The role of magnetic resonance (MR) imaging in the evaluation of renal pathologies is becoming increasingly important. MR imaging is now considered a modality complementary to computed tomography (CT) and ultrasound (US). Using up-to-date equipment, it is possible to obtain high-quality images of the kidneys and perirenal spaces; MR imaging provides information particularly useful for the staging of renal neoplasms. The use of fast imaging techniques may also provide information regarding renal function and allow for selective direct imaging of the entire urinary tract.

10.1.1 Coils and Patient Positioning

MR imaging of the kidneys is performed with a phased-array coil that increases the signal-to-noise ratio by factor of 2 to 3, allowing the use of smaller fields-of-view (FOV) to obtain high-resolution images. The patient is positioned supine in the gantry. It is preferable to ask the patient to fast from solid and liquid foods to avoid filling the intestinal loops. This is particularly important when performing MR urography, given that the gastrointestinal tract could be superimposed over the
upper urinary tract during three-dimensional reconstruction, and thereby impair the final image quality. To reduce motion artifacts due to excursion of the abdominal wall during respiration, it may be helpful to use a compression band. Breath-hold sequences or respiratory compensation should be used to avoid misregistration artifacts due to respiration. A further reduction of motion artifacts due to peristalsis of the gastrointestinal tract can be achieved by using either glucagon or scopolamine hydrobromide. Intramuscular and/or intravenous injection of one of these drugs immediately prior to MR examination reduces peristalsis.

10.1.2 Sequence Protocol

Both in-phase and opposed-phase T1-weighted gradient-echo (T1-GRE) and axial, fat-suppressed Turbo-Spin-Echo (TSE) T2-weighted images are acquired from the dome of the diaphragm to the lower pole of the kidneys (Table 10.1). These T1-weighted GRE images are acquired with both a TE of 4.2 ms (in-phase) and a TE of 2.1 ms (out of phase) to detect lipid in renal or adrenal lesions. Breath-hold fat-saturated T1-GRE images are acquired before and during the dynamic intravenous administration of gadolinium; the same GRE sequence is repeated over time, e.g., after 30 s, 60 s, 90 s, 120 s, and 180 s. The contrast-enhanced portion of the examination may be performed either as two-dimensional (2D) or three-dimensional (3D) sequences. The plane of 2D imaging should be chosen to allow dynamic evaluation of both kidneys and is generally the coronal plane. The coronal plane is often advantageous for imaging of renal neoplasms, because it allows evaluation of both kidneys, the renal vessels, the inferior vena cava, and the spine in a small number of slices. The imaging FOV generally varies between 30 cm and 40 cm, according to the size of the patient. The matrix size is 192–256 (phase) × 256–512 (frequency), depending on the characteristics of the MR equipment.

If the upper urinary tract has to be studied, MR urography can be performed. If a hydroureteronephrosis is present, either a respiratory-compensated 3D heavily T2-W TSE sequence or a breath-hold half-Fourier acquisition single-shot turbo spin-echo (HASTE) sequence can be acquired in the coronal plane (Table 10.1). To reduce the fat signal and increase the contrast resolution, a technique for fat suppression should be used when performing TSE MR urography. Contrast-enhanced MR urography is not routinely performed as part of the evaluation of renal masses, although it is included as part of the evaluation of suspected transitional cell carcinoma. For this examination, 10 mg of furosemide is injected along with the gadolinium, dynamic-enhanced 2D or 3D images of the kidney are acquired as described previously, and then the kidneys, ureters, and urinary bladder are imaged with a coronal, fat-suppressed 3D GRE sequence with or without respiratory triggering.

Table 10.1. Pulse sequence recommendations for the kidneys

<table>
<thead>
<tr>
<th>Sequence</th>
<th>WI</th>
<th>Plane</th>
<th>No. of slices</th>
<th>TR (ms)</th>
<th>TE (ms)</th>
<th>Flip angle</th>
<th>Slice thickness (mm)</th>
<th>Matrix</th>
<th>FOV</th>
<th>No. of acq.</th>
<th>Acq. time (min)</th>
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<tr>
<td>GRE (in-phase and opposed-phase) breath-hold</td>
<td>T1</td>
<td>Axial</td>
<td>10–20</td>
<td>50–300</td>
<td>4.2, 2.1</td>
<td>90</td>
<td>6</td>
<td>196×256</td>
<td>300–400</td>
<td>1</td>
<td>&lt;0.30</td>
</tr>
<tr>
<td>TSE (fat-suppressed) breath-hold</td>
<td>T2</td>
<td>Axial</td>
<td>10–20</td>
<td>4000–6000</td>
<td>100–150</td>
<td>60–90</td>
<td>6</td>
<td>256×256</td>
<td>300–400</td>
<td>2</td>
<td>&lt;0.30</td>
</tr>
<tr>
<td>GRE (fat-suppressed) breath-hold</td>
<td>T1</td>
<td>Axial or coronal</td>
<td>10–20</td>
<td>50–300</td>
<td>Min</td>
<td>90</td>
<td>6</td>
<td>128–192</td>
<td>300–400</td>
<td>1</td>
<td>&lt;0.30</td>
</tr>
<tr>
<td>MR urography 2D or 3D TSE/HASTE</td>
<td>T2</td>
<td>Coronal</td>
<td>15–20</td>
<td>&gt;3000</td>
<td>&gt;500</td>
<td>&lt;180</td>
<td>2–4</td>
<td>128×256</td>
<td>300–400</td>
<td>2–4</td>
<td>&lt;5</td>
</tr>
<tr>
<td>3D GRE (fat-suppressed) breath-hold</td>
<td></td>
<td>Coronal</td>
<td>10–20</td>
<td>Min</td>
<td>Min</td>
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<td>2</td>
<td>512×192</td>
<td>300–400</td>
<td>2</td>
<td>&lt;30</td>
</tr>
</tbody>
</table>

WI weighting of images, Matrix phase × frequency matrix, Acq. acquisition(s)
10 Kidneys and Adrenal Glands

Single TSE, HASTE MR urography and contrast-enhanced MR urography images have to be reconstructed to obtain a 3D display; this is typically done using a maximum intensity projection (MIP) algorithm. For the assessment of pathologies in MR urography, it is important also to evaluate the raw data, which allows identification of small obstructing pathologies that are often not visible on the 3D display.

10.1.3 Normal Anatomy and MR Imaging Patterns of the Kidney

T1-GRE images allow for differentiation between the hyperintense peripheral cortex of the kidneys and the hypointense central medulla. Although evident in all planes, the septa of Bertin and the medullary pyramids are particularly noticeable in coronal images. Differentiation between the cortex and medulla can be improved using FS T1-W sequences. The cortex is highly vascularized by the arterial network; therefore, dynamic studies following i.v. injection of contrast agent allow for better differentiation between the renal zones and enable the collection of functional information about the kidneys. On T2-WI, both the renal cortex and medulla are hyperintense. Therefore, T2-WI do not provide good anatomical information for differentiating between the two renal zones.

10.1.4 Clinical Applications

10.1.4.1 Congenital Anomalies

The kidneys may present with abnormalities in number, position, rotation, and fusion. Bilateral renal agenesis is not compatible with life, whereas unilateral agenesis is not so rare (0.01%–0.02%). The kidneys may also be located in an anomalous position (in any possible location from the thorax to the pelvis) or may be fused. Several fusion abnormalities exist, but the more common ones are the horseshoe and pancake kidneys. The multiplanar capabilities of MR imaging in combination with breath-hold sequencing greatly facilitate the identification of renal anomalies.

10.1.4.2 Medical Renal Diseases

MR imaging is not currently used for the assessment of medical renal pathologies, either infectious or noninfectious. In fact, US or CT are typically employed for this purpose. If CT is needed but the patient is intolerant to iodinated contrast agents, MR imaging may be requested. Diffuse bilateral enlargement of the kidneys may be seen in a variety of renal parenchymal diseases, including acute glomerulonephritis, interstitial nephritis, postactinic nephritis, and nephrotic syndrome. In all of these pathologies, edema and loss of the corticomedullary junction are evident in T1-WI. MR imaging may also be useful for demonstrating parenchymal atrophy in small kidneys that have reduced corticomedullary differentiation and sinus lipomatosis.

10.1.4.3 Obstructive Nephropathy

Dilatation of the renal collecting structures, pelvis, and ureters can be seen well in both T1-WI and T2-WI. The degree of obstruction can be determined by analyzing sequential axial images, heavily T2-W MR urography, and contrast-enhanced MR urography images. The cause of obstruction can also be determined by evaluating either axial images or coronal MR urograms (Fig. 10.1). The appearance of the renal parenchyma varies depending on the duration of the obstruction. In the case of chronic obstruction, a marked reduction of the corticomedullary junction is evident, whereas in the case of acute obstruction, it remains normal. Renal function can be evaluated using i.v. contrast agents, which normally do not become concentrated in obstructed kidneys.

10.1.4.4 Renal Cystic Disease

Simple renal cysts are the most common benign renal masses. They typically appear as well-defined round masses, with a homogeneously low signal intensity on T1-WI, a homogeneously high signal intensity on T2-WI, and no contrast enhancement (Fig. 10.2). Infected cysts may present with an inhomogeneous signal intensity on both T1-WI and T2-WI.

MR is particularly useful to differentiate typical simple cysts (Fig. 10.2) from complicated cysts, abscesses,
and cystic or hypovascular renal carcinomas. A good measure for this purpose is Bosniak's classification where cystic lesions are described into four categories.

Category 1: simple benign cyst (T1-hypointense, T2-hyperintense, T1+Gd-no enhancement) with a thin wall, protein content may cause high SI on T1-WI.

Category 2: probably benign cyst with some additional features like thin septa which may show some contrast enhancement, small calcifications, signs of hemorrhage or protein (T1-hypointense – hyperintense, T2-hyperintense – hypointense, T1+Gd-no enhancement), but homogeneous, a smooth wall, and no contrast enhancement.

Category 3: indeterminate cyst and potentially malignant with inhomogeneous signal, irregular walls, thick and irregular calcifications (CT), and thickened contrast enhancing septa.

Category 4: probably malignant cyst with an irregular and thickened wall, areas of contrast enhancement are typically present, solid components on T2-WI.

10.1.4.5
Benign Renal Neoplasms

Benign renal neoplasms are quite uncommon. The most frequent benign lesion that can be accurately diagnosed with MR imaging is angiomyolipoma, due to the presence of fat within the lesion. The use of fat-suppressed sequences, either T1-W or T2-W, allows for the detection of fat within the lesion and for making the diagnosis of an angiomyolipoma (Fig. 10.3).

Further clinically presenting benign renal neoplasm's are lipoma, oncocytoma, and adenoma. Lipomas are diagnosed applying the same criteria as explained for angiomyolipomas. Oncocytomas (Fig. 10.4) are typically small in size (<3 cm), may exhibit a central scar, a capsule, are hypointense on T1-WI, hyperintense on T2-WI, are well perfused, and may show a wheel-type perfusion pattern (20–80%). Adenomas do not present with typical imaging patterns.

10.1.4.6
Malignant Renal Neoplasms

Renal cell carcinoma is the most frequent malignant renal neoplasm. In many cases, it is quite advanced at the time of diagnosis, given that the neoplasm is asymptomatic when small. In the preoperative assessment, MR
Fig. 10.2. Renal cyst. Category 1 renal cysts (upper row) and category 2 renal cyst (lower row) in two different patients. The simple bilateral benign cysts show typical high SI on T2-W HASTE (left), low SI on plain FS-2D GRE-coronal T1 (middle), and no enhancement on Gd-enhanced FS-2D GRE-coronal T1 (right). The category 2 cyst (right kidney) shows signal characteristics consistent with hemorrhage. T2-W HASTE (left) demonstrates the cyst homogeneously hypointense, FS-3D GRE-axial T1 (middle) with homogeneous high SI, and with constant high SI on Gd-enhanced FS-3D GRE-axial T1 (right) without further enhancement.

Fig. 10.3A–C. Angiomyolipoma. GRE T1-W axial image (A) shows the presence of angiomyolipoma in the right kidney. The presence of fat is well demonstrated by GRE FS T1-weighted image in-phase (B) and T1-weighted image opposed-phase (C).
imaging may be useful in identifying the lesion and determining the degree of infiltration into the perinephric space and/or adjacent organs, the presence of enlarged lymph nodes, and venous tumoral thrombosis. Renal cell carcinoma has a variable appearance in MR images; in most instances, it is isointense in both T1-WI and T2-WI, although it is generally more obvious in T1-WI, especially if small. Postcontrast images may be helpful in identifying small renal cell carcinomas. Renal cell carcinoma is typically hypervascular and thus appears hyperintense in the early phase following i.v. administration of paramagnetic contrast agents. Rapid contrast-enhanced MR imaging has a greater sensitivity for the detection of small (<3 cm) renal cell carcinomas than conventional sequences (Fig. 10.5).

MR imaging has also proved accurate for staging renal cell carcinomas. Although the most accurate technique in all stages, MRI is particularly useful in stage III, in which there is infiltration of the renal vein and/or inferior vena cava, and in stage IV, in which there is infiltration of adjacent organs. The neoplastic thrombus generally has the same signal intensity as the tumor. MR imaging is more accurate for demonstrating tumor extension into the vena cava than CT or US; however, the accuracy of MR imaging for demonstrating renal vein thrombosis is somewhat lower. The infiltration of adjacent organs can be demonstrated by exploit-
ing the multiplanarity of MR imaging – particularly using coronal and sagittal images – and the alteration of signal intensity that can be observed in an infiltrated organ. The accuracy of MR imaging in stage IV ranges between 80% and 95%. MR imaging is at least comparable to CT in the assessment of recurrent renal cell carcinomas (Fig. 10.6).

10.1.4.7  
**Uroepithelial Neoplasms**

Uroepithelial neoplasms are much less common than renal cell carcinoma; uroepithelial carcinomas are generally localized in the ureter or in the bladder and rarely occur in the kidney. In most cases, they result in dilatation of the calices and/or the pelvis, depending on where the neoplasm is located. Conventional MR images do not have great sensitivity for the identification of uroepithelial carcinomas; these are better identified by means of MR urography, which can substitute for i.v. urography and more invasive exams, such as ascending pyelography (Fig. 10.7). Transitional-cell carcinomas appear as a filling defect within the collecting system, similar to that seen using conventional methods. The most common renal neoplasm in children is Wilms’ tumor or nephroblastoma. It is a large solid mass, which generally appears isointense on T1-WI and hyperintense on T2-WI.

10.1.4.8  
**Metastatic Disease**

Several primary neoplasms, including those of the lung, breast, colon, and stomach, and those associated with melanoma, leukemia, and lymphoma may metastasize to the kidneys. Focal renal metastasis is rare, usually small, and cannot be easily differentiated from renal cell carcinoma. Metastasis from lymphoma and leukemia generally determine an unilateral or bilateral parenchymal enlargement with loss of corticomedullary differentiation on T1-WI. Lymphoma may also produce focal metastasis to the kidneys, which is not different from other cases of focal metastasis.

10.1.4.9  
**Evaluation of Renal Allografts**

Transplanted kidneys must often be evaluated using several imaging modalities. For this purpose, sonography is generally utilized, although MR imaging may also provide important information about renal function and for identifying the presence of lymphoproliferative disorders. For this purpose, pre- and postcontrast images should be acquired. Precontrast T1-WI and T2-WI provide information about the morphology of the kidneys and the presence of surgical complications (fluid collections). Dynamic postcontrast images can be useful to determine renal function and, in particular, to demonstrate the presence of lymphoproliferation (with poor differentiation between the renal cortex and medulla).
10.2  
**MR Imaging of the Adrenal Glands**

The retroperitoneally located, paired adrenal glands are comprised of two separate functional units: the cortex, developing from the mesoderm, and the medulla, developing from ectodermal cells of the neural crest. The adrenal cortex comprises three distinct histological areas: (1) the zona glomerulosa, (2) zona fasciculata, and (3) zona reticularis. The mineralocorticoids, the main representative of which is aldosterone, are synthesized and secreted in the zona glomerulosa, whereas the glucocorticoid steroids and androgens are synthesized and secreted in the zona fasciculata and reticularis. In the adrenal medulla, the chromaffin cells synthesize, store, and secrete the catecholamines adrenaline and noradrenaline. The excellent soft-tissue contrast of MRI allows for good morphological delineation of adrenal masses. In addition to morphological evaluation, MRI is useful for differentiating between benign and malignant etiologies. MRI is frequently employed to further characterize adrenal masses incidentally identified on CT or US.

### 10.2.1  
**Coil and Patient Positioning**

The patient should be positioned so that the adrenal glands are at or near the plane of the isocenter of the magnet. Adrenal MRI is typically performed with a body phased-array coil.

### 10.2.2  
**Sequence Protocol**

The image quality can be further improved using flow compensation, spatial presaturation pulses above and below the imaging volume, and respiratory compensation (phase-encoding artifact reduction for T1-WI and respiratory triggering for T2-WI). The phase-encoding direction must, however, be chosen carefully in the different planes so as not to obscure the region of interest with ghost artifacts. In addition, axial FS T2-W TSE sequences and coronal T1-W GRE sequences may be helpful (Table 10.2). Fat suppression also reduces res-

---

Fig. 10.7A–C. Uroepithelial neoplasm. HASTE T2-WI, in coronal (A) and axial (B) view, show a dilatation of the left uretheres due to a mass in a distal portion (C)
piratory-motion-induced artifacts and noise, thus giving a sharper depiction of the adrenals. The dynamic range of the abdominal signal intensity is reduced and the gray scale expanded, accentuating small differences in tissue contrast. Although screening examinations generally require imaging in only the transverse plane, coronal T1-WI are useful for defining the relationships between the adrenal glands and the surrounding organs.

If an adrenal mass lesion is detected, in-phase and opposed-phase breath-hold GRE sequences are performed (Table 10.2). This approach reveals fat within adenomas, which is typically not present within metastases. The signal of an in-phase image is derived from the signal of water plus fat protons, whereas the signal of an opposed-phase image is derived from the difference between the signal of water and fat protons. A fat-containing lesion will therefore show significantly less signal in opposed-phase images than in in-phase images. Clinically, a 50% decrease in signal is accepted as a cut-off value for diagnosing an adenoma. No further imaging tests or biopsies are required to establish the diagnosis of an adenoma and to rule out a metastasis. If no signal decrease can be measured, further imaging is required. This includes T2-W and dynamic gadolinium-enhanced T1-W MR imaging. Postcontrast T1-WI are useful for determining the enhancement characteristics of adrenal masses. Angiographic studies are useful for identifying vascular structures or assessing vascular invasion of adrenal malignancy. Phase-contrast sequences and breath-hold CE 3D MR angiography (MRA) sequences are both useful.

### 10.2.3 Normal Anatomy and MR Imaging Patterns of Adrenal Glands

The adrenal glands are located at the level of the eleventh or twelfth rib, lateral to the vertebrae, bound by the superior portion of Gerota’s fascia in the anterosuperior aspect of the perinephric space, and surrounded by fatty areolar tissue. The right adrenal gland is superior to the upper renal pole, immediately posterior to the inferior vena cava, medial to the posterior segment of the right hepatic lobe, and lateral to the crus of the diaphragm. The left adrenal gland is slightly lower in relation to the left kidney and lies anteromedial to its upper pole, lateral to the crus, posterolateral to the aorta, and posteromedial to the splenic vessels and pancreatic tail. Morphologically, the adrenal gland is separated into an anteromedially located body and two posterior or posterolateral limbs. The configuration of the adrenals is quite varied, with inverted V or Y shapes being the most common (Fig. 10.8). The normal adrenal gland appears dark on both MR T1-WIs and T2-WIs, relative to most other tissues. The gland is of similar or lower signal intensity when compared with liver and muscle. MR cannot differentiate the cortex from the medulla.

<table>
<thead>
<tr>
<th>Sequence</th>
<th>WI</th>
<th>Plane</th>
<th>No. of slices</th>
<th>TR (ms)</th>
<th>TE (ms)</th>
<th>Flip angle</th>
<th>Slice thickness (mm)</th>
<th>Matrix</th>
<th>FOV</th>
<th>No. of acq.</th>
<th>Acq. time (min)</th>
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<tr>
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<td>T1</td>
<td>Axial</td>
<td>10–20</td>
<td>50–300</td>
<td>4.2, 2.1</td>
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<td>196×256</td>
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<tr>
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<td>10–20</td>
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<td>100–150</td>
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<td>Min</td>
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<td>TSE breath-hold</td>
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</table>

WI weighting of images, Matrix phase × frequency matrix, Acq. acquisition(s)
10.2.4
Clinical Applications of Adrenocortical Mass Lesions

10.2.4.1
Adrenal Hyperplasia

Hyperplasia of the adrenal cortex may develop in response to a variety of physiological and pathological stresses and may be associated with normal, elevated, or diminished production of adrenocortical hormones. Enlargement of the adrenal gland is usually more obvious in patients with Cushing’s syndrome than in those with Conn’s syndrome. Diffuse adrenocortical hyperplasia is characterized by bilateral homogeneous enlargement with preservation of normal glandular configuration and signal intensities on T1-WI and T2-WI. Macronodular hyperplasia, seen less commonly than diffuse hyperplasia, produces diffuse adrenal enlargement with one or more macroscopic cortical nodules, and it is more common in long-standing pituitary adrenocorticotropic hormone (ACTH) secretion. MRI demonstrates glandular enlargement and nodules based on contour distortion in patients with macronodular hyperplasia.

10.2.4.2
Adenoma

Adrenal adenomas consist of cords of clear cells separated by fibrovascular trabeculae. Macroscopically, the adrenal adenoma is a well-defined, rounded, homogeneous mass, typically less than 3 cm in diameter. Calcification, central necrosis, and hemorrhage are uncommon. Nonfunctioning adenomas are common, with a prevalence in the general population of approximately 3% and on abdominal CT examination of 0.6%–1.5%. Adrenal adenomas are imaged as homogeneous, localized masses of variable size, with a signal decrease on opposed-phase images relative to in-phase images (Table 10.2). The signal characteristics of nonhyperfunctioning adenomas are similar to those of the normal adrenal gland. They are typically hypointense on T1-WI and isointense or slightly hyperintense on T2-WI. On FS T2-WI, adenomas show a hyperintense rim that corresponds to a tumor capsule or peripherally compressed normal adrenal tissue, with a lower signal intensity core (Fig. 10.9). Relative to nonfunctioning adenomas, hyperfunctioning adenomas, especially aldosteronomas, exhibit increased signal intensities on T2-WI (Fig. 10.10). However, atypical nonfunctioning
adenomas exist that can be considerably hyperintense relative to liver on T2-WI, due to hemorrhage and necrosis. Thus, although a higher proportion of functional adenomas are hyperintense relative to the liver on T2-WI when compared with nonfunctioning adenomas, no consistent relationship between the MR characteristics and the adrenocortical function exists (Fig. 10.11).

10.2.4.3 Carcinoma

Adrenal cortical carcinoma is a rare, highly malignant tumor, accounting for less than 0.2% of all cancer deaths. It occurs more commonly on the left than on the right, and approximately 10% are bilateral. Approximately 50% of these tumors are functional, with hypercorticalism, virilization, and mixed syndromes predominating. Relative to liver, adrenal carcinomas typically show lower signal intensity in T1-WI and higher signal intensity in T2-WI (Fig. 10.12). Tumor heterogeneity, best demonstrated by the use of T2-WI, demonstrates areas of necrosis, hemorrhage, and dystrophic calcifications. Following the administration of paramagnetic contrast agents, large signal-intensity increases in the first minute, with delayed washout, are characteristic of adrenal carcinoma. Local invasion of adjacent organs is common, and extension through the adrenal vein, renal vein, or inferior vena cava may be seen. Lack of signal void in the morphological T1-WI and T2-WI indicates the presence of thrombus. Vascular involvement can be further evaluated using GRE imaging or CE 3D-MRA.

Fig. 10.9A–D. Nonfunctioning adrenal adenoma. Axial T1-W SE (A), T2-W TSE (B), in-phase (C), and opposed-phase GRE images (D) of a patient with a nonfunctioning adenoma within the right adrenal gland. The nonhyperfunctioning adenoma demonstrates similar signal characteristics to the normal adrenal gland with low signal intensity on T1-W image (A), moderate to slightly high signal intensity on T2-W image (B), and a signal decrease on the opposed-phase image (D) compared with the in-phase image (C).
10.2.4.4 Myelolipoma

Myelolipomas are benign tumors of the adrenal cortex, composed of mature adipose cells and hematopoietic tissue. Although associated endocrine disorders have been reported (Cushing’s syndrome, Conn’s syndrome, hermaphroditism, and intersex), those tumors are not hormonally active and are usually detected incidentally. On MR images, myelolipoma is hyperintense on all pulse sequences, and its intensity is similar to that of subcutaneous or retroperitoneal fat, with a significant signal decrease on FS T1-WI and FS T2-WI.

10.2.5 Clinical Applications of Medullary Mass Lesions

10.2.5.1 Pheochromocytoma

Pheochromocytomas are the most common tumors of the adrenal medulla. They arise from chromaffin cells and secrete catecholamines. Patients may present with a variety of symptoms, including episodic hypertension, flushing, and palpitations. The diagnosis of pheochromocytoma is made by the biochemical assay of catecholamines and their metabolites in blood or urine.
Fig. 10.11A–D. Bilateral adrenal adenomas. Axial T1-W SE (A), T2-W TSE (B), in-phase (C) and opposed-phase (D) GRE images of a patient with bilateral adenomas. The signal behavior on T1-W (A) and T2-W (B) images does not allow bilateral metastases in patients with malignant disease to be ruled out. However, the typical signal decrease on the opposed-phase image (D) compared with the in-phase image (C) clearly demonstrates the benign nature of the masses.

Fig. 10.12A,B. Adrenal carcinoma. Axial T1-W SE (A) and T2-W TSE (B) images of a large adrenal carcinoma within the right adrenal gland demonstrate low signal intensity on T1-W MR and high signal intensity on T2-W MR images.
Imaging tests are used primarily to localize the tumor. Pheochromocytomas can arise anywhere in the autonomic nervous system. However, 98% originate in the abdomen, predominantly (90%) in the adrenal medulla. Some 90% are sporadic, and 10% are part of a systemic disease, such as multiple endocrine neoplasia syndrome (MEN IIa or IIb), neurofibromatosis, or von Hippel-Lindau disease. Approximately 10% of pheochromocytomas are malignant, but the incidence is higher in extra-adrenal masses and in tumors greater than 6 cm in diameter. Malignancy can often be identified only by the presence of metastases and not by the microscopic appearance. Hormonal activity is detected in 90% of pheochromocytomas. Most pheochromocytomas are hypointense on T1-WI and markedly hyperintense on T2-WI. Although typical, these appearances on T2-WI are not specific, as there is some overlap with necrotic adrenal metastases, and 35% of pheochromocytomas may not have a long T2. Although the use of paramagnetic contrast agents is rarely necessary, as with CT, pheochromocytomas enhance markedly following injection (Fig. 10.13).

10.2.5.2 Hemorrhage

Adrenal hemorrhage is usually found in the adrenal medulla and invades the surrounding cortex. Adrenal hemorrhage may be spontaneous, traumatic, or related to anticoagulation. Most adrenal hematomas are resorbed, but sometimes they liquefy and persist as adrenal pseudocysts. The MR appearance of adrenal hemorrhage varies as it evolves from acute to chronic stages (see Chapter 3). High signal intensity on T1-WI and T2-WI in the acute and subacute stages of adrenal hemorrhage reflect the presence of hemoglobin oxidation products (methemoglobin) that are paramagnetic (Fig. 10.14).

10.2.5.3 Neuroblastoma

Neuroblastoma is the most common tumor in children younger than 5 years of age. The tumor originates from undifferentiated cells of the neural crest ectoderm of the sympathetic ganglia. Frequently, neuroblastomas are hormonally active, producing catecholamines or less-active precursors that may be detected in urine. Neuroblastomas are iso- to hyperintense in T1-WI and hyperintense in T2-WI, relative to muscle or liver. Calcifications, seen in 40%–50% of neuroblastomas, are not well imaged with MRI. This disadvantage is offset by the ability to use MRI to image the orthogonal planes, which may be of help in staging.

Fig. 10.13A–C. Pheochromocytoma. Axial plain T1-W SE (A), contrast-enhanced T1-W SE (B), and T2-W TSE (C) images demonstrate a large mass within the right adrenal gland. The mass is hypointense on T1-W MR (A) with strong contrast enhancement (B) and high signal intensity on T2-W MR (C), reflecting the hypervascular nature of this tumor.
10.2.6 Lesions Affecting Both Cortex and Medulla

10.2.6.1 Cysts

Adrenal cysts are uncommon lesions that may occur at any age. Based on their pathological origin, adrenal cysts have been classified into four types: (1) endothelial cysts (45%), (2) pseudocysts (39%), (3) epithelial cysts (9%), and (4) parasitic cysts (7%). Simple adrenal cysts are hypointense on T1-WI, hyperintense on T2-WI, and demonstrate no contrast enhancement.

10.2.6.2 Metastases

Virtually any malignancy may spread hematogenously to the adrenals. Lung and breast carcinomas are the most common source of adrenal metastasis, followed by gastric, thyroid, and pancreatic carcinomas. During autopsy, adrenal metastases have been detected in up to 27% of cancer patients. Adrenal metastases are pleomorphic; the majority are relatively small, although they may attain almost any size. As with other adrenal neoplasms, the small lesions are generally homogeneous; the larger ones are commonly heterogeneous as a result of hemorrhage and necrosis. Adrenal metastases are bilateral in approximately 40% of cases. In MR imaging, metastases are generally hypointense to liver on T1-WI but significantly hyperintense to liver on T2-WI obtained with or without fat-suppression techniques. Metastases show no significant signal decrease on opposed-phase images (Fig. 10.15).

10.2.7 Incidental Masses

Unknown adrenal masses are detected incidentally in up to 1% of abdominal CT examinations. Characterization is necessary in those patients with extra-adrenal primary malignancy, because curative surgery or radiation therapy for the primary tumor is usually contraindicated if the adrenal mass is depicted as a metastatic lesion. Different therapeutic approaches are usually undertaken for primary malignant lesions if the adrenal mass can be shown to be benign. On SE imaging, most adenomas appear hypointense to isointense in both T1-WI and T2-WI relative to liver; most nonadenomas, including metastasis, appear hyperintense in T2-WI. Quantitatively, when calculating signal-intensity ratios, a 20%–30% overlap between adenomas and nonadenomas exists. Gadolinium-enhanced images show mild enhancement of adenomas with a quick washout, whereas malignant tumors and pheochromocytomas show strong enhancement and slower washout. However, considerable overlap of benign and malignant masses also exists for gadolinium-enhanced MRI. The in-phase/opposed-phase approach provides a better discrimination of adenomas and nonadenomas, because adenomas generally contain large lipid-laden...
cells, whereas malignant lesions contain little or no fat. Therefore, adenomas homogeneously lose signal intensity on opposed-phase images when compared with in-phase images, whereas metastases remain unchanged (Figs. 10.9, 10.11, 10.15). Differential diagnoses to be considered when a heterogeneous signal decrease is present include fat-containing metastases, HCC, and liposarcoma. Rarely, functioning adenomas may contain such a low lipid content that a significant loss of signal on opposed-phase images cannot be observed.

**Further Reading**


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Fig. 10.15A–C. Bilateral adrenal metastases. Axial T1-W SE (A), T2-W FS TSE (B), and opposed-phase (C) GRE images of a patient with bilateral metastases from lung cancer. The signal behavior on T1-W MR (A) does not allow the diagnosis of bilateral metastases to be made. However, the irregular high signal intensity on T2-W FS TSE (B) and the absent signal decrease on opposed-phase GRE (C) demonstrate the malignant nature of the masses.