Comparison of Coronary Hemodynamics in Patients With Internal Mammary Artery and Saphenous Vein Coronary Artery Bypass Grafts: A Noninvasive Approach Using Combined Two-Dimensional And Doppler Echocardiography

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Blood flow in bypass grafts and recipient left anterior descending coronary arteries was evaluated with combined two-dimensional and Doppler echocardiography in 15 patients with an internal mammary artery graft and in 24 patients with a saphenous vein graft. Comparative studies of coronary hemodynamics were also performed regarding these two different grafting techniques.

The graft vessel was detected in 11 (79%) of 14 patients with an internal mammary artery graft and in 20 (87%) of 23 with a saphenous vein graft. The recipient left anterior descending coronary artery was detected in 10 (67%) of the former group and 17 (71%) of the latter. The blood flow patterns obtained were generally biphasic, consisting of systolic and diastolic phases with higher velocity during diastole. The maximal diastolic flow velocity in internal mammary artery grafts was much higher than that in saphenous vein grafts. In patients with an internal mammary artery graft, the flow pattern characteristics within the recipient coronary artery were quite similar to those within the arterial graft, and flow velocities within the recipient coronary artery and the arterial graft were quantitatively almost identical. This outcome may contribute to the long-term patency seen in internal mammary artery grafts.

On the other hand, the flow velocity in saphenous vein grafts was fairly low throughout the cardiac cycle. Flow velocity in the recipient coronary artery in patients with a saphenous vein graft was accelerated only in early diastole. As a result, the recipient coronary artery flow pattern and velocity differed substantially from those in the saphenous vein graft. Internal mammary artery and saphenous vein grafts showed average diastolic peak flow velocity of 57.7 ± 9.9 and 28.0 ± 8.9 cm/s, respectively, compared with 55.1 ± 7.2 and 93.5 ± 14.7 cm/s, respectively, in the recipient coronary arteries with artery grafts and vein grafts.

Thus, the Doppler method allowed us to evaluate not only the direct effects of bypass grafting on the coronary circulation, but also the differences in effects between these two different grafting techniques.

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Twenty years have passed since coronary artery bypass grafting was first performed by Favaloro (1), and today this operative procedure is considered to be one of the most valuable surgical techniques in treating patients with ischemic heart disease. In coronary artery bypass grafting, saphenous vein grafts have been used almost exclusively and satisfying results have been reported with regard to the short-term patency of this graft. Recently, however, saphenous vein grafts have been found to have poor long-term patency (2,3). On the other hand, it has been found that internal mammary artery grafts, having almost the same thickness as the recipient coronary artery, rarely develop irregularities of the graft wall, unlike saphenous vein grafts. Therefore, as expected, excellent long-term patency has been observed (4,5). Accordingly, the internal mammary artery has been increasingly employed as the graft vessel to ensure the continued therapeutic effectiveness of coronary artery bypass grafting.

We were the first group to carry out noninvasive measurement of left anterior descending coronary artery flow using combined two-dimensional and Doppler echocardiog-

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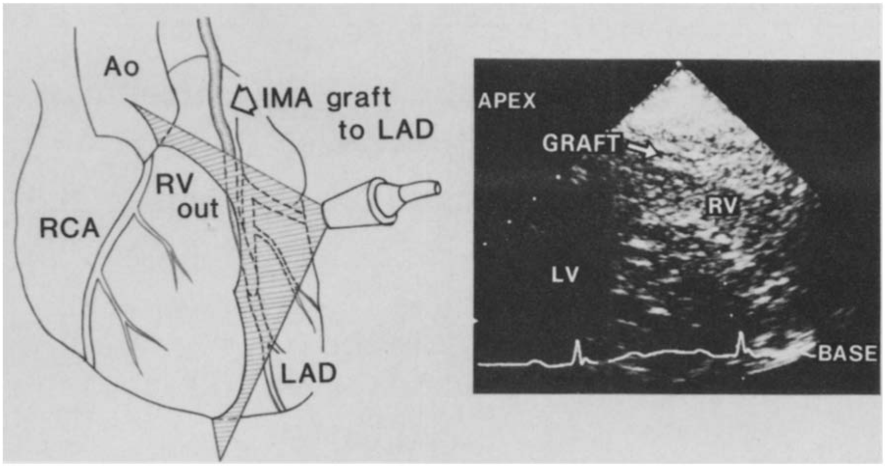

Figure 1. Detection of the internal mammary artery (IMA) graft to the left anterior descending (LAD) coronary artery. **Left panel,** Diagram illustrating the transducer position and the direction of the ultrasound beam for the long-axis echocardiographic section of the left ventricle used to detect the internal mammary artery graft. **Right panel,** A tubular structure about 2 mm in diameter is imaged in the area anterior to the right ventricle (RV) in the long-axis echocardiographic section of the left ventricle (LV). Ao = aorta; out = outflow tract; RCA = right coronary artery.

raphy, and we have analyzed coronary hemodynamics in a variety of cardiovascular diseases (6). In the present study, our combined two-dimensional and Doppler echocardiography technique was used in an attempt to measure, quantitatively analyze and compare blood flow in the two types of coronary bypass grafts and in the recipient coronary artery in patients with a bypass graft to the left anterior descending artery.

Methods

Study group. The study group consisted of 39 consecutive patients who received a bypass graft to the left anterior descending artery in the period from October 1986 to March 1988. They were 26 men and 13 women, aged 43 to 69 years (mean 58), with ischemic heart disease and severe stenosis in the proximal portion of the left anterior descending or left main coronary artery. Bypass grafting was performed to the mid-portion of the left anterior descending artery; 15 patients received an internal mammary artery graft and 24 received a saphenous vein graft. All patients underwent coronary arteriography within the 2 months before surgery. The degree of stenosis, which was determined with the criteria proposed in the American Heart Association Committee Report (7), was 90% to 100% (mean ± SD, 96% ± 5%) in patients with an internal mammary artery graft and 75% to 100% (94% ± 6%) in those with a saphenous vein graft. Postoperative graft patency was confirmed by coronary arteriography 4 to 5 weeks after surgery.

Echocardiographic equipment. The equipment used in this study was a real time two-dimensional echocardiographic unit incorporating a phased array and a pulsed Doppler flowmeter (Toshiba SSH60A/SDS60A). The ultrasonic frequency was set at 3.75 MHz with a pulse repetition rate of 6 or 4 kHz. The sample volume was teardrop in shape, 2 mm wide and 2 mm deep. A cutoff frequency of 200 Hz was generally selected for the high-pass filter to eliminate low frequency noise. This equipment provides a real time two-dimensional echocardiogram and a pulsed Doppler blood flow signal with a single transducer. It is possible to record the blood flow signal at any designated position on the two-dimensional echocardiogram. A dotted line and a parallel mark indicate, respectively, the orientation of the Doppler ultrasound beam and the position of the sample volume within the beam used for the blood flow signal. Frequency analysis of the reflected Doppler signal was carried out with fast Fourier transform spectral analysis and was displayed as a sound spectrogram. This was recorded at a paper speed of 5 cm/s with simultaneous recording of the M-mode echocardiogram, electrocardiogram and phonocardiogram.

Echocardiographic Procedure

Detection of the internal mammary artery graft (Fig. 1). The ultrasound beam was directed toward the heart from the left precordium through the third, fourth and fifth intercostal spaces with the patient in the left lateral decubitus position. First, the left ventricle was imaged in long-axis echocardiographic sections at these levels and then, under Doppler monitoring, the area anterior to the right ventricular outflow tract and anterior interventricular sulcus was carefully examined for the bypass graft to the left anterior descending artery. When a tubular structure, about 2 mm in diameter for the internal mammary artery graft, containing characteristic Doppler flow signals was detected, its shape and position were confirmed. After this procedure, intraluminal blood flow signals were evaluated with use of the Doppler method. The long-axis echocardiographic sections were carefully adjusted so that the sampling volume was located within the vessel lumen for as much of the cardiac cycle as possible. The Doppler signal and the two-dimensional echocardiogram were then recorded. Blood flow velocity was calculated, taking into consideration the angle between the Doppler beam and the longitudinal axis of the blood vessel as determined by the two-dimensional echocardiogram.

Detection of the saphenous vein graft. Following the same procedure as that described for the internal mammary artery graft, the left ventricle was imaged in long-axis echocardiographic sections: the area anterior to the right ventricular outflow tract and anterior interventricular sulcus were then carefully examined for the saphenous vein graft to the left anterior descending artery, as reported previously (6). When the vein graft, about 4 to 5 mm in diameter, was detected, the intraluminal blood flow signals were evaluated with use of the Doppler method and the blood flow velocity was calculated.

Detection of the left anterior descending artery. With use of the same procedure as that for the internal mammary artery graft, as reported previously (6), the left ventricle was imaged in long-axis echocardiographic sections and then the beam was inclined laterally to identify the anterior interventricular sulcus. Next, under Doppler monitoring, the area of the anterior interventricular sulcus was carefully examined for the coronary artery until a tubular structure (about 2 mm in diameter for the left anterior descending artery) containing characteristic Doppler flow signals was detected. After that, the intravascular blood flow signal was evaluated with the Doppler method. At this moment, the long-axis echocardiographic section was carefully adjusted to visualize clearly this tubular structure as long as possible and to keep the angle of incidence between the Doppler beam and the longitudinal axis of the blood vessel as small as possible, so that a major error in flow measurement could be reduced to the minimal extent. This also made it possible to determine accurately the angle of incidence. The Doppler signal and the two-dimensional echocardiogram were then recorded. Blood flow velocity was calculated by taking into consideration the angle of incidence as determined by the two-dimensional echocardiogram.

After informed consent was obtained, these blood flow measurements were made 2 or 3 weeks after surgery before postoperative angiography.

Statistical analysis. The differences between the two mean blood flow velocity values were compared by Student's t test. The criterion for statistical significance was $p < 0.001$. Values are expressed as mean values ± SD.

Results

Detection of each bypass graft and the left anterior descending artery. Internal mammary artery graft flow was detected in 11 of the 15 patients with this type of graft. In one of the four patients in whom flow detection was unsuccessful, graft occlusion was subsequently confirmed by arteriography. As a result, the detection rate for flow was 79% for internal mammary artery grafts.

Saphenous vein graft flow was detected in 20 of the 24 patients with this type of graft. Because one saphenous vein graft occlusion was confirmed by subsequent arteriography, the detection rate for saphenous vein graft flow was 87%. Bypass graft flow was detected at relatively distal portions of the graft, near the anastomotic site to the left anterior descending artery as observed on the two-dimensional echocardiogram. On the other hand, blood flow in the left anterior descending artery was detected in 10 (67%) and 17 (71%) of the 15 patients with an internal mammary artery graft and 24 patients with a saphenous vein graft, respectively.

The site for recipient coronary artery flow measurements was nearer the cardiac base than the site for graft flow measurements as observed on the echocardiogram. The direction of flow in the recipient coronary artery recorded at this site was opposite that in the graft. Therefore, coronary artery flow was generally detected at a position between the stenotic lesion and the anastomotic site of the bypass graft, corresponding to the mid-portion of the left anterior descending artery. However, in one patient with a saphenous vein graft, coronary artery flow was detected at a position distal to the anastomotic site, and in a second patient with a saphenous vein graft, coronary flow was detected both proximal and distal to the anastomotic site.

The angle of incidence between the Doppler beam and the longitudinal axis of the bypass graft or coronary artery as determined by the two-dimensional echocardiogram was 42° to 58° (51 ± 5°) for internal mammary artery grafts, 30° to 60° (46 ± 9°) for saphenous vein grafts and 42° to 62° (51 ± 5°) in recipient left anterior descending arteries.

Blood Flow Patterns in Patients With an Internal Mammary Artery Graft

Flow patterns in the bypass graft. Blood flow patterns in the internal mammary artery graft and the recipient coronary artery of one patient are shown in Figure 2. In this patient, bypass surgery had been performed for a 90% stenotic lesion in the proximal portion of the left anterior descending coronary artery. The graft flow pattern obtained basically showed two phases of anterograde flow corresponding to systole and diastole. The characteristic pattern showed slow, short-duration flow during systole and fast, long-duration flow during diastole (Fig. 2, upper panel). Graft flow velocity immediately after the first heart sound showed a low monophasic peak in early systole. After the second heart sound, blood flow increased abruptly to a higher peak and then slowly decreased toward the first heart sound. A small peak was also seen in late diastole. Then, blood flow velocity rapidly fell again immediately before the first heart sound of the subsequent cardiac cycle. The maximal flow velocity in early diastole was significantly higher than that seen in saphenous vein grafts, as will be described later, and the decrease in diastolic flow velocity toward late diastole was relatively slow. Retrograde, low velocity, spike-like flow, which was considered to be retrograde flow from the native

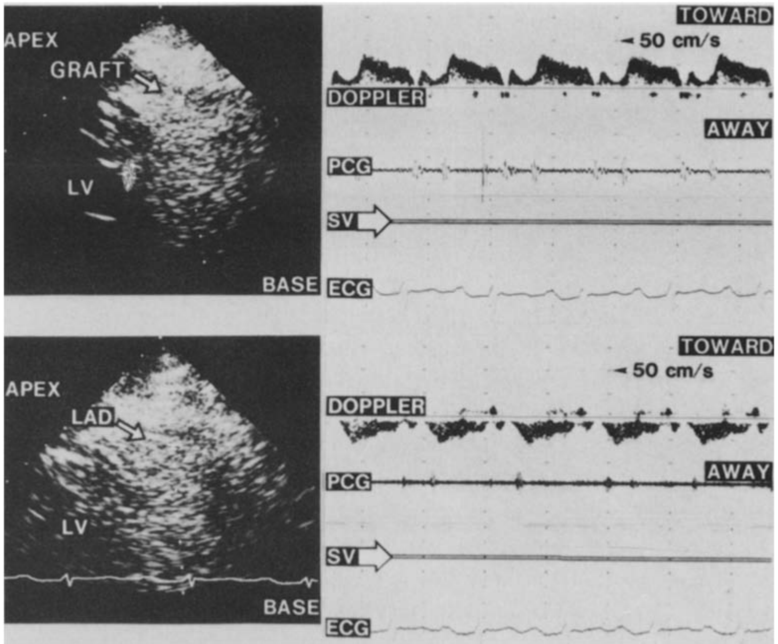

Figure 2. Flow patterns in a patient with an internal mammary artery graft. **Upper panel,** Flow pattern in the internal mammary artery graft characterized by biphasic flow, consisting of systolic and diastolic phases with higher velocity in diastole than in systole. The peak velocity is observed in early diastole. **Lower panel,** Flow pattern in the recipient left anterior descending coronary artery (LAD). The flow direction is toward the cardiac base from the apex. The flow characteristics are identical and flow velocity is approximately equal to that in the internal mammary artery graft. In early systole, anterograde spike-like flow is observed. ECG = electrocardiogram; PCG = phonocardiogram; SV = sample volume; other abbreviations as in Figure 1.

coronary artery, was observed during isometric contraction in some cases. The small peak in late diastole was not clearly seen in all cases.

To verify that the signals did indeed represent internal mammary artery graft flow, a contrast echo study was performed with use of selective injection of saline solution into the internal mammary artery graft during cardiac catheterization (Fig. 3). A marked enhancement of Doppler output was observed immediately after selective injection of saline solution due to the strong ultrasonic reflection exhibited by the microbubbles in the injected saline solution. Thus, the flow signal was identified as being within the internal mammary artery graft.

Flow patterns in the recipient coronary artery. Recipient left anterior descending artery flow was measured at a position between the stenotic lesion and the anastomotic site of the bypass graft. This flow exhibited a biphasic pattern, consisting of both systolic and diastolic phases with higher velocity during the latter (Fig. 2, lower panel). Blood flow was found to be directed toward the cardiac base from the apex, opposite the direction of graft flow. Flow characteristics were almost identical to those seen in the internal mammary artery graft and flow velocity also showed values similar to those seen in this type of graft. However, anterograde spike-like flow was usually observed in early systole corresponding to the phase of isometric contraction. This

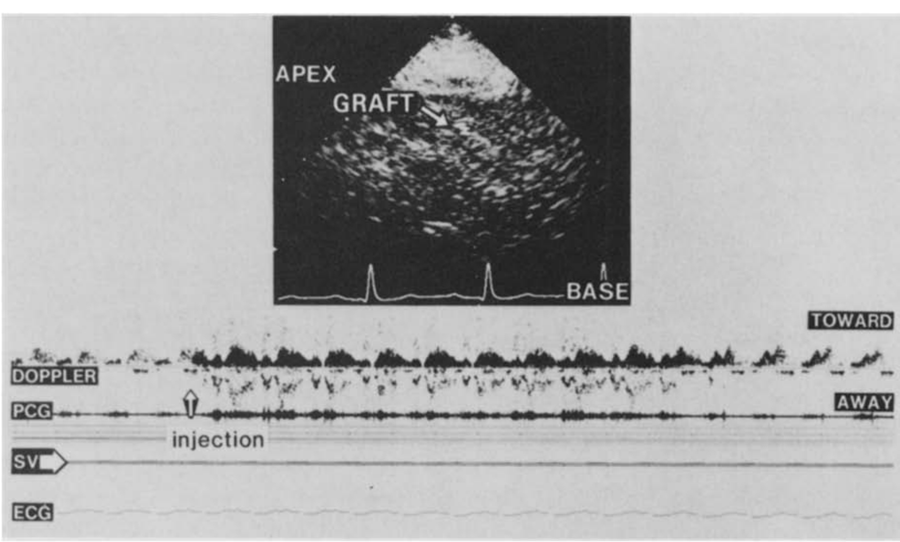

Figure 3. Contrast echo study using selective injection of saline solution into the internal mammary artery graft. Enhancement of Doppler flow output was observed immediately after selective injection (white arrow). Abbreviations as in Figures 1 and 2.

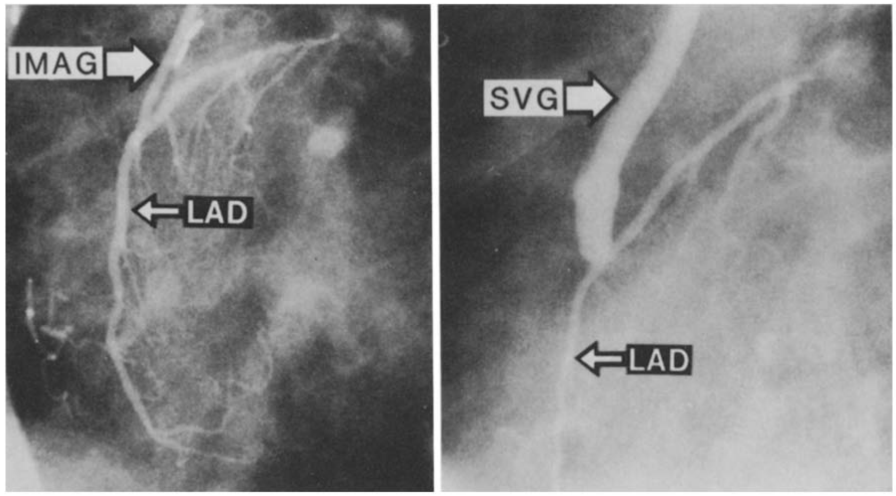

Figure 4. Cineangiograms of bypass grafts. **Left panel,** Angiogram of an internal mammary artery graft (IMAG) in the left anterior oblique view. The graft diameter is almost identical to that of the recipient left anterior descending coronary artery (LAD). The proximal portion of the recipient coronary artery between the stenotic portion and anastomotic site of the bypass graft is visualized by retrograde flow during angiography of the bypass graft. **Right panel,** Angiogram of a saphenous vein graft (SVG) in the left anterior oblique view. The graft diameter is about three times larger than that of the recipient coronary artery.

flow was considered to be flow passing through the stenotic portion of the coronary artery. Postoperative left coronary angiography also demonstrated that anterograde flow passing through the stenotic portion of the left anterior descending artery was detected only in early systole (6). This to and fro blood flow pattern between the stenotic portion and the anastomotic site of the bypass graft was clearly observed by the Doppler method.

Postoperative angiographic examination of the internal mammary artery graft demonstrated that the graft diameter was approximately the same as that of the recipient coronary artery (Fig. 4, left panel) and that regions distal to the site of coronary stenosis were receiving most of their blood supply through the bypass graft. The proximal portion of the recipient left anterior descending artery between the stenotic lesion and the anastomotic site of the bypass graft was visualized angiographically by retrograde flow.

Figure 5 shows the blood flow pattern in the recipient left anterior descending artery in another patient with an internal mammary artery graft (probably occluded) and with a 90% stenotic lesion in the proximal portion of that artery. In this patient, internal mammary artery graft flow was not detected by two-dimensional Doppler echocardiography, and recipient coronary artery flow showed an anterograde, low velocity flow pattern, rather than the characteristic retrograde, high velocity flow pattern described previously. This pattern indicated that regions distal to the site of coronary stenosis were perfused mainly by anterograde, low-velocity coronary artery flow passing through the stenotic lesion and that bypass graft occlusion or an extreme decrease in graft flow had developed. Postoperative angiography clearly demonstrated that the internal mammary artery graft was almost completely occluded and that regions distal to the site of coronary stenosis were visualized only by anterograde stenotic flow.

Blood Flow Patterns in Patients With a Saphenous Vein Graft

Flow patterns in the bypass graft. Flow patterns in the saphenous vein grafts showed the same characteristic diastolic dominance seen in internal mammary artery grafts. In saphenous vein grafts (Fig. 6, upper panel), however, the flow velocity pattern throughout the cardiac cycle was much

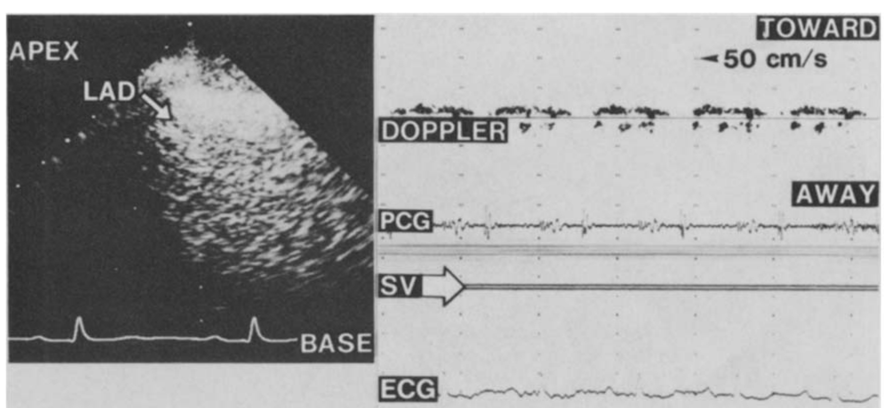

Figure 5. Flow patterns in the recipient coronary artery in a patient with an occluded internal mammary artery graft. Recipient coronary artery flow reveals an anterograde, low velocity flow pattern, rather than the characteristic retrograde high velocity flow pattern. Abbreviations as in Figures 1 and 2.

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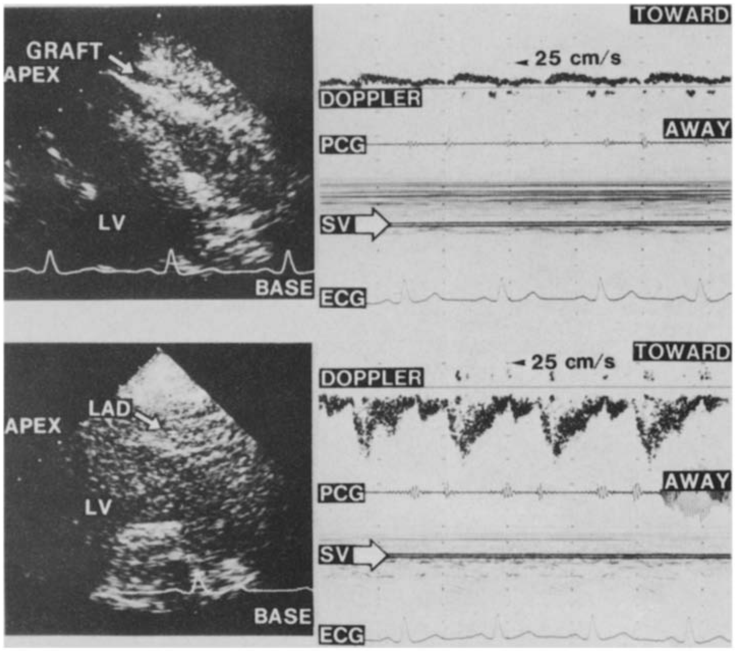

Figure 6. Flow patterns in a patient with a saphenous vein graft. **Upper panel,** Flow patterns in the saphenous vein graft exhibit the characteristics of diastolic dominance, but flow velocity throughout the cardiac cycle is much slower than that seen in internal mammary artery grafts. **Lower panel,** Flow patterns in the recipient coronary artery; flow is also directed toward the cardiac base. Although the maximal flow velocity is very high in early diastole, it then falls abruptly and is much smaller in late diastole than in early diastole. Abbreviations as in Figures 1 and 2.

slower than that seen in internal mammary artery grafts and the variations in velocity were also smaller. Postoperative angiography of saphenous vein grafts demonstrated that the diameter of the graft was about three times larger than that of the recipient coronary artery (Fig. 4, right panel).

Flow patterns in the recipient coronary artery. Blood flow in the recipient left anterior descending artery was basically directed toward the cardiac base, opposite that in the graft (Fig. 6, lower panel). The maximal diastolic flow velocity was significantly greater than that of the recipient coronary artery in patients with an internal mammary artery graft (Fig. 7). Although the flow velocity in the recipient coronary artery with a saphenous vein graft was very high in early diastole, it subsequently fell abruptly and became fairly low in late diastole. Thus, this flow pattern demonstrated high flow velocity and very large variations in velocity during diastole. This pattern was quite different, not only from that seen in saphenous vein grafts, but also from that seen in recipient coronary arteries with an internal mammary artery graft.

In two patients with a saphenous vein graft, however, recipient coronary artery flow was detected at a position

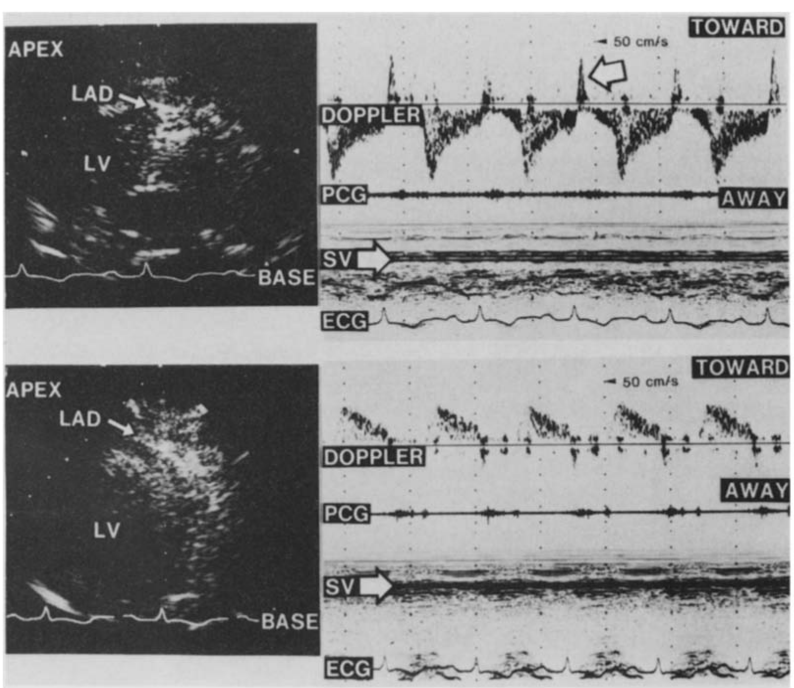

Figure 7. Flow patterns in the recipient coronary artery in a patient with a saphenous vein graft. **Upper panel,** Flow patterns at a position proximal to the graft anastomosis. This flow is basically directed toward the cardiac base, and its pattern exhibits high flow velocity and large variations in velocity during diastole. Anterograde, high velocity, spike-like flow is detected only in early systole (**large white arrow**). **Lower panel,** Flow patterns at a position distal to graft anastomosis. This flow is directed toward the cardiac apex, and anterograde spike-like flow is not detected in early systole. Abbreviations as in Figures 1 and 2.

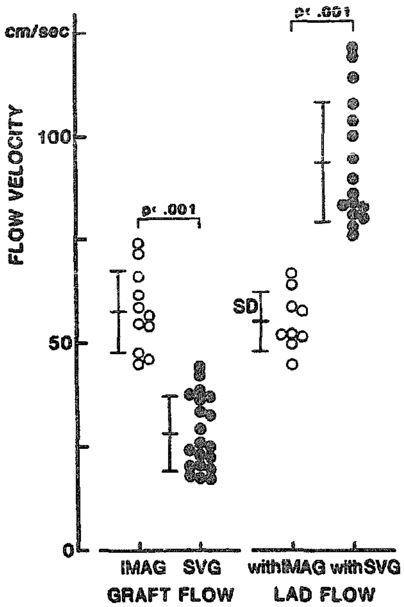

Figure 8. Peak flow velocity in bypass grafts and recipient left anterior descending coronary artery. **Left panel,** Peak flow velocity in internal mammary artery grafts (IMAG) and sapehnous vein grafts (SVG). **Right panel,** Peak flow velocity in the recipient left anterior descending (LAD) coronary artery, measured between the stenotic lesion and the anastomotic site of the bypass graft, in patients with internal mammary artery grafts (with IMAG) and with saphenous vein grafts (with SVG). Abbreviations as in Figures 1 and 4.

distal to graft anastomosis. Figure 7 shows the recipient coronary artery flow in one of these patients who had a 90% stenotic lesion in the proximal portion of the left anterior descending artery; recipient coronary flow was detected at positions both proximal and distal to the graft anastomosis. Blood flow proximal to the graft anastomosis was basically directed toward the cardiac base, and its pattern exhibited high flow velocity and large variations in velocity during diastole (Fig. 7, upper panel). Moreover, anterograde high velocity, spike-like flow passing through the stenotic portion of the recipient coronary artery was detected only in early systole. Blood flow distal to the graft anastomosis was directed toward the cardiac apex, and anterograde, spike-like flow was not detected in early systole (Fig. 7, lower panel). The flow velocity at this site was not as high as that proximal to the graft anastomosis.

Blood flow velocity in bypass grafts and the recipient coronary artery (Fig. 8). The maximal flow velocity in the bypass graft during systole and diastole in patients with an internal mammary artery graft was 30.9 ± 5.6 and 57.7 ± 9.9 cm/s, respectively, and in patients with a saphenous vein graft, 15.0 ± 4.9 and 28.0 ± 8.9 cm/s, respectively. On the other hand, the maximal flow velocity in the recipient left anterior descending artery during systole and diastole in patients with a patent internal mammary artery graft was 29.0 ± 5.0 and 55.1 ± 7.2 cm/s, respectively, and in the patients with a saphenous vein graft, the maximal flow velocity at a position proximal to the graft anastomosis was 50.2 ± 10.8 and 93.5 ± 14.7 cm/s, respectively. The maximal diastolic flow velocity was significantly greater in internal mammary artery grafts than in saphenous vein grafts, whereas flow velocity in the recipient left anterior descending artery tended to be significantly greater in that of patients with a saphenous vein graft than in those with an internal mammary artery graft.

In one patient whose internal mammary artery graft was almost totally occluded, blood flow velocity in the left anterior descending artery was markedly reduced. When maximal diastolic flow velocity in the bypass graft was compared with that in the recipient coronary artery, flow velocities were approximately equal in patients with an internal mammary artery graft. In patients with a saphenous vein graft, however, the difference between these flow velocities was large and the flow velocity in the recipient coronary artery was two to four times higher than that in the bypass graft.

Discussion

Comparison of graft flow patterns between internal mammary artery and saphenous vein grafts. In coronary artery bypass grafting it has been recognized that internal mammary artery grafts retain long-term patency (4,5). This can be attributed to several factors: 1) Internal mammary artery grafts do not manifest turbulent flow because the diameter of this type of graft is almost the same as that of the recipient coronary artery (8). 2) Arterial grafts undergo no histologic changes after implantation, whereas vein grafts undergo marked endothelial thickening (9). 3) Arterial grafts are "live" conduits for coronary bypass blood flow and are controlled by similar autoregulatory processes (10). 4) Arterial grafts produce more prostacyclin than do saphenous vein grafts (11). On the other hand, a number of disadvantages of internal mammary artery grafts have been noted: 1) Arterial grafts should not be used for large vessels in conditions in which there is high oxygen demand, as in left ventricular hypertrophy (12). 2) There have been cases in which arterial grafts have narrowed and become hypoplastic when the degree of stenosis is relatively mild in the recipient coronary artery (13).

In this study concerning the characteristics of the two types of grafts with respect to coronary hemodynamics, flow patterns in internal mammary artery grafts demonstrated that the early diastolic flow velocity was greater than that in saphenous vein grafts and that the decrease in flow velocity during diastole was relatively small toward late diastole. Furthermore, the flow pattern and velocity in mammary artery grafts were quite similar to those in the recipient coronary arteries. These findings indicate that blood flow in internal mammary artery grafts exhibits a high velocity pattern and no stagnation, resulting in smooth flow into the recipient coronary artery. The internal mammary artery has been called a "live" conduit for coronary bypass (10). The results of blood flow analysis in our study have also demonstrated that this type of graft exhibits characteristics quite similar to those of the recipient coronary artery.

On the other hand, blood flow patterns in saphenous vein grafts demonstrated that low velocity flow dominated throughout the cardiac cycle and that localized stagnation of blood flow was well predicted within the large diameter vein graft. Moreover, blood flow into the recipient coronary artery was not as smooth as in the case of an internal mammary artery graft because the flow pattern seen in the vein graft was appreciably different from that seen in the recipient left anterior descending artery. The long-term patency of this vein graft is thought to be greatly influenced by these factors.

Blood flow patterns in the recipient left anterior descending artery. As previously reported (6), the mean maximal flow velocity during diastole at the midportion of the left anterior descending artery measured by two-dimensional Doppler echocardiography was 33.5 cm/s in normal subjects. The maximal diastolic flow velocity at the same site of the recipient coronary artery in patients with a bypass graft was greater than that in normal subjects. Moreover, the flow patterns in the recipient coronary artery varied greatly, depending on the type of graft employed. In patients with an internal mammary artery graft, the flow velocity in the recipient coronary artery was not as high as that in patients with a saphenous vein graft, and the flow pattern characteristics in the recipient coronary artery were similar to those in the internal mammary artery graft.

On the other hand, flow patterns in the recipient coronary artery in patients with a saphenous vein graft demonstrated high flow velocity and very large variations in velocity during diastole. It has already been determined (14) that the internal mammary artery is a "live" conduit for coronary bypass and has a variable lumen that can adjust its diameter to changing myocardial blood flow demands, whereas the saphenous vein is less capable of such physiologic adaptability. It has been reported (15) that the flow volume in saphenous vein grafts is significantly greater than that in internal mammary artery grafts in intraoperative measurements, and it has also been claimed (15) that anastomosis of the saphenous vein graft often accelerates the progression of the stenotic lesion in the recipient coronary artery. Therefore, it has been suggested that in saphenous vein grafts, in which the diameter is disproportionately larger than that of the recipient coronary artery, a massive flow volume exceeding the oxygen demand of the myocardium may be supplied to the perfused area. The high velocity blood flow patterns in the recipient coronary artery in patients with a saphenous vein graft measured in our study suggest such excessive blood flow in the perfused area. Additionally, it is suggested that vein grafts inherently cause large variations in the diastolic flow velocity in the recipient coronary artery.

Clinical implications. Noninvasive detection of aortocoronary bypass graft flow has been carried out by other investigators (16,17) using the pulsed Doppler technique. This method, however, has not been widely applied clinically because many problems have been reported with regard to detection rate and specificity for the flow in grafted vessels. Moreover, a practical methodology for the noninvasive measurement of recipient coronary artery flow has not been established. In this study, noninvasive detection and flow analysis in two types of grafts (internal mammary artery and saphenous vein) and the recipient coronary artery were undertaken with use of two-dimensional Doppler echocardiography with satisfactory detection rates for flow in these vessels. Moreover, we were able to demonstrate clearly that this method made it possible to evaluate the blood flow status directly in the recipient coronary artery receiving its blood supply from the bypass graft. This noninvasive method was very useful for evaluating the effects of coronary artery bypass grafting and clarifying the differences in coronary hemodynamics between these grafting methods.

Because the detection rate of graft flow using this technique was unsatisfactory in the past, evaluation of graft patency was quite difficult if its flow could not be detected. In the present study, however, blood flow measurement in the recipient coronary artery in addition to graft flow evaluation allowed us to make confident assessments concerning graft occlusion. On the other hand, special consideration has to be taken of the mean Doppler incident angle that was as large as 49°. This represents some limitation in the precise calculation of maximal systolic and diastolic flow velocities. In general, the portion of the coronary artery system presently accessible to this method is limited to the left anterior descending artery. Further studies concerning the detection of coronary arteries other than the left anterior descending artery should be undertaken.

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