MRI in Diagnosis of Retroperitoneal Tumors

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1 MRI Technique to Image Abdominal (Pelvic) Retroperitoneum

1.1 Basic Working Principle of MRI

Magnetic resonance imaging (MRI) is an imaging technique by which image reconstruction is generated using nuclear resonance signal in strong magnetic fields. MRI scanners also use radio waves and field gradients to form images of the body. In the natural state, ^{1}H spins randomly. However, in the presence of a strong external magnetic field, ^{1}H aligns with or opposite to the direction of applied field at a specific frequency (the frequency of spin precession is determined by the external magnetic field), known as the equilibrium state of [1]H. At this point, if pulsed radiofrequency (PRF) stimulation with the same frequency is applied to the human body, ^{1}H in the body will absorb the energy of RF pulse. This process is called magnetic resonance. When the applied PRF suddenly disappears, the in vivo ^{1}H will release the absorbed energy and recovers to the equilibrium state. After comprehensively processing the released energy, a precise MRI image will be constructed. An MRI sequence is an ordered combination of RF and gradient pulses designed to acquire the data to form the image.

1.2 Relaxation Time

Relaxation is the process in which ^{1}H goes from a higher energy state back to the lower energy state after the applied RF pulse has disappeared, and relaxation time is the duration required for this whole process. It consists of two simultaneous events: (1) longitudinal relaxation time, which is required for ^{1}H to rise from zero to the maximum amount of magnetization along the Y-axis, i.e., T_1 relaxation time. The image that demonstrates the differences in T_1 relaxation times among tissues is called T_1-weighted image (T_1WI); (2) horizontal relaxation time, which is required for ^{1}H, reduces from the maximum amount of magnetization to zero along the X-axis, i.e., T_2 relaxation time. The image that reflects the differences in T_2 relaxation times among tissues is called T_2WI. Each tissue has relatively stable relaxation time.

1.3 MRI Signal

On T_1WI, signal intensity (SI) is inversely related to T_1 relaxation time: the longer T_1, the lower SI, and vice versa. For example, water, muscle, and adipose show low-, moderate-, and high-intensity signal on T_1WI, respectively. On T_2WI, SI is positively related to T_2 relaxation time: the longer

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the T_2, the higher SI, and vice versa. Here, water, muscle, and adipose show high-, moderate-, and moderate- to slightly high-intensity signal on T_2WI, respectively. Air and compact bone show low-intensity signal on both T_1WI and T_2WI due to less absorption of ^1H. Intravascular blood flow generally shows low signal (flow void effect).

1.4 Scanning Protocol

Spin-echo T_1WI and fast spin-echo T_2WI are conventional MRI sequences for detecting retroperitoneal lesions. On such basis, additional fat-suppressed T_1WI or T_2WI scan is performed when appropriate. Spin-echo or fast spin-echo sequence can be employed to conventional or dynamic Gd-DTPA-enhanced scanning, respectively. To show the relationship between the retroperitoneal tumor and adjacent important blood vessels or ureters, MR angiography (MRA) or MR urography (MRU) are performed to evaluate the ureteral or vascular invasion. Cross-sectional, sagittal and coronal planes are routine.

2 MRI Interpretation Skills for Retroperitoneal Tumors

Diagnostic MRI plays a vital role in localization and quantification of retroperitoneal tumors.

For retroperitoneal tumors, MRI is used to precisely localize the lesion, not only suggestive for qualitative diagnosis and is helpful in narrowing the differentiation range but also pivotal for the development of therapeutic strategies and the evaluation of clinical response. The first step is to determine whether the lesion is located in the retroperitoneal space. If yes, the second step is to narrow down to a specific space. For example, pancreatic cancer (in the tail of the pancreas) and liposarcoma are common in the left anterior extrarenal space; pancreatic cancer (in the head of the pancreas), liver cancer, liposarcoma, and gastrointestinal stromal tumors occur frequently in the right anterior extrarenal space; liposarcoma,

leiomyosarcoma, renal cancer, suprarenal gland tumor, and pedunculated hepatocellular carcinoma (P-HCC) (or extrahepatic growth of HCC) are often located in the perirenal space; malignant peripheral nerve sheath tumor (MPNST), malignant fibrous histiocytoma, leiomyosarcoma, paraganglioma, fibrosarcoma, teratoma, and lymphoma are usually located in the posterior renal space.

Retroperitoneal tumors are characterized by low incidence, numerous pathological types, and complex origins; in addition, MRI findings are varied and overlap each other and lack specificity (Goenka et al. 2012). Thus, it is not easy to quantitatively diagnose some retroperitoneal tumors with MRI images. A comprehensive analysis should be conducted based on the location, number, size, shape, margin, signal enhancement pattern of the lesion, as well as its relationship with surrounding organs, in combination with age, gender, medical, and clinical information of the patient. First, tumors should be roughly distinguished as benign from malignant; second, the possible cellular origin of the tumor should be considered, such as adipogenic, myogenic, neurogenic, and so on; and finally, the specific tumor may be determined successfully.

2.1 Location Diagnosis

The following signs are helpful in determining whether the tumor is located in the retroperitoneal space.

2.1.1 Retroperitoneal Organ or Vascular Displacement

Retroperitoneal tumors can push and compress retroperitoneal organs (such as the pancreas, suprarenal gland, kidney, ureter, ascending colon, descending colon, rectum, as well as the horizontal and ascending parts of duodenum) and blood vessels (such as abdominal aorta, celiac trunk, inferior vena cava, superior mesenteric artery, and superior mesenteric vein) to make them move forward or up and down. It is called

vascular or organ displacement syndrome. Tracking the direction of displaced organs or blood vessels is helpful in accurately locating the tumors (Nishino et al. 2003; Cohan et al. 1988).

2.1.2 Interface Signs of Retroperitoneal Tumors

When the boundary between the tumor and adjacent organs or structures disappears or becomes blurred, it is called the positive interface sign; vice versa, it is called the negative or absence of interface sign. Positive interface signs are defined when the fat space between the retroperitoneal tumor and posterior abdominal wall, psoas major or pelvic muscles, and retroperitoneal vessels or organs becomes invisible or blurred. Under the circumstance of a negative interface sign, compression and displacement of intraperitoneal viscera may suggest the tumor's location in the retroperitoneal space.

2.1.3 Imaging Signs of Tumors Originating from Retroperitoneal Organs (Nishino et al. 2003)

(a) Beak sign. When the boundary between the tumor and an adjacent organ becomes invisible, the interface is acute-angled, with the edge protruding like a beak. The beak sign indicates that the tumor may be derived from this specific organ. In contrast, if the edge of interface presents slightly arc shaped or obtuse angled, the tumor may arise from another organ. (b) Phantom (invisible) organ sign. The organ may become "undetectable" on MRI when a giant mass arises from it. However, false-positive findings cannot be completely ruled out. (c) Embedded organ sign. A tumor can encapsulate an adjacent organ partially or mostly, and closely relate to the organ, with disappearance of fat layer and ill-defined boundary. Such sign indicates the lesion originated from the specific organs being invaded. (d) Central area of the tumor. When the center or the main body of a tumor is located within an adjacent organ, the tumor may have originated from this organ. On the contrary, when the center

or the main body of the tumor is located outside an adjacent organ, the tumor may not arise from it. (e) Prominent feeding artery sign. MRI may display feeding arteries for hypervascular masses, thus providing important clues to identify the origin of the mass.

2.2 Etiologically Qualitative Diagnosis

2.2.1 Characteristic Components of Retroperitoneal Tumors

Specific tumor contents (such as fat, myxoid stroma, muscle fibers, calcification/ossification, hemorrhage, necrosis, and cystic degeneration) can be clearly demonstrated by MR imaging and thus provide vital clues for narrowing the scope of the differential diagnoses.

(a) Fat: The presence of fat is recognized as a high-intensity signal on T_1WI, middle to high-intensity signal on T_2WI, or loss of signal on fat-suppressed images, respectively. Fat-containing retroperitoneal tumors mainly include lipomyoma, lipoblastoma, liposarcoma, teratoma, angiomyolipoma, and myelolipoma.

(b) Myxoid stroma: Myxoid stroma appears hypointense on T_1WI, hyperintense on T_2WI, and progressive delayed enhancement after injection of contrast medium, respectively. Myxoid stroma-containing retroperitoneal tumors include neurogenic tumors, myxoid liposarcomas, and myxoid malignant fibrous histiocytoma (Otal et al. 2001; Kim et al. 1996).

(c) Collagen fiber: Collagen fiber displays as hypointense on both T_1WI and T_2WI and mild or progressive delayed enhancement after injection of contrast medium. Collagen fiber-containing retroperitoneal tumors mainly include neurofibromas, ganglioneuroma, leiomyosarcoma, malignant fibrous histiocytoma and fibrosarcoma.

(d) Calcification/ossification: Calcification/ossification is hypointense on T_2WI. MRI that cannot demonstrate the presence of

calcification/ossification as clearly as CT. Calcification/ossification-containing retroperitoneal benign tumors/tumor-like lesions include teratoma, hemangioma, giant lymph node hyperplasia, and benign lesions (such as cysts, hematoma, and abscess). Calcification/ossification-containing malignant tumors include malignant fibrous histiocytoma, neuroblastoma, angiosarcoma, liposarcoma, fibrosarcoma, ectopic osteosarcoma, synovial sarcoma, and ectopic chondrosarcoma.

(e) Necrosis: Necrotic areas within the tumor present as hypointense on T_1WI
and hyperintense on T_2WI, respectively and without contrast enhancement. Necrosis is usually seen in benign tumors (such as paraganglioma, neurilemmoma) as well as in malignant tumors (such as leiomyosarcoma, malignant fibrous histiocytoma, rhabdomyosarcoma, and synovial sarcoma).

(f) Cystic degeneration: cystic degeneration within the tumor has homogeneously long T_1 and long T_2 signals, similar to cerebrospinal fluid (CSF), without contrast enhancement. Retroperitoneal tumors or tumor-like lesions presenting as completely cystic denegation include lymphangioma, cystic myxoma (cystomyxoma), congenital cysts (epidermoid cyst, bronchogenic cyst, intestinal cyst, mesonephric tubular cyst) or pseudocyst. Solid-cystic masses include neurilemmoma, paragangliomas, and mucinous cystadenoma.

2.2.2 Enhancement Characteristics of Tumors

Enhanced scanning can reflect blood supply and angiogenesis of tumors to some extent (Otal et al. 2001). No enhancement or early enhancement with subsequently rapid clearance is common in benign lesions; however, early enhancement with slow or no clearance is common in malignant tumors (very few benign tumors); and delayed enhancement is frequent in malignant tumors (rarely in neurogenic tumors).

Extremely hypervascular retroperitoneal tumor/tumor-like lesions mainly include pheochromocytoma, paraganglioma, perivascular epithelioid cell tumor, and giant lymph node hyperplasia. Moderately hypervascular tumors include mucinous malignant fibrous histiocytoma, leiomyosarcoma, and the majority of sarcomas. Hypovascular tumors include well-differentiated liposarcoma, lymphoma, and the majority of benign tumors (Nishimura et al. 2001).

2.2.3 Determination of the Benign Versus Malignant Nature of Retroperitoneal Tumors

Benign tumors are generally small in size, with a regular shape, a smooth boundary, and homogeneous signals, which display no enhancement or relatively homogeneous enhancement after contrast media injection. They compress and deform the surrounding structures; however, a fat space between the tumor and the adjacent structure would remain.

Malignant tumors are generally large in size, with an irregular shape and an ill-defined boundary. They usually exhibit lobulated borders and heterogeneous signals. After contrast media injection, such tumors display heterogeneous enhancement. They often invade the surrounding structure and blood vessels, resulting in a blurred boundary between the tumor and normal adjacent organs. Importantly, they can spread to lymph nodes and distant sites (Nishino et al. 2003; Nakashima et al. 1997).

3 MRI Findings of Retroperitoneal Tumors of Different Nature

3.1 Adipose Tissue Tumors

3.1.1 Lipoma
Lipoma presents typical characteristics on MRI, with a clear boundary and homogeneous internal signals. It displays high signal on T_1WI similar to subcutaneous fat, medium, to high signal on T_2WI, and low signals on fat-suppressed T_1WI or T_2WI (when fat signals are significantly inhibited). After injection of contrast media, it exhibits no enhancement and minimum blood vessel

intensity. In the presence of fiber, smooth muscle, or mucus matrix within a lipoma, an abnormal strip and sheet-like, mesh-like, or cloud-like signals can be visible.

3.1.2   Liposarcoma

Manifestations of liposarcomas on MRI are correlated with its pathological subtype. Due to their complicated composition, MRI findings of liposarcomas are complex and diverse (Tateishi et al. 2003; Hekimoglu 2013). Most tumors present as large irregular lumps on MRI, with an ill-defined boundary or invasive growth, and are frequently lobulated. They exhibit heterogeneously mild to high enhancement after injection of contrast media. Fat-containing liposarcomas display characteristic MRI findings, with clearly short T_1 and long T_2 signals of fat intensity, or signals of cord-like or irregular soft tissue intensity. After injection of contrast media, their solid area exhibits mild, moderate, or even marked enhancement. Liposarcoma with minimal fat mostly shows a signal of soft tissue, without specificity due to lack of fat.

3.2   Muscle Tissue Tumors

3.2.1   Leiomyoma

Leiomyomas are most common in women between 20 and 50 years of age, and 40% of the patients have a history of surgery for uterine fibroids. It often presents a globular or an oval mass with equal T_1 and T_2 signals, smooth edges, and clear boundaries. It displays persistent and slow enhancement after injection of contrast media, mostly to a moderate to high degree. When it becomes larger in size, the tumor may present heterogeneous signals due to necrosis or cystic degeneration.

3.2.2   Leiomyosarcoma

Leiomyosarcomas are most common in the elderly, with smooth edges or lobes and clear boundaries. It mainly shows equal T_1 and T_2 signals, mixed with significantly long T_1 and T_2 signals. It mostly exhibits significantly but heterogeneously slow and persistent enhancement after injection of contrast media.

3.2.3   Rhabdomyosarcoma

Rhabdomyosarcoma is a common childhood malignancy, most often in children under the age of 15. It presents irregular edges with visible lobes and an ill-defined boundary. It displays homogeneous signals, with heterogeneously persistent enhancement, and especially peripheral enhancement after injection of contrast media, which gradually extends to the interior.

3.3   Fibrous Tissue Tumors

3.3.1   Fibrosarcoma

They present as a giant soft tissue mass and show unevenly low T_1WI, often accompanied by hemorrhage, necrosis, or calcification. They show unequally high signals on T_2WI, most of which are heterogeneous with significantly enhancement.

3.3.2   Malignant Fibrous Histiocytoma (MFH)

They are generally large in size and lack a clear boundary with the surrounding tissue. Due to necrosis, cystic degeneration, and hemorrhage, it often shows heterogeneous signals. The majority of such tumors have slightly lower or equal signals on T_1WI, while heterogeneously high, mixed, or extremely high signals on T_2WI. Fibrous tissue shows low signals on T_2WI, hemorrhage presents short T_1 and long T_2 signals, and cystic degeneration has long T_1 and T_2 signals, with unequal enhancement after injection of contrast media. Solid areas are slowly but persistently enhanced to a moderate-to-high degree. Areas between significant and no enhancement are visible within the tumor. Crisscross distribution is a prominent feature on the MRI image. Lumpish lesion of calcification is suggestive of MFH; however, for the unobvious calcification, MRI is inferior to CT.

3.4   Vascular Tissue Neoplasms

3.4.1   Hemangioma

It usually presents with a complete envelope and clear boundaries. It shows homogeneously low to

equal signal on T_1WI, or heterogeneous signals due to necrosis, mucinization, organization, or calcification. It has a high signal-based mixed signal on T_2WI. Multiple scattered plaque-like calcifications within the tumor, as well as intra-tumorally or peritumorally embedded blood vessels, are visible on images. It significantly is either homogeneously or heterogeneously enhanced after injection of contrast media.

3.4.2 Hemangiopericytoma

It often presents as an irregular soft tissue mass in the retroperitoneum, with visible lobes on the edge, and either a clear or ill-defined boundary. Because of significant bleeding and necrosis, it generally shows heterogeneous (mostly equal to high) T_2WI signals. Solid components show flaky-like delayed progressive enhancement to a substantial extent after injection of contrast media, similar to the vessels on the same section.

3.5 Neurogenic Tumors

3.5.1 Schwannoma

It is usually located in the track where the retroperitoneal neural stem is travelling, commonly seen on the paraspinal or on the medial side of kidneys. It is round, oval, dumbbell, or irregular shaped, with clear boundary. It can be cystic, solid, or a combination of both. It shows either homogeneous or heterogeneous signals on MRI images. After injection of contrast media, solid components most often show mild to moderate progressive delayed enhancement.

3.5.2 Neurofibromatosis

MRI findings of neurofibromatosis are similar to schwannoma. Neurofibromatosis can present as small and scattered loculation or cystization. By contrast, large flake-like cystic lesion tends to be considered as schwannoma.

3.5.3 Paraganglioma

It is usually located in the area where the paraganglia around the inferior vena cava, abdominal aorta, renal artery ,and superior mesenteric artery are distributed. It is round or oval shaped, with smooth edges and clear boundaries. It shows a heterogeneous signal, accompanied by the flow void sign (for vessels) within the tumor, with a persistent heterogeneous enhancement after injection of contrast media.

3.6 Reproductive Embryonic Tumors

3.6.1 Seminoma

MRI demonstrates a large mass located in midline with heterogeneous signals, accompanied by bleeding and necrosis. T_1WI shows slightly low to equal signal, whereas T_2WI has slightly high to high signals, mostly moderate and above heterogeneous enhancement.

3.6.2 Teratoma

On MRI, this tumor shows mixed signal intensity on both T_1WI and T_2WI. It may contain calcification, bone, teeth, and fat tissue, which are specific for the diagnosis of teratoma; however, MRI findings must be combined with CT and comprehensively interpreted.

3.7 Retroperitoneal Cystic Lesions

Retroperitoneal cystic lesions include mesonephric tubular cyst, Mullerian cyst, epidermoid cyst, bronchogenic cyst, and enterogenous cyst. They commonly present as round or oval cystic lesions with smooth edges and clear boundaries in the retroperitoneal space. They exhibit homogeneous long T_1 and T_2 signals with no enhancement after injection of contrast media. A fluid-fluid interface is visible in the presence of different components in the cyst. Diffusion-weighted imaging (DWI) shows high-signal intensity for epidermoid cysts.

4 Diagnostic Values of MRI in Surgical Treatment of Retroperitoneal Tumors

Before the surgical removal of retroperitoneal tumors, MRI should be used to address three major questions: tumor localization, tumor characterization, and tumor relationship with its surrounding

organs/large blood vessels, of which the last one is the key in preoperative examination.

MRI has distinct advantages over CT scans, such as identification of soft tissue with high resolution, multi-dimensional and multi-parameters imaging, without radiation injury (Testini et al. 1996). MRI provides more accurate and intuitive images, with higher diagnostic orientation value in defining the tumor. In addition, it is also superior to CT in determining tissue components by providing more detailed information. MRI can identify hematomas, effusion, empyema, tissue necrosis, and edema within tumors, thus playing an important role in determining the benign versus malignant nature of retroperitoneal tumors.

The relationship between retroperitoneal tumors and surrounding parenchymal organs can be clearly presented on T_1WI. T_2WI is suitable for displaying the invasion of retroperitoneal tumors to adjacent muscles, and especially valuable in determining the degree of invasion to the psoas major or quadratus lumborum. Fat-suppressed T_2WI displays small retroperitoneal tumors, whereas fat-suppressed T_1WI clearly presents enlarged retroperitoneal lymph nodes. Enhanced MRI can excellently overview the relationship between the tumor and surrounding large blood vessels and vital organs.

In summary, the exact location, size, shape, and scope of tumors, as well as the relationship between the tumor and adjacent organs, can be accurately determined by MR based on multi-directional scanning and comprehensive analysis, thus providing an important clue for judging resectability and developing a surgical strategy. MRI may assist in defining clinical stages and predicting the prognosis of retroperitoneal tumors. In addition, it is useful for postoperative follow-up.

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