Revascularization of Aortic Arch Branches and Visceral Arteries Using Minimally Invasive Endovascular Techniques

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Abstract

Minimally invasive techniques as the first line of management in vascular reconstruction are beginning to replace older surgical techniques. General and specific approaches in the endovascular reconstruction of branches off the aortic arch (innominate and subclavian arteries) and the visceral branches off the abdominal aorta (renal and mesenteric arteries) are described. The branches of the aortic arch and the visceral arteries are discussed together because of the similarity in the interventional techniques used for revascularization. Patient selection, endoluminal techniques, complications, and patient management will also be discussed.

Key Words: Endovascular techniques, aortic arch vessels, visceral arteries, renal arteries, mesenteric arteries, minimally invasive techniques.

Introduction

THE DIAGNOSTIC ANGIOGRAPHIC TECHNIQUES explained by Seldinger in 1953 began a new era in the field of vascular disease management (1). In 1964, Dotter and Judkins introduced a new method of treating vascular occlusive disease, a technique that has become known as percutaneous transluminal angioplasty (PTA) (2). Since then, transcatheter endovascular procedures have been used more frequently to treat symptomatic atherosclerosis and other vascular diseases. As we acquire a better understanding of disease processes, and as improvements in medical technology continue, minimally invasive techniques as the first line of management in vascular reconstruction are replacing older surgical techniques. We will describe general and specific approaches in the endovascular reconstruction of branches off the aortic arch (innominate and subclavian arteries) and the visceral branches off the abdominal aorta (renal and mesenteric arteries), discussed together because of similarities in interventional techniques used for revascularization. Patient selection, endoluminal techniques, complications, and patient management will be addressed.

General Principles

Pre-procedural Imaging

An attempt to gain the maximum anatomical information should be made to allow for advanced planning of therapy and thereby to improve patient outcome. These details include status of the aorta, angulation of the artery with the aorta, and status of the visceral organ (i.e. extent of the parenchymal disease in case of renal artery stenosis). Doppler ultrasound, computed tomography (CT), magnetic resonance imaging (MRI), and isotope scans are the usual noninvasive modalities to obtain this information. In special circumstances, a diagnostic angiogram may have to be performed as a separate procedure.

Case Selection and Patient Work-up

The relationship of a patient's complaints to vascular compromise must be established by

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history, physical examination and non-invasive studies. Note should be made of hypertension, coagulation status, cardiac and cerebrovascular disease, diabetes, renal insufficiency and patient medications. It is necessary to consult with the concerned medical and surgical specialists caring for the patient so that all management options are considered before the intervention to assure that the patient receives the best possible care. Surgical back up may be required for interventional procedures to manage some rare, but life-threatening potential complications of arterial rupture if necessary. Specifically, before the procedure, the bleeding parameters — prothrombin time (PT), partial thromboplastin time (PTT), platelets — and renal function (creatinine) must be evaluated. In suspected cases of arteritis, intervention should be considered after the erythrocyte sedimentation rate (ESR) becomes normal.

Patient Preparation and Medication

Patients should be fully informed of the procedure, including technical and clinical success rates, long-term outcomes, and any potential complications. An informed consent should be obtained. Understanding the procedure may reduce patient anxiety and yield better cooperation during the procedure. For example, often patients need to hold their breath and not move during digital subtraction imaging. This is best achieved when patients are relaxed and cooperative.

Patients may be admitted to the hospital for same-day surgery. Most often, the procedure can be performed under sedation and local anesthesia. Children and uncooperative/unconscious patients may require general anesthesia. Standard preangiography orders are written, including intravenous hydration and restriction of oral intake to clear fluids after midnight prior to the procedure.

Equipment and Materials

Angiographic equipment capable of digital subtraction is essential. The image intensifier must be large enough to accommodate imaging of the entire abdomen, if necessary. Materials include the following:

- Guiding catheters usually 6F, suitable length and shape according to the orientation and distance from the site of puncture).
- Diagnostic catheters including Pigtail (for aortic flush).
- Simmons, Cobra, Headhunter, Sos-Omni, and Berenstein catheters for selective catheterization.
- Balloon catheters.
- Wires (0.14–0.18” diameter wires, 0.35” diameter wires; exchange length wires 260 – 300 cm).
- Stents ranging from 4 – 10 mm diameter.

Vascular Access

Most commonly, right femoral arterial access is obtained. For renal arterial intervention, ipsilateral femoral approach is preferred. In the visceral branches, which are directed inferiorly, such as the superior mesenteric artery and occasionally the renal and celiac arteries, a brachial approach may be necessary. For a transplant kidney, the approach can be from the contralateral femoral artery.

Contrast Agents

Nonionic iodinated contrast is preferred. If the patient’s creatinine is elevated (greater than 1.5 mg/dL), the procedure can be performed with a presumed nephroprotective drug such as fenoldapam (3). Alternative contrast agents include CO_2 and gadolinium (4, 5). The resolution of these alternative contrast agents is less, and depending on the situation, regular contrast may be used for initial and final diagnostic imaging. A dialysis may be planned, if necessary.

Initial Diagnostic Study

Aortic flush angiogram using a 5F pigtail catheter is recommended. The aim is to confirm the extent of the disease by assessing the length of the stenosis, expected diameter and extent of vessel narrowing, orientation of the vessel to the aorta, and condition of the aorta so that a final plan can be developed. The artery should be demonstrated in profile, which may require oblique views (as in renal imaging) or lateral views (as in cases of celiac and superior mesenteric artery imaging). The near accurate length of the diseased segment is best measured in the profiled image of the vessel. Dimension assessment can be made with the help of computer software available in most of the digital subtractions angiography (DSA) machines by comparing the size with a known object like a diagnostic catheter. Intra-arterial pressure gradient measurements across the lesion may help in deciding whether the stenosis is significant or not.

A significant gradient is more than 20 mm Hg. The indications for renal artery intervention are outlined in the Table.

Reaching the Target Site

Access to the target vessel is first achieved with a diagnostic catheter of appropriate configuration. For example, a Headhunter 1 catheter (angular sickle shape) can access the vessels of the aortic arch from the femoral approach, and a reverse curved catheter can access the visceral vessels.

Once access is obtained, the diagnostic catheter may be exchanged for a guiding catheter, which is most often a 6F in size. The guiding catheter should be of appropriate length (enough to be placed in the origin of the artery) and shape so that it stays within the proximal portion of the artery. This allows contrast injection through the guiding catheter to facilitate imaging and proper placement of a balloon or stent once it has crossed the lesion.

A continuous flow of heparinized saline (500 mL normal saline with 2000 units heparin) at a minimal rate should be maintained by connecting the side arm of the vascular sheath to a pressure bag to prevent thrombosis.

TABLE

Indications for Renal Artery Intervention Recommended by Society of Cardiovascular & Interventional Radiology (July 1999)

Renal Artery Angioplasty

Presence of a hemodynamically significant renal artery stenosis (greater than 50% luminal stenosis and/or greater than a 20 mmHg pressure gradient) and there is one of the following conditions:

1. Hypertension that cannot be controlled medically on two drugs of different classifications.
2. There is unexpected deterioration of renal function.
3. There is evidence of loss of renal mass.
4. The etiology is fibromuscular dysplasia.
5. The degree of stenosis is of such a high degree that occlusion is anticipated in the near future.

Renal Artery Stent Deployment

Failure to attain a hemodynamically satisfactory result by renal artery angioplasty as indicated by one of the following conditions:

1. Less than 30% residual renal artery stenosis following balloon angioplasty measured from the outer margins of intimal fissures.
2. Greater than a 20 mm Hg peak systolic residual pressure gradient.
3. Presence of a flow limiting dissection of the renal artery.
4. Restenosis of a lesion that was treated by a technically successful angioplasty in the past.

www.sirweb.org/clinical/pdf/Ind_Renal_Angio.doc

Reconstruction / Revascularization

The stenotic segment may be negotiated with the help of a smaller hydrophilic catheter and a soft tip guide wire to minimize intimal dissection. If the lumen is totally occluded, a 0.18″ diameter wire may be considered. When probing the lesion, a digital vascular roadmap, a feature available on many digital subtraction angiographic units, can be used to direct the manipulations. A roadmap is obtained by contrast medium injection and storage of the resulting image for real-time subtraction during later fluoroscopy. This feature is helpful both for wire placement and balloon/stent placement. Once the catheter is across the lesion, 3,000 – 5,000 U of heparin is given. An appropriate balloon should be covering the entire length of the stenotic segment, and the diameter should be equal to the expected diameter of the artery. If the stenosis is significant, there may be associated post-stenotic dilatation, which should be kept in mind while deciding the expected diameter. Predilatation may be necessary with a smaller sized angioplasty balloon to facilitate the procedure if the stenosis is severe or a larger balloon catheter cannot be passed across an occlusive segment.

Angioplasty versus Stenting

Most often, stenting has a better initial success rate compared to balloon angioplasty and slightly higher long-term patency (6). A failed balloon angioplasty may require stenting. Stents are avoided in young pediatric patients because stents cannot expand as the patients grow. As a result, the duration of adequate patency may be longer for these patients with surgical intervention than with endovascular treatment.

Assessment of Reconstruction

Anatomical assessment comparing the percentage of patency with that of pre-procedural images can assess immediate success. Physiological assessment of flow and pressure measurements can give a better functional result. In clinical assessment, the patient must demonstrate clinical signs of improvement (i.e., in cases of renal artery intervention, significant reduction in the blood pressure with a corresponding decrease in serum BUN/creatinine levels and antihypertensive medication).

A diagnostic run that demonstrates the vessels distal to the site of reconstruction is essential to exclude complications like embolization.

Complications of Endovascular Revascularization

In general, the complications following endovascular procedures may be related to the puncture site, target site, and contrast material. Specific complications will be briefly described under individual sections.

Post-procedural Care and Follow-up

Unless there is a contraindication, platelet aggregation inhibitors (125 – 325 mg of aspirin orally) should be given prior to the procedure and continued for 3 – 6 months afterward. Additional medication, such as coumadin or clopidogrel bisulfate, may be given, if necessary (7).

Follow-up is usually done by assessing the patient's clinical status and by noninvasive vascular imaging, looking for the recurrence of the initial symptom (mesenteric angina in case of a mesenteric artery stenosis) or a sign (hypertension in case of renal artery stenosis).

Innominate and Subclavian Arteries

Although angioplasty has been performed extensively in the peripheral, renal, and coronary arteries since the 1970s, angioplasty of the supra-aortic arteries began in the 1980s. In the early years, it was done reluctantly, mainly because of the fear of cerebral embolization (8). Innominate and common carotid artery lesions usually have been treated with transthoracic surgery, which has a considerable morbidity and mortality rate (9). However, Hüttl et al. reported on the outcome of 89 patients who underwent innominate artery angioplasties (10). The authors concluded that angioplasty is a safe and effective procedure compared to that of open surgery. There were no deaths, a lower complication rate and an excellent initial success rate. Today, angioplasty/stenting is the treatment of choice in cases of symptomatic innominate artery and subclavian stenosis and short occlusions (10, 11).

The patients usually present with upper limb claudication, transient ischemic attack, or vertebrobasilar insufficiency. The initial diagnosis of innominate artery stenosis or occlusion is based on clinical data, pulse palpation of the radial arteries, comparative blood pressure measurement of both arms, and carotid and vertebral duplex scans. The diagnosis may be confirmed with CTA, MRA, or DSA. Subclavian stenosis with retrograde flow of blood within the vertebral artery may be seen in nearly half of the patients (10). A stenosis of greater than 60% usually requires intervention. Angioplasty is generally carried out via the femoral artery. A long guiding catheter is preferred, keeping the distal end of the catheter near the origin of the target artery. Balloons of a diameter equal to that of the innominate artery just beyond the lesion may be chosen for dilatation (9 – 12 mm) with a length to approximate the diseased arterial segment (usually 2 or 4 cm). In cases of technical difficulties in traversing the lesion with a larger balloon, predilation with a smaller balloon, such as a 3 – 4 mm coronary balloon may be necessary. If the lesion is predilated with a smaller balloon, the larger balloon catheters can then easily cross the diseased segment. There is a general feeling that primary stent deployment is not mandatory; however, it provides a better initial angiographic result and is required when there is a significant residual stenosis following balloon dilation. The primary success rate of innominate angioplasty and stenting has been reported to be greater than 95% (10, 11). Most of the reported interventions involving the innominate arteries were performed with angioplasty alone. However, stent implantation has now become a relatively common part of treating these lesions (12) (Fig. 1). When treating aortic arch vessels, a post procedure angiogram is required not only to confirm a satisfactory radiographic result but also to exclude embolism to the cerebral circulation.

Long-term follow-up includes blood pressure measurements on both arms as well as subclavian, right common carotid, and right vertebral duplex scans. The patency rates of 89% at 5 years (12) for innominate and subclavian artery revascularization is thought to be related to the large vessel size and high blood flow. The complications of innominate and subclavian artery endovascular reconstruction include cerebral infarction (2%), transient ischemic attacks (6%) (10), and mortality 0.2% (12). The use of new protection devices may further decrease the risk of embolization.

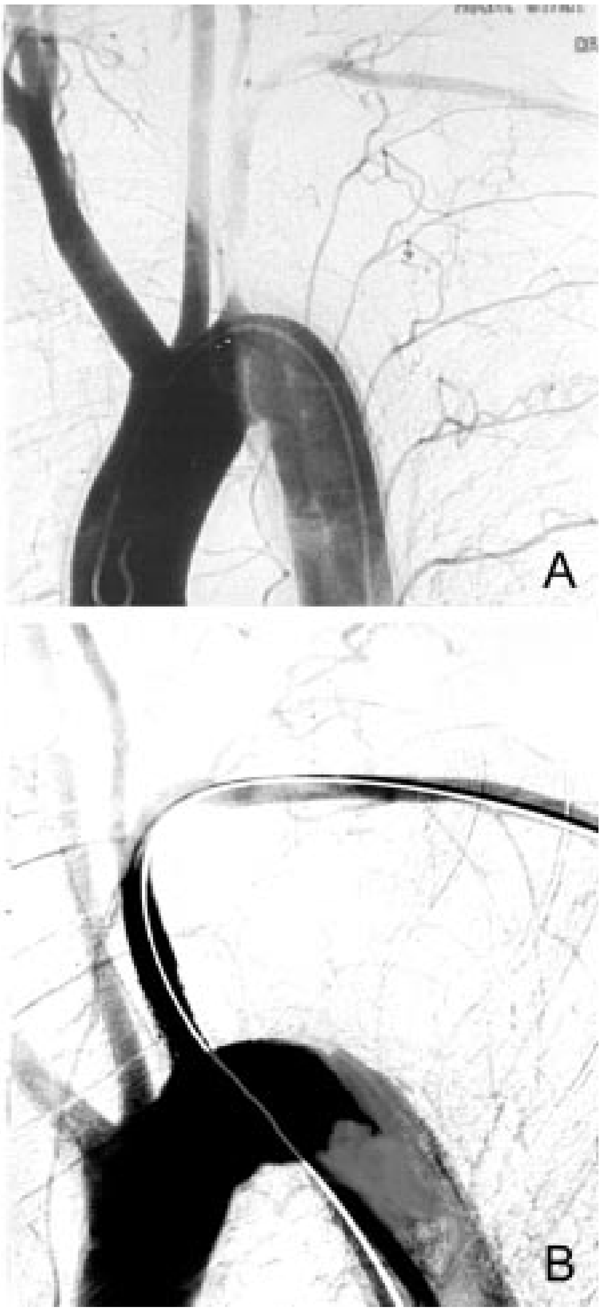

Fig. 1. Fifty-eight-year-old female presenting with left upper extremity claudication. **(A)** Arteriography from a groin approach demonstrates a severe focal stenosis of the left subclavian artery just beyond its origin. **(B)** Following stenting with a balloon expandable stent, full patency of the lumen is restored. The patient's symptoms resolved immediately after the procedure.

Renal Artery

Etiology of renal artery stenosis (RAS) is atherosclerosis in approximately 70% of patients (usually males over 50 years of age). The stenoses are localized mostly in the proximal segment of the renal artery and are ostial in 50% of the patients. In the remaining 30% of the patients, the stenoses are caused by fibromuscular dysplasia (FMD), which, most often, affects younger women.

The main indications for renal artery intervention are renovascular hypertension and ischemic nephropathy. Procedures are considered appropriate for kidneys with long axis exceeding 7 – 8 cm (Table).

The procedure usually is performed from the ipsilateral femoral approach; the axillary or brachial approaches, less frequent, may be required for the renal arteries with a downward angulation. The size of the most frequently used balloons is 5 – 8 mm. A guiding catheter with a suitable shape (i.e., hockey stick, cobra) should be selected. Patients with a pressure gradient of greater than 20 mm Hg are good candidates for renal arterial dilatation. The use of pressure gradients often determines whether to intervene or not (13). Balloon mounted stents are preferable compared to the unmounted stents (Figs. 2 and 3).

Stent placement has greatly improved the technical success and long-term patency of atherosclerotic osteal stenosis and main renal artery lesions treated unsuccessfully with angioplasty alone (12). Technical success is nearly 97% with major complications occurring in fewer than 6%. It is essential to demonstrate a good nephrogram with no filling defects at the end of the procedure. Approximately two thirds of patients treated for hypertension with use of stents are cured or have improved blood pressure control at 1-year follow-up. In FMD patients, the clinical success rate is higher, and up to 50% of patients become normotensive (off medication) after successful angioplasty. Stabilization of renal function is seen in nearly three fourths and improvement in 20% of the patients with ischemic nephropathy (12).

Mesenteric Arteries (Celiac/Superior Mesenteric)

Mesenteric angina is an uncommon and difficult diagnosis to make. The incidence has increased significantly over the past few decades because of the increasing number of elderly patients with atherosclerotic disease. Patients with mesenteric angina classically present with colicky abdominal pain following meals (14, 15). Over time, this leads to fear of eating and progressive weight loss. The symptoms, such as nausea, vomiting, diarrhea, and

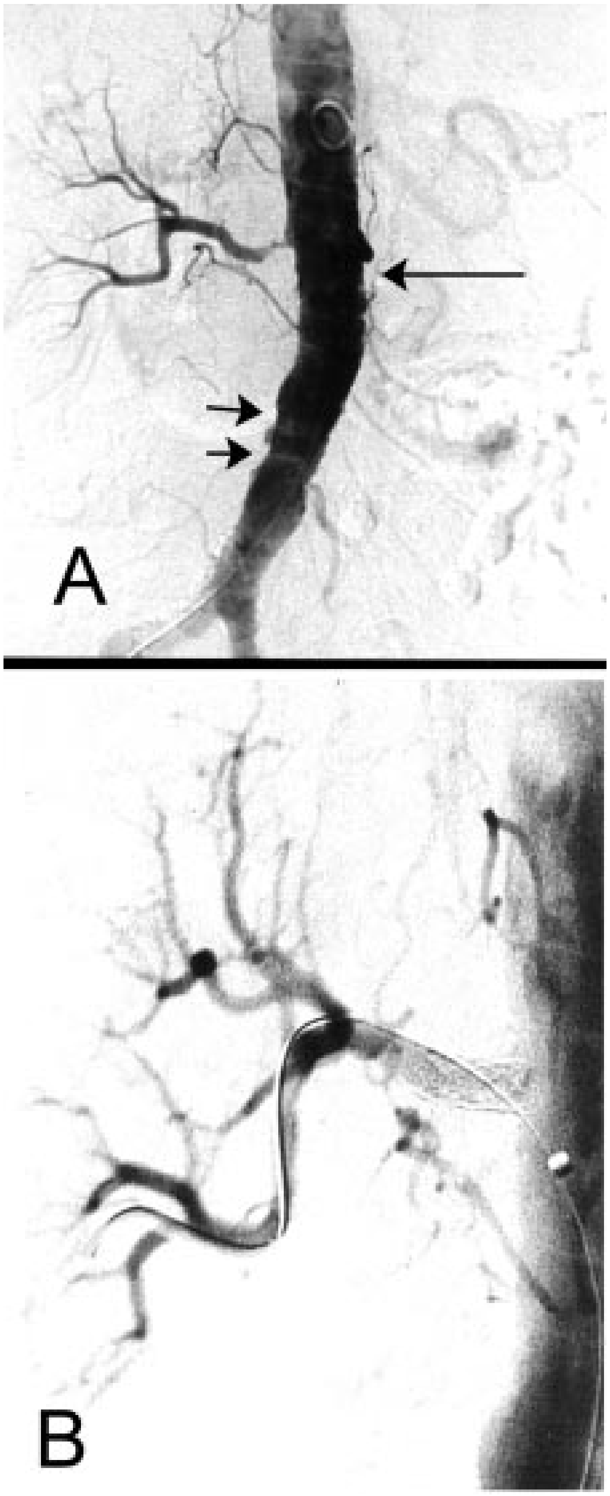

Fig. 2. Seventy-eight-year-old male with uncontrollable hypertension. **(A)** An aortic flush angiogram shows a severe stenosis in the proximal right renal artery. The left renal artery is completelly occluded (long arrow) and no left nephrogram is identified. Atherosclerotic plaques are seen (short arrows) in the aorta. **(B)** Images obtained immediately after a balloon expandable stent was placed and dilated to 8 mm demonstrate restoration of the renal artery to its original diameter. Note that predilatation with a 4 mm balloon was necessary to place the mounted stent across the lesion.

occasionally malabsorption, may be more vague (16).

Mesenteric angina occurs when stenosis or occlusion of the mesenteric artery limits blood flow to the intestine. Atherosclerosis is the most common cause and is related to an encroaching plaque located at the ostia of visceral vessels. Other causes are extremely rare. It is believed that 2 of the 3 vessels must be affected for the disease to become symptomatic. The treatment of mesenteric angina aims to restore intestinal blood flow to normal levels. Chronic mesenteric angina requires a high index of suspicion for the diagnosis to be made, and failure to institute treatment can result in high mortality and morbidity.

Usually, a brachial approach is necessary, considering the downward angulation of the vessels. Sometimes, a femoral approach may be necessary, especially if there is an atherosclerotic narrowing of the subclavian artery. A percutaneous transluminal angioplasty (PTA) and stenting are required to treat the stenosis in celiac and superior mesenteric arteries. A coronary stent may be required, considering the small size and sometimes the unusual angle of the vessels to aorta.

PTA and stenting carry a significantly lower morbidity (17) over surgical intervention but may, however, carry the risk of creating arterial spasm, emboli or thrombosis with significant morbidity (17, 18). Nevertheless, the limited evidence in the medical literature indicates that PTA and stenting are relatively safe procedures. The long-term results of this technique still need to be evaluated; the initial results are encouraging (17, 19) (Fig. 4).

Recurrence of the Disease

Recurrence of the stenosis may be due to progression of the disease. Failure to take antiplatelet drugs may result in early stenosis. A recurrent stenosis of an artery can be treated with re-angioplasty and stenting. In-stent restenosis is a therapeutic challenge affecting between 9% and 25% of patients undergoing renal artery stent placement. Despite the reported success of PTA in the treatment of renal artery in-stent restenosis, many patients require further intervention when PTA fails (20). A cutting balloon can be used to achieve technical success when stand-alone PTA fails (21). Repeat stent placement with a resulting "stent sandwich" offers excellent short-term technical success but has the disadvantage of overex-

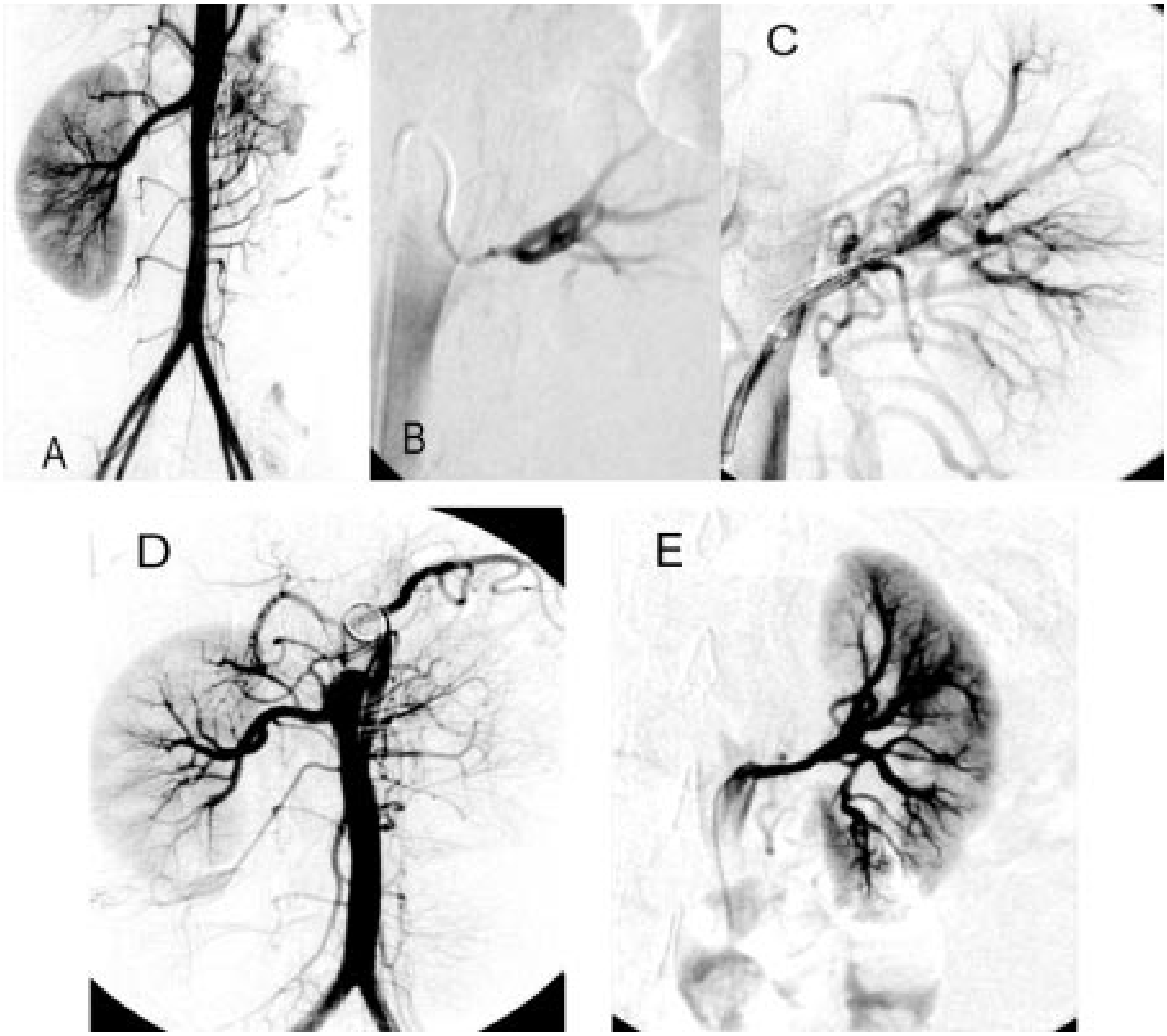

Fig. 3. Twenty-seven-year-old female with uncontrolled hypertension. **(A)** The flush aortogram shows nonopacification of left renal artery. **(B)** Cannulation of the left renal artery with a reverse curved catheter demonstrates near total occlusion of the left renal artery at its origin. **(C)** Predilation with a 3 mm balloon was necessary prior to placement of a stent. A balloon expandable stent was deployed and dilated to 5 mm. The proximal portion of the stent was deliberately placed so that 3 mm projected into the aorta. **(D)** At 6 months, the patient re-presented with the recurrence of uncontrollable hypertension. The patient had discontinued anti-platelet medication after 3 months. The aortogram shows re-occlusion of the left renal artery. **(E)** A selective left renal arteriogram obtained following balloon dilatation with a 5 mm balloon demonstrates full patency of the stent. The patient became normotensive following the repeat intervention.

panding the arterial wall with the potential induction of further neointimal proliferation (22).

Improvements in the stent technology, including drug-coated stents and covered stents, will be useful in the future to reduce restenosis rates. A recent publication examining the ability of endovascular brachytherapy to prevent recurrent in-stent restenosis in patients at high risk for this complication has yielded promising results. Eight (80%) of 10 patients alive at 1 year had no in-stent restenosis apparent on duplex sonography or angiography (23). Animal experiments are being performed to obtain covered stents coated with materials that would reduce the inflammation and intimal hyperplasia (24, 25).

Conclusion

Tremendous advances in the design and fabrication of catheters, wires, balloons, stents, and contrast media have occurred. As a result, "minimally invasive" procedures, which usually do not require an access larger than that to accommodate a 7F catheter, are becoming more common. The initial success rate of most of the revascularization/recon-

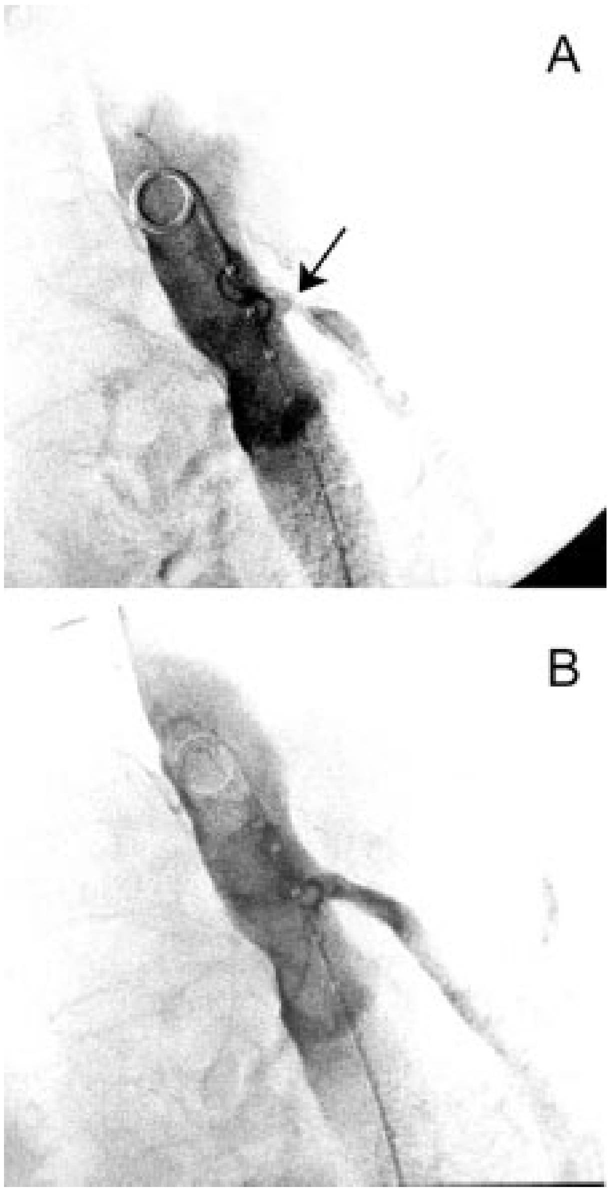

Fig. 4. Sixty-five-year-old female presenting with weight loss over several months and postprandial pain. **(A)** A lateral view of the abdominal aorta demonstrates a focal stenosis (arrow) in the superior mesenteric artery (SMA). **(B)** Following angioplasty with a 5 mm balloon full patency was restored. The patient showed significant clinical improvement.

struction techniques is better than 95% with only limited complications. A remaining problem of restenosis requires a satisfactory solution.

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