A Noninvasive Technic for Determining Patency of Saphenous Vein Coronary Bypass Grafts

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SUMMARY
A noninvasive method for determining patency of saphenous vein coronary bypass grafts has been developed in our laboratory. The system consists of a pulsed ultrasonic Doppler, a position-sensing arm for the Doppler transducer, a memory oscilloscope, an electrocardiogram, and strip-chart recorder. Patients are studied with the transducer in the suprasternal notch and intercostal spaces. Wherever flow is detected in the anterior mediastinum, a visible dot is stored on the oscilloscope screen at a point corresponding to the location of flow in the mediastinum. By repeated sampling at various depths a composite picture of a proximal section of graft is developed. Peak velocity flow signals from grafts occur during diastole distinguishing them from other arterial flow signals. Twenty-eight patients having 41 patent grafts were studied in a preliminary evaluation of the method. Three examples of angiograms with corresponding ultrasonic arteriograms demonstrate the feasibility and potential value of this new noninvasive technic for assessing patency of saphenous vein coronary bypass grafts.

Additional Indexing Words:
Coronary bypass surgery   Doppler
Ultrasound     Coronary artery disease

SAPHENOUS VEIN coronary bypass surgery is becoming common therapy for coronary artery disease. Although initial results in terms of symptomatic relief and graft patency are encouraging, more extensive studies are essential in order to determine its place in the therapeutic regimen for that disease. At present, cardiac catheterization and angiography are the only objective means of assessing patency of these grafts. The attendant morbidity and potential mortality of repeated angiography limit its routine use in postoperative studies. For this reason a noninvasive technic would be a powerful research and clinical tool in determining the efficacy of this surgical procedure. The present report describes the feasibility of an ultrasonic method for assessing patency of saphenous vein coronary bypass grafts.

Methods
A noninvasive method for arterial visualization has been developed in this laboratory, termed ultrasonic arteriography,1 2 and the initial clinical
application in man has been described.\textsuperscript{3} The ultrasonic arteriographic system used in this study consists of four parts: (1) a pulsed ultrasonic Doppler velocity detector, (2) a position-sensing arm which holds the Doppler transducer, (3) a storage or memory oscilloscope with an x-y axis display, and (4) an electrocardiogram and strip-chart recorder.

The ultrasonic arteriographic system is critically dependent upon the ability of a pulsed Doppler velocity detector\textsuperscript{5} to sample flow at any specified point along the sound beam. It differs from continuous-wave instruments in this important aspect.\textsuperscript{4, 5} In operation, a piezoelectric crystal is driven to emit a pulse of 5 MHz ultrasound of brief duration. The transmitting crystal, mounted in a probe, is coupled to the skin by an acoustic gel. The sound energy is thus transmitted through the skin and underlying tissues. When the pulse of ultrasound strikes moving blood cells, it is reflected back toward the probe where it activates the receiving crystal. By time gating the receiver, only those signals reflected from a point at a selected distance from the transmitter are detected. A target area as small as 2.5 mm can be sampled selectively.\textsuperscript{5} Flow is detected by the Doppler principle. If the transmitted ultrasound strikes moving blood cells, the frequency of reflected ultrasound is altered in proportion to the velocity of the moving particles. This reflected signal is mixed with the transmitted signal to produce a beat signal, the frequency of which is proportional to the velocity of blood flow. Thus, the pulsed ultrasonic Doppler has two outputs which are used to generate a picture of the vessel lumen on the oscilloscope screen: (1) an audio output whose frequency equals the Doppler shift and (2) a voltage which is proportional to the distance between the transducer and the sampling point.

![Image of Figure 1](http://circ.ahajournals.org/)

**Figure 1**

Patient N.S. with a saphenous vein right coronary bypass graft. (A) Lateral angiographic view of aorta and proximal segment of graft. (B) Longitudinal and (C) cross-sectional ultrasonic views. (D) Systolic flow signal from aorta and (E) diastolic flow signal from graft. (F) Electrocardiogram. Only part of the aortic lumen is visualized. The longitudinal ultrasonic section can be superimposed on the angiogram. The patient was supine.
The position of the transducer is relayed to the storage oscilloscope by three potentiometers mounted on a position-sensing arm. In use the transducer is constrained to move in x-y directions or rotate within a single plane. The potentiometers produce voltages corresponding to x-y motion and rotation. These voltages are coupled with the distance signal from the pulsed Doppler in order to locate the beam of the oscilloscope. When blood flow is detected, a dot corresponding to the Doppler signal is stored on the oscilloscope screen in the appropriate location. By moving the transducer over the area of interest and changing the range depth of the pulsed Doppler, the operator gradually develops an image of the flow stream on the oscilloscope screen. The picture obtained is either a cross-sectional or longitudinal view of the arterial lumen depending on the plane in which the transducer is moved.

Patients with saphenous vein bypass grafts are studied by the following procedure. Initially, the Doppler is used to survey the mediastinum through the suprasternal notch and intercostal spaces. Since flow in the coronary bypass occurs primarily during diastole, the timing of the Doppler signal in the cardiac cycle distinguishes flow in the bypass from predominantly systolic flow in other arteries. When an audible signal suggesting flow in the bypass graft is located, it is recorded on the strip chart and timed as diastolic or systolic by comparison to the electrocardiogram. If the signal is diastolic, indicating flow in the saphenous vein bypass, the transducer is positioned to sweep in a plane cutting through the graft. By repeated scans at various depths in the plane of the ultrasonic beam, a picture of the proximal bypass graft and a portion of the ascending aorta is developed on the oscilloscope and permanently recorded on Polaroid film. With

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**Figure 2**

Patient R.L. with a saphenous vein left anterior descending bypass graft. (A) Lateral angiographic view of aorta and proximal segment of graft. (B) Longitudinal ultrasonic section of graft superimposable on the angiogram. (C) Systolic and (D) diastolic flow signals from aorta and graft, respectively. (E) Electrocardiogram. The patient was supine.
practice an operator can identify the characteristic audible signal from the coronary bypass without having to develop an image on the oscilloscope. Thus, three types of information may be obtained: a cross-sectional or longitudinal image of the lumen of the bypass graft, a characteristic audible arterial flow signal during diastole, and a strip-chart recording of this flow signal simultaneously with the electrocardiogram.

As a preliminary feasibility study, 28 patients having 41 saphenous vein coronary bypass grafts proven to be patent by selective bypass angiography were studied by this technic. Approximately 30 min were required for studying each patient. However, this time varied considerably depending on the number of grafts present and the strength of the flow signals.

**Results**

Figures 1–3 show examples of angiograms, ultrasonic arteriograms, and flow signals from three patients. In figure 1 longitudinal and cross-sectional ultrasonic arteriograms of the right coronary bypass graft of patient N.S. are illustrated. A lateral angiographic view is

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**Figure 3**

*Patient R.G. with a saphenous vein left anterior descending bypass graft. (A) Lateral angiographic view of Judkins catheter, aorta, and graft. (B) Slanted cross-sectional ultrasonic view. (C) Systolic and (D) diastolic flow signals (50 mm/sec paper speed) from the aorta and bypass graft, respectively. (E) Electrocardiogram. The ultrasonic view shown is a cross section cutting through the origin of the graft and the aorta. The graft lies anterior to the aorta or on the right side of the angiogram and to the right of the dividing line in the ultrasonic view. The aorta lies on the left side of the angiogram and to the left of the dividing line in the ultrasonic view. Since this is a cross-sectional view the ultrasonic arteriogram cannot be superimposed on the angiogram. Only part of the aortic lumen is visualized. The patient was on his left side.*
shown corresponding to the longitudinal ultrasonic section. Whereas velocity signals from the aorta adjacent to the graft were recorded during systole, flow signals from the graft itself occurred during diastole. In this particular study, best results were obtained with the patient supine. For the longitudinal view the transducer was positioned in the right second intercostal space at the edge of the sternum and swept in the anterior-posterior plane; the cross-sectional view was obtained by sweeping in a right-left plane.

The left anterior descending bypass graft of patient R.L. is shown in figure 2. A longitudinal ultrasonic section and corresponding lateral angiographic view provide an excellent example of the results which can be obtained with this method. As in the previous example, the flow signal from the aorta was systolic and sharply changed to a diastolic arterial signal when the sound beam passed through the proximal graft. This patient was examined supine. The transducer was placed in the suprasternal notch, aimed to the left, and swept in an anterior-posterior plane.

The importance of positioning the patient to maximize flow signals is illustrated by the study conducted on patient R.C. in figure 3. With the patient supine satisfactory velocity signals from the left anterior descending graft could not be obtained. The ultrasonic arteriogram and flow tracings depicted in figure 3 were recorded only after the patient had been turned on his left side. Scanning was accomplished through the fourth left intercostal space with the transducer aimed cephalad and swept in a right-left plane. A slanted cross section of the graft and part of the ascending aorta were visualized. Again, peak flow during systole characterizes the aorta and a diastolic arterial signal, the bypass graft.

Distinct arterial flow signals during diastole, i.e., a positive study, were recorded from 24, or 59%, of the 41 grafts proven to be patent by angiography. Studies of an additional 10 grafts, or 24%, were probably positive on the basis of an arterial flow sound heard during diastole. However, due to a low signal-to-noise ratio the signal could not be adequately recorded on the strip-chart recorder. If these probably positive studies are included, the percent of identified patent grafts is 83% of those known to be open. Seven, or 17%, of the patent grafts could not be identified using this prototype instrument. If multiple grafts are present each one is identified separately by its anatomic location. For example, a right bypass graft is detected to the right of the sternum and a left graft to the left of the sternum.

Discussion

Initial clinical results of saphenous vein coronary bypass surgery for coronary artery disease have been promising. At present, however, thorough evaluation of this surgical procedure requires repeated postoperative cardiac catheterization and coronary bypass angiography with its attendant morbidity. The noninvasive technic presented in this report appears to be a potentially effective means of documenting patency of bypass grafts without the hazards of cardiac catheterization.

Several problems noted in these preliminary studies should be mentioned. As the examples illustrate, the position of the patient and orientation of the transducer may be critical in locating these grafts. Further experience will be necessary to determine the best patient position and location of the transducer for optimal results. Nearly all negative studies were due to the anatomic relationships of the graft to the chest wall. Increased A-P diameter, a graft deeper than 7 cm from the sternum or one with its origin low on the aortic root precluded adequate flow signals with this instrument. In patients with emphysema good signals are difficult to obtain due to the sound-absorbing properties of lung. Heavy scar tissue in the mediastinum may also attenuate ultrasound and prevent adequate examination. A more powerful transmitter emitting 2–3 MHz ultrasound will improve penetration of the sound beam and overcome some of these limitations, particularly in the group of "probably positive" patients where low signal-to-noise ratios are a problem. The only signal which may be erroneously ascribed to bypass flow is that from innominate veins.
However, this venous signal is received only with the transducer positioned in the suprasternal notch and directed at an angle of approximately 30–45° from the midline; it has a venous quality for anyone trained in recognition of Doppler flow sounds and is clearly different from the arterial quality characteristic of flow sounds in bypass grafts. The left innominate vein as it crosses the midline to enter the superior vena cava is the most frequently identified, although the right innominate (brachiocephalic) is also found on occasion. The range of this prototype instrument is usually inadequate to reach the superior vena cava which is located deep within the mediastinum.

At this state in its development a negative Doppler examination does not indicate coronary bypass occlusion. However, positive examination is diagnostic of an open graft. With the development of more sharply focused transducers and more noise-free instrumentation, and with accumulation of clinical experience, the role of the pulsed ultrasonic system in determining patency of coronary bypass grafts will become more clearly defined.

References

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