Transvenous Coronary Ultrasound Imaging
A Novel Approach to Visualization of the Coronary Arteries

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Background. Catheter-based ultrasound is a new imaging modality to examine endovascular detail in the coronary circulation. This technique requires direct placement of the catheter in the arterial segment of interest.

Methods and Results. We examined the feasibility of a less invasive approach by imaging the coronary arterial circulation by using a 5F (30 MHz) imaging catheter placed in the cardiac venous system. Using simultaneous fluoroscopy, we studied anesthetized closed-chest dogs (n=6) and human subjects undergoing right heart catheterization (n=11). After cannulation of the coronary sinus, the circumflex coronary artery (Cx) was visualized from the great cardiac vein (GCV), and on advancing the catheter into the anterior interventricular vein (AIV), the left anterior descending artery (LAD) was identified. Where artery and vein were parallel to each other, circular cross-sectional images of the coronary artery were obtained, whereas oblique and transverse orientation of artery to vein produced ellipsoid images or long-axis images. In the dogs, ultrasound-determined cross-sectional area of the coronary arteries (4.81±0.18 mm²) correlated closely with angiography (4.77±0.21 mm²) (r=0.91, p<0.001). In humans, the Cx was readily visualized from the GCV in all subjects but because of anatomic variability, the LAD was seen less consistently from the AIV (73%). There was significant correlation between ultrasound-determined cross-sectional areas of the coronary arteries (8.25±0.34 mm²) with those from angiography (8.59±0.3 mm²) (r=0.82, p=0.001) in humans. In all subjects, the ultrasound transducer could be safely advanced into the AIV to the cardiac apex. Limitations of the technique include ultrasonic penetration problems, caused in part by the large size of human coronary veins and variability in artery-vein relations.

Conclusions. We conclude that transvenous imaging of coronary arteries with intravascular ultrasound is a less invasive, promising new approach to the study of structure and morphology in the coronary vasculature. (Circulation 1991;84:1957–1961)

Catheter-based high-frequency intravascular ultrasound imaging has shown promise in demonstrating lumen morphology, wall structure, and extent of atheroma in coronary artery disease.4 Although the information provided by catheter ultrasound is significantly greater than contrast angiography, there may also be increased risk because the catheters must be advanced into the lumen of the coronary arteries.

The cardiac venous system comprises a network of veins that run in close proximity to their arterial counterparts. We therefore hypothesized that by placing a suitable imaging catheter in a cardiac vein lying parallel to an artery, we could visualize parts of the epicardial coronary vasculature. Coronary sinus cannulation is a safe, less invasive procedure that has been extensively used for diagnostic and therapeutic interventions.5–11 Recently, transvenous intracardiac imaging has been used to visualize the cardiac chambers12 and the pulmonary vasculature,13 and in one study in dogs, proximal coronary arteries were visualized.14 In the present study, we placed a catheter-based ultrasound transducer in the great cardiac vein (GCV) and the anterior interventricular vein (AIV) to obtain images of the circumflex (Cx) and left anterior descending (LAD) coronary arteries, respectively (Figure 1). Under fluoroscopic guidance, we examined the feasibility of the technique in closed-chest anesthetized dogs and in humans undergoing right heart catheterization.

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Methods

Ultrasound System Description

In all studies, images were obtained using a commercially available ultrasound imaging system (CVIS, Cardiovascular Imaging Systems, Sunnyvale, Calif.). The catheter design in this system consists of a fixed transducer (30 MHz) and a rotating mirror assembly with a 5F catheter. The depth of ultrasonic penetration during these studies varied between 7 and 10 mm. Axial resolution on the video display was about 150 μm and lateral resolution was approximately 250 μm. Gain, contrast, and reject settings were adjusted by the operator to achieve a well-balanced gray-scale appearance on the video display. Real-time images were stored on high-quality super VHS videotape for subsequent off-line analysis.

In Vivo Studies in Animals

Six adult dogs were studied to assess the feasibility of transvenous coronary ultrasound. Using the transfemoral approach, the left main coronary artery was engaged using a canine 8F giant lumen catheter (Interventional Medical, Danvers, Mass.). Under fluoroscopic control, the left internal jugular vein was cannulated and an 8F giant lumen MB-1 multipurpose guiding catheter (Interventional Medical) was advanced into the ostium of the coronary sinus (CS). A 0.014-in. guide wire was then introduced through the GCV into the AIV up to the apex of the heart. The imaging catheter was then delivered over the guide wire and the CS, GCV, and AIV were entered in sequence with images recorded continuously. Coronary arteriography was performed to outline the relation of the catheter to the arterial tree.

In Vivo Studies in Humans

Subjects were patients undergoing right heart catheterization. Indications for this procedure included hemodynamic studies in idiopathic dilated or ischemic cardiomyopathy (n=2) and endomyocardial biopsy in patients who had undergone orthotopic cardiac transplantation (n=9). Studies were performed at the cardiac catheterization laboratory, University of California at San Francisco, after obtaining informed consent. With the use of an 8F giant lumen multipurpose MB-1 guiding catheter (Interventional Medical), the CS was cannulated via the right internal jugular vein through the same introducer sheath.
used for the biopsy or the right heart hemodynamics. A 0.014-in. guide wire was threaded sequentially into the GCV and the AIV up to the cardiac apex. With fluoroscopic guidance, the imaging catheter was advanced through the CS, GCV, and AIV, and images were continuously obtained. In four patients in whom coronary arteriography was indicated, the position of the LAD and Cx with respect to the ultrasound catheter was examined to provide further information on catheter orientation and arteriovenous relations. Continuous electrocardiogram and hemodynamic monitoring were performed throughout the duration of the study. At the end of the procedure, the catheters and sheaths were removed and hemostasis was obtained. There were no complications during cannulation of the coronary venous system.

**Image Analysis**

Selected portions of the high-quality videotape, timed with the cardiac cycle, were digitized (12 bits, Rasterops 324, Santa Clara, Calif.) in real-time (30 frames per second) and transferred to a computer disk. Lumen outlines were traced and areas were determined using specialized software developed in our laboratory. To ensure precision in measurement, the image was played in real-time for best visualization of the lumen wall interface.

**Calculations and Statistical Analysis**

Gated ultrasound images, timed to the point in the cardiac cycle when cross-sectional area was maximum, were outlined a total of five times, and an average luminal area for each image was determined. Angiographic areas, similarly timed, were determined using the diameter of the guide catheter for calibration. Relations between ultrasound and angiographic measurements were examined using simple linear correlation.\(^{15}\) Values are expressed as mean±SEM.

**Results**

**In Vivo Animal Studies**

We were able to obtain real-time images of the Cx from the GCV in all dogs studied. Images of the LAD from the AIV were obtained only in four of the six animals. In the remaining two, there was difficulty in negotiating the angle formed by the AIV with the GCV, and postmortem examination revealed the AIV to be a vein of very small caliber, barely allowing entry of a 5F catheter. While the Cx always appeared as a circular or oval structure, the appearance of the LAD was more variable, often seen in long axis proximally and circular distally. In a total of 12 vessel sites examined, mean cross-sectional area of the coronary arteries by ultrasound (4.81±0.18 mm\(^2\)) correlated closely with angiography (4.77±0.21 mm\(^2\)) (\(r=0.91, p<0.001\)). In all instances, the CS and GCV were well visualized, yielding high-resolution real-time 360° images of this part of the cardiac venous system. Although AIV images could be identified next to the proximal LAD, the part of this vein near the cardiac apex had the same caliber as the imaging catheter and was less clearly visualized.

**In Vivo Human Studies**

In all cases, the guide wire was threaded into the GCV and then into the AIV up to the cardiac apex with little difficulty. Real-time dynamic cross-sectional images of the Cx were obtained in all patients and of the LAD in eight patients (73%). There was some variability with regard to the lengths of LAD and Cx coronary artery segments that could be visualized in humans. In general, the regions most consistently seen were the late proximal and midsegments of the LAD and the middle and parts of the distal Cx. Coronary angiography was performed in four patients, and correlations of cross-sectional area of 12 sites with corresponding transvenous images were performed. Mean coronary cross-sectional area by ultrasound was 8.25±0.34 mm\(^2\) compared with 8.59±0.3 mm\(^2\) obtained from angiography (\(r=0.82, p=0.001\)). In two patients, luminal narrowing caused by atherosclerotic plaque was identified by transvenous imaging (Figure 2). As in the animal studies, the shape of the arteries imaged varied depending on the orientation of vein to artery. In all cases, the CS and GCV appeared as large, highly mobile structures. Coaxial positioning of the catheters was not always maintained because of the mobility of the catheter within the vein. Because of the large size of the veins, ultrasonic penetration was frequently inadequate, resulting in poor visualization of the wall of the arteries despite reasonable luminal images. In some instances, the pericardium could be visualized superficial to the vein and was seen as a bright, reflecting structure. In most cases, tributaries of the major veins such as the middle cardiac vein could be visualized as the catheter traversed the venous system. Subjects tolerated the procedure well in all cases, and average imaging time was 10–15 minutes.

**Discussion**

The present study is the first to demonstrate the potential for obtaining real-time two-dimensional ultrasound images of the Cx and LAD coronary arteries by the transvenous approach. Unlike angiography and direct intracoronary ultrasound, transvenous ultrasound imaging has the obvious appeal of being less invasive. Although preliminary, the study has shown that the procedure can be performed safely. Selective cannulation of tributaries of the CS such as the AIV has been performed before for metabolic studies of the venous effluent from the territory of the LAD.\(^{16,17}\) Using similar techniques, we have tried to take advantage of the close relation of the cardiac veins to the coronary arteries to image parts of the coronary circulation.

**Limitations of the Method**

We note the following limitations of our technique: 1) Ultrasound penetration was often inadequate, particularly in human studies, because of the large
size of the CS. Improved visualization of the coronary arteries may be obtained by using catheters with lower frequency (20 MHz and below), and results from such studies are awaited. 2) In most sections, wall characteristics were less clearly demonstrated than with direct intravascular ultrasound, again a problem related to ultrasonic penetration. At present, we suggest limiting this technique to studies of the arterial lumen. 3) Because of the changing orientation of arteries to veins in different parts of the coronary circulation, images must be interpreted with caution and with a full understanding of the anatomy of the cardiac venous system; circular, ellipsoid, and long-axis images of the coronary arteries are obtained depending on artery-vein relations. 4) In humans, transducer alignment in the long axis of the vessel was often difficult because of the large diameter of the CS and the GCV, allowing considerable variability in lateral motion of the catheter. This is, however, less of a problem in the AIV.

Potential Clinical Applications

We suggest that this technique, with further development, may be useful in the study of coronary artery pathology. It may be particularly helpful in the follow-up of the orthotopic cardiac transplant recipient. In this situation, right-heart catheterization is repeatedly performed for endomyocardial biopsy; the insertion of a catheter into the cardiac venous system is a practical additional step to screen for coronary artery disease, which is a common complication. Transvenous imaging may also be useful in other clinical situations where repeated studies of the coronary arteries are necessary to track luminal changes. Examples include the development of restenosis after percutaneous transluminal coronary angioplasty and regression of atherosclerosis with lipid-lowering drugs. The transvenous approach may also be useful when intracoronary lesions cannot be safely crossed, preventing direct ultrasound visualization of plaque. As luminal cross-sectional area can be obtained from this approach, coronary vascular reactivity in response to vasoactive substances (a useful diagnostic procedure in the evaluation of coronary artery spasm) can be studied. Although we were able to visualize atherosclerotic plaque in two patients, the ability of the technique to quantitate luminal narrowing in this situation remains to be determined, but with improved ultrasound penetration, this should become feasible. Transvenous imaging may also be useful in the intraoperative setting during coronary artery bypass grafting to examine the anastomosis without directly entering the coronary arteries. Being inherently less invasive than direct entry into the coronary arteries, transvenous imaging could serve as a powerful research tool in the study of coronary pathophysiology in humans.

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References


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