Imaging and stenting for renal artery stenosis

RJ Dowling, AD Laing, JM Vincent

Renal artery stenosis is a potentially correctable cause of hypertension and renal failure, using endoluminal or, less commonly, surgical techniques. A number of imaging techniques can be used to diagnose renal artery stenosis, all with similar accuracy.

Renal artery stenosis (RAS) is caused by atheroma in approximately 70% of cases, usually associated with atheroma of abdominal, coronary and lower limb arteries. Fibromuscular hyperplasia is the next largest cause of RAS, and is more likely to be localized (Novick, 1994).

RAS of a haemodynamically significant degree (>65% area stenosis) is a causative factor in less than 1% of unselected hypertensives. If, however, a hypertensive population is selected to only include high-risk groups such as those with very severe (malignant) or accelerated hypertension, abrupt onset or treatment-resistant hypertension, hypertension associated with peripheral vascular disease, coronary artery disease, abdominal bruits or hypertension in women <30 years of age, the incidence increases up to 40% (Davis et al, 1979; Olin et al, 1995).

RAS can also adversely affect renal function and is implicated as the causative factor in 15% of patients with end-stage renal failure (Rimmer and Gennari, 1993; Mailloux et al, 1994). RAS does not always result in renovascular hypertension (Prigent, 1993) and so the question of who to treat remains controversial.

The USA Joint National Committee of the National High Blood Pressure Education Program recommends minimal investigation of patients who have controlled hypertension and stable renal function (Joint National Committee, 1997).

RAS resulting from atheroma is not a static disease. One large study has shown progression of RAS caused by atheroma in 53% of cases with 9% of vessels progressing to occlusion over a follow-up period averaging 7 years (Tollefson and Ernst, 1991).

A more recent study has shown that the progression of stenoses from <60% to >60% occurs at a rate of 20% per year, and the progression of stenoses of >60% to occlusion occurs at a rate of 5% per year (Zierler et al, 1994). Importantly, the presence of risk factors including smoking, diabetes mellitus, elevated serum lipids and coronary artery or peripheral vascular disease do not predict the degree or rate of progression, and serial blood pressure and creatinine measurements do not correlate with disease progression or even vessel occlusion (Tollefson and Ernst, 1991).

Conversely, fibromuscular hyperplasia rarely progresses to occlusion, although it can uncommonly lead to spontaneous vessel dissection (Novick, 1994). Well controlled blood pressure does not protect against this progression, and so there is a strong case for careful follow-up of all patients with known RAS.

The aim of treatment is to improve blood pressure control or to improve or halt a decline in renal function. It has become commonplace to treat haemodynamically significant RAS in the presence of uncontrollable hypertension or worsening renal function.

Proof of renovascular hypertension or ischaemic nephropathy is not usually obtained before treatment. Rather, anatomically significant lesions are treated, and the diagnosis of renovascular hypertension or ischaemic nephropathy is made if there is a favourable response (Baert, 1994).

Treatment options for revascularization include percutaneous transluminal angioplasty, angioplasty, stenting and surgical revascularization.

INVESTIGATIONS

With proper patient selection (listed above), a pretest probability of RAS of 35–40% can be achieved (Davis et al, 1979; Olin et al, 1995).

Dr RJ Dowling, Dr AD Laing and **Dr JM Vincent** are Consultant Radiologists in the University of Melbourne Department of Radiology, The Royal Melbourne Hospital, Victoria 3050, Australia

Correspondence to: Dr RJ Dowling

Many investigations are currently available including angiography (still regarded as the reference standard), colour Doppler ultrasound (CDU) with or without ultrasound contrast agents, captopril renography, magnetic resonance angiography (MRA) and computed tomography angiography (CTA). Carbon dioxide angiography is useful in the setting of renal failure, as there is no nephrotoxicity. Renal vein renin sampling is usually reserved for isolated cases and is not performed routinely. Intravenous urography in this setting has largely been abandoned.

All of these standard modalities are aimed at detecting anatomical stenoses (considered haemodynamically significant if >65% area stenosis). With the exception of captopril renography, these tests have no predictive value for the presence of renovascular hypertension or ischaemic nephropathy.

Captopril renography

Renography using an angiotensin-converting enzyme (ACE) inhibitor is the most commonly used scintigraphic technique for the diagnosis of renovascular hypertension.

When renal perfusion pressure is decreased (i.e. as a result of RAS) the driving forces maintaining glomerular filtration are maintained by the angiotensin-II dependent vasoconstriction of efferent arterioles. The administration of an ACE inhibitor (i.e. captopril) removes this efferent arteriolar vasoconstriction, and the resultant decrease in glomerular filtration (and urinary flow) can be measured non-invasively using radiopharmaceuticals (Sheps et al, 1993).

A variety of agents are used, but the two most common are technetium-99m diethylene triamine penta-acetic acid (DTPA) and technetium-99m mercaptosuccinylglyclglyclglycine (MAG3). DTPA is excreted by glomerular filtration, whereas MAG3 is excreted almost solely by tubular excretion. Criteria for the diagnosis of RAS include:

1. Percentage uptake of tracer by the affected kidney of less than 40% of the combined bilateral uptake
2. Delayed time to peak uptake of tracer of more than 5 minutes longer than the contralateral kidney
3. Delayed excretion of tracer, with retention at 15 minutes.

The test can be performed using a baseline examination followed by a captopril renogram, or as a post-captopril study alone.

In a review of captopril renography in over 1000 patients, sensitivity and specificity for diagnosing RAS was 73% and 90% using criteria of captopril-induced changes between a baseline test and a post-captopril study. If post-captopril abnormality alone is used, the sensitivity and specificity are 85% and 83% (Prigent, 1993).

Many centres therefore use post-captopril studies as the initial test, proceeding no further if the result is normal. If the post-captopril study is abnormal, a baseline test is then performed to decrease the number of false positive results. Using MAG3, the two tests can be performed on the same day, whereas with DTPA, the tests must be performed on separate days.

In a large European multicentre trial, the post-captopril study has been shown to have a sensitivity and specificity of 93% and 100% for the prediction of blood pressure response to intervention, providing the renal function is normal (Fommei et al, 1993).

Problems with captopril renography include a decreased sensitivity and specificity for RAS if renal function is poor (>123 μmol), and low sensitivity in the presence of bilateral RAS (Fommei et al, 1993). False positive tests result from unilateral renal disease and with asymmetrical renal size.

Colour Doppler ultrasound

The use of CDU in the diagnosis of RAS is attractive in terms of safety and availability, although the results are variable.

Initial studies utilizing pulse wave and later CDU relied upon the successful interrogation of both main renal arteries, in order to obtain angle corrected spectral traces from the entire length of both vessels. This technique, often referred to as the direct method, is based on the presence of elevated peak systolic velocities (PSV) to indicate the presence of RAS (*Figures 1a* and *b*). A ratio of PSV in the renal artery to PSV in the adjacent aorta (renal to aortic ratio; RAR) of >3.5 indicates a significant stenosis. Studies by Kohler et al (1986), Taylor et al (1988) and Hansen et al (1990) reported sensitivities and specificities approaching 90%. Later studies successfully used elevation of PSV to indicate RAS, using a cutoff value of 180 cm/sec (Zierler et al, 1994; Baumgartner et al, 1997).

The results of many subsequent studies were disappointing. Poor sensitivities and specificities using PSV >100 cm/sec and/or RAR > 3.5 were reported by Desberg et al (1990), Berland et al (1990) and Kliewer et al (1993). In addition, accessory renal arteries were rarely detected by this method, decreasing both sensitivity and

specificity (Hansen et al, 1990). The direct method was seen as a difficult and lengthy examination, with problems of bowel gas, obesity and respiratory movement leading to failure of the technique.

This led to enthusiasm for the so-called indirect method, whereby intrarenal spectral traces were obtained. Analysis of the spectral trace for the 'tardus parvus' pattern was made (*Figure 1c*). The loss of an early systolic peak (ESP), prolonged systolic acceleration time (AT), and decreased acceleration (ACC) were indicative of RAS (normal values AT< 70msec, ACC >3 m/sec^2).

It was hoped that this technique would be simpler, with fewer technical failures. It could detect stenoses upstream from the site of sampling, and in theory would detect stenoses in main renal arteries, accessory arteries and branch arteries. Initial reports of sensitivities and specificities as good, if not better than the best direct method studies appeared to be a major breakthrough (Stavros et al, 1992; Stavros and Harshfield, 1994).

Kliewer et al (1993) found that AT >70msec was sensitive for high grade stenoses, although lacked specificity. For lesser degrees of stenosis, AT, ACC and ESP loss were unreliable parameters. Baxter et al (1996) found AT reliable, although other parameters (ACC, ESP) were unreliable. Work at our own institution has found ACC and AT unreliable, and ESP assessment too subjective to be of use (House et al, 1999).

Branch and accessory artery stenoses were detected more frequently than with the direct method, although not reliably (Stavros and Harshfield, 1994). Neither the indirect or direct methods reliably distinguish between vessel occlusion and critical stenoses.

The use of echoenhancing or ultrasound contrast agents has lead to a renewed enthusiasm for CDU in the diagnosis of RAS. Initial studies utilizing saccharide-based contrast agents showed improved signal intensities from renal vessels, lasting up to 7 minutes (Schlief, 1993). When applied to renal artery Doppler, studies have demonstrated technical success rates improving to 91–95% by using echoenhancing agents. Sensitivity for RAS also improved to between 95 and 100%, although specificity in one study was 73%.

All these studies reported improved renal artery visualization, and two of the studies demonstrated a number of accessory arteries not visible before the administration of echoenhancing agent (Balen et al, 1994; Melany et al, 1997; Dowling et al, 1999).

It is unclear whether the use of these agents will reliably enable the distinction between occlusion and critical stenosis with trickle flow. The wide variation in reported accuracies of CDU with or without echoenhancement indicates the difficulties of the technique. Individual laboratories need to validate their own results against a suitable reference standard.

In our institution, the technical success rates of CDU for visualization of the main renal artery is 87%, increasing to nearly 100% with the use of echoenhancing agents. Sensitivity

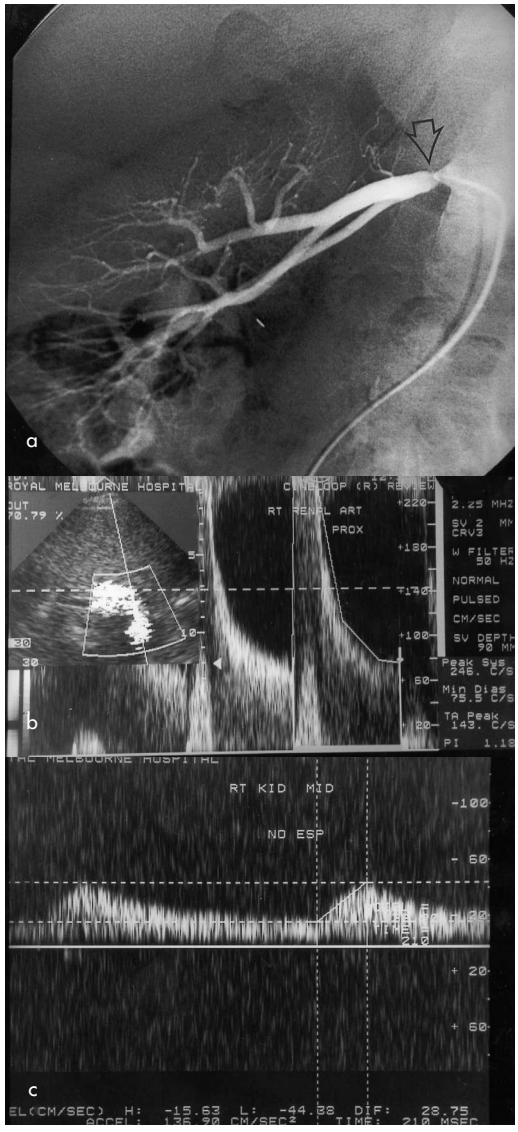

Figure 1. a. Selective right renal angiogram demonstrating moderate orificial renal artery stenosis (RAS) (arrow). b. Doppler ultrasound demonstrating elevated peak systolic velocity (246 cm/sec) at vessel origin, indicating haemodynamically significant RAS. c. Spectral trace downstream from significant orificial RAS, demonstrating tardus parvus waveform, prolonged acceleration time (210 msec) and lowered acceleration (136.5 cm/sec^2).

and specificity for diagnosis of RAS is 95% and 79% (House et al, 1999).

CTA

Helical CTA of the renal vessels involves a rapid, peripheral venous injection of iodinated contrast followed by rapid thin section scans through the renal areas. Overlapping images are obtained to allow three-dimensional (3D) reconstructions and reformatted images of the renal arteries (*Figures 2a–c*). The technique provides visualization of all main renal arteries and 78–100% of accessory renal arteries (Rubin et al, 1994; Beregi et al, 1996; Kaatee et al, 1997).

The quoted sensitivities and specificities for the detection of RAS by CTA compared with conventional angiography depends on the level of stenosis considered significant (Rubin, 1997). When defined as >50% stenosis, the quoted sensitivities range from 88% to 100% and the specificities range from 77% to 100% (Rubin et al, 1994; Beregi et al, 1996; Kaatee et al, 1997). When defined as >70% stenosis the range of sensitivities falls to 57% to 92% and the specificities range from 83% to 100% (Rubin et al, 1994; Rubin, 1997). Both Kaatee et al and Beregi et al demonstrated a 4% false positive rate.

CTA tends to overestimate the degree of RAS (Rubin et al, 1994; Kaatee et al, 1997). The presence of calcification in the wall of the vessel also makes assessment of RAS more difficult (*Figure 2b*) and depending on the 3D technique used can lead to either over or under estimation of the degree of stenosis (Rubin et al, 1994; Beregi et al, 1996).

The advantages of CTA include that it is non-invasive, easy and quick to perform and that helical CT is becoming widely available. The disadvantages include the use of contrast which is nephrotoxic and contraindicated on those patients with renal impairment, the use of ionizing radiation, and poor image quality in larger patients. CTA is a developing technique and will continue to improve with faster, subsecond scanning times, X-ray tubes with greater heat capacity and improved 3D rendering techniques.

Renal artery MRA

Phase contrast MRA, and more recently gadolinium contrast-enhanced MRA (*Figures 3a–c*) are the methods used for imaging the renal arteries. Time of flight (TOF) MRA produces good resolution of the proximal 1–2 cm of the renal arteries, but signal loss in blood flowing transversely within the imaging volume limits assessment more peripherally and is therefore of little practical use.

Phase contrast MRA is a flow sensitive technique. It provides anatomical and haemodynamic information, and can produce velocity and

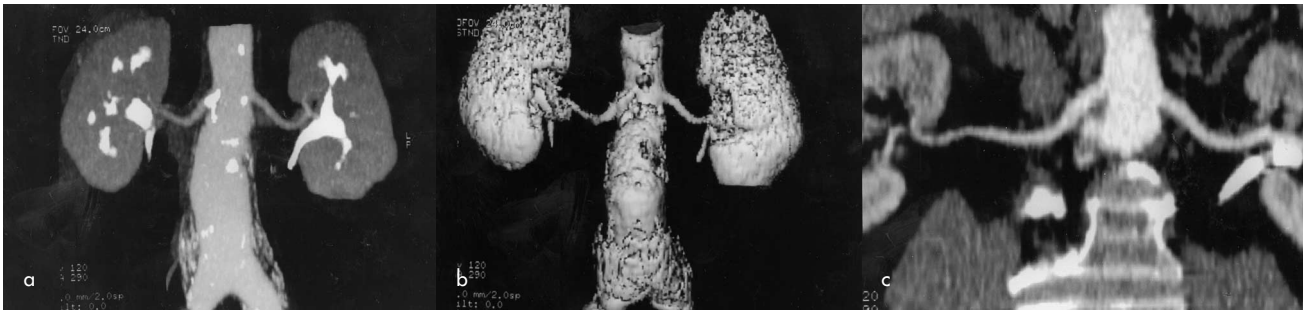

Figure 2. a. Three-dimensional model using maximum intensity projection, showing normal renal arteries with calcification at the origin on the right and an abdominal aortic aneurysm. b. Three-dimensional model of the same patient using surface rendered display. Note it is not possible to separate the contrast in the vessel from calcification of the vessel wall. c. Curved reformat demonstrating normal renal arteries.

Figure 3. a. Contrast-enhanced magnetic resonance angiograph (maximum intensity projection) showing left renal artery stenosis (RAS) (arrow). b. Contrast-enhanced magnetic resonance angiograph (surface rendered technique) showing left RAS. c. Same patient, conventional digital subtraction angiography of the aorta, demonstrating left RAS.

flow rate data similar to these obtained by Doppler ultrasound, but at present this aspect of phase contrast MRA remains a research tool and is not widely available.

In assessment of haemodynamically significant stenoses, as defined by those greater than 50%, phase contrast MRA has proved to be a sensitive technique, with Loubeyre et al (1996) and Silverman et al (1996) both reporting sensitivities of 100%. However, there is a significant false positive rate with a specificity of only 65% reported by Silverman et al (1996). Phase contrast MRA has a tendency to overestimate the degree of stenosis because of the dephasing effect of turbulent blood flow. This effect can produce apparent stenoses in normal arteries, and a severe stenosis can mimic an occluded artery. The high false positive rate with this technique is a significant problem if it is to be used as a screening test.

Gadolinium-enhanced MRA has a relatively short history, but it is rapidly gaining favour for assessing renal arteries in addition to carotid, aortic and lower limb artery angiography.

The technique involves injecting a bolus of gadolinium, followed by a single breath hold scan. The technique is effectively free of the saturation and turbulence dephasing problems experienced with TOF and phase contrast MRA.

De Cobelli et al (1997) have found this technique superior to phase contrast MRA for detecting accessory renal arteries, but found no statistically significant difference in detection of RAS. They achieved a sensitivity of 100% and a specificity of 97% for the detection of stenoses of greater than 50%. Bakker et al (1998) have achieved similar results with a sensitivity of 97% and specificity of 92%, diagnosing 3 of 10 occluded renal arteries as high grade stenoses.

MRA enables other parameters to be measured, which may be important in RAS. These include the degree of phase contrast dephasing from turbulent flow, vessel lumen calibre at the stenosis and poststenotic dilatation, as well as measurement of renal size, cortical thickness and parenchyma enhancement rate. Potentially gadolinium excretion concentration, perfusion and blood flow data could also be obtained (Prince et al, 1997).

Magnetic resonance imaging and MRA can provide much of the anatomical and physiological information currently provided by ultrasound, angiography and nuclear medicine. However, there remain some significant problems. Clinical experience remains limited, particularly in diagnosing fibromuscular dysplasia, and spatial resolution is inferior to conventional angiography, limiting visualization of parenchymal vessels and small accessory renal arteries. Many of these MR sequences are technically demanding, requiring high field strength magnets, high performance gradient coils, and high volumes of contrast media. These factors limit availability and raise the cost of MRA, particularly as a screening test for a large patient population. As MR scanners become more plentiful and technology improves many of these limitation will be overcome. MRA may well become the primary imaging modality for RAS within the next decade.

Renal artery stenting

The aim of treatment of RAS is to improve or cure hypertension, and to improve or halt the deterioration in renal function. As newer drugs can adequately control blood pressure in up to 95% of patients, it could be argued that in the presence of controlled blood pressure and stable renal function, no treatment of RAS is necessary (Textor, 1998). Given that RAS is a progressive disease (Tollefson and Ernst, 1991; Zierler et al, 1994), surveillance is mandatory even if revascularization is not performed.

It has become common to treat anatomically significant stenoses without the need to prove the presence of renovascular hypertension (Baert, 1994).

Surgical revascularization, which has very good outcome in terms of primary patency, has an unacceptably high level of morbidity and mortality when compared with endovascular techniques. It is generally reserved for failed endovascular treatment or as the first-line treatment if endovascular facilities or expertise are not available.

Percutaneous transluminal angioplasty (PTA) without stenting was the first endoluminal technique available for treatment of RAS. Initial enthusiasm was damped by a high rate of technical failures for ostial lesions, said to be as a result of elastic recoil or dissection. Technical success rates as low as 10–24% have been widely reported for ostial lesions (Rees et al, 1991; Baert, 1994; Blum et al, 1997). Restenosis, especially within the first year, was reported in the order of 30% (Rees et al, 1991; Baert, 1994; Baumgartner et al, 1997) with the immediate post-dilatation appearance being the single most important predictor of long-term success (Rees et al, 1991; Iannone et al, 1996).

These shortfalls lead to the use of metallic stents in the renal arteries either for failed PTA or as primary therapy for atheromatous lesions (*Figures 4a* and *b*).

Technical success is uniformly reported as near 100%. Although complete cure of hypertension is relatively uncommon, improvement is seen in approximately two thirds of patients. Improvement in renal function is seen in between 14 and 41%. These figures are similar for successful PTA.

Restenosis remains a problem. Most series report significant restenosis of between 14 and 38% within the first year (Kuhn et al, 1991; Rees et al, 1991; Wilms et al, 1991; Hennequin et al, 1994; Raynaud et al, 1994; Dorros et al, 1995; Macleod et al, 1995; van de Ven et al, 1995; Henry et al, 1996; Iannone et al, 1996; Boisclair et al, 1997). Much attention is being paid to the problem of stent restenosis as a result of neointimal hyperplasia, although currently the problem has not been overcome. Serious complications are relatively rare.

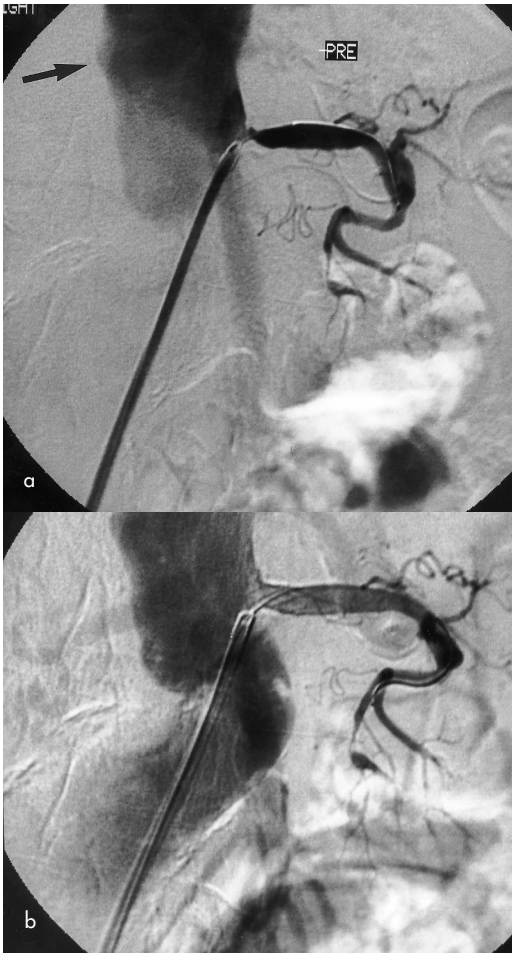

Figure 4. a. Selective left renal digital subtraction angiograph with tight irregular orificial stenosis and multiple branch vessel stenoses. Note occluded right renal artery (arrow) in patient with chronic worsening renal function. b. Post-stenting of left renal artery orificial stenosis with good angiographic result. Renal function stabilized post-procedure, although hypertension unchanged.

Deterioration in renal function can occur in up to 24% of cases (Hennequin et al, 1994; Dorros et al, 1995; van de Ven et al, 1995; Henry et al, 1996; Iannone et al, 1996; Blum et al, 1997; Boisclair et al, 1997). This deterioration occurs as a result of contrast nephrotoxicity and/or cholesterol embolization. A number of those with cholesterol emboli will progress to require dialysis, which is a cause for some concern (Textor, 1998).

Other complications include vessel dissection and stent migration — both of which are uncommon. These can usually be rectified at the time of the procedure, with very few requiring surgical intervention.

CONCLUSION

The emergence of safe and efficacious endoluminal techniques to treat RAS has lead to renewed enthusiasm in the investigation for RAS. Many techniques can be and are used, indicating that none are perfect. All have similar accuracy, and currently no one technique is outstanding. Which test to use is largely dictated by availability and local expertise. Availability of ultrasound is a major attribute of this modality, and the emergence of newer longer lasting contrast agents will add to its attractiveness.

MRA appears to be set to largely replace conventional diagnostic angiography. Currently availability and cost preclude its routine use. CTA can be performed on most helical scanners, and is therefore widely available. Contrast load and cost, however, are obstacles which may see this technique fail to gain widespread acceptance. Captopril renography remains popular although it is more expensive than ultrasound.

Even angiography is a more attractive investigation alternative than it used to be, largely as a result of smaller catheters (allowing outpatient studies) and non-toxic contrast agents (i.e. carbon dioxide) for patients with renal impairment.

Angioplasty and stenting will remain favoured treatment of RAS. Prevention of neointimal hyperplasia and recurrent atheroma remains the biggest challenge in this area. **HM**

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KEY POINTS

- Renal artery stenosis is a treatable cause of hypertension and renal failure.
- Renal artery stenosis can be diagnosed using captopril renography, colour Doppler ultrasound, magnetic resonance angiography, angiography or computerized tomography angiography.
- Renal artery stenosis as a result of atheroma is a progressive disease.
- Renal artery stenosis is amenable to treatment by endovascular techniques including angioplasty and stenting.
- Surgery for renal artery stenosis is largely reserved for failed endovascular treatment or when endovascular treatment is not successful.