Evaluation of Dynamic Gadolinium-Enhanced Breath-Hold MR Angiography in the Diagnosis of Renal Artery Stenosis

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OBJECTIVE. The aim of our study was to evaluate a three-dimensional gadolinium-enhanced breath-hold MR angiography sequence using standard MR gradients in detecting renal artery stenosis.

SUBJECTS AND METHODS Forty-two patients referred for angiography for suspected renal artery stenosis underwent both conventional digital subtraction angiography (DSA) and MR angiography. MR angiography was performed on a 1.5-T scanner with standard gradients. A fast multiplanar spoiled gradient-echo sequence was used with the following parameters: TR/TE, 10.3/1.9; flip angle, 45°; field of view, 36 x 32 cm; matrix size, 256 x 128; one excitation; volume thickness, 70 mm; and partitions, 28. Gadolinium was administered IV as a dynamic bolus of 30–40 ml. Conventional and MR angiographic images were interpreted by two radiologists in consensus.

RESULTS. DSA revealed 87 renal arteries, of which 79 were in 35 patients with native kidneys and eight arteries were in seven patients with transplanted kidneys. Gadolinium-enhanced MR angiography showed 85 (98%) of 87 renal arteries. Seventeen patients had 20 significant (>50% stenosis) renal artery stenoses and five patients had five occluded renal arteries revealed by DSA. MR angiography revealed 85 renal arteries (98%), 20 stenoses (100%), and five occlusions (100%). Gadolinium-enhanced MR angiography led to one false-positive interpretation for renal artery stenosis and no false-negative interpretations. Thus, the sensitivity, specificity, and accuracy of MR angiography for renal artery stenosis were 100%, 98%, and 99%, respectively.

CONCLUSION. The MR angiography pulse sequence we used was an effective and reliable technique for the diagnosis of renal artery stenosis. The sequence can be performed on widely available MR equipment that does not require fast gradient hardware.

Renal artery stenosis, which is found in 3-10% of the general hypertensive population, is a treatable condition [1]. In patients within certain subgroups-such as those with peripheral vascular disease, those who are 60 years old or older, or those who are attending hypertension clinics—the incidence is much higher, at 25–45% [2–4]. Renal artery stenosis also contributes to renal failure, with 14% of patients who are more than 50 years old and require hemodialysis in the United Kingdom having angiographic evidence of renal artery stenosis [5].

In view of the clinical significance, progressive nature, and reversibility of renal artery stenosis, an accurate, reproducible, and noninvasive diagnostic test is the goal of renal artery imaging. To date the gold standard for diagnosis has been conventional or digital subtraction angiography (DSA). Noninvasive techniques of imaging the renal arteries include Doppler sonography [6–10], CT angiography [11–14], and MR angiography [15–36]. Multiple MR sequences are available for MR angiography. The challenge is to find the optimal sequence that will give the best demonstration of normal and abnormal renal arteries using the MR scanner and the software available. The ideal sequence should be rapid to overcome respiratory motion of the kidneys and with minimal flow artifacts to prevent overestimation of severity of stenosis. We performed a prospective comparison of dynamic gadolinium-enhanced breath-hold MR angiography with conventional DSA-for the detection of renal artery stenosis.

Subjects and Methods

Forty-two consecutive patients (27 men and 15 women, 20–75 years old; mean, 50 years old) with

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hypertension that was clinically suspected of being secondary in type were referred for renal angiography over an 18-month period. All patients were included in the study after informed consent was obtained. All patients underwent conventional renal angiography (DSA) and gadolinium-enhanced MR angiography.

The Seldinger technique was used for vascular access in the right femoral artery for conventional angiography. A S-French pigtail catheter (Cook, Bjacverskov, Denmark) was placed in the aorta at the level of the renal arteries. A flush aortic injection of 45 ml of iohexol (Omnipaque 300; Nycomed, Oslo, Norway) at 15 ml/sec was performed, and digital subtraction images were obtained in the anteroposterior and oblique planes to identify the renal artery origins.

AU patients underwent gadolinium-enhanced MR angiography of the renal arteries 2-3 hr before the DSA examination. We used a three-dimensional (3D) fast multiplanar spoiled gradient-echo sequence. All MR imaging was performed on a 1.5-T unit (General Electric Medical Systems, Milwaukee, WI). We used a sagittal localizing pulse sequence followed by image acquisition in the coronal plane. The following imaging parameters were used: TR/TE, 10.3/1.9; flip angle, 45"; field of view, 36 x 32 cm: matrix size, 256 x 128; and one excitation. These parameters allowed 28 partitions to be acquired in 32 sec. Partition thickness was 2.5 mm, yielding a 70-mm-thick volume. The volume was centered at the level of the native or transplanted renal arteries. We used a torso wrap-around coil for all patient imaging.

For gadolinium administration, an XV cannula was placed into an antecubital arm vein and connected to a long-extension tubing. We used 30–40 ml of gadopentetate dimeglumine for each patient. Gadolinium was administered as a bolus starting 15 sec before commencement of imaging by rapid hand injection and followed by a 20-ml saline flush. We used sequential imaging for K-space acquisition because we do not have the capability for centric imaging. Before contrast administration all patients were given breathing instructions and hyperventilated on room air. All patients were able to hold their breaths adequately for the 32 sec required for image acquisition. Two further sets of images were acquired immediately (-15 sec) after the first acquisition without changing any imaging parameters. This procedure ensured that even in the presence of increased circulation time, we obtained an image set with optimal image contrast from the gadolinium bolus. Image reconstruction was performed using both maximal-intensity-projection and reformatting techniques.

The conventional and MR angiographic studies were interpreted by two radiologists who are experienced in the interpretation of both conventional and other forms of MR angiography. The conventional DSA images were interpreted first, followed by the MR angiography images after a period of 4 weeks. Both types of reformatted images and source images were interpreted in assessing the MR angiography studies. A consensus opinion was obtained in all cases regarding the presence or absence of stenosis or occlusion, the number of renal arteries present, and the length of renal artery seen, Renal artery stenosis was determined by visual inspection of the renal arteries for decreased diameter of the lumen of the renal artery with or without poststenotic dilatation. Only renal arteries with significant (>50%) renal artery stenoses were considered to be abnormal. This method of assessment was used for both MR angiography and DSA techniques. The location of any stenosis was further categorized into ostial (<5 mm from the renal artery origin) or nonostial (>5 mm from the origin of the renal artery). Stenosis length was also calculated.

The renal artery was divided into thirds to calculate its length as seen on MR angiography. Arbitrarily, the renal artery from its origin to the renal hilum was considered to represent two thirds, and the intrarenal portion was considered to represent the remaining third. Any early renal artery branching (proximal two thirds) was also recorded.

Results

Conventional DSA revealed 87 renal arteries in 42 patients, including six patients with single transplanted renal arteries, one patient with two transplanted arteries, and seven patients with 10 accessory arteries. Seventeen patients had 20 significant (>50%) renal artery stenoses and five patients had five occluded renal arteries. Renal artery stenoses were ostial in 10 renal arteries and nonostial in 10. The mean length of stenoses was 5.2 mm (range, 3-10 mm).

MR angiography revealed 85 (98%) of 87 renal arteries (Fig. 1). The two arteries not seen were both accessory arteries (each <2 mm in size), one in a transplanted kidney and the other in a patient with five renal arteries (Fig. 2). MR angiography diagnosed 20 of 20 stenoses (Fig. 3) and five of five occluded arteries. Similar to findings on DSA, renal artery stenoses were ostial in 10 renal arteries and nonostial in 10. The mean length of renal artery stenoses on MR angiography was 4.9 mm (range, 3-10 mm). In addition, MR angiography made a single false-positive diagnosis of renal artery stenosis in a patient with five renal arteries. The patient had an occluded artery on the right and four arteries on the left. On MR angiography, the two upper vessels on the left were seen as a single vessel with a stenosis (Fig. 2).

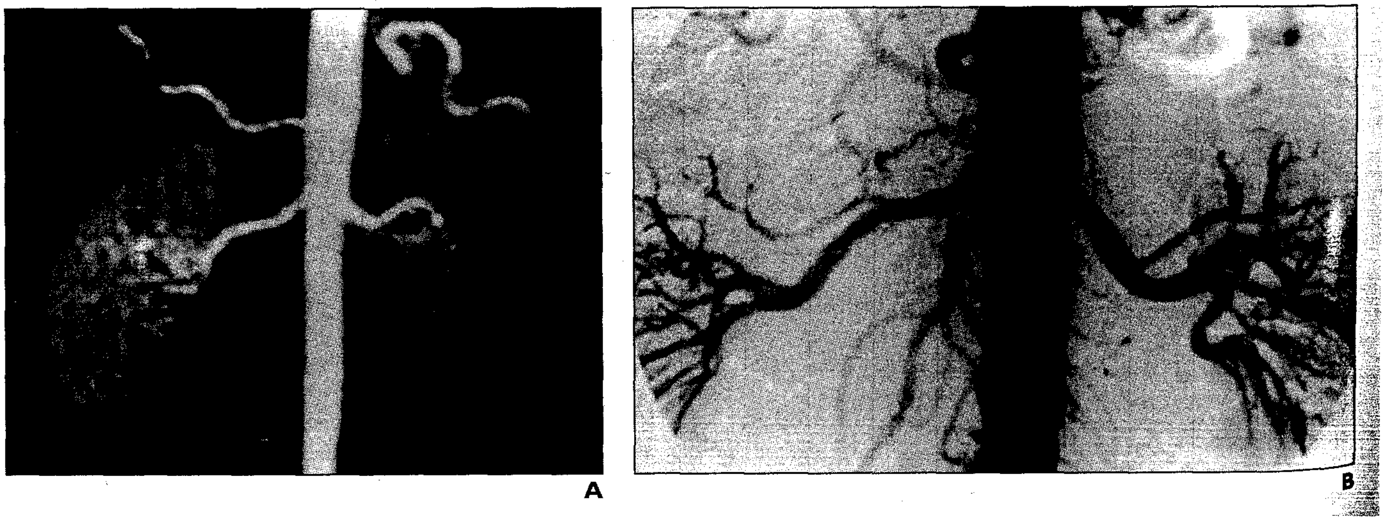

Fig. 1.—47-year-old man with suspected secondary hypertension.

A, Reformatted gadolinium-enhanced MR angiogram shows single normal renal arteries bilaterally. Note that renal arteries are seen as far as renal hilum. Also note hepatic and splenic arteries.

B, Conventional digital subtraction angiogram obtained 3 hr after A shows normal renal arteries, which correlates with findings in A. Early left branching renal artery seen here was seen on other MI? images (not shown).

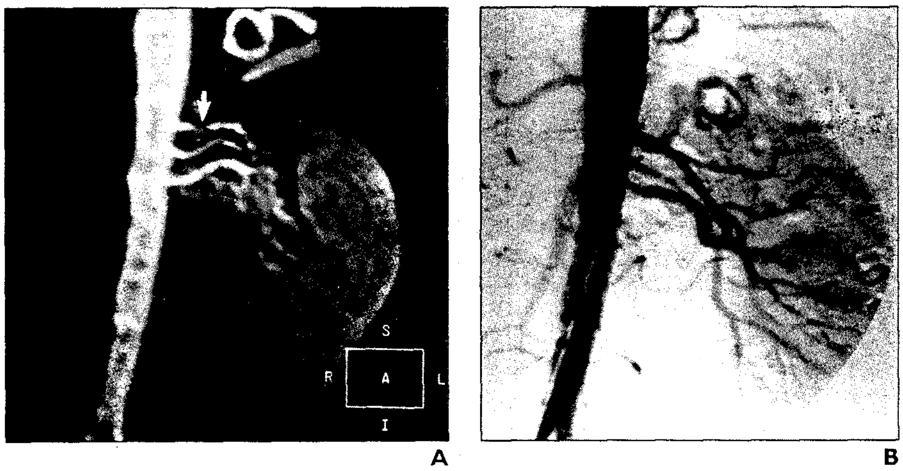

Fig. 2.—52-year-old woman with hypertension and **occluded right renal artery.**

A, Maximum-intensity-projection image **from** gadolinium-enhanced **MR angiogram shows three left renal** arteries **and** occluded right renal artery Apparent stenosis (*arrow*) noted in left uppermost renal artery was false-positive finding.

B, Conventional digital subtraction angiogram obtained 3 hr after A shows right renal artery occlusion and four left renal arteries with upper two renal arteries overlapping each other. MR angiography was unable to differentiate upper two renal arteries from each other Hepatic artery is faintly visible.

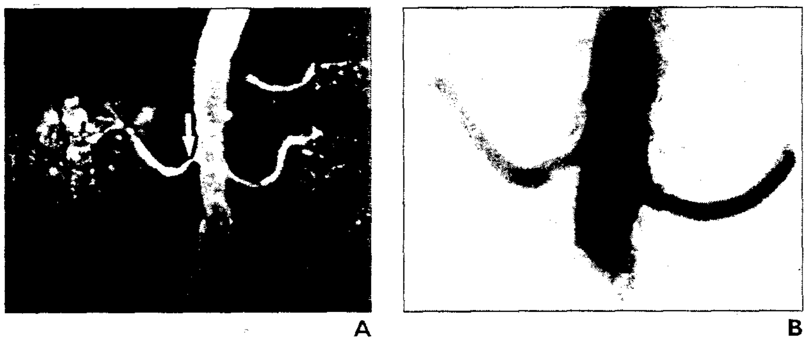

Fig. 3.—59-year-old man with hypertension and suspected renal artery stenosis.

A, Maximum-intensity-projection image from MR angiogram shows single renal arteries bilaterally with significant stenosis at origin of right renal artery (*arrow*)

B, Conventional digital subtraction angiogram obtained 3 hr after A shows stenosis similar to that in A at origin of right renal artery.

Using this breath-hold technique. we saw all renal arteries as far as the renal hilum, which corresponds to 66% of the renal artery. No intrarenal branches were seen in this study. Early (proximal two thirds of the renal artery) renal artery branching was identified in three patients on both DSA and MR angiography.

When considering only those patients with renal transplants, we found that DSA revealed seven arteries in six patients. One patient had significant stenosis of a transplanted renal artery. MR angiography revealed six arteries (one accessory artery was undetectable) and one stenosis correlating with DSA findings.

Three-dimensional gadolinium-enhanced breath-hold MR angiography had a sensitivity of 100%, a specificity of 98%, and an accuracy of 99% in the detection of hemodynamically significant stenosoocclusive disease of the renal arteries.

Discussion

Doppler sonography has been extensively evaluated as a screening tool for the detection of renal artery stenosis [6–10]. That technique has the theoretic advantage of being simple, noninvasive. safe. and inexpensive. However, whether one uses velocity measurement across the stenosis or intraparenchymal Doppler waveforms, with or without the use of contrast material or captopril. Doppler sonography is subject to controversy. with variable results being reported for each technique [6–10]. The technique is difficult and time-consuming and requires a great deal of expertise: with the use of contrast material or captopril (or both), Doppler sonography loses some of its initially perceived advantages.

Helical CT angiography is another noninvasive technique used to image the renal arteries in patients with suspected renal artery stenosis. This technique has also been used to examine patients with abdominal aortic aneurysms and potential renal donors [11–13]. Although debate is ongoing as to the optimal parameters for imaging [14], the initial results are promising. However. CT does suffer from the disadvantages of requiring iodinated contrast material that may be injurious to patients with renal failure and the fact that ionizing radiation is required.

MR angiography has been performed using several different sequences, including phase-contrast and time-of-flight sequences using two-dimensional or 3D techniques [15–38]. Early results were encouraging but not totally satisfactory. Two significant areas of difficulty were identified. First, MR angiography sequences. which depend on flow for signal, have the inherent problem of trying to assess an abnormality that alters flow dynamics within the artery being imaged. Although one could consider the imaging to be physiologic or functional. difficulty in interpretation arises. Second. the relationship between the severity of stenosis and signal loss attributed to turbulent flow is unclear. Dephasing in phase-contrast image acquisition can lead to overestimation of the severity of stenosis. Similarly, time-of-flight imaging suffers from loss of signal from "in-plane" flow. This problem has been largely overcome by the use of gadolinium-enhanced gradient-echo pulse sequences that derive signal from the T1 shortening effect of gadolinium [24–27] rather than from blood flow.

Gadolinium-enhanced breath-hold MR angiography has been described for renal artery imaging [27–33]. Prince et al. [27] described the use of a breath-hold gadolinium-enhanced spoiled gradient-echo pulse sequence in 63 patients. Significantly improved signal-to-noise and contrast-to-noise ratios were found compared with free breathing pulse sequences. However. only 18 patients had conventional angiographic correlation. Three renal artery stenoses and one renal artery occlusion were identified in this study [27]. Holland et al. [28] described an ultrafast gadolinium-enhanced 3D spoiled gradient-refocused acquisition in the steady state pulse sequence using a fast gradient MR system with excellent results in 31 stenosed renal arteries. De Cobelli et al. [29], Hany et al. [30], Snidow et al. [31], and Steffens et al. [32], also using fast gradient systems, showed sensitivities and specificities exceeding 90% in 18, 15. five. and 22 significant (>50%) renal artery stenoses, respectively. In a study similar to ours. Bakker et al. [33] used a standard gradient MR unit and 30 ml of gadolinium to diagnose 30 of 31 renal artery stenoses and seven of 10 occlusions. Similarly, Tello et al. [34] used standard gradients and 15 ml of gadopentetate dimeglumine to reveal 10 renal artery stenoses exceeding 50%. In that study, the sensitivity and specificity of MR angiography for renal artery stenosis detection were 97% and 100%, respectively.

The results of our study compare favorably with results in the literature from both standard and fast gradient scanners. In our study, all stenoses and occluded vessels seen on conventional DSA were diagnosed on MR angiography, giving 100% sensitivity, The one false-positive diagnosis occurred in a complex anatomic situation with an occluded right renal artery and four renal arteries on the left. The two superior accessory arteries on the left overlapped each other and were considered to represent a single stenosed artery rather than two separate arteries. In our study, the specificity and accuracy for the diagnosis of significant (>50%) renal artery stenosis were 98% and 99%, respectively.

Our imaging sequences, which were acquired in the coronal plane, visualized all but two renal arteries. Axial imaging is limited in the z-axis by the number of partitions and their thickness and may lead to nonvisualization of accessory arteries, which should not occur when imaging is performed in the coronal plane with an appropriate volume size. The two missed accessory vessels were not missed because they were outside the imaging volume but because of their small size and proximity to other renal arteries.

In comparison with non-breath-hold renal MR angiography, even with a similar dose of gadolinium, breath-holding allows visualization of an increased length of the renal artery. In this study we were able to see the renal arteries as far as the renal hilar areas, which we consider represents 66% of'the renal artery. The intraparenchymal renal artery branches were not reliably seen. This finding is most likely a limitation of resolution rather than motion artifacts. Our own experience with non–breath-hold MR angiography enabled us to see only 33% of the length of the renal artery [25]. Although most stenoses occur in the proximal one third of the artery, it seems logical to try to visualize as much of the renal artery as possible to identify abnormalities such as branch occlusion and fibromuscular hyperplasia.

Most previous studies describing MR angiography techniques for identifying renal artery stenosis focused on native renal arteries. Only a small number of studies have reported the use of MR angiography for identifying stenosis of a transplanted renal artery [35–37]. Gedroyc et al. [35] found 3D phase-contrast MR angiography to be 83% sensitive and 97% specific in 48 patients with 14 stenoses. Smith and Bakke [36] found agreement between conventional angiography and 3D time-of-fright MR angiography without gadolinium enhancement in six of eight patients. Stafford Johnson et al. [37] obtained a sensitivity and a specificity of 100% with a combination of 3D phase-contrast and 3D gadolinium-enhanced MR angiography in nine patients. We found no technical difficulty in performing 3D gadolinium-enhanced MR angiography for stenosis of a transplanted renal artery and found the images to be of diagnostic quality in all patients. Three-dimensional gadolinium-enhanced MR angiography visualized six of seven transplanted renal arteries and accurately depicted the one stenosis of a transplanted renal artery.

We recognize limitations in our study. We did not precisely measure each stenosis but, rather, used a subjective assessment to identify and quantify renal artery stenoses. However, this kind of subjective measurement was used by Prince et al. [26] and by other groups [29-32, 34]. Subjective assessment more accurately reflects day-to-day practice and is thus widely used. Of the other groups that used a technique similar to ours, only one group, Bakker et al. [33], described quantification of renal artery stenosis using callipers. We also did not grade the stenoses into those less than 50%, those between 50% and 75%, and those greater than 75%. Again, we believed that identifying significant (50%) stenoses more accurately reflected day-to-day practice. We also recognize that image quality can be improved using fast gradient MR units, bolus timing methods, and even fluoroscopic MR imaging [28–32, 38]. None of these technical advances was available to us during this study. We overcame the issue of bolus timing by repeating the image acquisition twice. In this way we obtained good contrast enhancement even in patients who had slower blood circulation times.

In summary, the high sensitivity, specificity, and accuracy of breath-hold gadolinium-enhanced MR angiography in this select subset of patients suggest that this technique is a robust noninvasive diagnostic tool for the examination of patients with suspected renovascular hypertension. In addition, the use of standard gradients, as opposed to fast gradients, should help make this technique widely available.

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