Revised 2026

American College of Radiology
ACR Appropriateness Criteria®
Renovascular Hypertension

<u>Variant: 1</u> Adult. Suspected renovascular hypertension. Normal renal function. Initial imaging.

Procedure	Appropriateness Category	Relative Radiation Level
US duplex Doppler kidneys retroperitoneal	Usually Appropriate	O
MRA abdomen without and with IV contrast	Usually Appropriate	O
CTA abdomen with IV contrast	Usually Appropriate	☢☢☢
MRA abdomen without IV contrast	May Be Appropriate (Disagreement)	O
Arteriography kidney	Usually Not Appropriate	☢☢☢
Venography with renal vein sampling	Usually Not Appropriate	Varies
ACE inhibitor renography	Usually Not Appropriate	☢☢☢

<u>Variant: 2</u> Adult. Suspected renovascular hypertension. Decreased renal function, eGFR less than 30 mL/min/1.73 m2. Initial imaging.

Procedure	Appropriateness Category	Relative Radiation Level
US duplex Doppler kidneys retroperitoneal	Usually Appropriate	O
MRA abdomen without and with IV contrast	Usually Appropriate	O
MRA abdomen without IV contrast	May Be Appropriate (Disagreement)	O
Arteriography kidney	Usually Not Appropriate	☢☢☢
Venography with renal vein sampling	Usually Not Appropriate	Varies
ACE inhibitor renography	Usually Not Appropriate	☢☢☢
CTA abdomen with IV contrast	Usually Not Appropriate	☢☢☢

<u>Variant: 3</u> Adult. Suspected renovascular hypertension. Known renal artery stenosis. Normal renal function. Follow-up imaging.

Procedure	Appropriateness Category	Relative Radiation Level
US duplex Doppler kidneys retroperitoneal	Usually Appropriate	O
MRA abdomen without and with IV contrast	Usually Appropriate	O
CTA abdomen with IV contrast	Usually Appropriate	☢☢☢
Arteriography kidney	Usually Not Appropriate	☢☢☢
Venography with renal vein sampling	Usually Not Appropriate	Varies
MRA abdomen without IV contrast	Usually Not Appropriate	O
ACE inhibitor renography	Usually Not Appropriate	☢☢☢

<u>Variant: 4</u> Adult. Suspected renovascular hypertension. Known renal artery stenosis. Decreased renal function. eGFR less than 30 mL/min/1.73 m2. Follow-up imaging.

Procedure	Appropriateness Category	Relative Radiation Level
US duplex Doppler kidneys retroperitoneal	Usually Appropriate	O
MRA abdomen without and with IV contrast	Usually Appropriate	O
MRA abdomen without IV contrast	May Be Appropriate	O
Arteriography kidney	Usually Not Appropriate	☢☢☢

Venography with renal vein sampling	Usually Not Appropriate	Varies
ACE inhibitor renography	Usually Not Appropriate	☢☢☢
CTA abdomen with IV contrast	Usually Not Appropriate	☢☢☢

Variant: 5 Adult. Known renovascular hypertension. Posttreatment evaluation of renal artery stenosis.

Procedure	Appropriateness Category	Relative Radiation Level
US duplex Doppler kidneys retroperitoneal	Usually Appropriate	O
MRA abdomen without and with IV contrast	Usually Appropriate	O
CTA abdomen with IV contrast	Usually Appropriate	☢☢☢
Arteriography kidney	Usually Not Appropriate	☢☢☢
Venography with renal vein sampling	Usually Not Appropriate	Varies
MRA abdomen without IV contrast	Usually Not Appropriate	O
ACE inhibitor renography	Usually Not Appropriate	☢☢☢

Panel Members

Refky Nicola, DO, MSc[a], Richard Thomas, MD[b], Andrei S. Purysko, MD[c], Ayaz Aghayev, MD[d], Sandeep S. Hedgire, MD[e], Dianne Goede, MD[f], Susie Q. Lew, MD[g], Timothy McClure, MD[h], Sasan Partovi, MD[i], Sachin S. Saboo, MD[j], Akash Sharma, MD, MBA[k], Venkateswar R. Surabhi, MD[l], Myles T. Taffel, MD[m], Bill S. Majdalany, MD[n], Gaurav Khatri, MD[o]

Summary of Literature Review

Introduction/Background

Hypertension affects approximately half of the United States adult population [1]. Primary hypertension or essential hypertension represents hypertension without a clear etiology. Secondary hypertension, defined as hypertension with a demonstrable etiology, affects 5% to 10% of all cases of hypertension. An example of secondary hypertension includes renovascular hypertension, a disorder that affects between 0.5% and 5% of individuals with hypertension. A higher prevalence of renovascular hypertension can be appreciated in those with difficult-to-control blood pressure and older adult patients with end-stage kidney disease [2]. Among patients diagnosed with renal artery stenosis (RAS), atherosclerotic disease accounts for 90% and fibromuscular dysplasia for the remainder [3]. Other causes for reduced renal perfusion include vasculitis, embolic disease, dissection, posttraumatic occlusion, and extrinsic compression of a renal artery or a kidney [4]. Clinical features associated with an increased likelihood of renovascular hypertension include an abdominal bruit, malignant or accelerated hypertension, significant (diastolic pressure >110 mm Hg) hypertension in a young adult (<35 years of age), new-onset after 50 years of age, sudden development or worsening of hypertension, refractory hypertension, deterioration of renal function in response to angiotensin-converting enzyme (ACE) inhibitors, and generalized arteriosclerotic occlusive disease with hypertension [5].

A critical problem in diagnosing renovascular hypertension is selecting an appropriate end point against which to judge the accuracy of new tests. Calculations of these examinations' sensitivity, specificity, and accuracy are generally based on a comparison with a standard such as conventional angiography. However, the definition of a significant RAS has varied. Most investigators consider stenosis to be significant at 50% to 60%, yet perfusion pressure in a large artery is generally not reduced until stenosis exceeds 70% to 75% [5]. Ultimately, the defining criterion for renovascular hypertension is a fall in blood pressure after intervention (angioplasty, intravascular stent placement, or surgery) [5]. Bilateral renal artery disease remains a problem in that it is difficult in such cases to quantify the effect on the blood pressure of one side versus the other.

Testing for RAS is not appropriate for patients who have a low likelihood of renovascular hypertension. Investigating renovascular hypertension is appropriate when the clinical presentation suggests secondary hypertension rather than primary hypertension, when there is no other known cause of secondary hypertension, and when intervention would be performed if a significant RAS were identified. Recent investigation has directed the appropriateness of workup for RAS. Specifically, the Cardiovascular Outcomes in Renal Atherosclerotic Lesions trial—a randomized controlled trial of 947 patients from 113 centers—showed no difference in multiple end points between medical therapy and renal stenting in patients with atherosclerotic RAS and hypertension or chronic kidney disease [6]. This trial concluded that testing for RAS is not typically warranted for patients whose hypertension is well managed with medical therapy. Scenarios in which testing for RAS may be justified include new-onset hypertension before the age of 35 and after the age of 50 [5], failure to respond to appropriate antihypertensive medical therapy, progressive renal insufficiency suspected to be attributable to renovascular disease, episodes of flash pulmonary edema, and young patients with suspected fibromuscular dysplasia (for whom renal artery angioplasty may be preferable to long-term medical therapy) [4,7]. Given the limited scenarios in which testing for renovascular hypertension is considered appropriate, the decision to perform diagnostic imaging to identify RAS should ideally be based on a multidisciplinary assessment of an individual patient's clinical presentation, comorbidities, and the likelihood of response to intervention [7].

Initial Imaging Definition

Initial imaging is defined as imaging at the beginning of the care episode for the medical condition defined by the variant. More than one procedure can be considered usually appropriate in the initial imaging evaluation when:

- There are procedures that are equivalent alternatives (ie, only one procedure will be ordered to provide the clinical information to effectively manage the patient's care)

OR

- There are complementary procedures (ie, more than one procedure is ordered as a set or simultaneously wherein each procedure provides unique clinical information to effectively manage the patient's care).

Discussion of Procedures by Variant

Variant 1: Adult. Suspected renovascular hypertension. Normal renal function. Initial imaging.

Adults with normal renal function who are suspected of having renovascular hypertension due to new-onset hypertension or hypertension diagnosed before the age of 35 and after the age of 50 or unable to manage hypertension with medical therapy. The objective of imaging is to exclude the possibility for RAS.

Variant 1: Adult. Suspected renovascular hypertension. Normal renal function. Initial imaging.
A. ACE inhibitor Renography

ACE inhibitor renography or renal scintigraphy was first used for evaluating renal function in the late 1950s. Initial attempts to use renography specifically for evaluating renovascular hypertension had a high rate of false-positive and false-negative results. ACE inhibitor, such as captopril, was later added to the examination to improve the accuracy of the test for diagnosing renovascular hypertension and predicting blood pressure reduction after surgery or angioplasty. Administration of an ACE inhibitor leads to a decrease in glomerular filtration pressure, prolonged transit time of tubular agents such as Tc-99m-mercaptoacetyltriglycine (MAG3), and decreased uptake of glomerular agents such as Tc-99m-diethylenetriaminepentaacetic acid (DTPA).

ACE inhibitor renal scintigraphy analysis is based on the characterization of renal function deterioration when compared with a baseline study, with decreased glomerular filtration rate (GFR) reflected in time-activity curves. ACE inhibitor renography is, therefore, a functional assessment of renal perfusion and function rather than a method of directly visualizing the vasculature. The sensitivity and specificity of this examination are decreased in patients without clinical features of renovascular hypertension, and in the setting of bilateral RAS, impaired renal function, or urinary obstruction [8]. The reported sensitivity of ACE inhibitor renal scintigraphy for renovascular hypertension ranges from 34% to 93%, with a meta-analysis of 14 studies between 1990 and 2000 by Vasbinder et al [9] showing a mean sensitivity of approximately 81%. There have also been inconsistent results regarding the predictive value of ACE inhibitor renal scintigraphy in identifying patients who will respond to revascularization. A high correlation between a positive result on ACE inhibitor renal scintigraphy and a reduction in blood pressure after intervention has been reported in some studies [10]. However, the predictive value has been dismissed in other studies, with documented positive predictive values (PPVs) as low as 51% [11-14].

In summary, ACE inhibitor renal scintigraphy has decreased sensitivity and specificity in patients with bilateral RAS and impaired renal function. It is no longer a valuable tool for detecting renovascular hypertension in patients suspected of it. As a functional evaluation of renal perfusion and function, ACE inhibitor scintigraphy is only helpful to determine the physiologic sequelae of a known stenosis and assess each kidney's relative function before intervention [15,16].

Variant 1: Adult. Suspected renovascular hypertension. Normal renal function. Initial imaging.
B. Arteriography Kidney

Intraarterial digital subtraction angiography (IADSA) can demonstrate RAS and is an integral part of angioplasty and stenting procedures. Angiography has a high spatial resolution for evaluating the main and branch renal arteries. There is a high interobserver agreement for the identification of severe stenoses by angiography [17], but substantial interobserver variability is reported in the visual estimation of moderate RAS. IADSA allows for measuring pressure gradients across a stenosis and assessing its hemodynamic significance before intervention. A pressure gradient >20 mm Hg, or >10% of mean arterial pressure, indicates hemodynamic importance [18,19].

Smith et al [20] in a small study of 19 patients reported the sensitivity and specificity of intravenous (IV) digital subtraction angiography (IVDSA) to be as high as 87%. However, false-positive rates ranged from 26% to 37%, which they attributed to limited spatial resolution, subtraction artifacts, and quantum noise. Other reported that limitations of this technique have included obscuration of renal artery stenoses by overlap with opacified mesenteric vessels and suboptimal evaluation of fibromuscular lesions [21-23]. Wilms et al [23] in a study of 45 patients found fewer false-positives, which they attributed to technical advances and software improvements. They also reported that IVDSA grading of stenosis was accurate in 94% of cases of atherosclerotic RAS but in only 56% of fibromuscular stenosis cases. Dunnick et al [24] in a prospective study of 94 patients reported 100% sensitivity and 93% specificity for RAS. However, the 100% sensitivity was achieved in part by including inadequate examinations as positive, and the authors acknowledged the limitations of IVDSA for evaluating vessels affected by fibromuscular dysplasia. Although good results can be achieved with IVDSA, its resolution remains inferior to that of IADSA, and it is less sensitive than IADSA for evaluating fibromuscular dysplasia and atherosclerotic stenosis of branch vessels [25]. In addition, the contrast dose is often substantially higher than in arteriography and requires a central injection in the inferior vena cava or right atrium. For these reasons, IVDSA is not an initial imaging examination for renovascular hypertension.

In summary, the use of IADSA to assess for RAS is typically only in the setting of angioplasty and stenting procedures. It has a high spatial resolution for evaluating the main and branch renal arteries. There is a high interobserver agreement for the identification of severe stenoses by angiography [17], but variability with moderate RAS. It has a sensitivity and a specificity of 87%, but it is limited due to false-positives, which are caused by spatial resolution and artifacts [25]. Therefore, it is usually not an appropriate primary modality for initial evaluation of suspected renovascular hypertension in patients with normal renal function.

Variant 1: Adult. Suspected renovascular hypertension. Normal renal function. Initial imaging.

C. CTA Abdomen With IV Contrast

Contrast-enhanced CT angiography (CTA) provides accurate anatomic images of the renal arteries with isotropic data sets that enable the reconstruction of high-resolution images in any plane. Two studies comparing CTA with digital renal arteriography [26,27] have reported the sensitivity of CTA for detecting >50% stenoses (>50% diameter) to be 88% to 96% and the specificity to be 77% to 98%, and in one study, the accuracy was 89%. In diagnosing the narrowing of only the main renal arteries, one study found the sensitivity and specificity to be 100% and 98%, respectively [26]. Negative results from CTA virtually rule out RAS. Maximum-intensity projection and volume-rendering techniques are helpful and complementary in CT evaluation of RAS [28]. Secondary signs of RAS seen on CTA include post-stenotic dilatation, renal atrophy, and decreased cortical enhancement. A threshold of 800 mm2 for cortical area and 8 mm for mean cortical thickness seen on CT can be helpful morphologic markers of renal parenchymal atrophy [29].

Similar to MR angiography (MRA), CTA is more accurate in diagnosing proximal rather than distal lesions, although CTA generally provides better depiction of branch renal arteries than MRA [30].

In summary, contrast-enhanced CTA has demonstrated a high sensitivity and specificity as high as 96% for the detection of >50% stenosis and is often used as an initial test to evaluate patients with suspected renovascular hypertension and normal renal function.

Variant 1: Adult. Suspected renovascular hypertension. Normal renal function. Initial imaging.

D. MRA Abdomen Without and With IV Contrast

MRA is suited for noninvasive workup of RAS and has been widely applied in clinical practice. The reliability of MRA is not affected by the presence of bilateral renovascular disease [5]. Hydrating the patients or stopping diuretics before the examination is unnecessary. Three-dimensional contrast-enhanced MRA with an IV injection of gadolinium-based contrast agent has been the backbone of MRA examinations of renal arteries.

Several investigators report using angiography as the standard of reference, with the sensitivity of MRA ranging from 88% to 100% and the specificity ranging from 71% to 100% compared with angiography [31-33]. In a meta-analysis of 25 studies [34] the sensitivity and specificity of gadolinium-enhanced MRA were 97% and 93%, respectively. Solar et al [35] compared contrast-enhanced MRA with Doppler ultrasound (US) using angiography as the reference and found contrast-enhanced MRA to be superior, with a sensitivity of 93% and a specificity of 93%, compared with US, with a sensitivity of 85% and a specificity of 84%. With the use of high-spatial-resolution, small-field-of-view contrast-enhanced MRA techniques, it is possible to evaluate not only the main renal arteries but also the accessory renal arteries and distal stenosis. Improved gradient hardware and parallel imaging techniques have reduced acquisition times and improved spatial resolution.

Another technique, the blood oxygen level-dependent (BOLD) MRI, is able to assess renal oxygenation by measuring R2* values in the renal parenchyma. This may allow for functional assessment in patients with RAS [36-38]. However, more research is needed on BOLD MRI to establish its routine use in clinical practice.

MRA is an excellent alternative to CTA abdomen with IV contrast, with sensitivities and specificities ranging from 88% to 100% and 71% to 100%, respectively [31-33], and can be used as an initial test for evaluation of patients with suspected renovascular hypertension and normal renal function.

Variant 1: Adult. Suspected renovascular hypertension. Normal renal function. Initial imaging.

E. MRA Abdomen Without IV Contrast

In the same way as CTA, MRA can also visualize the renal arteries with 3-D reconstructions and their cross-sectional anatomy. This is done with inflow inversion recovery for noncontrast imaging. The use of modified balanced steady-state free precession (SSFP) pulse sequences, and special gradient echo-based sequences that provide good visualization of the renal arteries with high signal-to-noise ratio and inherent flow compensation, is combined with arterial spin labeling to allow for background suppression [39]. The sensitivity and specificity of noncontrast MRA are 90% to 97% and 82% to 87%, respectively, whereas gadolinium-enhanced MRI has a greater sensitivity of 93% to 98% and a specificity of 91% to 95% [34].

In comparison to CT or IADSA, Utsunomiya et al [40] demonstrated that unenhanced SSFP MRA with CT or IADSA in 26 patients had a sensitivity, specificity, PPV, and negative predictive value (NPV) of 78%, 91%, 64%, and 96%, respectively. Mohrs et al [41] comparing an SSFP technique with contrast-enhanced MRA in 45 patients found sensitivity, specificity, PPV, and NPV of 75%, 99%, 75%, and 99%, respectively, for detecting renal artery stenoses >50%. Braidy et al [42] compared an unenhanced SSFP technique with contrast-enhanced MRA, with a sensitivity, specificity, PPV, and NPV of 85%, 96%, 94%, and 96%, respectively, but emphasized that when stenosis is found, other modalities should be employed for better estimation. Albert et al [43] in a report of a multicenter trial of 75 patients compared an unenhanced MRA technique with contrast-enhanced CT with a sensitivity of 74% and specificity of 93% for >50% stenosis. In summary, although MRA abdomen without IV contrast can be used to evaluate for renovascular hypertension, MRA abdomen without and with IV contrast, CTA abdomen with IV contrast, and US duplex Doppler of the kidneys are typically preferred as initial tests in patients with normal renal function.

Variant 1: Adult. Suspected renovascular hypertension. Normal renal function. Initial imaging.
F. US Duplex Doppler Kidneys Retroperitoneal

Duplex Doppler US of the kidneys is commonly used as a noninvasive screening test for renovascular hypertension because it does not require IV contrast material and can be used in patients with any level of renal function. As with many noninvasive imaging examinations, numerous parameters and abnormal criteria indicate possible renovascular disease.

Two of the most frequently used parameters are peak systolic velocity (PSV) in the main renal artery and renal artery-to-aortic ratio (RAR), which depend on a direct evaluation of elevated velocity in a stenotic segment of the renal artery. PSV cutoff values ranging from 180 cm/s to 300 cm/s have been proposed in various studies. Hua et al [44] showed a PSV of 200 cm/s to have a sensitivity of 91% and a specificity of 75%. In contrast, Motew et al [45] reported a PSV of 200 cm/s with a sensitivity of 91% and a specificity of 96%. AbuRahma et al [46] stated a PSV of 200 cm/s has a sensitivity of 73% and specificity of 82% for stenosis ≥60%. To improve specificity, some authors recommend a higher PSV threshold of 300 cm/s [4].

An elevated RAR value is also a valuable criterion for identifying stenosis because PSV may be elevated based on hypertension without underlying RAS. The suggested RAR cutoff value also varies between authors, although an RAR of 3.5 is a commonly reported threshold value [47]. It is noted that identification of elevated PSV and RAR depends on adequate visualization of a stenotic segment of the renal artery, patient body habitus type, and the presence of obscuring bowel gas, dense atherosclerotic plaques, or impeding accessory renal arteries. In these cases, distal criteria may be helpful as an indirect indicator of stenosis. A parvus-tardus intrarenal waveform with a small peak and a slow upstroke highly suggest more proximal stenosis [48]. This is reflected by an acceleration time of >70 ms and the early systolic peak loss. Although an elevated resistive index (RI), defined as (PSV − end-diastolic velocity)/PSV, is not a specific indicator of RAS, an RI >0.80 has been reported to be a negative prognostic sign for response to revascularization [49,50]. However, other studies have not confirmed a significant difference in revascularization outcomes according to RI and have argued against using an elevated RI as a contraindication to revascularization [51,52].

In summary, Doppler US has high sensitivity and specificity for detection of RAS and is often used as an initial screening tool in patients with suspected renovascular hypertension.

Variant 1: Adult. Suspected renovascular hypertension. Normal renal function. Initial imaging.
G. Venography With Renal Vein Sampling

In patients with unilateral RAS, the ischemic kidney secretes increased renin, and there is relative suppression of renin release by the contralateral kidney. This results in asymmetry in renal vein renin levels. With bilateral RAS, there is also lateralization of renin secretion, with higher renal vein renin for the kidney with a greater degree of stenosis. This forms the basis for renal vein renin assays for evaluating renovascular hypertension. Various parameters have been described, including renal vein–to–inferior vena cava ratios and right renal vein–to–left renal vein ratios. Renal vein renin assays were initially considered the best means to predict response to revascularization in patients with suspected renovascular hypertension, with most studies before 1980 supporting the validity of this procedure. However, later studies have shown a high rate of false-negative and false-positive results. Sellars et al [53] reviewed 37 cases and found a false-positive rate of 39% and a false-negative rate of 71%. Luscher et al [54] in a study involving 95 patients reported a high sensitivity of 92% for a positive renal vein renin assay but a low specificity of 42% and a high number of false-positive and false-negative results. Roubidoux et al [55] measured captopril-stimulated renal vein renin ratios in 133 patients and found a sensitivity of 65%, a false-positive rate of 47.8%, a PPV of 18.6%, and an NPV of 89.3%. Postma et al [13] in a retrospective study of 25 patients with documented RAS found that a positive renal vein renin assay had a sensitivity of 72% and a specificity of only 29%. In general, the high rates of false-negative and false-positive studies limit the use of renal vein renin assays as screening tests for renovascular hypertension. Therefore, venography with renal vein sampling is usually not appropriate in the assessment of renovascular hypertension in the setting of normal renal function.

Variant 2: Adult. Suspected renovascular hypertension. Decreased renal function, eGFR less than 30 mL/min/1.73 m2. Initial imaging.

In this clinical setting, patients have decreased renal function with an estimated GFR (eGFR) <30 mL/min/1.73 m2 and are suspected of having new onset hypertension or onset of hypertension at an early age. The objective of imaging is to preserve renal function while providing an accurate diagnosis.

Variant 2: Adult. Suspected renovascular hypertension. Decreased renal function, eGFR less than 30 mL/min/1.73 m2. Initial imaging.
A. ACE inhibitor Renography

ACE inhibitor renography or renal scintigraphy was first used for evaluating renal function in the late 1950s. Initial attempts to use renography specifically for evaluating renovascular hypertension had a high rate of false-positive and false-negative results. ACE inhibitor, such as Captopril, was later added to the examination to improve the accuracy of the test for diagnosing renovascular hypertension and predicting blood pressure reduction after surgery or angioplasty. Administration of an ACE inhibitor leads to a decrease in glomerular filtration pressure, prolonged transit time of tubular agents such as Tc-99m-MAG3, and decreased uptake of glomerular agents such as Tc-99m-DTPA [5].

ACE inhibitor renography is based on the characterization of renal function deterioration when compared with a baseline study, with decreased GFR reflected in time-activity curves. ACE inhibitor renography is, therefore, a functional assessment of renal perfusion and function rather than a method of directly visualizing the vasculature. The sensitivity and specificity of this examination are decreased in patients without clinical features of renovascular hypertension, and in the setting of bilateral RAS, impaired renal function, or urinary obstruction [8]. The reported sensitivity of ACE inhibitor renal scintigraphy for renovascular hypertension ranges from 34% to 93%, with a meta-analysis of 14 studies between 1990 and 2000 by Vasbinder et al [9] showing a mean sensitivity of approximately 81%. There have also been inconsistent results regarding the predictive value of ACE inhibitor renal scintigraphy in identifying patients who will respond to revascularization. A high correlation has been reported between a positive result on ACE inhibitor renal scintigraphy and a reduction in blood pressure after intervention in some studies [10]. However, the predictive value has been dismissed in other studies, with documented PPVs as low as 51% [11-14]. As a functional evaluation of renal perfusion and function, ACE inhibitor renal scintigraphy is only helpful to determine the physiologic sequelae of a known stenosis and assess each kidney's relative function before intervention [15,16]. Thus ACE inhibitor renal scintigraphy is usually not appropriate for initial evaluation of patients with suspected renovascular hypertension in setting of decreased renal function.

Variant 2: Adult. Suspected renovascular hypertension. Decreased renal function, eGFR less than 30 mL/min/1.73 m2. Initial imaging.
B. Arteriography Kidney

IADSA can demonstrate RAS and is an integral part of angioplasty and stenting procedures. Angiography has a high spatial resolution for evaluating the main and branch renal arteries. There is a high interobserver agreement for the identification of severe stenoses by angiography [17], but substantial interobserver variability is reported in the visual estimation of moderate RAS. IADSA has a sensitivity and a specificity of 87%, but it is limited due to false-positives, which are caused by spatial resolution and artifacts [25]. IADSA allows for measuring pressure gradients across a stenosis and assessing its hemodynamic significance before intervention. A pressure gradient >20 mm Hg, or >10% of mean arterial pressure, indicates hemodynamic importance [18,19]. Although good results can be achieved with IVDSA, its resolution is inferior to that of IADSA, and it is less sensitive than IADSA for evaluating fibromuscular dysplasia and atherosclerotic stenosis of branch vessels [25]. In addition, the contrast dose is often substantially higher than in arteriography and requires a central injection in the inferior vena cava or right atrium. For these reasons, IVDSA is not an initial imaging examination for renovascular hypertension. Impaired renal function may limit using iodinated contrast material for angiography-based interventional procedures. Thus, arteriography is generally not used for initial evaluation of patients with decreased renal function who are suspected of having renovascular hypertension.

Variant 2: Adult. Suspected renovascular hypertension. Decreased renal function, eGFR less than 30 mL/min/1.73 m2. Initial imaging.
C. CTA Abdomen With IV Contrast

Contrast-enhanced CTA is generally not preferred in patients with advanced renal dysfunction because of potential nephrotoxicity of contrast material. The causal relationship between contrast material for CT and acute kidney injury has been disputed, and recent data suggest a low risk of clinically relevant contrast material-induced nephropathy (CIN). Cutoff values for serum creatinine and eGFR beyond which iodinated-contrast material would not be administered vary by institution. However, eGFR has been recognized to be a better indicator of baseline renal function than serum creatinine. Studies from Davenport et al [56,57] in 2013 and McDonald et al [58,59] in 2013 indicate that IV iodinated contrast material is not an independent nephrotoxic risk factor in patients with a stable baseline eGFR of >45 mL/min/1.73 m2 and that iodinated contrast material is rarely nephrotoxic in patients with a stable baseline eGFR between 30 and 44 mL/min/1.73 m2. Conflicting results were obtained for patients with more severe renal dysfunction with an eGFR of <30 mL/min/1.73 m2, with the 2013 study by Davenport et al reporting an excess of acute kidney injury in these patients receiving IV contrast material versus controls but with the 2014 study by McDonald et al [58] showing no significant difference in acute kidney injury for contrast material recipients versus control patients with this baseline eGFR [56-60]. The ACR Manual on Contrast Media notes that if a threshold for CIN risk is used, an eGFR of 30 mL/min/1.73 m2 has the most significant level of evidence [61]. In summary, CTA abdomen with IV contrast is not generally preferred as the initial test to evaluate for suspected renovascular hypertension in patients with decreased renal function.

Variant 2: Adult. Suspected renovascular hypertension. Decreased renal function, eGFR less than 30 mL/min/1.73 m2. Initial imaging.
D. MRA Abdomen Without and With IV Contrast

MRA is suited for noninvasive workup of RAS and has been widely applied in clinical practice. The reliability of MRA is not affected by the presence of bilateral renovascular disease. Hydrating the patients or stopping diuretics before the examination is unnecessary. Gadolinium-based contrast media if administered at FDA-approved dose has been found not to cause contrast-induced acute renal injury. Furthermore, ACR group II MRI contrast agents are associated with few, if any, unconfounded cases of nephrogenic systemic fibrosis. For further discussion, the ACR Manual on Contrast Media is recommended [61]. Three-dimensional contrast-enhanced MRA with an IV injection of gadolinium-based contrast agent has been the backbone of MRA examinations of renal arteries.

Several investigators report using angiography as the standard of reference, with the sensitivity of MRA ranging from 88% to 100% and the specificity ranging from 71% to 100% compared with angiography [31-33]. In a meta-analysis of 25 studies [34] the sensitivity and specificity of gadolinium-enhanced MRA were 97% and 93%, respectively. Solar et al [35] compared contrast-enhanced MRA with Doppler US using angiography as the reference and found contrast-enhanced MRA to be superior, with a sensitivity of 93% and a specificity of 93%, compared with US, with a sensitivity of 85% and a specificity of 84%. With the use of high-spatial-resolution, small-field-of-view contrast-enhanced MRA techniques, it is possible to evaluate not only the main renal arteries but also the accessory renal arteries and distal stenosis. Improved gradient hardware and parallel imaging techniques have reduced acquisition times and improved spatial resolution.

Another technique, the BOLD MRI, can assess renal oxygenation by measuring R2* values in the renal parenchyma. This may allow for functional assessment in patients with RAS [36-38]. However, more research is needed on BOLD MRI to establish its routine use in clinical practice.

MRA is an excellent alternative to CTA abdomen with IV contrast with sensitivities and specificities ranging from 88% to 100% and 71% to 100%, respectively [31-33], and can generally be used to evaluate for renovascular hypertension in patients with decreased renal function.

Variant 2: Adult. Suspected renovascular hypertension. Decreased renal function, eGFR less than 30 mL/min/1.73 m2. Initial imaging.
E. MRA Abdomen Without IV Contrast

Although MRA abdomen without and with IV contrast can generally be performed safely in most patients with decreased renal function, MRA abdomen without IV contrast may also be used for evaluation of patients with suspected renovascular hypertension. In the same way as CTA, MRA can also visualize the renal arteries with 3-D reconstructions and their cross-sectional anatomy. This is done with inflow inversion recovery for noncontrast imaging. The use of modified balanced SSFP pulse sequences, and special gradient echo-based sequences that provide good visualization of the renal arteries with high signal-to-noise ratio and inherent flow compensation, is combined with arterial spin labeling to allow for background suppression [39]. The sensitivity and specificity of noncontrast MRA are 90% to 97% and 82% to 87%, respectively, whereas gadolinium-enhanced MRI has a greater sensitivity of 93% to 98% and a specificity of 91% to 95% [34].

Utsunomiya et al [40], comparing unenhanced SSFP MRA with CT or IADSA in 26 patients, found a sensitivity, specificity, PPV, and NPV of 78%, 91%, 64%, and 96%, respectively. Mohrs et al [41] comparing an SSFP technique with contrast-enhanced MRA in 45 patients found sensitivity, specificity, PPV, and NPV of 75%, 99%, 75%, and 99%, respectively, for detecting renal artery stenoses >50%. Braidy et al [42] compared an unenhanced SSFP technique to contrast-enhanced MRA with a sensitivity, specificity, PPV, and NPV of 85%, 96%, 94%, and 96%, respectively, but emphasized that when stenosis is found, other modalities should be employed for better estimation. Albert et al [43] in a report of a multicenter trial of 75 patients compared an unenhanced MRA technique that demonstrated a sensitivity less than contrast-enhanced CT of 74% and specificity of 93% for >50% stenosis.

Variant 2: Adult. Suspected renovascular hypertension. Decreased renal function, eGFR less than 30 mL/min/1.73 m2. Initial imaging.
F. US Duplex Doppler Kidneys Retroperitoneal

Duplex Doppler US of the kidneys is commonly used as a noninvasive screening test for renovascular hypertension because it does not require IV contrast material and can be used in patients with any level of renal function. As with many noninvasive imaging examinations, numerous parameters and abnormal criteria indicate possible renovascular disease.

Two of the most frequently used parameters are PSV in the main renal artery and RAR, which depend on a direct evaluation of elevated velocity in a stenotic segment of the renal artery. PSV cutoff values ranging from 180 cm/s to 300 cm/s have been proposed in various studies. Hua et al [44] showed a PSV of 200 cm/s to have a sensitivity of 91% and a specificity of 75%. In contrast, Motew et al [45] reported a PSV of 200 cm/s with a sensitivity of 91% and a specificity of 96%. AbuRahma et al [46] stated a PSV of 200 cm/s has a sensitivity of 73% and a specificity of 82% for stenosis ≥60%. To improve specificity, some authors recommend a higher PSV threshold of 300 cm/s [4].

An elevated RAR value is also a valuable criterion for identifying stenosis because PSV may be elevated based on hypertension without underlying RAS. The suggested RAR cutoff value also varies between authors, although an RAR of 3.5 is a commonly reported threshold value [47]. It is noted that identification of elevated PSV and RAR depends on adequate visualization of a stenotic segment of the renal artery, patient body habitus type, and the presence of obscuring bowel gas, dense atherosclerotic plaques, or impeding accessory renal arteries. In these cases, distal criteria may be helpful as an indirect indicator of stenosis. A parvus-tardus intrarenal waveform with a small peak and a slow upstroke highly suggest more proximal stenosis [48]. This is reflected by an acceleration time of >70 ms and the early systolic peak loss. Although an elevated RI, defined as (PSV − end-diastolic velocity)/PSV, is not a specific indicator of RAS, an RI >0.80 has been reported to be a negative prognostic sign for response to revascularization [49,50]. However, other studies have not confirmed a significant difference in revascularization outcomes according to RI and have argued against using an elevated RI as a contraindication to revascularization [51,52].

In summary, Doppler US has high sensitivity and specificity for detection of RAS and is often used as an initial screening tool in patients with suspected renovascular hypertension.

Variant 2: Adult. Suspected renovascular hypertension. Decreased renal function, eGFR less than 30 mL/min/1.73 m2. Initial imaging.

G. Venography With Renal Vein Sampling

In patients with unilateral RAS, the ischemic kidney secretes increased renin, and there is relative suppression of renin release by the contralateral kidney. This results in asymmetry in renal vein renin levels. With bilateral RAS, there is also lateralization of renin secretion, with higher renal vein renin for the kidney with a greater degree of stenosis. This forms the basis for renal vein renin assays for evaluating renovascular hypertension. Various parameters have been described, including renal vein–to–inferior vena cava ratios and right renal vein–to–left renal vein ratios. Renal vein renin assays were initially considered the best means to predict response to revascularization in patients with suspected renovascular hypertension, with most studies before 1980 supporting the validity of this procedure. However, later studies have shown a high rate of false-negative and false-positive results. Sellars et al [53] reviewed 37 cases and found a false-positive rate of 39% and a false-negative rate of 71%. Luscher et al [54] in a study involving 95 patients reported a high sensitivity of 92% for a positive renal vein renin assay but a low specificity of 42% and a high number of false-positive and false-negative results. Roubidoux et al [55] measured captopril-stimulated renal vein renin ratios in 133 patients and found a sensitivity of 65%, a false-positive rate of 47.8%, a PPV of 18.6%, and an NPV of 89.3%. Postma et al [13] in a retrospective study of 25 patients with documented RAS found that a positive renal vein renin assay had a sensitivity of 72% and a specificity of only 29%. In general, the high rates of false-negative and false-positive studies limit the use of renal vein renin assays as screening tests for renovascular hypertension. Impaired renal function may also limit using iodinated contrast material for angiography-based interventional procedures. Therefore, venography with renal vein sampling is usually not appropriate in the assessment of renovascular hypertension in the setting of decreased renal function.

Variant 3: Adult. Suspected renovascular hypertension. Known renal artery stenosis. Normal renal function. Follow-up imaging.

Some groups of patients with known RAS and normal renal function may be managed medically without intervention. These include patients with mild RAS resulting in no hypertension or medically controlled hypertension and patients considered to be at a high risk of percutaneous or surgical treatment of RAS. Such patients may benefit from serial imaging studies to monitor for disease progression or development of complications [62].

Variant 3: Adult. Suspected renovascular hypertension. Known renal artery stenosis. Normal renal function. Follow-up imaging.
A. ACE inhibitor Renography

ACE inhibitor renography or renal scintigraphy was first used for evaluating renal function in the late 1950s. Initial attempts to use renography specifically for evaluating renovascular hypertension had a high rate of false-positive and false-negative results. ACE inhibitor, such as Captopril, was later added to the examination to improve the accuracy of the test for diagnosing renovascular hypertension and predicting blood pressure reduction after surgery or angioplasty. Administration of an ACE inhibitor leads to a decrease in glomerular filtration pressure, prolonged transit time of tubular agents such as Tc-99m-MAG3, and decreased uptake of glomerular agents such as Tc-99m-DTPA [5].

ACE inhibitor renal scintigraphy analysis is based on the characterization of renal function deterioration when compared with a baseline study, with decreased GFR reflected in time-activity curves. ACE inhibitor renography is, therefore, a functional assessment of renal perfusion and function rather than a method of directly visualizing the vasculature. The sensitivity and specificity of this examination are decreased in patients without clinical features of renovascular hypertension, and in the setting of bilateral RAS, impaired renal function, or urinary obstruction [8]. The reported sensitivity of ACE inhibitor renal scintigraphy for renovascular hypertension ranges from 34% to 93%, with a meta-analysis of 14 studies between 1990 and 2000 by Vasbinder et al [9] showing a mean sensitivity of approximately 81%. There have also been inconsistent results regarding the predictive value of ACE inhibitor renal scintigraphy in identifying patients who will respond to revascularization. A high correlation between a positive result on ACE inhibitor renal scintigraphy and a reduction in blood pressure after intervention has been reported in some studies [10]. However, the predictive value has been dismissed in other studies, with documented PPVs as low as 51% [11-14].

As a functional evaluation of renal perfusion and function, ACE inhibitor scintigraphy can be useful to determine the physiological sequence of a known stenosis and to assess the relative function of each kidney [47,48]; however, ACE inhibitor renography does not directly visualize changes in the degree of vascular stenosis and is usually not appropriate in the follow-up of suspected renovascular hypertension in the setting of known RAS with normal renal function.

Variant 3: Adult. Suspected renovascular hypertension. Known renal artery stenosis. Normal renal function. Follow-up imaging.
B. Arteriography Kidney

IADSA can demonstrate RAS and is an integral part of angioplasty and stenting procedures. Angiography has a high spatial resolution for evaluating the main and branch renal arteries. There is a high interobserver agreement for the identification of severe stenoses by angiography [17], but there is reported substantial interobserver variability in visual estimation of moderate RAS. IADSA allows for measuring pressure gradients across a stenosis and assessing its hemodynamic significance before intervention. A pressure gradient >20 mm Hg, or >10% of mean arterial pressure, indicates hemodynamic importance [18,19].

Smith et al [20] in a small study of 19 patients reported the sensitivity and specificity of IVDSA to be as high as 87%. However, false-positive rates ranged from 26% to 37%, which they attributed to limited spatial resolution, subtraction artifacts, and quantum noise. Other reported that limitations of this technique have included obscuration of renal artery stenoses by overlap with opacified mesenteric vessels and suboptimal evaluation of fibromuscular lesions [21-23]. Wilms et al [23] in a study of 45 patients found fewer false-positives, which they attributed to technical advances and software improvements. They also reported that IVDSA grading of stenosis was accurate in 94% of cases of atherosclerotic RAS but in only 56% of fibromuscular stenosis cases. Dunnick et al [24] in a prospective study of 94 patients reported 100% sensitivity and 93% specificity for RAS. However, the 100% sensitivity was achieved in part by including inadequate examinations as positive, and the authors acknowledged the limitations of IVDSA for evaluating vessels affected by fibromuscular dysplasia. Thus, compared with IADSA, IVDSA has lower resolution, is less sensitive for evaluating fibromuscular dysplasia and atherosclerotic stenosis of branch vessels, and requires a higher dose of contrast [20-23].

There is no specific literature on the role of renal arteriography for the follow-up of known RAS. Both IADSA and IVDSA are invasive procedures and therefore are not optimal examinations for follow-up of patients with RAS.

Variant 3: Adult. Suspected renovascular hypertension. Known renal artery stenosis. Normal

renal function. Follow-up imaging.
C. CTA Abdomen With IV Contrast

Contrast-enhanced CTA provides accurate anatomic images of the renal arteries with isotropic data sets that enable the reconstruction of high-resolution images in any plane. Two studies comparing CTA with digital renal arteriography [26,27] have reported the sensitivity of CTA for detecting >50% stenoses (>50% diameter) to be 88% to 96% and the specificity to be 77% to 98%, and in one study, the accuracy was 89%. In diagnosing the narrowing of only the main renal arteries, one study found the sensitivity and specificity to be 100% and 98%, respectively [26]. Negative results from CTA virtually rule out RAS. Maximum-intensity projection and volume-rendering techniques are helpful and complementary in CT evaluation of RAS [28]. Secondary signs of RAS seen on CTA include poststenotic dilatation, renal atrophy, and decreased cortical enhancement. A threshold of 800 mm2 for cortical area and 8 mm for mean cortical thickness seen on CT can be helpful morphologic markers of renal parenchymal atrophy [29]. Similar to MRA, CTA is more accurate in diagnosing proximal rather than distal lesions, although CTA generally provides better depiction of branch renal arteries than MRA [30].

In patients with normal renal function, CTA can be a useful tool to follow-up patients with suspected renovascular hypertension in the setting of known RAS when clinically necessary.

Variant 3: Adult. Suspected renovascular hypertension. Known renal artery stenosis. Normal renal function. Follow-up imaging.
D. MRA Abdomen Without and With IV Contrast

MRA is a useful modality for the evaluation of RAS. The reliability of MRA is not affected by the presence of bilateral renovascular disease [5]. Several investigators report using angiography as the standard of reference, with the sensitivity of MRA ranging from 88% to 100% and the specificity ranging from 71% to 100% compared with angiography [31-33]. In a meta-analysis of 25 studies [34] the sensitivity and specificity of gadolinium-enhanced MRA were 97% and 93%, respectively. Solar et al [35] compared contrast-enhanced MRA with Doppler US using angiography as the reference and found contrast-enhanced MRA to be superior, with a sensitivity of 93% and a specificity of 93%, compared with US, with a sensitivity of 85% and a specificity of 84%. With the use of high-spatial-resolution, small-field-of-view contrast-enhanced MRA techniques, it is possible to evaluate not only the main renal arteries but also the accessory renal arteries and distal stenosis. Improved gradient hardware and parallel imaging techniques have reduced acquisition times and improved spatial resolution.

Another technique, the BOLD MRI, is able to assess renal oxygenation by measuring R2* values in the renal parenchyma. This may allow for functional assessment in patients with RAS [36-38]. However, more research is needed on BOLD MRI to establish its routine use in clinical practice.

ACR group II MRI contrast agents are associated with few, if any, unconfounded cases of nephrogenic systemic fibrosis [63]. Therefore, MRA can be a useful substitute for studies requiring the use of iodinated CT contrast agents.

In summary, MRA is an excellent tool for evaluation of RAS with sensitivities and specificities ranging from 88% to 100% and 71% to 100%, respectively [31-33], and can be used for follow-up of patients with suspected renovascular hypertension and known RAS in setting of normal renal function when clinically necessary.

Variant 3: Adult. Suspected renovascular hypertension. Known renal artery stenosis. Normal renal function. Follow-up imaging.
E. MRA Abdomen Without IV Contrast

Noncontrast MRA has been shown to have high specificity and NPV with moderate to high sensitivity and PPV in the evaluation of RAS [42]. However, Albert et al [43] in a report of a multicenter trial of 75 patients compared an unenhanced MRA technique that demonstrated a sensitivity less than contrast-enhanced CT of 74% and specificity of 93% for >50% stenosis. The commonly used techniques are SSFP and time-spatial labeling inversion pulse [41-43]. Another technique, the BOLD MRI, is able to assess renal oxygenation by measuring R2* values in the renal parenchyma. This may allow for functional assessment in patients with RAS [36-38]. However, more research is needed on BOLD MRI to establish its routine use in clinical practice. Noncontrast MRA has the advantage of not requiring contrast media; however, when stenosis is found on unenhanced MRA, it is generally recommended to use other modalities for better estimation [42]. Thus, in the setting of normal renal function, contrast-enhanced examinations are preferred and MRA abdomen without IV contrast is not generally used for follow up of patients with suspected renovascular hypertension and known RAS.

Variant 3: Adult. Suspected renovascular hypertension. Known renal artery stenosis. Normal renal function. Follow-up imaging.
F. US Duplex Doppler Kidneys Retroperitoneal

Duplex Doppler US of the kidneys is commonly used as a noninvasive screening test for renovascular hypertension because it does not require IV contrast material and can be used in patients with any level of renal function. As with many noninvasive imaging examinations, numerous parameters and abnormal criteria indicate possible renovascular disease.

Two of the most frequently used parameters are PSV in the main renal artery and RAR, which depend on a direct evaluation of elevated velocity in a stenotic segment of the renal artery. PSV cutoff values ranging from 180 cm/s to 300 cm/s have been proposed in various studies. Hua et al [44] showed a PSV of 200 cm/s to have a sensitivity of 91% and a specificity of 75%. In contrast, Motew et al [45] reported a PSV of 200 cm/s with a sensitivity of 91% and a specificity of 96%. AbuRahma et al [46] stated a PSV of 200 cm/s has a sensitivity of 73% and a specificity of 82% for stenosis ≥60%. To improve specificity, some authors recommend a higher PSV threshold of 300 cm/s [4].

An elevated RAR value is also a valuable criterion for identifying stenosis because PSV may be elevated based on hypertension without underlying RAS. The suggested RAR cutoff value also varies between authors, although an RAR of 3.5 is a commonly reported threshold value [47]. It is noted that identification of elevated PSV and RAR depends on adequate visualization of a stenotic segment of the renal artery, patient body habitus type, and the presence of obscuring bowel gas dense atherosclerotic plaques, or impeding of accessory renal arteries. In these cases, distal criteria may be helpful as an indirect indicator of stenosis. A parvus-tardus intrarenal waveform with a small peak and a slow upstroke highly suggest more proximal stenosis [48]. This is reflected by an acceleration time of >70 ms and the early systolic peak loss. Although an elevated RI, defined as (PSV − end-diastolic velocity)/PSV, is not a specific indicator of RAS, an RI >0.80 has been reported to be a negative prognostic sign for response to revascularization [49,50]. However, other studies have not confirmed a significant difference in revascularization outcomes according to RI and have argued against using an elevated RI as a contraindication to revascularization [51,52].

In summary, Doppler US has been shown to be a helpful tool for follow-up of patients with suspected renovascular hypertension and known RAS in the setting of normal renal function when clinically necessary [62].

Variant 3: Adult. Suspected renovascular hypertension. Known renal artery stenosis. Normal renal function. Follow-up imaging.
G. Venography With Renal Vein Sampling

In patients with unilateral RAS, the ischemic kidney secretes increased renin, and there is relative suppression of renin release by the contralateral kidney. This results in asymmetry in renal vein renin levels. With bilateral RAS, there is also lateralization of renin secretion, with higher renal vein renin for the kidney with a greater degree of stenosis. This forms the basis for renal vein renin assays for evaluating renovascular hypertension. Various parameters have been described, including renal vein–to–inferior vena cava ratios and right renal vein–to–left renal vein ratios. Renal vein renin assays were initially considered the best means to predict response to revascularization in patients with suspected renovascular hypertension, with most studies before 1980 supporting the validity of this procedure. However, later studies have shown a high rate of false-negative and false-positive results. Sellars et al [53] reviewed 37 cases and found a false-positive rate of 39% and a false-negative rate of 71%. Luscher et al [54] in a study involving 95 patients reported a high sensitivity of 92% for a positive renal vein renin assay but a low specificity of 42% and a high number of false-positive and false-negative results. Roubidoux et al [55] measured captopril-stimulated renal vein renin ratios in 133 patients and found a sensitivity of 65%, a false-positive rate of 47.8%, a PPV of 18.6%, and an NPV of 89.3%. Postma et al [13] in a retrospective study of 25 patients with documented RAS found that a positive renal vein renin assay had a sensitivity of 72% and a specificity of only 29%. There is no relevant literature on the use of renal vein sampling to follow-up known RAS.

Moreover, its high rates of false-negative and false-positive results and its invasive nature limit its use in the follow-up of known RAS [13].

Variant 4: Adult. Suspected renovascular hypertension. Known renal artery stenosis. Decreased renal function. eGFR less than 30 mL/min/1.73 m2. Follow-up imaging.

Some groups of patients with RAS and impaired renal function may be managed medically without intervention. These include patients with mild RAS resulting in no hypertension or medically controlled hypertension and patients considered to be at high risk of percutaneous or surgical treatment of RAS. Such patients may benefit from serial imaging studies to monitor for disease progression or the development of complications [62].

Variant 4: Adult. Suspected renovascular hypertension. Known renal artery stenosis. Decreased renal function. eGFR less than 30 mL/min/1.73 m2. Follow-up imaging.
A. ACE inhibitor Renography

ACE inhibitor renography or renal scintigraphy was first used for evaluating renal function in the late 1950s. Initial attempts to use renography specifically for evaluating renovascular hypertension had a high rate of false-positive and false-negative results. ACE inhibitor, such as captopril, was later added to the examination to improve the accuracy of the test for diagnosing renovascular hypertension and predicting blood pressure reduction after surgery or angioplasty. Administration of an ACE inhibitor leads to a decrease in glomerular filtration pressure, prolonged transit time of tubular agents such as Tc-99m-MAG3, and decreased uptake of glomerular agents such as Tc-

99m-DTPA [5].

ACE inhibitor renal scintigraphy analysis is based on the characterization of renal function deterioration when compared with a baseline study, with decreased GFR reflected in time-activity curves. ACE inhibitor renography is, therefore, a functional assessment of renal perfusion and function rather than a method of directly visualizing the vasculature. The sensitivity and specificity of this examination are decreased in patients without clinical features of renovascular hypertension, in the setting of bilateral RAS, impaired renal function, or urinary obstruction [8]. The reported sensitivity of ACE inhibitor renal scintigraphy for renovascular hypertension ranges from 34% to 93%, with a meta-analysis of 14 studies between 1990 and 2000 by Vasbinder et al [9] showing a mean sensitivity of approximately 81%. There have also been inconsistent results regarding the predictive value of ACE inhibitor renal scintigraphy in identifying patients who will respond to revascularization. A high correlation between a positive result on ACE inhibitor renal scintigraphy and a reduction in blood pressure after intervention has been reported in some studies [10]. However, the predictive value has been dismissed in other studies, with documented PPVs as low as 51% [11-14]. As a functional evaluation of renal perfusion and function, ACE inhibitor scintigraphy can be useful to determine the physiological sequence of a known stenosis and to assess the relative function of each kidney [47,48].

Because of its low sensitivity and specificity in patients with impaired renal function, ACE inhibitor renal scintigraphy is not a reliable test in patients with known RAS and impaired renal function.

Variant 4: Adult. Suspected renovascular hypertension. Known renal artery stenosis. Decreased renal function. eGFR less than 30 mL/min/1.73 m2. Follow-up imaging.
B. Arteriography Kidney

IADSA can demonstrate RAS and is an integral part of angioplasty and stenting procedures. Angiography has a high spatial resolution for evaluating the main and branch renal arteries. There is a high interobserver agreement for the identification of severe stenoses by angiography [17], but there is reported substantial interobserver variability in visual estimation of moderate RAS. IADSA has a sensitivity and a specificity of 87%, but it is limited due to false-positives, which are caused by spatial resolution and artifacts [25]. IADSA allows for measuring pressure gradients across a stenosis and assessing its hemodynamic significance before intervention. A pressure gradient >20 mm Hg, or >10% of mean arterial pressure, indicates hemodynamic importance [18,19].

Smith et al [20] in a small study of 19 patients reported the sensitivity and specificity of IVDSA to be as high as 87%. However, false-positive rates ranged from 26% to 37%, which they attributed to limited spatial resolution, subtraction artifacts, and quantum noise. Other reported that limitations of this technique have included obscuration of renal artery stenoses by overlap with opacified mesenteric vessels and suboptimal evaluation of fibromuscular lesions [21-23]. Wilms et al [23] in a study of 45 patients found fewer false-positives, which they attributed to technical advances and software improvements. They also reported that IVDSA grading of stenosis was accurate in 94% of cases of atherosclerotic RAS but in only 56% of fibromuscular stenosis cases. Dunnick et al [24] in a prospective study of 94 patients reported 100% sensitivity and 93% specificity for RAS. However, the 100% sensitivity was achieved in part by including inadequate examinations as positive, and the authors acknowledged the limitations of IVDSA for evaluating vessels affected by fibromuscular dysplasia. Thus, compared with IADSA, IVDSA has lower resolution, is less sensitive for evaluating fibromuscular dysplasia and atherosclerotic stenosis of branch vessels, and requires a higher dose of contrast [20-23]. In addition, the contrast dose is often substantially higher than in arteriography and requires a central injection in the inferior vena cava or right atrium.

There is no specific literature on the role of renal arteriography for the follow-up of known RAS; however, both IADSA and IVDSA are invasive procedures and therefore are not optimal examinations for follow-up of patients with RAS. In addition, impaired renal function may limit the use of iodinated contrast material for angiography-based interventional procedures. Carbon dioxide, supplemented by gadolinium-based agents, may be used as alternatives to iodinated contrast in patients, although images obtained with these alternative contrast agents are less desirable when compared with those obtained with iodinated contrast material [64,65].

Therefore, arteriography of the kidney in patients for follow-up with suspected renovascular hypertension, decreased GFR, and a history of RAS is not usually appropriate.

Variant 4: Adult. Suspected renovascular hypertension. Known renal artery stenosis. Decreased renal function. eGFR less than 30 mL/min/1.73 m2. Follow-up imaging.
C. CTA Abdomen With IV Contrast

Contrast-enhanced CTA provides accurate anatomic images of the renal arteries with isotropic data sets that enable the reconstruction of high-resolution images in any plane. Two studies comparing CTA with digital renal arteriography [26,27] have reported the sensitivity of CTA for detecting >50% stenoses (>50% diameter) to be 88% to 96% and the specificity to be 77% to 98%, and in one study, the accuracy was 89%. In diagnosing the narrowing of only the main renal arteries, one study found the sensitivity and specificity to be 100% and 98%, respectively [26]. Negative results from CTA virtually rule out RAS. Maximum-intensity projection and volume-rendering techniques are helpful and complementary in CT evaluation of RAS [28]. Secondary signs of RAS seen on CTA include poststenotic dilatation, renal atrophy, and decreased cortical enhancement. A threshold of 800 mm2 for cortical area and 8 mm for mean cortical thickness seen on CT can be helpful morphologic markers of renal parenchymal atrophy [29]. Similar to MRA, CTA is more accurate in diagnosing proximal rather than distal lesions, although CTA generally provides better depiction of branch renal arteries than MRA [30].

However, contrast-enhanced CTA is generally not preferred in patients with advanced renal dysfunction because of potential nephrotoxicity of contrast material. The ACR Manual on Contrast Media notes that if a threshold for CIN risk is used, an eGFR of 30 mL/min/1.73 m2 has the greatest level of evidence [61]. Reduced iodine dose should be considered in patients with borderline renal function, but other parameters are similar to patients with normal renal function. Therefore, CTA abdomen with IV contrast in patients for follow-up with suspected renovascular hypertension, decreased GFR, and a history of RAS is not usually appropriate.

Variant 4: Adult. Suspected renovascular hypertension. Known renal artery stenosis. Decreased renal function. eGFR less than 30 mL/min/1.73 m2. Follow-up imaging.
D. MRA Abdomen Without and With IV Contrast

MRA is a useful modality for the evaluation of RAS. Several investigators report using angiography as the standard of reference, with the sensitivity of MRA ranging from 88% to 100% and the specificity ranging from 71% to 100% compared with angiography [31-33]. In a meta-analysis of 25 studies [34] the sensitivity and specificity of gadolinium-enhanced MRA were 97% and 93%, respectively. Solar et al [35] compared contrast-enhanced MRA with Doppler US using angiography as the reference and found contrast-enhanced MRA to be superior, with a sensitivity of 93% and a specificity of 93%, compared with US, with a sensitivity of 85% and a specificity of

84%. With the use of high-spatial-resolution, small-field-of-view contrast-enhanced MRA techniques, it is possible to evaluate not only the main renal arteries but also the accessory renal arteries and distal stenosis. Improved gradient hardware and parallel imaging techniques have reduced acquisition times and improved spatial resolution.

Another technique, the BOLD MRI, can assess renal oxygenation by measuring R2* values in the renal parenchyma. This may allow for functional assessment in patients with RAS [36-38]. However, more research is needed on BOLD MRI to establish its routine use in clinical practice.

The reliability of MRA is not affected by the presence of bilateral renovascular disease. ACR group II MRI contrast agents are associated with few, if any, unconfounded cases of nephrogenic systemic fibrosis [63]. Therefore, MRA is an excellent alternative to CTA abdomen with IV contrast with sensitivities and specificities ranging from 88% to 100% and 71% to 100%, respectively [31-33], and can generally be used to follow patients with suspected renovascular hypertension and known RAS in the setting of decreased renal function.

Variant 4: Adult. Suspected renovascular hypertension. Known renal artery stenosis. Decreased renal function. eGFR less than 30 mL/min/1.73 m2. Follow-up imaging.
E. MRA Abdomen Without IV Contrast

Although MRA abdomen without and with IV contrast can generally be performed safely in most patients with decreased renal function, MRA abdomen without IV contrast may also be used for evaluation of patients with suspected renovascular hypertension and known RAS in setting of decreased renal function. Noncontrast MRA has been shown to have high specificity and NPV with moderate to high sensitivity and PPV in the evaluation of RAS. The commonly used techniques are balanced SSFP and time-spatial labeling inversion pulse [41-43]. Another technique, the BOLD MRI, is able to assess renal oxygenation by measuring R2* values in the renal parenchyma. This may allow for functional assessment in patients with RAS [36-38]. However, more research is needed on BOLD MRI to establish its routine use in clinical practice. Noncontrast MRA has the advantage of not requiring contrast media. When stenosis is found on unenhanced MRA, it is generally recommended to use other modalities for better estimation [42]. Albert et al [43] in a report of a multicenter trial of 75 patients compared an unenhanced MRA technique that demonstrated a sensitivity less than contrast-enhanced CT of 74% and specificity of 93% for >50% stenosis.

Variant 4: Adult. Suspected renovascular hypertension. Known renal artery stenosis. Decreased renal function. eGFR less than 30 mL/min/1.73 m2. Follow-up imaging.
F. US Duplex Doppler Kidneys Retroperitoneal

Duplex Doppler US of the kidneys is commonly used as a noninvasive screening test for renovascular hypertension because it does not require IV contrast material and can be used in patients with any level of renal function. As with many noninvasive imaging examinations, numerous parameters and abnormal criteria indicate possible renovascular disease.

Two of the most frequently used parameters are PSV in the main renal artery and RAR, which depend on a direct evaluation of elevated velocity in a stenotic segment of the renal artery. PSV cutoff values ranging from 180 cm/s to 300 cm/s have been proposed in various studies. Hua et al [44] showed a PSV of 200 cm/s to have a sensitivity of 91% and a specificity of 75%. In contrast, Motew et al [45] reported a PSV of 200 cm/s with a sensitivity of 91% and a specificity of 96%. AbuRahma et al [46] stated a PSV of 200 cm/s has a sensitivity of 73% and a specificity of 82% for stenosis ≥60%. To improve specificity, some authors recommend a higher PSV threshold of 300 cm/s [4].

An elevated RAR value is also a valuable criterion for identifying stenosis because PSV may be elevated based on hypertension without underlying RAS. The suggested RAR cutoff value also varies between authors, although an RAR of 3.5 is a commonly reported threshold value [47]. It is noted that identification of elevated PSV and RAR depends on adequate visualization of a stenotic segment of the renal artery, patient body habitus type, and the presence of obscuring bowel gas, dense atherosclerotic plaques, or impeding accessory renal arteries. In these cases, distal criteria may be helpful as an indirect indicator of stenosis. A parvus-tardus intrarenal waveform with a small peak and a slow upstroke highly suggest more proximal stenosis [48]. This is reflected by an acceleration time of >70 ms and the early systolic peak loss. Although an elevated RI, defined as (PSV − end-diastolic velocity)/PSV, is not a specific indicator of RAS, an RI >0.80 has been reported to be a negative prognostic sign for response to revascularization [49,50]. However, other studies have not confirmed a significant difference in revascularization outcomes according to RI and have argued against using an elevated RI as a contraindication to revascularization [51,52].

In summary, Doppler US has been shown to be a helpful tool for follow-up of patients with suspected renovascular hypertension and known RAS on observation [62].

Variant 4: Adult. Suspected renovascular hypertension. Known renal artery stenosis. Decreased renal function. eGFR less than 30 mL/min/1.73 m2. Follow-up imaging.
G. Venography With Renal Vein Sampling

In patients with unilateral RAS, the ischemic kidney secretes increased renin, and there is relative suppression of renin release by the contralateral kidney. This results in asymmetry in renal vein renin levels. With bilateral RAS, there is also lateralization of renin secretion, with higher renal vein renin for the kidney with a greater degree of stenosis. This forms the basis for renal vein renin assays for evaluating renovascular hypertension. Various parameters have been described, including renal vein–to–inferior vena cava ratios and right renal vein–to–left renal vein ratios. Renal vein renin assays were initially considered the best means to predict response to revascularization in patients with suspected renovascular hypertension, with most studies before 1980 supporting the validity of this procedure. However, later studies have shown a high rate of false-negative and false-positive results. Sellars et al [53] reviewed 37 cases and found a false-positive rate of 39% and a false-negative rate of 71%. Luscher et al [54] in a study involving 95 patients reported a high sensitivity of 92% for a positive renal vein renin assay but a low specificity of 42% and a high number of false-positive and false-negative results. Roubidoux et al [55] measured captopril-stimulated renal vein renin ratios in 133 patients and found a sensitivity of 65%, a false-positive rate of 47.8%, a PPV of 18.6%, and an NPV of 89.3%. Postma et al [13] in a retrospective study of 25 patients with documented RAS found that a positive renal vein renin assay had a sensitivity of 72% and a specificity of only 29%. There is no relevant literature on the use of renal vein sampling to follow-up known RAS in the setting of impaired renal function. However, its high rates of false-negative and false-positive results, its invasive nature, and its requirement for iodinated contrast media limits its use in the follow-up of known RAS with impaired renal function [13]. Therefore, venography with renal vein sampling in patients with suspected renovascular hypertension, known RAS, and decreased renal function is usually not appropriate for follow-up.

Variant 5: Adult. Known renovascular hypertension. Posttreatment evaluation of renal artery stenosis.

In select patients, RAS may be managed by revascularization [66]. Percutaneous renal artery angioplasty and stenting are the preferred methods of revascularization in such patients. Complications of revascularization include atheroemboli, renal artery dissection, renal artery rupture, renal infarct, and renal failure, among others. Surgical revascularization is limited to cases of failed or complicated percutaneous revascularization. Follow-up imaging may be needed in such patients to monitor for recurrence of stenosis and to follow-up known procedure-related complications.

Variant 5: Adult. Known renovascular hypertension. Posttreatment evaluation of renal artery stenosis.
A. ACE inhibitor Renography

Renal scintigraphy was first used for evaluating renal function in the late 1950s. Initial attempts to use renography specifically for evaluating renovascular hypertension had a high rate of false-positive and false-negative results. ACE inhibitors, such as captopril, were later added to the examination to improve the accuracy of the test for diagnosing renovascular hypertension and predicting blood pressure reduction after surgery or angioplasty. Administration of an ACE inhibitor leads to a decrease in glomerular filtration pressure, prolonged transit time of tubular agents such as Tc-99m-MAG3, and decreased uptake of glomerular agents such as Tc-99m-DTPA [5].

ACE inhibitor renal scintigraphy analysis is based on the characterization of renal function deterioration when compared with a baseline study, with decreased GFR reflected in time-activity curves. ACE inhibitor renography is, therefore, a functional assessment of renal perfusion and function rather than a method of directly visualizing the vasculature. The sensitivity and specificity of this examination are decreased in patients without clinical features of renovascular hypertension and in the setting of bilateral RAS, impaired renal function, and urinary obstruction [8]. The reported sensitivity of ACE inhibitor renal scintigraphy for renovascular hypertension ranges from 34% to 93%, with a meta-analysis of 14 studies between 1990 and 2000 by Vasbinder et al [9] showing a mean sensitivity of approximately 81%. There have also been inconsistent results regarding the predictive value of ACE inhibitor renal scintigraphy in identifying patients who will respond to revascularization. A high correlation between a positive result on ACE inhibitor renal scintigraphy and a reduction in blood pressure after intervention has been reported in some studies [10]. However, the predictive value has been dismissed in other studies, with documented PPVs as low as 51% [11-14]. As a functional evaluation of renal perfusion and function, ACE inhibitor scintigraphy can be useful to determine the physiological sequence of a known stenosis and to assess the relative function of each kidney [47,48].

Currently, there is no relevant literature on the use of ACE inhibitor renal scintigraphy for follow-up of RAS after revascularization.[15,16]. Therefore, ACE inhibitor renal scintigraphy is usually not an appropriate imaging modality patients with known RAS for follow-up after revascularization.

Variant 5: Adult. Known renovascular hypertension. Posttreatment evaluation of renal artery stenosis.
B. Arteriography Kidney

IADSA can demonstrate RAS and is an integral part of angioplasty and stenting procedures. Angiography has a high spatial resolution for evaluating the main and branch renal arteries. There is a high interobserver agreement for the identification of severe stenoses by angiography [17], but there is reported substantial interobserver variability in visual estimation of moderate RAS. IADSA allows for measuring pressure gradients across a stenosis and assessing its hemodynamic significance before intervention. A pressure gradient >20 mm Hg, or >10% of mean arterial pressure, indicates hemodynamic importance [18,19].

Although there are no specific data in the posttreatment setting, in the setting of untreated RAS, Smith et al [20] in a small study of 19 patients reported the sensitivity and specificity of IVDSA to be as high as 87%. However, false-positive rates ranged from 26% to 37%, which they attributed to limited spatial resolution, subtraction artifacts, and quantum noise. Other reported that limitations of this technique have included obscuration of renal artery stenoses by overlap with opacified mesenteric vessels and suboptimal evaluation of fibromuscular lesions [21-23]. Wilms et al [23] in a study of 45 patients found fewer false-positives, which they attributed to technical advances and software improvements. They also reported that IVDSA grading of stenosis was accurate in 94% of cases of atherosclerotic RAS but in only 56% of fibromuscular stenosis cases. Dunnick et al [24] in a prospective study of 94 patients reported 100% sensitivity and 93% specificity for RAS. However, the 100% sensitivity was achieved in part by including inadequate examinations as positive, and the authors acknowledged the limitations of IVDSA for evaluating vessels affected by fibromuscular dysplasia. Thus, compared with IADSA, IVDSA has lower resolution, is less sensitive for evaluating fibromuscular dysplasia and atherosclerotic stenosis of branch vessels, and requires a higher dose of contrast [20-23].

Because of its invasive nature, arteriography is not the first-line of imaging to follow-up after RAS revascularization. Arteriography may be used if US and CTA are inconclusive and the patient has recurrent clinical symptoms [66].

Variant 5: Adult. Known renovascular hypertension. Posttreatment evaluation of renal artery stenosis.
C. CTA Abdomen With IV Contrast

Although there are no specific data in the posttreatment setting, in the case of untreated RAS, contrast-enhanced CTA provides accurate anatomic images of the renal arteries with isotropic data sets that enable the reconstruction of high-resolution images in any plane. Two studies comparing CTA with digital renal arteriography [26,27] have reported the sensitivity of CTA for detecting >50% stenoses (>50% diameter) to be 88% to 96% and the specificity to be 77% to 98%, and in one study, the accuracy was 89%. In diagnosing the narrowing of only the main renal arteries, one study found the sensitivity and specificity to be 100% and 98%, respectively [26]. Negative results from CTA virtually rule out RAS. Maximum-intensity projection and volume-rendering techniques are helpful and complementary in CT evaluation of RAS [28]. Secondary signs include poststenotic dilatation, renal atrophy, and decreased cortical enhancement. A threshold of 800 mm2 for cortical area and 8 mm for mean cortical thickness seen on CT can be helpful morphologic markers of renal parenchymal atrophy [29]. Similar to MRA, CTA is more accurate in diagnosing proximal rather than distal lesions, although CTA generally provides better depiction of branch renal arteries than MRA [30].

CTA is an excellent tool to assess the patency of renal stents [29,67,68]. CTA can be particularly helpful if duplex US is inconclusive [69]. Steinwender et al [69] described CTA evaluation of 95 renal artery stents, in which 98% of the stents were assessable on CTA, and there was 100% sensitivity and 99% specificity for detecting in-stent stenosis. CTA can also be useful to follow-up complications of revascularization. Depending on the degree of impaired renal function, contrast-enhanced CTA has been considered to be precluded because of potential nephrotoxicity of contrast material [61]. Reduced iodine dose should be considered in patients with borderline renal function.

Variant 5: Adult. Known renovascular hypertension. Posttreatment evaluation of renal artery stenosis.
D. MRA Abdomen Without and With IV Contrast

MRA is a useful modality for the evaluation of RAS. Several investigators report using angiography as the standard of reference for detection of RAS, the sensitivity of MRA ranging from 88% to 100% and the specificity ranging from 71% to 100% [31-33]. In a meta-analysis of 25 studies [34] the sensitivity and specificity of gadolinium-enhanced MRA were 97% and 93%, respectively. Solar et al [35] compared contrast-enhanced MRA with Doppler US using angiography as the reference and found contrast-enhanced MRA to be superior, with a sensitivity of 93% and a specificity of 93%, compared with US, with a sensitivity of 85% and a specificity of 84%. With the use of high-spatial-resolution, small-field-of-view contrast-enhanced MRA techniques, it is possible to evaluate not only the main renal arteries but also the accessory renal arteries and distal stenosis. Improved gradient hardware and parallel imaging techniques have reduced acquisition times and improved spatial resolution. Another technique, the BOLD MRI, is able to assess renal oxygenation by measuring R2* values in the renal parenchyma. This may allow for functional assessment in patients with RAS [36-38]. However, more research is needed on BOLD MRI to establish its routine use in clinical practice. The reliability of MRA is not affected by the presence of bilateral renovascular disease. ACR group II MRI contrast agents are associated with few, if any, unconfounded cases of nephrogenic systemic fibrosis [63]. Therefore, MRA can be a useful substitute for studies requiring the use of iodinated CT contrast agents. MRA may be used to evaluate in-stent stenosis and has been especially successful when nonferromagnetic stents such as platinum, nitinol, or cobalt-chromium are used, as compared with stainless steel stents [70-72].

Variant 5: Adult. Known renovascular hypertension. Posttreatment evaluation of renal artery stenosis.
E. MRA Abdomen Without IV Contrast

Noncontrast MRA has been shown to have high specificity and NPV with moderate to high sensitivity and PPV in the evaluation of RAS. The commonly used techniques are SSFP and time-spatial labeling inversion pulse [41-43]. Another technique, the BOLD MRI, is able to assess renal oxygenation by measuring R2* values in the renal parenchyma. This may allow for functional assessment in patients with RAS [36-38]. However, more research is needed on BOLD MRI to establish its routine use in clinical practice. Noncontrast MRA has the advantage of not requiring contrast media. When stenosis is found on unenhanced MRA, it is generally recommended to use other modalities for better estimation [42]. There is no specific literature on the use of noncontrast MRA for follow-up of RAS after revascularization. Similar to contrast-enhanced MRA, this technique may be less affected by artifacts in the presence of nonferromagnetic stents such as platinum, nitinol, or cobalt-chromium, as compared with stainless steel stents [70-72]. Furthermore, Albert et al [43] in a report of a multicenter trial of 75 patients compared an unenhanced MRA technique that demonstrated a sensitivity less than contrast-enhanced CT of 74% and specificity of 93% for >50% stenosis. Therefore, MRA abdomen without IV contrast is usually not appropriate for posttreatment evaluation of patients with RAS after revascularization.

Variant 5: Adult. Known renovascular hypertension. Posttreatment evaluation of renal artery stenosis.
F. US Duplex Doppler Kidneys Retroperitoneal

Duplex Doppler US is frequently used to follow-up patients after RAS revascularization [66].

Compared with native renal arteries, higher PSV and RAR thresholds indicate stenosis in stented arteries. A PSV threshold of 395 cm/s has been shown to yield a sensitivity of 83%, a specificity of 88%, and an overall accuracy of 87% to predict ≥70% in-stent restenosis. RAR threshold of 5.1 yielded the highest accuracy rate (88%), with a sensitivity of 94% and a specificity of 86% in detecting ≥70% in-stent restenosis [73]. Similarly, Del Conde et al [74] in a study of 132 stented renal arteries reported a mean PSV of 382 cm/s and RAR of 5.3 in arteries with >60% stenosis.

Variant 5: Adult. Known renovascular hypertension. Posttreatment evaluation of renal artery stenosis.

G. Venography With Renal Vein Sampling

In patients with unilateral RAS, the ischemic kidney secretes increased renin, and there is relative suppression of renin release by the contralateral kidney. This results in asymmetry in renal vein renin levels. With bilateral RAS, there is also lateralization of renin secretion, with higher renal vein renin for the kidney with a greater degree of stenosis. This forms the basis for renal vein renin assays for evaluating renovascular hypertension. Various parameters have been described, including renal vein–to–inferior vena cava ratios and right renal vein–to–left renal vein ratios. Renal vein renin assays were initially considered the best means to predict response to revascularization in patients with suspected renovascular hypertension, with most studies before 1980 supporting the validity of this procedure. However, later studies have shown a high rate of false-negative and false-positive results. Sellars et al [53] reviewed 37 cases and found a false-positive rate of 39% and a false-negative rate of 71%. Luscher et al [54] in a study involving 95 patients reported a high sensitivity of 92% for a positive renal vein renin assay but a low specificity of 42% and a high number of false-positive and false-negative results. Roubidoux et al [55] measured captopril-stimulated renal vein renin ratios in 133 patients and found a sensitivity of 65%, a false-positive rate of 47.8%, a PPV of 18.6%, and an NPV of 89.3%. Postma et al [13] in a retrospective study of 25 patients with documented RAS found that a positive renal vein renin assay had a sensitivity of 72% and a specificity of only 29%. There is no relevant literature on the use of renal vein sampling to follow-up after RAS revascularization. However, its high rates of false-negative and false-positive results and its invasive nature limits its use in follow up after RAS revascularization [13].

Summary of Highlights

This is a summary of the key recommendations from the variant tables. Refer to the complete narrative document for more information.

- **Variant 1**: For the evaluation of renovascular hypertension in patients with normal renal function, US duplex Doppler of the kidneys, CTA abdomen with IV contrast, and MRA abdomen without and with IV contrast are usually considered appropriate. MRA abdomen without IV contrast is considered may be appropriate.

- **Variant 2**: For the evaluation of renovascular hypertension in patients with suspected RAS, but decrease renal function, US duplex Doppler of the kidneys and MRA abdomen without and with IV contrast are usually considered appropriate. MRA abdomen without IV contrast is considered may be appropriate.

- **Variant 3**: For the evaluation of renovascular hypertension in patients with known RAS, but normal renal function, US duplex Doppler of the kidneys, CTA abdomen with IV contrast, and MRA abdomen without and with IV contrast are usually considered appropriate.

- **Variant 4**: For the evaluation of renovascular hypertension in patients with known RAS and decreased renal function, US duplex Doppler of the kidneys and MRA abdomen without and with IV contrast are usually considered appropriate. MRA abdomen without contrast is considered may be appropriate.

- **Variant 5**: For the evaluation of renovascular hypertension in patients following posttreatment of RAS, US duplex Doppler of the kidneys, CTA abdomen with IV contrast, and MRA abdomen without and with IV contrast are usually considered appropriate.

Supporting Documents

The evidence table, literature search, and appendix for this topic are available at https://acsearch.acr.org/list. The appendix includes the strength of evidence assessment and the final rating round tabulations for each recommendation.

For additional information on the Appropriateness Criteria methodology and other supporting documents, please go to the ACR website at https://www.acr.org/Clinical-Resources/Clinical-Tools-and-Reference/Appropriateness-Criteria.

Gender Equality and Inclusivity Clause

The ACR acknowledges the limitations in applying inclusive language when citing research studies that predates the use of the current understanding of language inclusive of diversity in sex, intersex, gender, and gender-diverse people. The data variables regarding sex and gender used in the cited literature will not be changed. However, this guideline will use the terminology and definitions as proposed by the National Institutes of Health.

Appropriateness Category Names and Definitions

Appropriateness Category Name	Appropriateness Rating	Appropriateness Category Definition
Usually Appropriate	7, 8, or 9	The imaging procedure or treatment is indicated in the specified clinical scenarios at a favorable risk-benefit ratio for patients.
May Be Appropriate	4, 5, or 6	The imaging procedure or treatment may be indicated in the specified clinical scenarios as an alternative to imaging procedures or treatments with a more favorable risk-benefit ratio, or the risk-benefit ratio for patients is equivocal.
May Be Appropriate (Disagreement)	5	The individual ratings are too dispersed from the panel median. The different label provides transparency regarding the panel's recommendation. "May be appropriate" is the rating category and a rating of 5 is assigned.
Usually Not Appropriate	1, 2, or 3	The imaging procedure or treatment is unlikely to be indicated in the specified clinical scenarios, or the risk-benefit ratio for patients is likely to be unfavorable.

Relative Radiation Level Information

Potential adverse health effects associated with radiation exposure are an important factor to consider when selecting the appropriate imaging procedure. Because there is a wide range of radiation exposures associated with different diagnostic procedures, a relative radiation level (RRL) indication has been included for each imaging examination. The RRLs are based on effective dose, which is a radiation dose quantity that is used to estimate population total radiation risk associated with an imaging procedure. Patients in the pediatric age group are at inherently higher risk from exposure, because of both organ sensitivity and longer life expectancy (relevant to the long latency that appears to accompany radiation exposure). For these reasons, the RRL dose estimate ranges for pediatric examinations are lower as compared with those specified for adults (see Table below). Additional information regarding radiation dose assessment for imaging examinations can be found in the ACR Appropriateness Criteria® Radiation Dose Assessment Introduction document.

Relative Radiation Level Designations

Relative Radiation Level*	Adult Effective Dose Estimate Range	Pediatric Effective Dose Estimate Range
O	0 mSv	0 mSv
☢	<0.1 mSv	<0.03 mSv
☢☢	0.1-1 mSv	0.03-0.3 mSv
☢☢☢	1-10 mSv	0.3-3 mSv
☢☢☢☢	10-30 mSv	3-10 mSv
☢☢☢☢☢	30-100 mSv	10-30 mSv

*RRL assignments for some of the examinations cannot be made, because the actual patient doses in these procedures vary as a function of a number of factors (e.g., region of the body exposed to ionizing radiation, the imaging guidance that is used). The RRLs for these examinations are designated as “Varies.”

References

1. Centers for Disease Control and Prevention. Million Hearts. Estimated Hypertension Prevalence, Treatment, and Control Among U.S. Adults. Available at: https://millionhearts.hhs.gov/data-reports/hypertension-prevalence.html.
2. O'Neill WC, Bardelli M, Yevzlin AS. Imaging for renovascular disease. Semin Nephrol. 2011;31(3):272-282.
3. Baumgartner I, Lerman LO. Renovascular hypertension: screening and modern management. Eur Heart J 2011;32:1590-8.
4. Textor SC, Lerman L. Renovascular hypertension and ischemic nephropathy. Am J Hypertens. 2010; 23(11):1159-1169.
5. Hartman RP, Kawashima A. Radiologic evaluation of suspected renovascular hypertension. Am Fam Physician 2009;80:273-9.
6. Cooper CJ, Murphy TP, Cutlip DE, et al. Stenting and medical therapy for atherosclerotic renal-artery stenosis. N Engl J Med. 2014;370(1):13-22.
7. Herrmann SM, Saad A, Textor SC. Management of atherosclerotic renovascular disease after Cardiovascular Outcomes in Renal Atherosclerotic Lesions (CORAL). Nephrol Dial Transplant. 2015;30(3):366-375.

8. Soulez G, Oliva VL, Turpin S, Lambert R, Nicolet V, Therasse E. Imaging of renovascular hypertension: respective values of renal scintigraphy, renal Doppler US, and MR angiography. Radiographics. 2000; 20(5):1355-1368; discussion 1368-1372.

9. Vasbinder GB, Nelemans PJ, Kessels AG, Kroon AA, de Leeuw PW, van Engelshoven JM. Diagnostic tests for renal artery stenosis in patients suspected of having renovascular hypertension: a meta-analysis. Ann Intern Med. 2001; 135(6):401-411.

10. Geyskes GG, de Bruyn AJ. Captopril renography and the effect of percutaneous transluminal angioplasty on blood pressure in 94 patients with renal artery stenosis. Am J Hypertens. 1991; 4(12 Pt 2):685S-689S.

11. Bolduc JP, Oliva VL, Therasse E, et al. Diagnosis and treatment of renovascular hypertension: a cost-benefit analysis. AJR. 2005; 184(3):931-937.

12. Huot SJ, Hansson JH, Dey H, Concato J. Utility of captopril renal scans for detecting renal artery stenosis. Arch Intern Med. 2002; 162(17):1981-1984.

13. Postma CT, van Oijen AH, Barentsz JO, et al. The value of tests predicting renovascular hypertension in patients with renal artery stenosis treated by angioplasty. Arch Intern Med.1991; 151(8):1531-1535.

14. Soulez G, Therasse E, Qanadli SD, et al. Prediction of clinical response after renal angioplasty: respective value of renal Doppler sonography and scintigraphy. AJR 2003; 181(4):1029-1035.

15. Bongers V, Bakker J, Beutler JJ, Beek FJ, De Klerk JM. Assessment of renal artery stenosis: comparison of captopril renography and gadolinium-enhanced breath-hold MR angiography. Clin Radiol. 2000; 55(5):346-353.

16. Taylor A. Renovascular hypertension: nuclear medicine techniques. Q J Nucl Med. 2002; 46(4):268-282.

17. van Jaarsveld BC, Pieterman H, van Dijk LC, et al. Inter-observer variability in the angiographic assessment of renal artery stenosis. DRASTIC study group. Dutch Renal Artery Stenosis Intervention Cooperative. J Hypertens. 1999; 17(12 Pt 1):1731-1736.

18. De Bruyne B, Manoharan G, Pijls NH, et al. Assessment of renal artery stenosis severity by pressure gradient measurements. J Am Coll Cardiol. 2006; 48(9):1851-1855.

19. Mangiacapra F, Trana C, Sarno G, et al. Translesional pressure gradients to predict blood pressure response after renal artery stenting in patients with renovascular hypertension. Circ Cardiovasc Interv. 2010; 3(6):537-542.

20. Smith CW, Winfield AC, Price RR, et al. Evaluation of digital venous angiography for the diagnosis of renovascular hypertension. Radiology. 1982; 144(1):51-54.

21. Illescas FF, Ford K, Braun SD, Dunnick NR. Intraarterial digital subtraction angiography in hypertensive azotemic patients. AJR. 1984; 143(5):1065-1067.

22. Norman D, Ulloa N, Brant-Zawadzki M, Gould RG. Intraarterial digital subtraction imaging cost considerations. Radiology. 1985; 156(1):33-35.

23. Wilms GE, Baert AL, Staessen JA, Amery AK. Renal artery stenosis: evaluation with intravenous digital subtraction angiography. Radiology. 1986; 160(3):713-715.

24. Dunnick NR, Svetkey LP, Cohan RH, et al. Intravenous digital subtraction renal angiography:

use in screening for renovascular hypertension. Radiology. 1989; 171(1):219-222.

25. King BF, Jr. Diagnostic imaging evaluation of renovascular hypertension. Abdom Imaging 1995;20:395-405.

26. Beregi JP, Elkohen M, Deklunder G, Artaud D, Coullet JM, Wattinne L. Helical CT angiography compared with arteriography in the detection of renal artery stenosis. AJR. 1996; 167(2):495-501.

27. Farres MT, Lammer J, Schima W, et al. Spiral computed tomographic angiography of the renal arteries: a prospective comparison with intravenous and intraarterial digital subtraction angiography. Cardiovasc Intervent Radiol. 1996; 19(2):101-106.

28. Berg MH, Manninen HI, Vanninen RL, Vainio PA, Soimakallio S. Assessment of renal artery stenosis with CT angiography: usefulness of multiplanar reformation, quantitative stenosis measurements, and densitometric analysis of renal parenchymal enhancement as adjuncts to MIP film reading. J Comput Assist Tomogr. 1998; 22(4):533-540.

29. Mounier-Vehier C, Lions C, Devos P, et al. Cortical thickness: an early morphological marker of atherosclerotic renal disease. Kidney Int. 2002; 61(2):591-598.

30. Francois CJ. Noninvasive imaging workup of patients with vascular disease. Surg Clin North Am. 2013;93(4):741-760, vii.

31. Kramer U, Wiskirchen J, Fenchel MC, et al. Isotropic high-spatial-resolution contrast-enhanced 3.0-T MR angiography in patients suspected of having renal artery stenosis. Radiology. 2008; 247(1):228-240.

32. McGregor R, Vymazal J, Martinez-Lopez M, et al. A multi-center, comparative, phase 3 study to determine the efficacy of gadofosveset-enhanced magnetic resonance angiography for evaluation of renal artery disease. Eur J Radiol. 2008; 65(2):316-325.

33. Soulez G, Pasowicz M, Benea G, et al. Renal artery stenosis evaluation: diagnostic performance of gadobenate dimeglumine-enhanced MR angiography--comparison with DSA. Radiology. 2008; 247(1):273-285.

34. Tan KT, van Beek EJ, Brown PW, van Delden OM, Tijssen J, Ramsay LE. Magnetic resonance angiography for the diagnosis of renal artery stenosis: a meta-analysis. Clin Radiol. 2002; 57(7):617-624.

35. Solar M, Zizka J, Krajina A, et al. Comparison of duplex ultrasonography and magnetic resonance imaging in the detection of significant renal artery stenosis. Acta Medica (Hradec Kralove). 2011;54(1):9-12.

36. Gloviczki ML, Lerman LO, Textor SC. Blood oxygen level-dependent (BOLD) MRI in renovascular hypertension. Curr Hypertens Rep. 2011;13(5):370-377.

37. Gloviczki ML, Saad A, Textor SC. Blood oxygen level-dependent (BOLD) MRI analysis in atherosclerotic renal artery stenosis. Curr Opin Nephrol Hypertens. 2013;22(5):519-524.

38. Niendorf T, Pohlmann A, Arakelyan K, et al. How bold is blood oxygenation level-dependent (BOLD) magnetic resonance imaging of the kidney? Opportunities, challenges and future directions. Acta Physiol (Oxf). 2015;213(1):19-38.

39. Lal H, Singh RKR, Yadav P, Yadav A, Bhadauria D, Singh A. Non-contrast MR angiography versus contrast enhanced MR angiography for detection of renal artery stenosis: a comparative analysis in 400 renal arteries. Abdom Radiol. 46(5):2064-2071, 2021 05.

40. Utsunomiya D, Miyazaki M, Nomitsu Y, et al. Clinical role of non-contrast magnetic resonance angiography for evaluation of renal artery stenosis. Circ J. 2008; 72(10):1627-1630.

41. Mohrs OK, Petersen SE, Schulze T, et al. High-resolution 3D unenhanced ECG-gated respiratory-navigated MR angiography of the renal arteries: comparison with contrast-enhanced MR angiography. AJR. 2010; 195(6):1423-1428.

42. Braidy C, Daou I, Diop AD, et al. Unenhanced MR angiography of renal arteries: 51 patients. AJR 2012;199:W629-37.

43. Albert TS, Akahane M, Parienty I, et al. An international multicenter comparison of time-SLIP unenhanced MR angiography and contrast-enhanced CT angiography for assessing renal artery stenosis: the renal artery contrast-free trial. AJR Am J Roentgenol. 2015;204(1):182-188.

44. Hua HT, Hood DB, Jensen CC, Hanks SE, Weaver FA. The use of colorflow duplex scanning to detect significant renal artery stenosis. Ann Vasc Surg. 2000;14(2):118-124.

45. Motew SJ, Cherr GS, Craven TE, et al. Renal duplex sonography: main renal artery versus hilar analysis. J Vasc Surg. 2000;32(3):462-469; 469-471.

46. AbuRahma AF, Srivastava M, Mousa AY, et al. Critical analysis of renal duplex ultrasound parameters in detecting significant renal artery stenosis. J Vasc Surg. 2012; 56(4):1052-1059, 1060 e1051; discussion 1059-1060.

47. Labropoulos N, Ayuste B, Leon LR, Jr. Renovascular disease among patients referred for renal duplex ultrasonography. J Vasc Surg. 2007;46(4):731-737.

48. Li JC, Yuan Y, Qin W, et al. Evaluation of the tardus-parvus pattern in patients with atherosclerotic and nonatherosclerotic renal artery stenosis. J Ultrasound Med. 2007;26(4):419-426.

49. Radermacher J. Echo-doppler to predict the outcome for renal artery stenosis. J Nephrol. 2002;15 Suppl 6:S69-76.

50. Viazzi F, Leoncini G, Derchi LE, Pontremoli R. Ultrasound Doppler renal resistive index: a useful tool for the management of the hypertensive patient. [Review]. J Hypertens. 32(1):149-53, 2014 Jan.

51. Garcia-Criado A, Gilabert R, Nicolau C, et al. Value of Doppler sonography for predicting clinical outcome after renal artery revascularization in atherosclerotic renal artery stenosis. J Ultrasound Med. 2005;24(12):1641-1647.

52. Krumme B, Hollenbeck M. Doppler sonography in renal artery stenosis--does the Resistive Index predict the success of intervention? Nephrol Dial Transplant. 2007;22(3):692-696.

53. Sellars L, Shore AC, Wilkinson R. Renal vein renin studies in renovascular hypertension--do they really help? J Hypertens. 1985; 3(2):177-181.

54. Luscher TF, Greminger P, Kuhlmann U, Siegenthaler W, Largiader F, Vetter W. Renal venous renin determinations in renovascular hypertension. Diagnostic and prognostic value in unilateral renal artery stenosis treated by surgery or percutaneous transluminal angioplasty. Nephron. 1986; 44 Suppl 1:17-24.

55. Roubidoux MA, Dunnick NR, Klotman PE, et al. Renal vein renins: inability to predict response to revascularization in patients with hypertension. Radiology. 1991; 178(3):819-

822.

56. Davenport MS, Khalatbari S, Cohan RH, Dillman JR, Myles JD, Ellis JH. Contrast material-induced nephrotoxicity and intravenous low-osmolality iodinated contrast material: risk stratification by using estimated glomerular filtration rate. Radiology. 268(3):719-28, 2013 Sep.

57. Davenport MS, Khalatbari S, Dillman JR, Cohan RH, Caoili EM, Ellis JH. Contrast material-induced nephrotoxicity and intravenous low-osmolality iodinated contrast material. Radiology. 267(1):94-105, 2013 Apr.

58. McDonald JS, McDonald RJ, Carter RE, Katzberg RW, Kallmes DF, Williamson EE. Risk of intravenous contrast material-mediated acute kidney injury: a propensity score-matched study stratified by baseline-estimated glomerular filtration rate. Radiology. 271(1):65-73, 2014 Apr.

59. McDonald RJ, McDonald JS, Bida JP, et al. Intravenous contrast material-induced nephropathy: causal or coincident phenomenon?. Radiology. 267(1):106-18, 2013 Apr.

60. McDonald RJ, McDonald JS, Newhouse JH, Davenport MS. Controversies in Contrast Material-induced Acute Kidney Injury: Closing in on the Truth? Radiology 2015;277:627-32.

61. American College of Radiology. ACR Committee on Drugs and Contrast Media. Manual on Contrast Media. Available at: https://www.acr.org/Clinical-Resources/Clinical-Tools-and-Reference/Contrast-Manual.

62. Taylor DC, Moneta GL, Strandness DE, Jr. Follow-up of renal artery stenosis by duplex ultrasound. J Vasc Surg 1989;9:410-5.

63. Weinreb JC, Rodby RA, Yee J, et al. Use of Intravenous Gadolinium-based Contrast Media in Patients with Kidney Disease: Consensus Statements from the American College of Radiology and the National Kidney Foundation. Radiology. 298(1):28-35, 2021 01.

64. Caridi JG, Stavropoulos SW, Hawkins IF, Jr. CO2 digital subtraction angiography for renal artery angioplasty in high-risk patients. AJR. 1999; 173(6):1551-1556.

65. Spinosa DJ, Matsumoto AH, Angle JF, Hagspiel KD, McGraw JK, Ayers C. Renal insufficiency: usefulness of gadodiamide-enhanced renal angiography to supplement CO2-enhanced renal angiography for diagnosis and percutaneous treatment. Radiology. 1999; 210(3):663-672.

66. Prince M, Tafur JD, White CJ. When and How Should We Revascularize Patients With Atherosclerotic Renal Artery Stenosis? JACC Cardiovasc Interv 2019;12:505-17.

67. Lufft V, Hoogestraat-Lufft L, Fels LM, et al. Contrast media nephropathy: intravenous CT angiography versus intraarterial digital subtraction angiography in renal artery stenosis: a prospective randomized trial. Am J Kidney Dis. 2002; 40(2):236-242.

68. Mallouhi A, Rieger M, Czermak B, Freund MC, Waldenberger P, Jaschke WR. Volume-rendered multidetector CT angiography: noninvasive follow-up of patients treated with renal artery stents. AJR. 2003; 180(1):233-239.

69. Steinwender C, Schutzenberger W, Fellner F, et al. 64-Detector CT angiography in renal artery stent evaluation: prospective comparison with selective catheter angiography. Radiology. 2009; 252(1):299-305.

70. Buecker A, Spuentrup E, Ruebben A, Gunther RW. Artifact-free in-stent lumen visualization by standard magnetic resonance angiography using a new metallic magnetic resonance imaging stent. Circulation. 2002;105(15):1772-1775.

71. Spuentrup E, Ruebben A, Stuber M, Gunther RW, Buecker A. Metallic renal artery MR imaging stent: artifact-free lumen visualization with projection and standard renal MR angiography. Radiology. 2003;227(3):897-902.

72. Wang Y, Truong TN, Yen C, et al. Quantitative evaluation of susceptibility and shielding effects of nitinol, platinum, cobalt-alloy, and stainless steel stents. Magn Reson Med. 2003;49(5):972-976.

73. Chi YW, White CJ, Thornton S, Milani RV. Ultrasound velocity criteria for renal in-stent restenosis. J Vasc Surg. 2009;50(1):119-123.

74. Del Conde I, Galin ID, Trost B, et al. Renal artery duplex ultrasound criteria for the detection of significant in-stent restenosis. Catheterization & Cardiovascular Interventions. 83(4):612-8, 2014 Mar 01.

75. Measuring Sex, Gender Identity, and Sexual Orientation.

76. American College of Radiology. ACR Appropriateness Criteria® Radiation Dose Assessment Introduction. Available at: https://edge.sitecorecloud.io/americancoldf5f-acrorgf92a-productioncb02-3650/media/ACR/Files/Clinical/Appropriateness-Criteria/ACR-Appropriateness-Criteria-Radiation-Dose-Assessment-Introduction.pdf.

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[a]SUNY Upstate Medical University, Syracuse, New York. [b]Lahey Hospital and Medical Center, Burlington, Massachusetts. [c]Panel Chair, Cleveland Clinic, Cleveland, Ohio. [d]Secondary Panel Chair, Brigham & Women's Hospital and Harvard Medical School, Boston, Massachusetts. [e]Panel Vice-Chair, Massachusetts General Hospital and Harvard Medical School, Boston, Massachusetts. [f]University of Florida College of Medicine, Gainesville, Florida; Society of General Internal Medicine. [g]The George Washington University School of Medicine and Health Sciences, Washington, District of Columbia; American Society of Nephrology. [h]Weill Cornell Medicine, New York, New York; American Urological Association. [i]Cleveland Clinic, Cleveland, Ohio. [j]South Texas Radiology Group, P.A., San Antonio, Texas. [k]Mayo Clinic, Jacksonville, Florida; Commission on Nuclear Medicine and

Molecular Imaging. [l]The University of Texas MD Anderson Cancer Center, Houston, Texas. [m]New York University Langone Medical Center, New York, New York. [n]Secondary Specialty Chair, The University of Vermont Medical Center, Burlington, Vermont. [o]Specialty Chair, UT Southwestern Medical Center, Dallas, Texas.