coronary artery. A large amount of subcutaneous tissue normally lies between the transducer and this epicardial fat, so filtering of the ultrasound may occur and explain why this sparkling appearance has not been noted in vivo. Deposits of epicardial fat have been noted by M-mode echocardiography to appear as an anterior clear space overlying the right ventricle, and Feigenbaum emphasized that these must not be misinterpreted as pericardial effusion. Similarly, caution must be used when studies are performed to evaluate the LAD not to confuse epicardial fat deposition with abnormalities of the coronary artery.

The LCCA was visualized in 70% of the cases. Study of the anatomic relationships of this portion of the coronary artery relative to other cardiac structures in the ultrasonic tomographic plane demonstrated three important points. First, this vessel tended to arise at a sharper angle from the LMCA and course posteriorly toward the atrial ventricular groove. This placed the proximal LCCA nearly parallel to the ultrasonic beam very soon after its origin. Because of this, the segment of LCCA that was visible echocardiographically averaged less than 1 cm. Second, the first branches of the LCCA arose distal to this segment in all cases. Finally, the LCCA was found to be covered by the left atrial appendage in each specimen. The left atrial appendage and overlying epicardial fat often covered the entire LCCA to the bifurcation of the LMCA. Thus, the LCCA is likely to remain much more difficult to record echocardiographically.

This investigation has demonstrated that the LMCA, proximal LAD and proximal LCCA lie within the resolving power of current echocardiographic equipment. The use of an in vitro model has allowed confirmation of the position of the proximal LAD and LCCA within this cross-sectional tomographic plane. Several variables in the location and course of each of these three vessels has been described. This work should provide a better anatomic background for future echocardiographic study of the proximal left coronary arteries. In addition, several anatomic features have been noted that may represent technical limitations to the use of this type of investigation.

References

M-mode and Two-dimensional Echocardiography in Chronic Chagas’ Heart Disease

A Clinical and Pathologic Study

HARRY ACQUATELLA, M.D., NELSON B. SCHILLER, M.D., JUAN JOSE PUIGBÓ, M.D.,
HUGO GIORDANO, M.D., JOSE ANGEL SUÁREZ, M.D., HUMBERTO CASAL, M.D.,
NESTOR ARREAZA, M.D., RAFAEL VALECLELLO, M.D., and EDUARDO HIRSCHHAUT, M.D.

SUMMARY Sixty-four patients prospectively identified as having Chagas’ disease were studied with M-mode echocardiography to identify characteristic functional and anatomic features of cardiac involvement. The control groups consisted of 10 normal subjects and 16 patients with nonischemic cardiomyopathy not due to Chagas’ disease. Seventeen of the patients with Chagas’ disease were asymptomatic and all had normal M-mode echocardiograms. Arrhythmias or congestive heart failure caused symptoms in 47 of the patients with Chagas’ disease, 18 of whom had a distinct M-mode pattern characterized by left ventricular posterior wall hypokinesis and relatively preserved septal motion. Eleven of the 47 had diffuse hypokinesis indistinguishable from the nonspecific pattern of congestive cardiomyopathy. These motion patterns were quantitated by computing the ratio of the percentage of septal systolic wall thickening to the percentage of posterior wall thickening from measurements taken at the levels of the chordae and papillary muscles. This ratio (normal 0.45 ± 0.20 [± SD]) separated symptomatic patients with Chagas’ disease (arrhythmia 0.83 ± 0.66, congestive heart failure 1.50 ± 1.68) from those in whom congestive cardiomyopathy was not due to Chagas’ disease (0.29 ± 0.37) (p = 0.02–0.005).

In addition, two-dimensional echocardiograms were obtained in 41 of 64 patients with Chagas’ disease. These sector scans identified apical aneurysms and/or dyskinesis in 31 patients. We also found apical abnormalities in three of seven asymptomatic patients with Chagas’ disease who had normal ECG and M-mode echocardiograms.

Echocardiographic findings were confirmed in 15 patients by cineangiography, in four at autopsy and in two at autopsyectomy. We conclude that in some patients with chronic Chagas’ disease, echocardiography shows a pattern indistinguishable from that of diffuse congestive cardiomyopathy. However, in the majority, echocardiography can detect a characteristic apical abnormality that often involves the posteroinferior left ventricular wall, with the interventricular septum relatively spared. In asymptomatic patients, two-dimensional echocardiography is of particular value in detecting early changes of the left ventricular apex.

Methods

Patients

The clinical data in this study were obtained from 116 subjects, prospectively identified from the wards and clinics of the Hospital Universitario de Caracas of the Universidad Central de Venezuela. Seventy-five were considered clinically to have Chagas’ heart disease or serologic evidence of past or present infestation with Trypanosoma cruzi, and had a positive Machado-Guerrero serum complement fixation and hemagglutinin test (MGT) performed and interpreted according to the method of Mackelt at the Institute of Tropical Medicine of the Universidad Central de Venezuela. Eleven patients were eliminated due to technically poor echocardiograms. The 64 subjects who formed the study population were divided into three groups according to clinical presentation. The
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E W Rogers, H Feigenbaum, A E Weyman, R W Godley and S T Vakili

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