

ACR Appropriateness Criteria® Renal Failure

Expert Panel on Urologic Imaging: *Jade J. Wong-You-Cheong, MD^a, Paul Nikolaidis, MD^b, Gaurav Khatri, MD^c, Vikram S. Dogra, MD^d, Dhakshinamoorthy Ganeshan, MBBS^e, Stanley Goldfarb, MD^f, John L. Gore, MD, MS^g, Rajan T. Gupta, MD^h, Marta E. Heilbrun, MD, MSⁱ, Andrej Lyshchik, MD, PhD^j, Darlene F. Metter, MD^k, Andrei S. Purysko, MD^l, Stephen J. Savage, MD^m, Andrew D. Smith, MD, PhDⁿ, Zhen J. Wang, MD^o, Darcy J. Wolfman, MD^p, Mark E. Lockhart, MD, MPH^q*

Abstract

Renal failure can be divided into acute kidney injury and chronic kidney disease. Both are common and result in increased patient morbidity and mortality. The etiology is multifactorial and differentiation of acute kidney injury from chronic kidney disease includes clinical evaluation, laboratory tests, and imaging. The main role of imaging is to detect treatable causes of renal failure such as ureteral

^aUniversity of Maryland School of Medicine, Baltimore, Maryland, Vice Chair, Quality and Safety, Diagnostic Radiology, University of Maryland Medical Center.

^bPanel Chair, Northwestern University, Chicago, Illinois.

^cPanel Vice-Chair, UT Southwestern Medical Center, Dallas, Texas.

^dUniversity of Rochester Medical Center, Rochester, New York.

^eThe University of Texas MD Anderson Cancer Center, Houston, Texas.

^fUniversity of Pennsylvania School of Medicine, Philadelphia, Pennsylvania, American Society of Nephrology.

^gUniversity of Washington, Seattle, Washington, American Urological Association.

^hDuke University Medical Center, Durham, North Carolina, Chair, Meetings Sub-Committee, ACR, Member, Commission on Publications and Lifelong Learning.

ⁱEmory University School of Medicine, Atlanta, Georgia.

^jThomas Jefferson University Hospital, Philadelphia, Pennsylvania, Deputy Editor, Journal of Ultrasound in Medicine.

^kUT Health San Antonio, San Antonio, Texas, Past-President and Alternate Councilor, Texas Radiological Society, Chair, IT Health San Antonio Radioactive Drug and Research Committee, Chair, Nuclear Regulatory Commission Advisory Committee on the Medical Uses of Isotopes, Vice-Speaker, Society of Nuclear Medicine and Molecular Imaging House of Delegates, Member, Texas Department of State Health Services Texas Radiation Advisory Board.

^lCleveland Clinic, Cleveland, Ohio.

^mMedical University of South Carolina, Charleston, South Carolina, American Urological Association.

ⁿUniversity of Alabama at Birmingham, Birmingham, Alabama.

^oUniversity of California San Francisco School of Medicine, San Francisco, California.

^pJohns Hopkins University School of Medicine, Washington, District of Columbia.

^qSpecialty Chair, University of Alabama at Birmingham, Birmingham, Alabama, Chair, ACR Appropriateness Committee.

Corresponding author: Jade J. Wong-You-Cheong, MD, Department of Diagnostic Radiology, University of Maryland Medical Center, 22 S. Greene Street, Baltimore, MD 21201-1595; e-mail: jwong@som.umaryland.edu.

The American College of Radiology seeks and encourages collaboration with other organizations on the development of the ACR Appropriateness Criteria through society representation on expert panels. Participation by representatives from collaborating societies on the expert panel does not necessarily imply individual or society endorsement of the final document. Reprint requests to: publications@acr.org.

Dr Lockhart reports Deputy Editor salary from Journal of Ultrasound in Medicine, other support from Elsevier, Oxford Publishers, Jaypee Brothers Medical Publishers, outside the submitted work. Dr Lyshchik reports research support: GE Healthcare, Bracco Diagnostics, Siemens Healthineers, Canon Medical Systems; Advisory Board: Bracco Diagnostics; Consulting: GE Healthcare, Bioclinica, World Care Clinical; Speaker Panel: GE Healthcare; Book Royalties: Elsevier. Dr Smith reports personal fees from GE, Canon Medical, Algomedica, grants from GE, outside the submitted work; In addition, Dr. Smith has a patent issued to AI Metrics LLC. Dr Wong-You-Cheong reports personal fees from Elsevier outside the submitted work. The other authors state that they have no conflict of interest related to the material discussed in this article. All the authors are non-partner/non-partnership track employees.

The ACR Appropriateness Criteria documents are updated regularly. Please go to the ACR website at www.acr.org/ac to confirm that you are accessing the most current content.

Disclaimer: The ACR Committee on Appropriateness Criteria and its expert panels have developed criteria for determining appropriate imaging examinations for diagnosis and treatment of specified medical condition(s). These criteria are intended to guide radiologists, radiation oncologists and referring physicians in making decisions regarding radiologic imaging and treatment. Generally, the complexity and severity of a patient's clinical condition should dictate the selection of appropriate imaging procedures or treatments. Only those examinations generally used for evaluation of the patient's condition are ranked. Other imaging studies necessary to evaluate other co-existent diseases or other medical consequences of this condition are not considered in this document. The availability of equipment or personnel may influence the selection of appropriate imaging procedures or treatments. Imaging techniques classified as investigational by the FDA have not been considered in developing these criteria; however, study of new equipment and applications should be encouraged. The ultimate decision regarding the appropriateness of any specific radiologic examination or treatment must be made by the referring physician and radiologist in light of all the circumstances presented in an individual examination.

obstruction or renovascular disease and to evaluate renal size and morphology. Ultrasound is the modality of choice for initial imaging, with duplex Doppler reserved for suspected renal artery stenosis or thrombosis. CT and MRI may be appropriate, particularly for urinary tract obstruction. However, the use of iodinated and gadolinium-based contrast should be evaluated critically depending on specific patient factors and cost-benefit ratio.

The American College of Radiology Appropriateness Criteria are evidence-based guidelines for specific clinical conditions that are reviewed annually by a multidisciplinary expert panel. The guideline development and revision include an extensive analysis of current medical literature from peer reviewed journals and the application of well-established methodologies (RAND/UCLA Appropriateness Method and Grading of Recommendations Assessment, Development, and Evaluation or GRADE) to rate the appropriateness of imaging and treatment procedures for specific clinical scenarios. In those instances where evidence is lacking or equivocal, expert opinion may supplement the available evidence to recommend imaging or treatment.

Key Words: Acute kidney injury, Appropriateness Criteria, Appropriate Use Criteria, AUC, Chronic kidney disease, Neurogenic bladder, Renal failure

J Am Coll Radiol 2021;18:S174-S188. Copyright © 2021 American College of Radiology

ACR Appropriateness Criteria® Renal Failure. Variants 1 to 4 and Tables 1 and 2.

Variant 1. Renal failure. Acute kidney injury (AKI), unspecified. Initial imaging.

Procedure	Appropriateness Category	Relative Radiation Level
US kidneys retroperitoneal	Usually Appropriate	○
US duplex Doppler kidneys retroperitoneal	May Be Appropriate	○
CT abdomen and pelvis without IV contrast	May Be Appropriate	⦿⦿⦿⦿
MAG3 renal scan	May Be Appropriate	⦿⦿⦿
MRA abdomen without IV contrast	May Be Appropriate	○
MRI abdomen and pelvis without IV contrast	May Be Appropriate	○
MRI abdomen without IV contrast	May Be Appropriate	○
CT abdomen without IV contrast	Usually Not Appropriate	⦿⦿⦿
MRU without contrast	Usually Not Appropriate	○
CTA abdomen and pelvis with IV contrast	Usually Not Appropriate	⦿⦿⦿
DMSA renal scan	Usually Not Appropriate	⦿⦿⦿
MRA abdomen without and with IV contrast	Usually Not Appropriate	○
MRI abdomen and pelvis without and with IV contrast	Usually Not Appropriate	○
MRI abdomen without and with IV contrast	Usually Not Appropriate	○
MRU without and with IV contrast	Usually Not Appropriate	○
Radiography abdomen and pelvis (KUB)	Usually Not Appropriate	⦿⦿
Arteriography kidney	Usually Not Appropriate	⦿⦿⦿
CT abdomen and pelvis with IV contrast	Usually Not Appropriate	⦿⦿⦿⦿
CT abdomen and pelvis without and with IV contrast	Usually Not Appropriate	⦿⦿⦿⦿
CT abdomen with IV contrast	Usually Not Appropriate	⦿⦿⦿
CT abdomen without and with IV contrast	Usually Not Appropriate	⦿⦿⦿⦿
CTU without and with IV contrast	Usually Not Appropriate	⦿⦿⦿⦿

Variant 2. Renal failure. Chronic kidney disease (CKD). Initial imaging.

Procedure	Appropriateness Category	Relative Radiation Level
US kidneys retroperitoneal	Usually Appropriate	0
CT abdomen and pelvis without IV contrast	May Be Appropriate	⚠⚠⚠⚠
MRA abdomen without IV contrast	May Be Appropriate	0
MRI abdomen without IV contrast	May Be Appropriate	0
US duplex Doppler kidneys retroperitoneal	May Be Appropriate	0
CT abdomen without IV contrast	Usually Not Appropriate	⚠⚠⚠
MRA abdomen without and with IV contrast	Usually Not Appropriate	0
MRI abdomen and pelvis without IV contrast	Usually Not Appropriate	0
CTA abdomen and pelvis with IV contrast	Usually Not Appropriate	⚠⚠⚠
DMSA renal scan	Usually Not Appropriate	⚠⚠⚠
MAG3 renal scan	Usually Not Appropriate	⚠⚠⚠
MRI abdomen and pelvis without and with IV contrast	Usually Not Appropriate	0
MRU without contrast	Usually Not Appropriate	0
Arteriography kidney	Usually Not Appropriate	⚠⚠⚠
CT abdomen and pelvis with IV contrast	Usually Not Appropriate	⚠⚠⚠⚠
CT abdomen and pelvis without and with IV contrast	Usually Not Appropriate	⚠⚠⚠⚠
CT abdomen with IV contrast	Usually Not Appropriate	⚠⚠⚠
CT abdomen without and with IV contrast	Usually Not Appropriate	⚠⚠⚠⚠
CTU without and with IV contrast	Usually Not Appropriate	⚠⚠⚠⚠
MRI abdomen without and with IV contrast	Usually Not Appropriate	0
MRU without and with IV contrast	Usually Not Appropriate	0
Radiography abdomen and pelvis (KUB)	Usually Not Appropriate	⚠⚠

Variant 3. Renal failure. Kidney disease of unknown duration. Initial imaging.

Procedure	Appropriateness Category	Relative Radiation Level
US kidneys retroperitoneal	Usually Appropriate	0
CT abdomen and pelvis without IV contrast	May Be Appropriate	⚠⚠⚠⚠
US duplex Doppler kidneys retroperitoneal	May Be Appropriate (Disagreement)	0
MRA abdomen without IV contrast	May Be Appropriate	0
MRI abdomen and pelvis without IV contrast	May Be Appropriate	0
MRI abdomen without IV contrast	May Be Appropriate	0
CT abdomen without IV contrast	Usually Not Appropriate	⚠⚠⚠
MRA abdomen without and with IV contrast	Usually Not Appropriate	0
MRU without contrast	Usually Not Appropriate	0
DMSA renal scan	Usually Not Appropriate	⚠⚠⚠
MAG3 renal scan	Usually Not Appropriate	⚠⚠⚠
MRU without and with IV contrast	Usually Not Appropriate	0

(continued)

Variant 3. Continued

Procedure	Appropriateness Category	Relative Radiation Level
Arteriography kidney	Usually Not Appropriate	⚠⚠⚠
CT abdomen and pelvis with IV contrast	Usually Not Appropriate	⚠⚠⚠⚠
CT abdomen and pelvis without and with IV contrast	Usually Not Appropriate	⚠⚠⚠⚠
CT abdomen with IV contrast	Usually Not Appropriate	⚠⚠⚠
CT abdomen without and with IV contrast	Usually Not Appropriate	⚠⚠⚠⚠
CTA abdomen and pelvis with IV contrast	Usually Not Appropriate	⚠⚠⚠
CTU without and with IV contrast	Usually Not Appropriate	⚠⚠⚠⚠
MRI abdomen and pelvis without and with IV contrast	Usually Not Appropriate	0
MRI abdomen without and with IV contrast	Usually Not Appropriate	0
Radiography abdomen and pelvis (KUB)	Usually Not Appropriate	⚠⚠

Variant 4. Renal failure. Neurogenic bladder. Initial imaging.

Procedure	Appropriateness Category	Relative Radiation Level
US kidneys retroperitoneal	Usually Appropriate	0
CT abdomen and pelvis without IV contrast	May Be Appropriate	⚠⚠⚠⚠
DMSA renal scan	May Be Appropriate	⚠⚠⚠
MRI abdomen and pelvis without IV contrast	May Be Appropriate	0
CT abdomen without IV contrast	Usually Not Appropriate	⚠⚠⚠
US duplex Doppler kidneys retroperitoneal	Usually Not Appropriate	0
Fluoroscopy voiding cystourethrography	Usually Not Appropriate	⚠⚠
MRI abdomen without IV contrast	Usually Not Appropriate	0
CT abdomen and pelvis with IV contrast	Usually Not Appropriate	⚠⚠⚠⚠
CT abdomen and pelvis without and with IV contrast	Usually Not Appropriate	⚠⚠⚠⚠
CT abdomen with IV contrast	Usually Not Appropriate	⚠⚠⚠
CT abdomen without and with IV contrast	Usually Not Appropriate	⚠⚠⚠⚠
CTA abdomen and pelvis with IV contrast	Usually Not Appropriate	⚠⚠⚠
CTU without and with IV contrast	Usually Not Appropriate	⚠⚠⚠⚠
Fluoroscopy cystography	Usually Not Appropriate	⚠⚠⚠
MAG3 renal scan	Usually Not Appropriate	⚠⚠⚠
MRI abdomen and pelvis without and with IV contrast	Usually Not Appropriate	0
MRI abdomen without and with IV contrast	Usually Not Appropriate	0
MRU without and with IV contrast	Usually Not Appropriate	0
MRU without contrast	Usually Not Appropriate	0
Radiography abdomen and pelvis (KUB)	Usually Not Appropriate	⚠⚠

Table 1. 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.

Table 2. Relative radiation level designations

RRL	Adult Effective Dose Estimate Range (mSv)	Pediatric Effective Dose Estimate Range (mSv)
○	0	0
⊕	<0.1	<0.03
⊕⊕	0.1-1	0.03-0.3
⊕⊕⊕	1-10	0.3-3
⊕⊕⊕⊕	10-30	3-10
⊕⊕⊕⊕⊕	30-100	10-30

Note: Relative radiation level (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 (eg, region of the body exposed to ionizing radiation, the imaging guidance that is used). The RRLs for these examinations are designated as "varies."

SUMMARY OF LITERATURE REVIEW

Introduction/Background

Renal failure is defined as the inability of the kidney to secrete nitrogenous wastes and maintain fluid and electrolyte homeostasis, leading to azotemia. Acute kidney injury (AKI) is the preferred term for an abrupt decline in function. Chronic kidney disease (CKD) is abnormal renal function present for >3 months. AKI is defined as an increase in creatinine by ≥ 0.3 mg/dL within 48 hours or an increase in serum creatinine to ≥ 1.5 times baseline (within prior 7 days) or urine volume ≤ 0.5 mL/kg/hr for 6 hours [1,2]. The need for renal replacement therapy (dialysis or hemofiltration) indicates stage 3 AKI, the highest stage. Although oliguria reflects decreased glomerular filtration rate (GFR), changes in urine output may be physiologic. Thus, urine volume measurement is less important than measurement of serum creatinine in the diagnosis of AKI.

AKI is common, affecting up to 20% of hospital inpatients and between 30% to 60% of critically ill patients [3] with a rising incidence worldwide. Hospital-acquired AKI is 5 to 10 times more common than community-acquired AKI. AKI has a significant impact on patient morbidity and mortality with increased health care costs. AKI may be reversible or can lead to CKD.

AKI is often multifactorial but generally categorized as prerenal, renal, or postrenal. Prerenal factors include impaired blood flow from any cause including hypotension, hypovolemia, decreased cardiac output, or renal artery occlusion. Renal causes include any disease that damages renal parenchyma, such as vasculitis, acute tubular necrosis, glomerulonephritis, interstitial nephritis, renal infection or infiltration, drugs, and toxins. Postrenal AKI results from ureteral, bladder, or urethral obstruction. Renal and prerenal

etiologies far outweigh obstruction as a cause of AKI, accounting for >97% of AKI [4].

For appropriate intervention, identification of the specific cause of AKI is critical, as there are different treatments for diseases such as glomerulonephritis, vasculitis, and ureteral obstruction. Evaluation of the patient with AKI includes a thorough history, physical examination, and laboratory analysis of blood (for serum creatinine, blood urea nitrogen, complete blood count, and differential) and urine (microscopy for casts and epithelial cells, chemistry, and biomarkers) [3]. Renal biopsy may be indicated for differentiation of nephritic and nephrotic syndromes [3].

CKD is common, affecting 10% of the world population. It is defined as an abnormality of kidney structure or function, present for >3 months, with health consequences [5]. The definition requires knowledge of laboratory values in the preceding 3 months. Hypertension and diabetes are the predominant risk factors for CKD [6]. Five stages of CKD are based on estimated GFR calculated using serum creatinine and standard equations such as the Modification of Diet in Renal Disease study equation or CKD Epidemiology Collaboration equation [7]. Stage 5 with a GFR <15 mL/min per 1.73 m² body surface area is considered kidney failure [5]. CKD may be silent, progressing through stages of CKD to renal failure. Patients with CKD are at increased risk for hypertension, cardiovascular disease, bone disease, and anemia with increased morbidity and mortality.

Evaluation of the patient with CKD will include a thorough history, physical examination, laboratory, and serologic workups. Markers of kidney damage include measurement of albuminuria and urinary sediment; urinary albumin-to-creatinine ratio is a sensitive and specific marker for CKD. Abnormal histology on kidney biopsy or structural abnormalities on imaging (small echogenic kidneys, dysplastic or polycystic kidneys, renal scarring, hydronephrosis) will also qualify as CKD [8].

Special Imaging Considerations

The use of iodinated contrast or gadolinium-based contrast agents merits special discussion in the context of renal failure. Generally, iodinated contrast is avoided in AKI unless there is an over-riding clinical question that cannot be answered with an alternative imaging modality or when an intravascular intervention is required [9]. Avoidance of other nephrotoxic drugs, adequate hydration, and close assessment are part of the management. In CKD, the risk-benefit ratio is determined by the level and acuity of kidney disease, specifically weighing the benefits versus risks of any contrast agent. Patients already on hemodialysis or peritoneal dialysis may undergo contrast-enhanced CT if there is no residual renal function.

For MRI, there are risk-benefit considerations with respect to the type of gadolinium-based contrast agents. Unenhanced MR angiography (MRA) techniques may be diagnostic. Group II gadolinium-based contrast agents and lowest diagnostic contrast dose should be standard for contrast-enhanced MRA. Patients already on hemodialysis may undergo contrast-enhanced MRI with group II agents if safety guidelines are followed. For more details please refer to the ACR Manual on Contrast Media [9].

Ultrasound (US) contrast media are not nephrotoxic, which makes these potentially ideal agents for microvascular imaging in AKI or CKD [10]. Contrast-enhanced US has the potential to provide dynamic quantitative information about renal perfusion and can diagnose acute cortical necrosis and infarction in allografts and native kidneys [11-13].

For the purposes of distinguishing between CT and CT angiography (CTA), ACR Appropriateness Criteria topics use the definition in the ACR–NASCI–SIR–SPR Practice Parameter for the Performance and Interpretation of Body Computed Tomography Angiography (CTA) [14]:

CTA uses a thin-section CT acquisition that is timed to coincide with peak arterial or venous enhancement. The resultant volumetric dataset is interpreted using primary transverse reconstructions as well as multiplanar reformations and 3-D renderings.

All elements are essential: 1) timing, 2) reconstructions/reformats, and 3) 3-D renderings. Standard CTs with contrast also include timing issues and reconstructions/reformats. Only in CTA, however, is 3-D rendering a **required** element. This corresponds to the definitions that the CMS has applied to the Current Procedural Terminology codes.

CT urography (CTU) is an imaging study that is tailored to improve visualization of both the upper and lower urinary tracts. There is variability in the specific parameters, but it usually involves unenhanced images followed by intravenous (IV) contrast-enhanced images, including nephrographic and excretory phases acquired at least 5 minutes after contrast injection. Alternatively, a split-bolus technique uses an initial loading dose of IV contrast and then obtains a combined nephrographic-excretory phase after a second IV contrast dose; some sites include arterial phase. CTU should use thin-slice acquisition. Oral hydration, IV saline hydration, compression bands, and low-dose furosemide have all been reported as methods to improve urinary distension. Reconstruction methods commonly include maximum intensity projection or 3-D volume rendering. For the purposes of this document, we make a distinction between CTU and CT abdomen and pelvis without and with IV contrast. CT abdomen and pelvis

without and with IV contrast is defined as any protocol not specifically tailored for evaluation of the upper and lower urinary tracts and without both the precontrast and excretory phases.

MR urography (MRU) is also tailored to improve imaging of the urinary system. Unenhanced MRU relies upon heavily T2-weighted imaging of the intrinsic high signal from urine for evaluation of the urinary tract. IV contrast is administered to provide additional information regarding obstruction, urothelial thickening, focal lesions, and stones. Contrast-enhanced T1-weighted series should include corticomedullary, nephrographic, and excretory phase. Thin-slice acquisition and multiplanar imaging should be obtained. MRU is most commonly performed on a 1.5T machine, but imaging at 3T has become more widely used; however, comparison of 3T MRU and CTU has not been published in the literature. For the purposes of this document, we make a distinction between MRU and MR abdomen and pelvis without and with IV contrast. MR abdomen and pelvis without and with IV contrast is defined as any protocol not specifically tailored for evaluation of the upper and lower urinary tracts, without both the precontrast and excretory phases and without heavily T2-weighted images of the urinary tract.

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 in which each procedure provides unique clinical information to effectively manage the patient's care).

DISCUSSION OF PROCEDURES BY VARIANT

Variant 1: Renal failure. Acute kidney injury (AKI), unspecified. Initial imaging

Arteriography Kidney. Arteriography is reserved for intervention rather than for the initial diagnosis of AKI. Renal revascularization may be considered in a very select group of patients with AKI. There is no relevant literature regarding the use of arteriography in the evaluation of AKI.

CT Abdomen and Pelvis. Unenhanced CT abdomen and pelvis is useful for further evaluation of US-detected

hydronephrosis by determining level and cause of obstruction. CT is the most sensitive modality for urinary tract calculi and more sensitive than US for retroperitoneal pathology [15]. Although CT can also provide an assessment of renal size and volume, it is generally not considered the first-line imaging modality for AKI [16]. CT may be considered if US is not feasible or is nondiagnostic because body habitus.

The use of iodinated contrast hinges on renal function and specific indication. CT with IV contrast is not appropriate for the diagnosis of and determination of the cause of AKI. There is no relevant literature regarding the use of CT abdomen and pelvis with IV contrast in the evaluation of AKI.

CT abdomen and pelvis without and with IV contrast is not appropriate for the diagnosis of and determination of the cause of AKI. There is no relevant literature regarding the use of CT abdomen and pelvis without and with IV contrast in the evaluation of AKI.

CT Abdomen. There is no relevant literature regarding the use of CT abdomen in the evaluation of AKI.

CTA Abdomen and Pelvis. Contrast-enhanced CTA is very rarely indicated for initial diagnosis of AKI given the potential nephrotoxicity. The risk-benefit ratio should be carefully evaluated if CTA is necessary to diagnose vascular thrombosis or stenosis. The lowest dose of contrast needed for a diagnostic study should be used and supplemented with adequate volume expansion [9]. There is no relevant literature regarding the use of CTA in the evaluation of AKI.

CTU. There is no relevant literature regarding the use of CTU in the evaluation of AKI. The requirement for IV contrast limits its utility.

MRA Abdomen. MRA may be considered when there is a high suspicion of a renovascular cause of AKI such as renal artery stenosis, thrombosis, or arterial injury after trauma, all of which are rare [4,17].

However, there is no relevant literature regarding the use of MRA abdomen without and with IV contrast in the evaluation of AKI. If contrast-enhanced MRA is needed after consideration of the risks and benefits, group II contrast agents should be used [9]. Contrast-enhanced MRA has a sensitivity of 93% and a specificity of 93% compared with 85% and 84%, respectively, for Doppler US for diagnosis of >60% stenosis [18].

Unenhanced MRA techniques, such as time-spatial labeling inversion pulse or steady-state free precession, may be considered in AKI. These techniques have a sensitivity of 73% to 100%, specificity of 82% to 99%, and negative predictive value of 88% to 100% for the diagnosis of >50% renal artery stenosis [19,20].

MRI Abdomen and Pelvis. MRI with IV contrast is generally not indicated in AKI. Unenhanced MRI may be used to evaluate extent and cause of suspected distal urinary tract obstruction. However, there is no relevant literature regarding the use of MRI abdomen and pelvis without IV contrast in the evaluation of AKI.

There is no relevant literature regarding the use of MRI abdomen and pelvis without and with IV contrast in the evaluation of AKI.

MRI Abdomen. MRI without IV contrast can be sufficient for characterization of the cause and level of obstruction and for evaluation of some renal morphologic abnormalities. Alterations in corticomedullary differentiation are recognized but are nonspecific. Functional MRI techniques—such as bold oxygen level dependent imaging (BOLD), arterial spin labeling (ASL), diffusion-weighted imaging (DWI), and diffusion kurtosis imaging (DKI) that provide information on renal perfusion, oxygenation, and diffusion—are still the subject of active research [21,22].

MRI with IV contrast is generally not indicated in AKI. However, acute cortical necrosis can be specifically diagnosed when there is a low T2 signal rim at the corticomedullary junction and absence of cortical enhancement [23].

MR Urography. There is no relevant literature regarding the use of MRU in the evaluation of AKI. However, a nonenhanced contrast MRU may provide additional information in patients with renal failure secondary to obstruction.

Radiography Abdomen and Pelvis (KUB). There is no role for radiography in AKI, other than for evaluation of renal stone disease, which acknowledges that radiography is less sensitive than CT for stone disease [24].

DMSA Renal Scan. Tc-99m dimercaptosuccinic acid (DMSA) scintigraphy is ideal for functional renal cortical imaging and is most useful for detection of focal renal parenchymal abnormalities and scars in the setting of acute or chronic pyelonephritis or for differential renal function. There is no relevant literature regarding its use in the evaluation of AKI.

MAG3 Renal Scan. Tc-99m mercaptoacetyl triglycine (MAG3) is the most frequently used renal tubular agent, specifically to quantify renal tubular extraction. Its rate of clearance can be used as an independent measure of renal function. The Tc-99m MAG3 radionuclide angiogram assesses renal perfusion, and the following scintigraphic renogram can quantify split renal function. Diuretic furosemide renography can help to confirm a dilated obstructed

versus a dilated nonobstructed renal collecting system. A persistent nephrogram without excretion suggests acute tubular necrosis [25]. Measurement of effective renal plasma flow may provide prognostic information. However, Tc-99m MAG3 is not widely used in the differentiation of causes of AKI.

US Kidneys Retroperitoneum. US has the greatest diagnostic value in the detection of hydronephrosis associated with acute urinary tract obstruction [4]. Grayscale US is highly sensitive (>90%) for hydronephrosis and bladder distension, allowing localization of the level of obstruction and guiding intervention such as Foley catheter placement or nephrostomy/stenting [26]. However, even in hospitalized patients with AKI, the prevalence of hydronephrosis is low, ranging from 5% to 10%, with obstruction being the cause of AKI in <45.2% of patients with hydronephrosis [4,27-29]. The highest yield for US is in patients with risk factors for urinary obstruction, such as pelvic tumors, bladder disorders, prostate hypertrophy, stone disease, and pelvic surgery. In patients without risk factors for obstruction, <1% of patients had US-detected obstruction [4]. Hydronephrosis does not necessarily indicate obstruction; a distended bladder, reflux, pregnancy, postobstructive dilation, or diuresis may cause ureteral and collecting system dilatation. When the bladder is distended, the patient should be re-evaluated after the bladder has been decompressed by voiding or catheterization. False-negative US studies may be secondary to suboptimal image quality, dehydration, early obstruction, or compression of the renal pelvis or ureters by tumor or fibrosis.

A secondary role of US is the evaluation of renal size, echogenicity, and morphology to differentiate AKI from CKD and allow determination of prognosis. Normal renal length is >10 cm in the third decade, but renal length correlates with height, sex, age (negative correlation), and weight in normal patients and varies with the state of hydration or presence of an obstruction [3]. Renal size/volume correlates with creatinine clearance [30]. Both kidney size and parenchymal thickness decrease in CKD [31]. Therefore, a normal kidney size suggests AKI rather than CKD. However, infiltrative and inflammatory diseases, as well as renal vein thrombosis, may increase kidney size and parenchymal thickness in AKI or CKD. Increased renal echogenicity is associated with acute and chronic medical renal disease, but this is nonspecific and does not correlate well with renal function. Patients with AKI have only a 30% to 40% chance of increased echogenicity [4,28]. Alternatively, small echogenic kidneys are diagnostic of CKD.

Color Doppler is routinely used to assess global perfusion and confirm arterial and venous patency. Color

Doppler will differentiate a dilated pelvis from prominent renal veins in the renal sinus and can confirm presence or absence of ureteral jets in the bladder.

If there is contemporaneous imaging such as CT or MRI showing normal kidneys and no new risk factors for obstruction, additional US is not indicated.

US Duplex Doppler Kidneys Retroperitoneal.

Renovascular causes of AKI are rare; renal artery stenosis was found in 1.5% of cases with AKI even when it was not the cause of AKI [4]. In an older series of intensive care patients, AKI was attributed to renal artery thrombosis, stenosis, or trauma in 1% [17]. The diagnosis of significant renal artery stenosis can be made by obtaining angle-corrected measurements of the peak systolic velocities in the aorta and main renal arteries. Using a cutoff value of 285 cm/s achieved sensitivity, specificity, and overall accuracy of 67%, 90%, and 81%, respectively, for >60% stenosis [32]. In a smaller series, using a cutoff value of 180 cm/s, the sensitivity and specificity of US were 85% and 84%, respectively, for >60% stenosis [18]. Renal artery duplex Doppler studies may be appropriate in selected patients with a high clinical suspicion of renal artery stenosis.

Resistive index (RI) has been studied in patients with AKI as a means to detect intrarenal vasoconstriction and differentiate renal from prerenal AKI. An elevated RI has been reported to be an early predictor of early or persistent postoperative AKI after cardiac or hip surgery [33,34] or persistent AKI in critically ill patients [35] and is associated with intensive care unit mortality [36]. An elevated RI can predict progression to CKD [37]. However, an elevated intrarenal RI is not specific to the cause of AKI as RI depends on multiple physiologic and pathologic factors, including vascular compliance, age, atherosclerosis, renal damage, hypertension, heart rate, as well as intrinsic renal disease [33,37]. Serial RI measurement is largely a research tool at this time.

Variant 2: Renal failure. Chronic kidney disease (CKD). Initial imaging

Arteriography Kidney. Arteriography is reserved for intervention rather than for initial diagnosis. Treatment of renal artery stenosis may be considered, but a recent meta-analysis does not indicate a benefit in the preservation of renal function [38].

CT Abdomen and Pelvis. Unenhanced CT is useful for further evaluation of US-detected hydronephrosis by determining level and cause of obstruction. CT is the most sensitive modality for urinary tract calculi [15]. Although CT can determine if there is hydronephrosis and assess renal size/volume, it is generally not considered the first-

line imaging modality [16]. CT may be considered if US is not feasible or is nondiagnostic because of body habitus.

There is no relevant literature regarding the use of CT abdomen and pelvis without and with IV contrast for initial evaluation of CKD. Although CT with IV contrast may be feasible depending on the stage of CKD, it is not appropriate for the diagnosis of and determination of the cause of CKD.

There is no relevant literature regarding the use of CT abdomen and pelvis with IV contrast for initial evaluation of CKD.

CT Abdomen. There is no relevant literature regarding the use of CT abdomen in the initial evaluation of CKD.

CTA Abdomen and Pelvis. In CKD, contrast-enhanced CTA might be carefully considered for vascular thrombosis or stenosis depending on the GFR and risk-benefit ratio. In one study of 1,007 patients with CKD undergoing US, renal artery stenosis was found in 4.3% of patients [39]. There is no relevant literature regarding the use of CTA abdomen and pelvis for initial evaluation of CKD.

CT Urography. There is no relevant literature regarding the use of CTU in the initial evaluation of CKD.

MRA Abdomen. MRA is indicated when there is a high suspicion of a renovascular cause of CKD, which is rare. In one study of 1,007 patients with CKD undergoing US, renal artery stenosis was found in 4.3% of patients [39]. Unenhanced MRA techniques may be an option. When compared with contrast-enhanced CTA in the detection of <50% or >50% renal artery stenosis, an unenhanced MRA was reported to have a sensitivity, specificity, and accuracy of 74%, 93%, and 90%, respectively [19].

For contrast-enhanced MRA, a group II contrast agent using lowest dose that obtains a diagnostic study should be used [9]. In the detection of >60% renal artery stenosis, contrast-enhanced MRA has a sensitivity of 93% and specificity of 93% compared to 85% and 84%, respectively, for Doppler US [18].

MRI Abdomen and Pelvis. There is no relevant literature regarding the use of MRI abdomen and pelvis without and with IV contrast in the initial evaluation of CKD.

MRI Abdomen. Unenhanced MRI may be used for characterization of level and cause of obstruction or evaluation of renal morphologic abnormalities. Functional MRI techniques such as BOLD, ASL, DWI, and DKI that provide information on renal perfusion, oxygenation, and diffusion are still the subject of active research [21,22].

The use of contrast should be considered only after evaluation of the risk-benefit ratio and degree of renal

function [9]. There is no literature to support any added diagnostic value of the use of IV contrast and its attendant risks, and it is not appropriate for the diagnosis of and determination of the cause of CKD.

There is no relevant literature regarding the use of MRI abdomen without and with IV contrast in the initial evaluation of CKD.

MR Urography. There is no relevant literature regarding the use of MRU in the initial evaluation of CKD.

Radiography Abdomen and Pelvis (KUB). The role of abdominal radiography in CKD is limited to evaluation of renal stone disease, which acknowledges that radiography is less sensitive than CT for stone disease [24]. Signs of renal osteodystrophy confirm the presence of CKD.

DMSA Renal Scan. Tc-99m DMSA scintigraphy is ideal for functional renal cortical imaging and is most useful for detection of focal renal parenchymal abnormalities and scars in the setting of acute or chronic pyelonephritis or for differential renal function. Serial imaging may be useful for monitoring renal cortical scarring.

The literature search did not identify any studies regarding the use of Tc-99m DMSA as a first-line test in the evaluation of CKD.

MAG3 Renal Scan. The literature search did not identify any studies regarding the use of Tc-99m MAG3 as a first-line test in the evaluation of CKD.

US Kidneys Retroperitoneum. US can differentiate AKI from CKD by determining renal size and volume. Renal length correlates with renal function in CKD [30,40-42]. Renal volume may be less useful given the contribution of renal sinus fat. In CKD, the kidneys are typically small with loss of global parenchymal and cortical thickness [42,43]. Renal length <9 cm in an adult is definitely abnormal [44]. It should be emphasized that normal-sized kidneys do not exclude CKD as renal size is initially preserved in diabetic nephropathy or infiltrative disorders.

Increase in renal echogenicity is a nonspecific subjective manifestation of renal disease. In a series of 1,007 patients with CKD, abnormalities were detected in 26.8% of patients at initial US evaluation [39]. The most common US findings were increased echogenicity in 10.3%, cortical thinning in 4.3%, renal artery stenosis in 4.3%, and hydronephrosis in 1.9% of patients [39]. However, these findings contributed to the diagnosis in only 5.9% of patients and affected management in 3.3% of patients [39].

The low impact on management does not support the use of US for routine surveillance of CKD. US may be indicated when there is a prior history of stones or obstruction, renal artery stenosis, frequent urinary tract

infections, or family history of autosomal dominant polycystic kidney disease [39]. In patients with CKD and diabetes or hypertension, US has minimal impact on diagnosis and management [6,8].

US Duplex Doppler Kidneys Retroperitoneal. A high RI can be a predictor of progression of CKD, but an elevated RI is not specific to renal disease [37], and threshold values vary in the literature. The literature search did not identify any studies regarding the use of RIs in the initial evaluation of CKD.

For renovascular disease, US is a low-yield test unless the patient has a history of renal artery stenosis [39].

Variant 3: Renal failure. Kidney disease of unknown duration. Initial imaging. Some patients will present without prior laboratory results and cannot be definitively categorized into AKI or CKD. In these patients, a detailed history, physical examination, and laboratory analysis of blood (for serum creatinine, blood urea nitrogen, complete blood count, and differential) and urine (microscopy for casts and epithelial cells, chemistry, and biomarkers) will be obtained in addition to imaging. More frequent measurement of serum creatinine will detect the more rapid deterioration of AKI. The imaging workup is similar to patients with AKI.

Arteriography Kidney. Arteriography is reserved for intervention rather than for the initial diagnosis of renal failure. Renal revascularization may be considered in a very select group of patients with AKI. There is no relevant literature regarding the use of arteriography in the evaluation of renal failure of unknown duration.

CT Abdomen and Pelvis. Unenhanced CT of the abdomen and pelvis is useful for characterization of US-detected hydronephrosis by determining level and cause of obstruction. CT is the most sensitive modality for urinary tract calculi and more sensitive than US for retroperitoneal pathology [15]. Although CT can determine whether there is hydronephrosis and measure renal size/volume, it is generally not considered a first-line imaging modality [16]. CT may be considered if US is not feasible or is nondiagnostic because body habitus.

There is no relevant literature regarding the use of CT abdomen and pelvis without and with IV contrast in the evaluation of renal failure of unknown duration. Iodinated contrast may be administered to patients established on dialysis without residual renal function. However, CT with IV contrast is not appropriate for the diagnosis of and determination of the cause of kidney failure.

CT Abdomen. There is no relevant literature regarding the use of CT abdomen in the initial evaluation of renal failure of unknown duration.

CTA Abdomen and Pelvis. Contrast-enhanced CTA abdomen and pelvis is very rarely indicated in these patients, given the potential nephrotoxicity. The risk-benefit ratio should be carefully evaluated if CTA is necessary to diagnose vascular thrombosis or stenosis. The lowest dose of contrast needed for a diagnostic study should be used and supplemented with adequate volume expansion [9]. There is no relevant literature regarding the use of CTA abdomen and pelvis in the evaluation of renal failure of unknown duration.

CT Urography. There is no relevant literature regarding the use of CTU in the evaluation of renal failure of unknown duration and the requirement for IV contrast limits its applicability.

MRA Abdomen and Pelvis. There is no relevant literature regarding the use of MRA abdomen and pelvis without and with IV contrast in the evaluation of renal failure of unknown duration.

MRA may be indicated when there is a high suspicion of a renovascular cause of AKI/CKD, such as renal artery stenosis, thrombosis, or arterial injury after trauma, all of which are rare [4,17]. Unenhanced MRA techniques, such as time-spatial labeling inversion pulse or steady-state free precession, have a sensitivity of 73% to 100%, specificity of 82% to 99%, and negative predictive value of 88% to 100% in the diagnosis of >50% renal artery stenosis [19,20].

There is no relevant literature regarding the use of MRA abdomen without IV contrast in the evaluation of renal failure of unknown duration.

For contrast-enhanced MRA, a group II contrast agent should be used [9]. For the detection of >60% renal artery stenosis, a contrast-enhanced MRA has a sensitivity of 93% and a specificity of 93% compared with 85% and 84%, respectively, for Doppler US [18].

MRI Abdomen and Pelvis. Unenhanced MRI of the abdomen and pelvis may be used to evaluate extent and cause of suspected urinary tract obstruction. However, there is no relevant literature regarding the use of MRI abdomen and pelvis in the initial evaluation of renal failure of unknown duration.

MRI Abdomen. There is no relevant literature regarding the use of MRI abdomen without and with IV contrast in the initial evaluation of renal failure of unknown duration.

MRI performed without IV contrast can be used for further characterization of the cause and level of obstruction and for evaluation of some renal morphologic abnormalities. Alterations in corticomedullary differentiation are recognized but are nonspecific. Acute cortical necrosis can be specifically diagnosed when there is a low T2 signal rim at

the corticomedullary junction and absence of cortical enhancement following contrast administration [23]. Functional MRI techniques, such as BOLD, ASL, DWI, and DKI that provide information on renal perfusion, oxygenation, and diffusion are still the subject of active research [21,22].

MR Urography. There is no relevant literature regarding the use of MRU in the initial evaluation of renal failure of unknown duration. However, nonenhanced contrast MRU may provide additional information in patients with renal failure secondary to obstruction.

Radiography Abdomen and Pelvis (KUB). There is no role for radiography in AKI/CKD other than for evaluation of renal stone disease, which acknowledges that radiography is less sensitive than CT for stone disease [24].

DMSA Renal Scan. Tc-99m DMSA scintigraphy is ideal for functional renal cortical imaging and is most useful for detection of focal renal parenchymal abnormalities and scars in the setting of acute or chronic pyelonephritis or for differential renal function. The literature search did not identify any studies regarding the use of Tc-99m DMSA as a first-line test in the evaluation of renal failure of unknown duration.

MAG3 Renal Scan. The literature search did not identify any studies regarding the use of Tc-99m MAG3 as a first-line test in the evaluation of renal failure of unknown duration.

US Kidneys Retroperitoneum. US has greatest diagnostic value in the detection of hydronephrosis associated with urinary tract obstruction [4] with a sensitivity >90% for hydronephrosis and bladder distension [26]. However, even in hospitalized patients with AKI, the prevalence of hydronephrosis is low, ranging from 5% to 10%, with obstruction the cause of AKI in <45.2% of patients with hydronephrosis [4,27-29]. The highest yield for US is in patients with risk factors for urinary obstruction, such as pelvic tumors, bladder disorders, prostate hypertrophy, stone disease, and pelvic surgery. In patients without risk factors for obstruction, <1% of patients had US-detected obstruction [4]. Hydronephrosis does not necessarily indicate obstruction; a distended bladder, reflux, pregnancy, postobstructive dilation, or diuresis may cause ureteral and collecting system dilatation. A distended bladder should be decompressed, and the patient should be reevaluated. False-negative US studies may be secondary to suboptimal quality, dehydration, early obstruction, or compression of the renal pelvis or ureters by tumors or fibrosis.

A secondary role of US is the evaluation of renal size, echogenicity, and morphology to differentiate AKI from

CKD and allow determination of prognosis. Normal renal length is >10 cm in the third decade, but renal length correlates with height, sex, age (negative correlation), and weight in normal patients and varies with the state of hydration or presence of an obstruction [3]. Renal size/volume correlates with creatinine clearance [30]. Both kidney size and parenchymal thickness decrease in CKD [31]. Therefore, a normal kidney size suggests AKI rather than CKD. However, infiltrative and inflammatory diseases, as well as renal vein thrombosis, may increase kidney size and parenchymal thickness in AKI or CKD. Increased renal echogenicity is associated with acute and chronic medical renal disease, but this is nonspecific and does not correlate well with renal function. Patients with AKI have only a 30% to 40% chance of increased echogenicity [4,28]. Alternatively, small echogenic kidneys are diagnostic of CKD.

Color Doppler is routinely used to assess global perfusion and confirm arterial and venous patency. Color Doppler will differentiate a dilated pelvis from prominent renal veins in the renal sinus and can confirm presence or absence of ureteral jets in the bladder.

US Duplex Doppler Kidneys Retroperitoneal. Renovascular causes of AKI/CKD are rare; renal artery stenosis was found in 1.5% of cases with AKI even when not the cause of AKI [4]. In an older series of intensive care patients, AKI was attributed to renal artery thrombosis, stenosis, or trauma in 1% [17]. The diagnosis of significant renal artery stenosis can be made by obtaining angle-corrected measurements of the peak systolic velocities in the aorta and main renal arteries. Using a cutoff value of 285 cm/s achieved sensitivity, specificity, and overall accuracy of 67%, 90%, and 81%, respectively, for >60% stenosis [32]. In a smaller series, using a cutoff value of 180 cm/s, the sensitivity and specificity of US were 85% and 84%, respectively, for >60% stenosis [18]. Renal artery duplex Doppler studies may be appropriate in selected patients with a high clinical suspicion of renal artery stenosis.

RI has been studied in patients with AKI as a means to detect intrarenal vasoconstriction and differentiate renal from prerenal AKI. An elevated RI has been reported to be an early predictor of early or persistent postoperative AKI after cardiac or hip surgery [33,34], or persistent AKI in critically ill patients [35], and is associated with intensive care unit mortality [36]. An elevated RI can predict progression to CKD [37]. However, an elevated intrarenal RI is not specific to the cause of AKI, as RI depends on multiple physiologic and pathologic factors; including vascular compliance, age, atherosclerosis, renal damage, hypertension, heart rate, as well as intrinsic renal disease [33,37]. Serial RI measurement is largely a research tool at this time.

Variant 4: Renal failure. Neurogenic bladder. Initial imaging

Patients with neurogenic bladder due to disorders affecting the central nervous system typically present with signs of urinary frequency, urgency, and bladder overactivity, but there is little recent peer-reviewed original research on the initial imaging of this condition associated with renal failure. Underactivity of the bladder is less common, and it is characterized by prolonged voiding with a sensation of incomplete emptying and hesitancy; however, imaging is not generally part of the evaluation of underactive bladder [45]. Approximately 26% of patients with neurogenic bladder from spina bifida will develop renal failure, but <2% progress to end-stage renal disease [46].

Nearly all patients with spinal cord injury have historically developed renal dysfunction, which has been a major cause of death until more recent advances in diagnosis and care [47]. Patients with spinal cord injury have a 7% risk of stone development within 10 years, and this can contribute to renal insufficiency [47]. Review of clinical history, physical examination, US and urodynamic studies are the key components of an initial diagnosis of neurogenic bladder in Europe [48], but recommendations vary by country. For example, urodynamic evaluation is not recommended in British guidelines [49].

CT Abdomen and Pelvis. Unenhanced CT is useful for characterization of US-detected hydronephrosis by determining the level and cause of obstruction. CT can determine if there is hydronephrosis, measure renal size/volume, and assess urinary bladder distension and wall thickening but it is generally not considered a first-line imaging modality [16]. CT may be considered if US is not feasible or is nondiagnostic because of body habitus.

There is no relevant literature regarding the use of CT abdomen and pelvis without and with IV contrast in the evaluation of renal failure associated with neurogenic bladder, but CT with IV contrast is not a first-line test for evaluation of kidney failure due to neurogenic bladder. Other options that do not use iodinated contrast are available.

CT Abdomen. Unenhanced CT is useful for characterization of US-detected hydronephrosis by determining the level and cause of obstruction if the pelvis is included. CT can determine if there is hydronephrosis and measure renal size/volume, but it is generally not considered a first-line imaging modality [16].

There is no relevant literature regarding the use of CT abdomen without and with IV contrast in the evaluation of renal failure associated with neurogenic bladder, but CT with IV contrast is not a first-line test for evaluation of

kidney failure due to neurogenic bladder. Other options that do not use iodinated contrast are available.

CTA Abdomen and Pelvis. There is no role for CTA in the initial evaluation of renal failure associated with neurogenic bladder.

CT Urography. There is no relevant literature for CTU in the initial evaluation of renal failure associated with neurogenic bladder.

Fluoroscopy Cystography. There is no role for cystography in the evaluation of neurogenic bladder other than as a method of visualization during video urodynamics.

Fluoroscopy Voiding Cystourethrography. Voiding cystourethrography is used to image the bladder wall and urethra and evaluate for vesicoureteral reflux but is not part of the evaluation of renal failure. There is no relevant literature regarding the use of voiding cystourethrography in the initial renal failure in a patient with neurogenic bladder.

MRI Abdomen and Pelvis. MRI can show the urinary system well, and T2-weighted imaging can demonstrate hydronephrosis and hydroureter as well as US. Likewise, the urinary bladder can be well-visualized. In one review from Asia, MRI was favored above US for better evaluation of the collecting systems and ureters, which were shown in the coronal plane [50]. However, MRI of the abdomen and pelvis is not routinely used in the evaluation of renal failure associated with neurogenic bladder regardless of whether or not IV contrast is administered.

MRI Abdomen. There is no relevant literature for MRI abdomen in the initial evaluation of renal failure associated with neurogenic bladder, regardless of whether or not IV contrasted series are included.

MR Urography. There is no relevant literature for MRU in the initial evaluation of renal failure associated with neurogenic bladder. However, contrast-enhanced MRU is not routinely performed in this setting, and the majority of the information is obtained by unenhanced MRI sequences.

Radiography Abdomen and Pelvis (KUB). There is no role for radiography in initial evaluation of neurogenic bladder. However, it may be used in the long-term surveillance for development of renal stone disease, acknowledging that radiography is less sensitive than CT for detection of stone disease [24].

DMSA Renal Scan. Tc-99m DMSA renography may be useful for the detection of focal renal scarring from urinary tract infection in patients with neurogenic bladders [51]. Serial imaging may be used to monitor renal cortical scarring. Tc-99m DMSA renal scintigraphy may also

provide useful information if US is “difficult to interpret” because of patient or technical issues [52]. For this document, it is assumed that the procedure is widely available and is performed and interpreted by an expert.

MAG3 Renal Scan. There is no relevant literature regarding the use of Tc-99m MAG3 as a first-line test in the evaluation of renal failure associated with neurogenic bladder.

US Kidneys Retroperitoneum. The American Urological Association supports clinical evaluation and measurement of postvoid residual but does not specifically endorse US for this measurement. However, US is routinely used by urologists in the initial workup because it can easily measure bladder volume. In patients with neurogenic bladder and lower urinary tract symptoms, US and postvoid residual measurement is also supported by international guidelines [48,49,53].

In a study of 60 patients with neurogenic lower urinary tract dysfunction after spinal cord injury, a distended bladder anterior wall detrusor (hypoechoic layer) with a thickness <0.97 mm on US was 92% sensitive and 63% specific for risk assessment of renal damage [54]. Although bladder wall thickness can be characterized by US, this aspect of the examination is not supported as part of any current guideline recommendations [49].

In patients at high risk for upper tract disease, US should include the kidneys to evaluate for hydronephrosis, parenchymal scarring, and stones [49] because it has high sensitivity for upper tract dilatation [55]. The bladder should also be evaluated, for trabeculations, wall thickness, and shape. Sensitivity of US for renal scarring in spinal dysraphism patients is variable, and in one study was unacceptably low relative to scintigraphy (negative predictive value, 0.6) [52]. Predictors of positive US in these patients include time since injury, previous stone removal, nontraumatic spinal cord injury, and previous bladder surgery [56].

US Duplex Doppler Kidneys Retroperitoneal. Although US has been widely accepted as a first-line imaging modality for neurogenic bladder, there is not any literature to support a role for Doppler.

SUMMARY OF RECOMMENDATIONS

- **Variant 1:** US kidneys retroperitoneal is usually appropriate for the initial imaging of unspecified AKI. US is used to detect hydronephrosis and evaluate renal size and morphology.
- **Variant 2:** US kidneys retroperitoneal is usually appropriate for the initial imaging of CKD. Small and/or scarred kidneys confirm the diagnosis.

■ **Variant 3:** US kidneys retroperitoneal is usually appropriate for the initial imaging of renal failure of unknown duration. US is used to detect hydronephrosis and evaluate renal size and morphology. The panel did not agree on recommending US duplex Doppler kidneys retroperitoneal for the initial imaging of renal failure of unknown duration. There is insufficient medical literature to conclude whether or not these patients would benefit from US duplex Doppler kidneys retroperitoneal for the initial imaging of renal failure of unknown duration. US duplex Doppler kidneys retroperitoneal in this patient population is controversial but may be appropriate.

■ **Variant 4:** US kidneys retroperitoneal is usually appropriate for the initial imaging of renal failure associated with neurogenic bladder. US is used to detect hydronephrosis, renal scarring, and stones as well as to evaluate the bladder.

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 go to www.acr.org/ac.

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 2). Additional information regarding radiation dose assessment for imaging examinations can be found in the ACR Appropriateness Criteria® Radiation Dose Assessment Introduction document [57].

REFERENCES

1. Palevsky PM, Liu KD, Brophy PD, et al. KDOQI US commentary on the 2012 KDIGO clinical practice guideline for acute kidney injury. *Am J Kidney Dis* 2013;61:649-72.
2. Kellum JA, Lameire N, Group KAGW. Diagnosis, evaluation, and management of acute kidney injury: a KDIGO summary (Part 1). *Crit Care* 2013;17:204.
3. Kidney International. KDIGO clinical practice guideline for acute kidney injury. Available at: <http://kdigo.org/wp-content/uploads/2016/10/KDIGO-2012-AKI-Guideline-English.pdf>. Accessed September 30, 2020.
4. Podoll A, Walther C, Finkel K. Clinical utility of gray scale renal ultrasound in acute kidney injury. *BMC Nephrol* 2013;14:188.
5. Inker LA, Astor BC, Fox CH, et al. KDOQI US commentary on the 2012 KDIGO clinical practice guideline for the evaluation and management of CKD. *Am J Kidney Dis* 2014;63:713-35.
6. Mendu ML, Lundquist A, Aizer AA, et al. The usefulness of diagnostic testing in the initial evaluation of chronic kidney disease. *JAMA Intern Med* 2015;175:853-6.
7. The National Institute of Diabetes and Digestive and Kidney Diseases. Health Information Center. Estimating glomerular filtration rate. Available at: <https://www.niddk.nih.gov/health-information/communication-programs/nkdep/laboratory-evaluation/glomerular-filtration-rate/estimating>. Accessed September 30, 2020.
8. Vassalotti JA, Centor R, Turner BJ, et al. Practical approach to detection and management of chronic kidney disease for the primary care clinician. *Am J Med* 2016;129:153-162 e7.
9. American College of Radiology. Manual on contrast media. Available at: <https://www.acr.org/Clinical-Resources/Contrast-Manual>. Accessed September 30, 2020.
10. Piscaglia F, Nolsoe C, Dietrich CF, et al. The EFSUMB guidelines and recommendations on the clinical practice of contrast enhanced ultrasound (CEUS): update 2011 on non-hepatic applications. *Ultraschall Med* 2012;33:33-59.
11. Fernandez CP, Ripolles T, Martinez MJ, Blay J, Pallardo L, Gavela E. Diagnosis of acute cortical necrosis in renal transplantation by contrast-enhanced ultrasound: a preliminary experience. *Ultraschall Med* 2013;34:340-4.
12. McKay H, Ducharlet K, Temple F, Sutherland T. Contrast enhanced ultrasound (CEUS) in the diagnosis of post-partum bilateral renal cortical necrosis: a case report and review of the literature. *Abdom Imaging* 2014;39:550-3.
13. Girometti R, Stocca T, Serena E, Granata A, Bertolotto M. Impact of contrast-enhanced ultrasound in patients with renal function impairment. *World J Radiol* 2017;9:10-6.
14. American College of Radiology. ACR–NASCI–SIR–SPR practice parameter for the performance and interpretation of body computed tomography angiography (CTA). Available at: <https://www.acr.org/-/media/ACR/Files/Practice-Parameters/body-cta.pdf>. Accessed September 30, 2020.
15. Ripolles T, Agramunt M, Errando J, Martinez MJ, Coronel B, Morales M. Suspected ureteral colic: plain film and sonography vs unenhanced helical CT. A prospective study in 66 patients. *Eur Radiol* 2004;14:129-36.
16. Gupta S, Singh AH, Shabbir A, Hahn PF, Harris G, Sahani D. Assessing renal parenchymal volume on unenhanced CT as a marker for predicting renal function in patients with chronic kidney disease. *Acad Radiol* 2012;19:654-60.
17. Mehta RL, Pascual MT, Soroko S, et al. Spectrum of acute renal failure in the intensive care unit: the PICARD experience. *Kidney Int* 2004;66:1613-21.
18. 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;54:9-12.
19. Albert TS, Akahane M, Parienty I, et al. An international multi-center 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;204:182-8.
20. Angeretti MG, Lumia D, Cani A, et al. Non-enhanced MR angiography of renal arteries: comparison with contrast-enhanced MR angiography. *Acta Radiol* 2013;54:749-56.
21. Gillis KA, McComb C, Patel RK, et al. Non-contrast renal magnetic resonance imaging to assess perfusion and corticomedullary differentiation in health and chronic kidney disease. *Nephron* 2016;133:183-92.
22. Zhou HY, Chen TW, Zhang XM. Functional magnetic resonance imaging in acute kidney injury: present status. *Biomed Res Int* 2016;2016:2027370.
23. Francois M, Tostivint I, Mercadal L, Bellin MF, Izzedine H, Deray G. MR imaging features of acute bilateral renal cortical necrosis. *Am J Kidney Dis* 2000;35:745-8.
24. Fulgham PF, Assimos DG, Pearle MS, Preminger GM. Clinical effectiveness protocols for imaging in the management of ureteral calculous disease: AUA technology assessment. *J Urol* 2013;189:1203-13.
25. Blaustein DA, Myint MM, Babu K, Avram MM, Chandramouli BS. The role of technetium-99m MAG3 renal imaging in the diagnosis of acute tubular necrosis of native kidneys. *Clin Nucl Med* 2002;27:165-8.
26. Ellenbogen PH, Scheible FW, Talner LB, Leopold GR. Sensitivity of gray scale ultrasound in detecting urinary tract obstruction. *AJR Am J Roentgenol* 1978;130:731-3.
27. Gamss R, Stein MW, Rispoli JM, et al. What is the appropriate use of renal sonography in an inner-city population with new-onset acute kidney injury? *J Ultrasound Med* 2015;34:1639-44.
28. Keyserling HF, Fielding JR, Mittelstaedt CA. Renal sonography in the intensive care unit: when is it necessary? *J Ultrasound Med* 2002;21:517-20.
29. Licurse A, Kim MC, Dziura J, et al. Renal ultrasonography in the evaluation of acute kidney injury: developing a risk stratification framework. *Arch Intern Med* 2010;170:1900-7.
30. Jovanovic D, Gasic B, Pavlovic S, Naumovic R. Correlation of kidney size with kidney function and anthropometric parameters in healthy subjects and patients with chronic kidney diseases. *Ren Fail* 2013;35:896-900.
31. Takata T, Koda M, Sugihara T, et al. Left renal cortical thickness measured by ultrasound can predict early progression of chronic kidney disease. *Nephron* 2016;132:25-32.
32. 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;56:1052-9, 60 e1; discussion 1059-60.
33. Guinot PG, Bernard E, Abou Arab O, et al. Doppler-based renal resistive index can assess progression of acute kidney injury in patients undergoing cardiac surgery. *J Cardiothorac Vasc Anesth* 2013;27:890-6.
34. Marty P, Ferre F, Labaste F, et al. The Doppler renal resistive index for early detection of acute kidney injury after hip fracture. *Anaesth Crit Care Pain Med* 2016;35:377-82.
35. Ninet S, Schnell D, Dewitte A, Zeni F, Meziani F, Darmon M. Doppler-based renal resistive index for prediction of renal dysfunction reversibility: A systematic review and meta-analysis. *J Crit Care* 2015;30:629-35.
36. Boddi M, Bonizzoli M, Chiostrì M, et al. Renal resistive index and mortality in critical patients with acute kidney injury. *Eur J Clin Invest* 2016;46:242-51.
37. Grun OS, Herath E, Weihrauch A, et al. Does the measurement of the difference of resistive indexes in spleen and kidney allow a selective assessment of chronic kidney injury? *Radiology* 2012;264:894-902.
38. Balk EM, Raman G, Adam GP, et al. Renal artery stenosis management strategies: an updated comparative effectiveness review. Rockville (MD): Agency for Healthcare Research and Quality (US); 2016 Aug. Report No.: 16-EHC026-EF.
39. Mendu ML, Lundquist A, Aizer AA, et al. Clinical predictors of diagnostic testing utility in the initial evaluation of chronic kidney disease. *Nephrology (Carlton)* 2016;21:851-9.
40. Lucisano G, Comi N, Pelagi E, Cianfrone P, Fuiano L, Fuiano G. Can renal sonography be a reliable diagnostic tool in the assessment of chronic kidney disease? *J Ultrasound Med* 2015;34:299-306.
41. Makusidi MA, Chijioke A, Braimoh KT, Aderibigbe A, Olanrewaju TO, Liman HM. Usefulness of renal length and volume by ultrasound in determining severity of chronic kidney disease. *Saudi J Kidney Dis Transpl* 2014;25:1117-21.
42. Yaprak M, Cakir O, Turan MN, et al. Role of ultrasonographic chronic kidney disease score in the assessment of chronic kidney disease. *Int Urol Nephrol* 2017;49:123-31.
43. Beland MD, Walle NL, Machan JT, Cronan JJ. Renal cortical thickness measured at ultrasound: is it better than renal length as an indicator of renal function in chronic kidney disease? *AJR Am J Roentgenol* 2010;195:W146-9.
44. Kidney International. KDIGO clinical practice guideline for acute kidney injury. Suppl Appendices A to F. Available at: https://kdigo.org/wp-content/uploads/2016/10/KDIGO-AKI-Suppl-Appendices-A-F_March2012.pdf. Accessed September 30, 2020.
45. Dewulf K, Abraham N, Lamb LE, et al. Addressing challenges in underactive bladder: recommendations and insights from the Congress on Underactive Bladder (CURE-UAB). *Int Urol Nephrol* 2017;49:777-85.
46. Veenboer PW, Bosch JL, van Asbeck FW, de Kort LM. Upper and lower urinary tract outcomes in adult myelomeningocele patients: a systematic review. *PLoS One* 2012;7:e48399.
47. Dray EV, Cameron AP. Identifying patients with high-risk neurogenic bladder: beyond detrusor leak point pressure. *Urol Clin North Am* 2017;44:441-52.
48. Groen J, Pannek J, Castro Diaz D, et al. Summary of European Association of Urology (EAU) guidelines on neuro-urology. *Eur Urol* 2016;69:324-33.
49. Panicker JN, Fowler CJ, Kessler TM. Lower urinary tract dysfunction in the neurological patient: clinical assessment and management. *Lancet Neurol* 2015;14:720-32.
50. Liao L. Evaluation and management of neurogenic bladder: what is new in China? *Int J Mol Sci* 2015;16:18580-600.
51. Olandoski KP, Koch V, Trigo-Rocha FE. Renal function in children with congenital neurogenic bladder. *Clinics (Sao Paulo)* 2011;66:189-95.
52. Veenboer PW, Hobbelink MG, Ruud Bosch JL, et al. Diagnostic accuracy of Tc-99m DMSA scintigraphy and renal ultrasonography for detecting renal scarring and relative function in patients with spinal dysraphism. *Neurourol Urodyn* 2015;34:513-8.
53. Amarenco G, Sheikh Ismael S, Chesnel C, Charlanes A, LE Breton F. Diagnosis and clinical evaluation of neurogenic bladder. *Eur J Phys Rehabil Med* 2017;53:975-80.
54. Pannek J, Bartel P, Gocking K, Frotzler A. Clinical usefulness of ultrasound assessment of detrusor wall thickness in patients with neurogenic lower urinary tract dysfunction due to spinal cord injury: urodynamics made easy? *World J Urol* 2013;31:659-64.
55. Cameron AP, Rodriguez GM, Schomer KG. Systematic review of urological followup after spinal cord injury. *J Urol* 2012;187:391-7.
56. Adriaansen JJE, van Asbeck FWA, Bongers-Janssen HMH, et al. Description of urological surveillance and urologic ultrasonography outcomes in a cohort of individuals with long-term spinal cord injury. *Top Spinal Cord Inj Rehabil* 2017;23:78-87.
57. American College of Radiology. ACR Appropriateness Criteria® radiation dose assessment introduction Available at: <https://www.acr.org/-/media/ACR/Files/Appropriateness-Criteria/RadiationDoseAssessmentIntro.pdf>. Accessed September 30, 2020.