

Follow-up evaluation after renal artery bypass surgery with use of carbon dioxide arteriography and color-flow duplex scanning

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Purpose: Postoperative evaluation of renal artery bypass grafts historically has been obtained by contrast renal arteriography before discharge from the hospital. Recent reports have advocated replacing arteriography with abdominal duplex scanning for evaluating and monitoring the integrity of renal artery bypasses. We propose a combination of these two techniques, which provides minimal risk to the patient and renal parenchymal function.

Purpose: Between July 1, 1990, and Dec. 31, 1991, 17 patients (8 men, 9 women) underwent 24 renal artery bypasses for poorly controlled hypertension or deteriorating renal function. In the immediate postoperative period each patient underwent carbon dioxide (CO₂) renal arteriography to detect any technical defects and to define bypass graft anatomy. Subsequently, color-flow duplex scanning of the renal artery bypass grafts were done at 3-month intervals with the postoperative CO₂ arteriogram for baseline comparison. CO₂ arteriography clearly defined proximal/distal anastomotic anatomy, bypass conduit integrity, and bypass conduit runoff.

Results: Procedural morbidity was zero because no hematomas developed and serum creatinine remained stable. Duplex scanning for a mean follow-up of 8.3 months revealed antegrade flow in 23 bypasses with peak systolic velocity of 60 to 100 cm/sec. One bypass graft had a peak systolic velocity greater than 150 cm/sec suggestive of a proximal anastomotic stenosis; however, the patient died before a repeat, verifying CO₂ arteriogram could be obtained. Recurrent hypertension developed in one patient with velocities less than 100/cm/sec, and repeat CO₂ arteriography revealed no evidence of graft or anastomotic stenosis.

Conclusion: CO₂ arteriography and duplex scanning provide an accurate means of initially evaluating and subsequently monitoring renal artery bypass grafts, with minimal risk of renal or patient morbidity. (J VASC SURG 1993;18:23-30.)

Renovascular hypertension or rapidly progressive renal insufficiency or both caused by severe renal artery occlusive disease can be treated effectively by renal artery bypass surgery.¹⁻⁷ However, early postoperative graft failure often leading to loss of the kidney has been reported to occur in 5% to 11% of

cases.⁸⁻¹⁰ Late bypass graft failure occurs in an additional 7% to 20% of patients,^{8,10,11} so that up to 30% of patients undergoing renal artery bypass grafting may be at risk for early or late graft occlusion.

Early renal artery bypass graft failure is reported to be due to technical errors.^{9,10} Consequently, it is recommended that all renal artery reconstructions be evaluated with use of arteriography before discharge of the patient from the hospital. However, arteriography with iodinated contrast is not without risk,^{12,13} particularly in a patient whose kidneys have recently been subjected to a period of ischemia.

Late renal artery bypass graft failure is thought to be due to either extensive fibrosis on the exterior surface of the graft compressing the lumen or to anastomotic or midgraft intimal hyperplasia.⁸⁻¹⁰ If these lesions are to be detected before graft occlusion, serial bypass graft evaluations are necessary. How-

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Presented at the Sixth San Diego Symposium on Vascular Diagnosis, San Diego, Calif., Feb. 17-21, 1992.

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0741-5214/93/\$1.00 + .10 24/1/41752

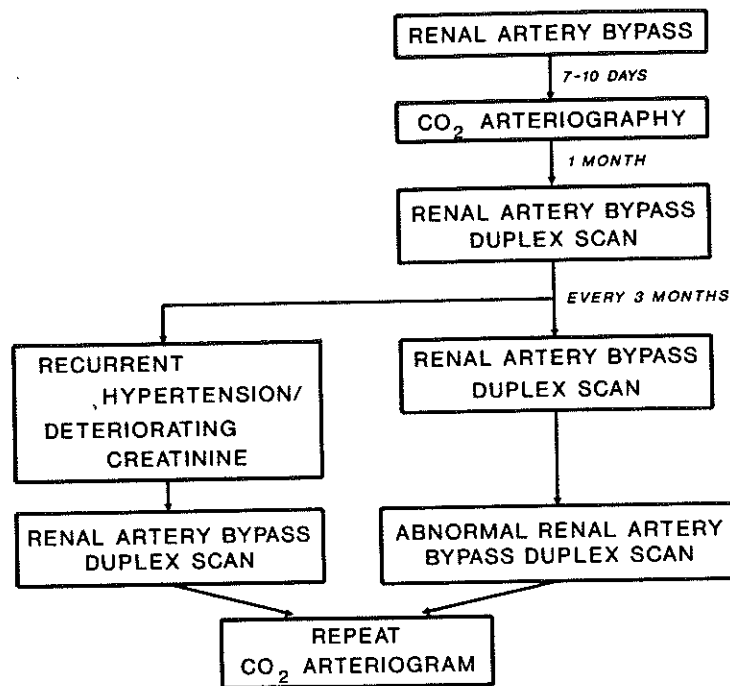


Fig. 1. Algorithm for the postoperative evaluation of renal artery bypass grafts performed to treat either renovascular hypertension or deteriorating renal function.

ever, serial contrast arteriography is not only impractical but risky. Thus failing or occluded renal artery bypass grafts are usually detected only when the patient's hypertension or renal insufficiency recurs.

Recently carbon dioxide (CO_2) has been demonstrated to be a safe contrast medium for arteriography.^{14,15} In addition, duplex scanning has been shown to be an effective technique for detecting renal artery stenosis.^{11,16,17} Therefore a prospective study was begun at the University of Florida to investigate whether early postoperative renal artery bypass graft visualization with CO_2 arteriography combined with long-term follow-up evaluation with use of color-flow duplex scanning provided an effective and safe method of early and late postoperative renal artery bypass graft evaluation.

PATIENTS AND METHODS

Between July 1990 and December 1991, 17 patients (8 men, 9 women) underwent 24 renal artery bypasses for poorly controlled hypertension or rapidly deteriorating renal function or both. Mean age of these patients was 62.7 years (range, 29 to 75 years). Associated medical diseases included cardiac disease in 13 (76%), smoking in 10 (59%), and diabetes mellitus in 3 (18%). Renal artery bypass was done

concomitantly with aortic reconstruction in 11 patients (aortobifemoral, 8; abdominal aortic aneurysm repair, 3) or alone in six patients. The reconstruction was bilateral in seven patients and unilateral in 10 patients. The proximal anastomosis was constructed end to side to the anterolateral aspect of the native aorta or to the Dacron graft.^{6,11} The distal anastomosis was end to end in all cases. Nonreversed saphenous vein was the conduit of choice in 22 bypasses, whereas one patient required bilateral polytetrafluoroethylene conduits when saphenous vein was not available.

All patients survived the operative procedure without complications. After operation renovascular hypertension was cured in seven patients, improved in seven patients, and unchanged in two patients. In the single patient with progressive renal failure who underwent bilateral renal artery bypass for salvage of renal function, serum creatinine improved from 3.0 to 1.7 mg/dl.

Before discharge from the hospital, each patient ($n = 17$) underwent CO_2 renal arteriography to define the bypass graft anatomy and to detect technical defects in the renal artery reconstruction. During postoperative follow-up, color-flow pulsed-wave Doppler studies of the renal artery bypass grafts

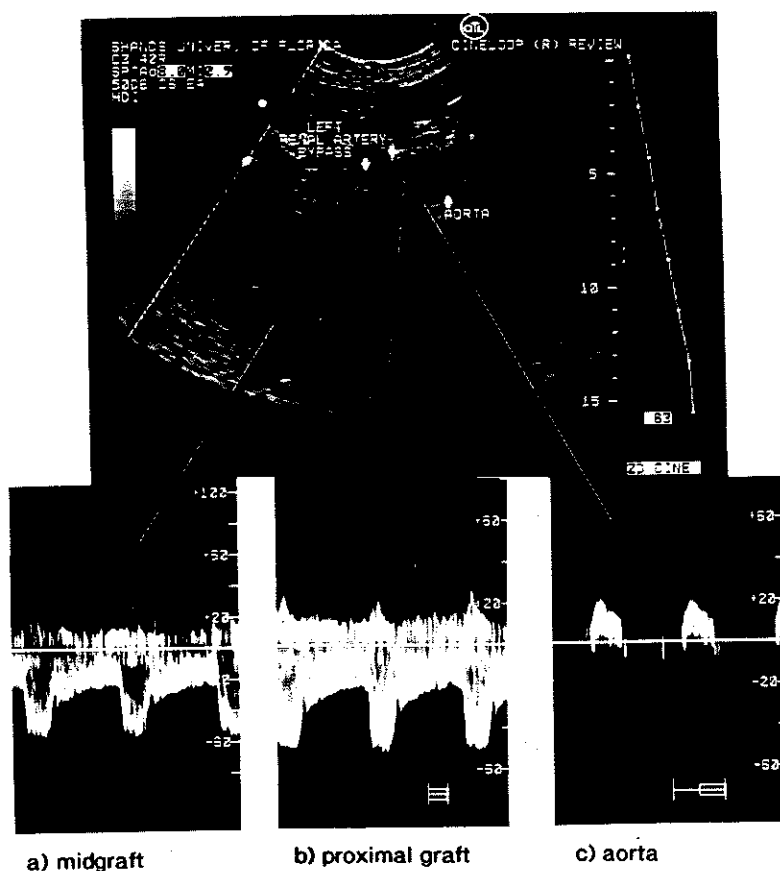


Fig. 2. Duplex scan of a left-sided saphenous vein renal artery bypass graft. Easily seen in the oblique projection is the distal aorta and the renal artery bypass graft. Pulsed-wave Doppler tracings show the PSVs along the bypass graft to be 50 to 60 cm/sec.

were done initially at 1 month ($n = 17$), then at 3-month intervals with use of the postoperative CO_2 arteriogram for baseline comparison. Abdominal duplex scanning was not done before 1 month after operation because of patient complaints of increased incisional tenderness caused by scan probe pressure/manipulation required to visualize the aortorenal grafts. Also, during the early postoperative period, incisional staples and edema/induration added to the technical difficulties of the study. If color-flow duplex scanning suggested a graft or anastomotic stenosis (peak systolic velocity [PSV] ≥ 150 cm/sec), repeat CO_2 arteriography was obtained. Also, if hypertension control or renal function deteriorated, the patient was returned to the vascular laboratory for repeat color-flow duplex scanning followed by repeat CO_2 arteriography, regardless of the results of abdominal duplex scanning (Fig. 1).

TECHNIQUES

CO_2 arteriography

Each patient undergoes an overnight fast and is given an intravenous bolus of glucagon (0.5 mg) before the study to decrease the effects of intraabdominal bowel gas. After the patient is placed in the supine position on a standard tilting arteriographic table, the common femoral or axillary artery is punctured, and a 4F catheter is introduced and positioned in the infrarenal aorta cephalad to the renal artery bypass grafts. This catheter is then connected to a dedicated CO_2 gas prototype arterial injector (Angiodynamics, Glen Falls, N.Y.) developed at the University of Florida. This injector is equipped with multiple check valves that ensure a controlled delivery of the CO_2 gas volume; thereby preventing the intraluminal explosive effect caused by the easy compressibility of the CO_2 gas. The injector is filled with CO_2 gas from a disposable CO_2 cylinder

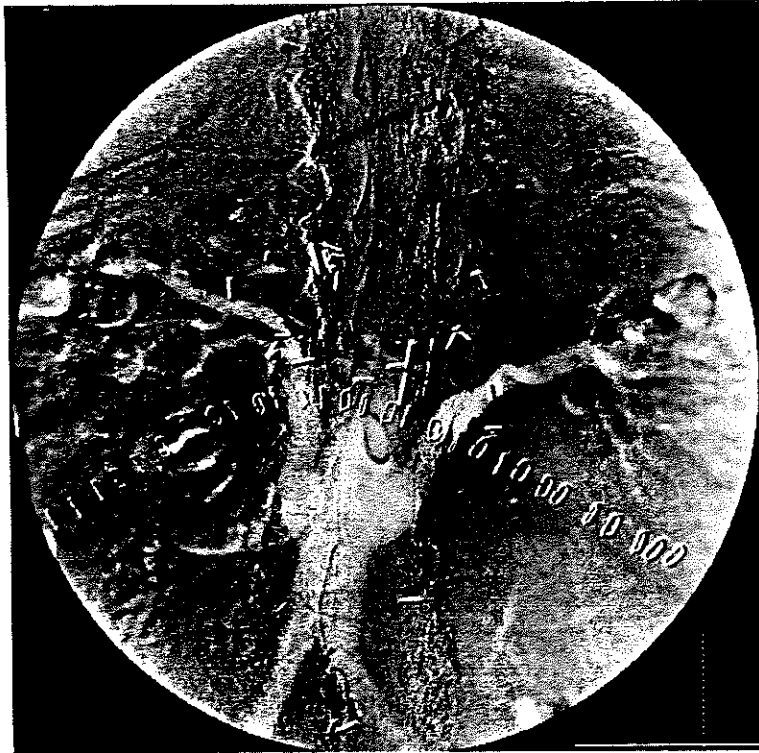


Fig. 3. Early postoperative CO₂ arteriogram demonstrates the distal aorta and bilateral saphenous vein renal artery bypass grafts. Proximal and distal anastomoses are easily visualized, and no technical defects are seen. Also, second order arterial branches of the renal artery are seen in the renal parenchyma (*arrows*).

(Medipure Carbon Dioxide, Union Carbon Gases, Linde Division, Danbury, Conn.). Next, 70 ml of CO₂ gas is delivered into the aorta at a rate of 140 ml/sec, and arterial images are generated with computer-enhanced digital subtraction techniques. Occasionally, the final picture is improved by compiling multiple digital images into a single composite image with use of a "stacking" software program (Toshiba America, Tustin, Calif.).

Renal artery color-flow duplex scanning

All examinations were done with a 2.5 MHz transducer for both real-time B-mode ultrasonic imaging and pulsed-wave color-flow Doppler insonation (Ultramark-9, Advanced Technology Laboratories, Bothell, Wash.). Each patient was examined early in the morning after an overnight fast. With the patient in the relaxed supine or lateral decubitus position, the infrarenal aorta was visualized in the sagittal plane. The left renal vein was identified, and moving caudally, the renal artery bypass grafts were visualized. A diagonal flank probe position was often required because of the oblique (cephalopos-

terolateral) pathway of the bypass graft. With use of color-flow B-mode imaging to assist accurate placement of the sample volume, pulsed-wave Doppler velocity tracings were obtained from the midportion of the graft as well as just distal to the proximal and distal anastomoses (Fig. 2).

RESULTS

CO₂ arteriography was done an average of 9.8 days after operation (range, 6 to 20 days). All studies were obtained before discharge from the hospital. The native aorta or Dacron aortic replacement, the renal artery bypass grafts, including proximal and distal anastomoses (Fig. 3), as well as the second order and occasionally third order renal artery branches (Fig. 4) were visualized. All bypass grafts were widely patent without anastomotic stenoses. The only defect noted was a minor kink in a single saphenous vein graft (Fig. 5).

Procedural morbidity from CO₂ arteriography was zero because no groin hematomas developed, minimal blood loss occurred, and renal function remained stable in all patients. Mean prearterio-

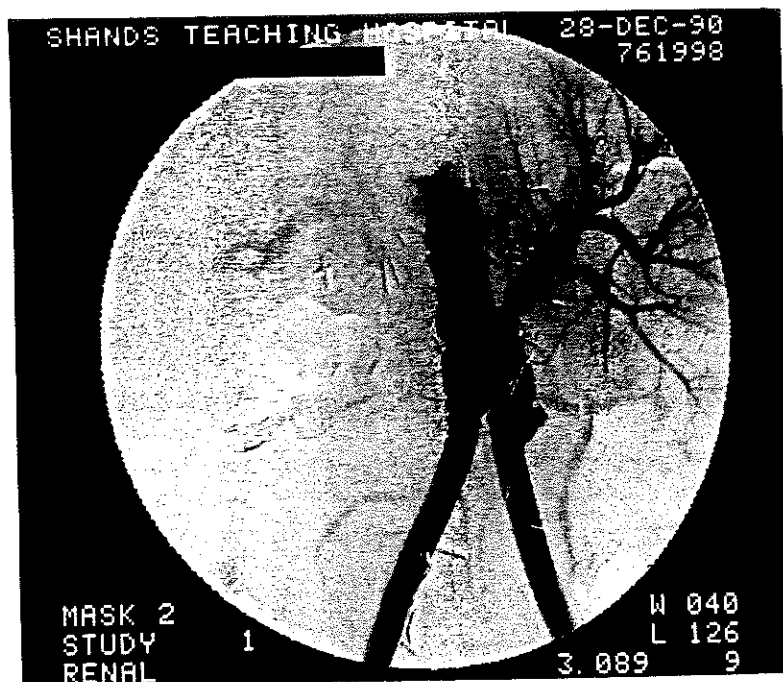


Fig. 4. Postoperative renal artery bypass CO₂ arteriogram illustrates second and third order branches of the renal artery. Patient was positioned with the left side up so that CO₂ gas floated upward and more easily filled the bypass graft and the branches of the kidney.

graphic serum creatinine was 1.3 mg/dl (range, 0.7 to 3.0), whereas the postprocedure value equaled 1.2 mg/dl (range, 0.8 to 2.7) ($p = NS$). Only one value changed more than 0.2 mg/dl. In this individual renal artery reconstruction was done to ameliorate progressive renal insufficiency and a rising creatinine level. After operation and postoperative CO₂ arteriography, the serum creatinine continued its decline for several more weeks.

Renal artery bypass grafts were successfully evaluated and followed after operation with color-flow duplex scanning in all 17 patients. Two patients died during follow-up, for a mortality rate of 12%. One patient died 2 months after operation when massive upper gastrointestinal hemorrhage from an aortoenteric fistula developed. The second patient died of pneumonia 5 months after renal artery bypass. Mean follow-up for the remaining 15 patients was 8.3 months, during which the group underwent an average of 2.8 follow-up scans (range, 1 to 6).

All 24 grafts were visualized by color-flow imaging and found to have antegrade blood flow. Simultaneous pulsed-wave Doppler analysis along the bypass graft demonstrated PSVs between 60 and 100 cm/sec in all but one patient. In this latter patient the 4-month postoperative color-flow duplex scan demonstrated an increased PSV of 150 cm/sec just

beyond the proximal anastomosis, whereas distal graft velocities were consistently 15 to 20 cm/sec. This study was distinctly different from her original postoperative duplex scan where the PSV was consistently less than 100 cm/sec. Attempts to verify a proximal vein graft stenosis with use of repeat CO₂ arteriography were unsuccessful because pneumonia developed and the patient died soon thereafter. Recurrent hypertension developed in one patient 16 months after bilateral renal artery bypasses. Repeat color-flow duplex scanning demonstrated normal and unchanged PSV (< 100 cm/sec) along the length of the bypass conduit and native renal artery bilaterally. Repeat CO₂ arteriography verified normal bypass conduit and native renal artery anatomy. End-diastolic velocities were also recorded in each patient and analyzed but did not provide further insight into bypass graft flow hemodynamics.

DISCUSSION

As in any arterial bypass, early failure of renal artery bypasses caused by technical defects or late graft failure as a result of anastomotic hyperplasia/recurrent arterial disease can occur. With use of standard contrast arteriography to investigate this problem, Dean et al.¹⁰ reported a 15.7% (17/108) incidence of problems with aortorenal



Fig. 5. CO₂ arteriogram obtained 10 days after operation illustrates a minor kink (*arrow*) in the saphenous vein graft just distal to the proximal anastomosis. This minor defect was not detected by either color-flow imaging or by pulsed-wave Doppler spectral analysis.

saphenous vein bypass grafts during the early postoperative period (7 to 10 days). These problems consisted of suture line stenosis in 10 grafts and graft thrombosis in seven cases. Graft thrombosis led to nephrectomy in five patients, and nephrectomy was recommended but refused in the remaining two. Likewise, Stanley et al.⁹ reported a 7.8% (8/102) incidence of aortorenal saphenous vein bypass graft thrombosis during the early postoperative period. Again, a nephrectomy was required in seven patients, and the kidney was salvaged in the remaining patient by reoperation.⁹ Although not proved, Stanley et al.⁹ thought that all graft thromboses were due to preventable intraoperative errors. Therefore renal artery arteriography before discharge from the hospital has been advocated for all patients after aortorenal bypass. Alternatively, Hansen et al.¹⁸ and Okuhn et al.¹⁹ have advocated the use of intraoperative ultrasonography to detect and repair these defects before the completion of the reconstructive procedure.

A policy of early postoperative arteriography after

all renal artery bypasses has been followed at the University of Florida. However, the risk of contrast arteriography early after aortorenal bypass remains a major concern.^{12,13} Martin-Paredero et al.¹² found an 11.3% incidence of acute renal dysfunction in patients undergoing aortography. This incidence increased to 41% with a prior history of abnormal renal function and was more common with aortic injection of iodinated contrast material. More importantly, the risk of renal injury with contrast arteriography appears to be particularly high immediately after an episode of acute renal ischemia, such as occurs with all renal artery bypasses.

Alternatively, CO₂ gas can be used as a contrast agent for arteriography with minimal risk of renal injury, even in the face of preexisting renal dysfunction.^{14,15,20} The use of CO₂ in the 1960s for detection of pericardial effusions documented its minimal human toxicity.²¹ However, its use as a contrast agent for arteriography did not become practical until the advent of digital subtraction techniques. Electronic enhancement is necessary to detect and amplify the

small difference in density between CO₂ gas and the surrounding soft tissue. In addition, special injection techniques had to be developed to avoid explosive delivery and to ensure complete displacement of the blood from the artery being studied.

The chemical properties of CO₂ gas readily explain why its use leads to low patient morbidity. First, it has a very low viscosity (1/400 of iodinated contrast), which allows delivery of large volumes through very small catheters (e.g., 3F to 4F); therefore arterial puncture holes are small and hemostasis is easy to achieve. Second, CO₂ gas is readily soluble in blood (20 × O₂); therefore it dissolves quickly into blood and is rapidly cleared from the body via the lungs. Finally, being a normal body metabolite, CO₂ gas injection produces minimal patient discomfort and does not cause hypersensitivity reactions or renal toxicity. Experimentally, use of technitium TC 99M dimercaptosuccinic acid and hippuran scans, no deterioration in renal function was demonstrated after direct injection of large quantities of CO₂ gas into normal canine renal arteries.²² Similarly, as shown in this study, renal function, as measured by serum creatinine levels, remains stable in patients after undergoing CO₂ arteriography.

Despite the innocuous nature of CO₂ gas, proper use is essential to ensure accurate and safe arteriography. CO₂ gas is extremely buoyant and floats on blood. If an insufficient amount of CO₂ gas is infused, complete displacement of the blood from the lumen of the artery will not occur, and a distorted, inaccurate image will be recorded. The kidney is located posterolateral to the aorta, and the proximal anastomosis of a bypass graft is positioned on the anterolateral surface of the aorta. If the arteriogram is done with the patient in a supine position, CO₂ gas must travel in a posterior (i.e., downward) direction to fill the bypass graft and the renal artery branches; therefore it is difficult to consistently infuse sufficient CO₂ gas into the renal artery bypass graft to displace blood from parenchymal arterial branches (third order or smaller) before it dissolves. This can be overcome by positioning the bypass graft and kidney to be studied higher than the level of the catheter through which the CO₂ gas is injected. However, if the organ supplied by the artery being evaluated with CO₂ gas is located in a nondependent position (i.e., up) for a prolonged period of time (e.g., the kidney of a patient in the lateral decubitus position), organ ischemia can occur if CO₂ gas becomes entrapped after completely displacing the blood, creating a "vapor lock" similar to that which can occur in the

fuel line of an automobile carburetor. This problem has occurred only once in the entire experience at the University of Florida and can easily be avoided by occasional repositioning of the patient.

Over the past 10 years more than 700 CO₂ arteriograms have been done at the University of Florida, with only two complications being directly attributed to the use of CO₂ gas. Transient sigmoid colon ischemia developed in one patient after the patient received more than 2000 cc of CO₂ gas into the aorta. Transient lower extremity mottling developed in a second patient after the patient received multiple injections of CO₂ gas during the lower extremity runoff evaluation.²⁰

Long-term evaluation of aortorenal bypass grafts with use of arteriography has demonstrated bypass dilation in 13% to 45% of saphenous vein grafts and late stenoses in 5.6% to 9.5%.⁸⁻¹⁰ In addition, deterioration in hypertension control and/or renal function will develop in as many as 20% of patients after an initially successful aortorenal artery bypass. Thus almost one half of patients with aortorenal saphenous vein bypass grafts will have some abnormality over time.⁸⁻¹⁰ In all these patients serial or repeat evaluation with standard contrast arteriography is invasive and not without risk.

Recent advances in ultrasound technology have provided a noninvasive technique by which renal artery bypass grafts can be studied. Sandager et al.²³ initially reported using duplex scanning to evaluate and follow renal artery bypass grafts. In a more definitive study, Eidt et al.¹¹ demonstrated duplex scanning to have an overall diagnostic accuracy of 86% in defining the presence or absence of renal artery bypass graft stenosis or occlusion. They concluded that an abnormal duplex scan, especially if positive clinical correlation exists, warranted arteriography. Kohler et al.¹⁶ suggested that the ratio of renal artery to aortic PSV 3.5 or greater accurately predicted 60% or greater stenosis in the appropriate renal artery. However, Eidt et al.¹¹ were able to correctly identify only three of seven (43%) 60% or greater stenoses using the renal aortic ratio criteria. Recently Hoffmann et al.²⁴ have shown renal artery PSV alone to be more accurate in predicting renal artery stenoses than the renal aortic velocity ratio. Therefore in this study, a PSV 150 cm/sec or greater suggested the presence of a 50% or greater graft stenoses. In addition, because of the minimal risk of CO₂ arteriography, we recommended verifying the result of any abnormal duplex scan, regardless of clinical correlation.

In this study all but one of the aortorenal bypass

grafts was shown by use of color-flow duplex scanning, to be widely patent without stenoses, dilations, or aneurysms. Included in this group was the single patient with recurrent hypertension found to have patent bypass grafts without stenoses verified with CO₂ arteriography. Unfortunately, the one abnormal scan could not be verified because of the patient's untimely death. It is interesting to note that the postoperative scans were of adequate quality regardless of conduit type (polytetrafluoroethylene, 2, saphenous vein, 22) or the position of the bypass conduit (infrarenal, 23 vs suprarenal aorta, 1). In each instance the bypass graft was visualized with color-flow mapping, and clear Doppler tracings were obtained.

In conclusion, the combination of CO₂ arteriography and abdominal color-flow duplex scanning provide an excellent method to assess both short-term and long-term results of renal artery reconstructions. In our series both techniques were done without risk of renal or patient morbidity; therefore patient acceptance is excellent. With routine use of these techniques, both initial technical errors and later recurrent disease or graft stenoses should be detected before the occurrence of bypass graft thrombosis or deterioration in renal function or both.

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Submitted March 4, 1992; accepted Aug. 12, 1992.