MR imaging of the pancreas

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Résumé
IRM et maladies pancréatiques
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L’IRM du pancréas a connu beaucoup de changements notamment grâce à sa capacité à visualiser de façon optimale les canaux pancréatiques et les modifications de signal du parenchyme. La cholangio-pancréatographie IRM permet la reconnaissance de variantes anatomiques comme le pancréas divisum.Bien que le scanner soit la méthode de référence dans la pancréatite aiguë et pour la détection des calcifications pancréatiques au cours de la pancréatite chronique, l’IRM du pancréas et l’IRM avec injection de sécrétine sont utiles pour la recherche de la cause de la pancréatite, et l’évaluation des complications telles que les pseudokystes et la rupture canalaire. Le rôle de l’IRM est toujours débattu dans les tumeurs pancréatiques en dehors des lésions kystiques où l’IRM apporte des informations capitales en vue de la caractérisation en étudiant le nombre de kystes, le contenu des lésions et le caractère communiquant ou non avec les canaux pancréatiques. L’IRM est aussi intéressante pour d’autres pathologies pancréatiques comme la pancréatite auto-immune (diagnostic positif, cholangite associée ?) ou la pancréatite de la jante (kystes d’une dystrophie kystique sur pancréas aberrant ?).

Mots-clés : Pancréas. Technique d’exploration. IRM.


Abstract
Magnetic resonance (MR) imaging of the pancreas has undergone a major change because it can provide noninvasive images of the pancreatic ducts and the parenchyma. MR cholangiopancreatography (MRCP) enables detection of anatomic variants such as pancreas divisum. Although contrast material-enhanced CT is still considered the gold standard in acute pancreatitis and for the detection of calcifications in chronic pancreatitis, MR imaging and secretin-enhanced MRCP are useful in evaluating pseudocysts and pancreatic disruption. The role of MR is still debated in pancreatic neoplasms except the cystic lesions where MR imaging provides critical information regarding the lesion’s content and a possible communication with the pancreatic ducts. MRCP and MR of the pancreas are also useful in identifying other pancreatic diseases such as lymphoplasmocytic pancreatitis and groove pancreatitis.

Technique
The optimal MRI of the pancreas requires the use of high-magnetic-field magnets, powerful and fast gradients, phased array surface coil, and adapted sequences; in these conditions MRI of the pancreas is done in a reasonable amount of time.

Imaging the pancreatic parenchyma
The pancreas is explored in T2- and T1-weighted sequences in axial and coronal planes (1).

T2-weighted sequences
These include:
• a Fast spin-echo (HASTE, RARE) sequence, which is a single-shot sequence with acquisition of half of the Fourier plane using the symmetry of the K space to reconstruct the image with a short echo time (40-80 ms) and long echo time, in axial and coronal views (fig. 1a). The main advantage of this sequence is its low sensitivity to movement artifacts, notably if the patient does not hold his breath. Each slice is acquired in approximately 1 s. It has the disadvantages of a signal-to-noise ratio lower than the fast multishot spin-echo sequence and slight blurring, which explains the lower sensitivity in detection of small, low-contrast lesions. With this sequence, fluid lesions in or around the pancreas appear as highly hyperintense, such as the common bile duct and the main pancreatic duct. It is not usually taken with fat suppression, but this is indicated when looking for peripancreatic collections.
• A conventional T2-weighted fast spin-echo sequence with fat suppression and respiratory compensation because it is acquired in free breathing (fig. 1b). This is the reference T2-weighted sequence for liver imaging; it is not indispensable for MRI of the pancreas but clearly shows liquid infiltrations in acute pancreatitis.
T1-weighted sequences
Two types of gradient echo T1-weighted sequences can be used. The first is chemical shift imaging, with in-phase or opposition-phase images taken during the same sequence, the latter being T1-weighted with fat suppression; however, the number of slices is limited to one breath hold (fig. 1c). The alternative is water excitation, which can cover the entire pancreas during a single breath hold. Fat suppression or water excitation produces the same image: a pancreas that appears homogenous and hyperintense surrounded by hypointense fat. This is an excellent sequence for identifying the disease focus in focal pancreatitis or pancreas lesions that are less intense than the normal intensity of the pancreas. In diffuse chronic pancreatitis, pancreatic fibrosis is responsible for homogenous intensity of the pancreas. Other T1-weighted sequences such as spin-echo sequences and inversion recovery sequences are not part of routine protocols.

Dynamic imaging after injection of gadolinium chelates is indicated when a pancreatic tumor is suspected, which can be done with 2D or 3D gradient echo fat saturation or water excitation sequences at three different times: 15-20 s, 45 s, and 90 s after injection of contrast medium. When looking for fibrous material, a delayed sequence can be added 10 min after injection of the contrast. The best enhancement of the pancreas is obtained 15 s after the contrast material arrives in the abdominal aorta, and the optimal enhan-
cement of the liver and peripancreatic vessels is observed beyond 20 s after bolus arrival (2). Three-dimensional sequences are a variant of angio-MR with a small tip angle, fat suppression, and slice interpolation. These sequences have been suggested to combine parenchyma and vascular imaging. They are valuable because the slices are thinner than in 2D sequences; however, vascular reconstructions do not have the same quality as in classical angio-MR.

In addition to the sequences taken after contrast medium injection, the examination can be completed by sequences that provide a spontaneously high contrast between hyperintense vessels and parenchyma: short repetition and echo time balanced echo sequences whose signal combines the T2*/T1 ratio. They provide excellent anatomical resolution and can substantiate the permeability of large vascular vessels such as the portal system, the aorta, or the celiac trunk.

**MR cholangiopancreatography**

MRI of the biliary and pancreatic ducts requires highly T2-weighted sequences that render static fluid or slow-flow structures very hyperintense. Generally, two different and complementary approaches are used: thick T2-weighted single-shot sequences and thin multislice T2-weighted sequences. The 20- to 40-mm thick-slab sequence is used. It can be obtained in all its planes and only requires a less than 3-s breath hold. It provides excellent biliary and pancreatic mapping, with no respiratory artifacts and few susceptibility artifacts and good planar resolution. Because of the main pancreatic duct’s trajectory, we usually take two radial acquisitions, one centered on an axial slice on the main duct of the left-hand portion of the pancreas body (three to four slices) and the other on the biliopancreatic confluent on the right (at least nine slices) (fig. 2). The latter also makes it possible to clearly visualize the Wirsung duct. Imaging provides information equivalent to imaging obtained during retrograde catheterism. The biliary or pancreatic ducts are even more visible if they are not surrounded by organs containing fluids such as the stomach and the duodenum. This is why the patient is requested to be fasting for at least 4 h. Oral administration of a T2-negative contrast agent is not used by all authors but gives good results. This can be a true contrast agent (1 ml gadolinium chelate in 250 ml water) or fruit juice (pineapple, blueberry, cranberry, etc.) or administration of blueberries, which is the solution we have adopted (fig. 3).

The highly T2-weighted single-shot multislice sequence is the HASTE sequence described above. This is a series of 4- to 6-mm contiguous slices acquired with a shorter echo time and echo train than thicker slices. This sequence therefore visualizes not only the ducts, but also the solid organs. Finally, as with MR cholangiopancreatography of the bile ducts, it is possible to explore the pancreatic ducts during a single volume, but the benefit compared to 2D sequences is not known.

**Secretin MRI**

Administration of secretin stimulates the secretion of pancreatic fluid and bicarbonate by the exocrine pancreas (3). This effect is transitory and is associated with an increase in the main pancreatic duct’s pressure at 1 min, with return to baseline at 5 min. Secretin’s action is explained by both the increase in the secretion of pancreatic fluid by the ductal cells and the increase in Oddi sphincter tone. In MR cholangiopancreatography, the visibility of the main pancreatic duct increases through a rise in the fluid volume. Dynamic recording requires taking MR cholangiopancreatography sequences in thick slices repeated every 15-30 s for 10-15 min after IV administration of 1 ml/kg bw secretin. The advantages of secretin MRI are therefore both morphological and functional: morphological with a better visualization of the main pancreatic duct, an easier detection of the anatomical variants, and functional through its estimation of duodenal filling by pancreatic fluid, which is an indirect sign of exocrine pancreas function.

The arguments in favor of a pancreatic anomaly after secretin MRI are the following (3): the persistence in main pancreatic duct...
dilatation at 10 min, visualization of the accessory ducts in the body and tail of the pancreas, enhancement of pancreatic parenchyma, and a reduction in duodenal filling. Secretin MRI can also be used to evaluate pancreatic function after surgery, notably cephalic duodenopancreatectomy. Monill et al. showed that visualizing the main pancreatic duct and pancreatic-digestive anastomosis was improved after administering secretin; similarly, there is a relation between the reduction in jejunal filling and diabetes (4). One of the disadvantages of secretin today is the very high price of this drug.

Some authors have suggested improving the distension of the biliary and pancreatic ducts by intravenously administering morphine (5) because morphine induces a contraction of the Oddi sphincter, which results in an increase in the endoluminal pressure of the biliary ducts and the pancreatic ducts. This examination is done before, then 10 and 20 min after IV injection of a 0.04-mg/kg bw dose of morphine sulfate, injected over 1-2 min. The classical side effects of morphine are rarely observed at this dose.

Routine minimal exploration
- T2 FSE single-shot axial with breath hold;
- T1 with water excitation gradient echo before injection;
- Dynamic sequences during gadolinium injection;
- MR cholangiopancreatography in two series of thick radial slices (nine biliopancreatic slices, four body-tail slices of the pancreas).

MRI features of the pancreas

Most pancreatic diseases are visible on MRI on T1-weighted fat-suppression or water excitation sequences and T2-weighted sequences. T1-weighted gradient echo sequences are the most important for the pancreas because the pancreas (normally more hyperintense than the liver) is highly hyperintense in T1-weighted images. This particular signal is attributed to the presence of large quantities of aqueous protein in the ductal parts of the pancreas, the abundance of endoplasmic reticulum in the acinus cells, and the paramagnetic ion-rich content, notably manganese. This hypersignal persists with fat infiltration, and the pancreas therefore takes on a more irregular, punctuated aspect corresponding to fat infiltration in the lobules of pancreatic parenchyma. The hypersignal is reduced in elderly subjects, probably because of pancreatic fibrosis development.

After intravenous injection of gadolinium chelates, pancreas enhancement is greater than liver enhancement in the arterial phase. In T2-weighted images, the signal of the normal pancreas is variable: equal to the liver signal or higher. Tumor detection, in particular adenocarcinoma, is difficult, and adding fat saturation increases detection of liver metastases and endocrine tumors. The T2-weighted signal of the pancreas can be greatly reduced, notably when there is a pancreatic overload in iron during genetic hemochromatosis, but there is no relation between the drop in the pancreas signal and the iron overload. In T2-weighted sequences, the common bile duct, the gallbladder, and the main pancreatic duct can be perfectly visualized. This is also a useful sequence when looking for peripancreatic fluid collections. On MRI, the main pancreatic duct is seen in 100% of cases in the head, the body, and the tail of the pancreas, measuring rarely less than 1 mm (fig. 4). The accessory pancreatic duct and the pancreatic loop are very frequently visualized (6). Accessory ducts are very rarely identified in normal subjects (7).

Anatomical variants

Pancreas divisum

Pancreas divisum is observed in 5.5%-7.5% of subjects and is the most frequent variant of the pancreatic ducts. It occurs when the ductal systems of the ventral and dorsal pancreatic ducts fail to fuse, resulting in two separated drainage canals for the pancreatic ducts. The majority of the pancreas is drained by the dorsal duct, which drains into the minor papilla, whereas the rest of the pancreas is drained by a small ventral duct that drains into the major papilla. Even though the relation of cause and effect between pancreas divisum and acute pancreatitis remains controversial, pancreas divisum is observed more often in patients with idiopathic pancreatitis than in the general population; the mechanism suggested is an obstruction of the pancreatic flow stemming from the dorsal duct. Diagnosis was based on endoscopic retrograde cholangiopancreatography (ERCP). MRI has since demonstrated excellent performance, with high interobserver agreement (fig. 5). Administration of secretin has improved the results and better demonstrated Santorinicle (8), which is also associated with a reduction in duodenal filling.

Biliopancreatic junction anomaly

This anomaly is observed in 1.5%-3% of subjects and is defined by a common duct...
that is unusually long (>15 mm) (fig. 6) (9). It is found in 33%-83% of congenital cystic dilatations of the bile duct; it is hypothesized that it is the cause of the reflux of pancreatic enzymes into the common bile duct, ending in a bile duct cyst. Similarly, the incidence of gallbladder cancer is more frequent in patients with a junction abnormality and the cancer is more serious at diagnosis and occurs earlier, with no associated gallstone.

**Anular pancreas**

Anular pancreas is a rare but well-known congenital anomaly in which the head of the pancreas partially or totally surrounds the duodenum. The most frequent clinical manifestation is a duodenal obstruction, notably in children. In MRI, tissue tightly holding the second duodenum with an intensity similar to the rest of the pancreas can be observed (10).

**Other variants**

Variants of the pancreas itself are much rarer. Agenesis of the dorsal pancreas can be observed in isolation or associated with a polysplenic syndrome that includes interruption of the lower vena cava, azygos continuation, and other digestive tract and cardiovascular defects. In addition to these very rare anomalies, a fatty overload of the pancreas is observed. With age, fat infiltration can be heterogeneously distributed in the pancreas, with involvement generally more serious in the anterior part of the head and, on the contrary, no involvement in the pancreatic parenchyma around the common bile duct.

**Acute pancreatitis**

**MRI signs**

During mild pancreatitis, the pancreas generally remains hyperintense in T1-weighted fat-saturation images, and the diagnosis of acute pancreatitis is made based on the increase in the size of the pancreas and peripancreatic inflammatory phenomena: hypointensity of the peripancreatic fat on T2-weighted sequences and hyperintensity on T2-weighted images because of edema or fluid collections. The main pancreatic duct is thin or invisible. When acute pancreatitis is severe, the pancreas loses its T1-weighted fat-saturated hyperintensity (fig. 7). Intravenous injection of gadolinium chelates demonstrates the pancreatic necrosis that is manifested by the absence of enhancement in the arterial phase (aspect similar to that observed on CT).

The complications of pancreatitis are also clearly identified: pseudocysts, abscess formation, fistulae, hemorrhage, venous and arterial complications, and duct rupture that shows up as an interruption of the main pancreatic duct with visualization of a fistulous trajectory.

**The role of MRI in acute pancreatitis**

CT is the reference examination in acute pancreatitis, leaving little place today for clinical use of MRI (11). It is particularly useful when there is doubt in the diagnosis and has a high prognostic value in showing the extent of both peripancreatic collections and pancreatic necrosis, which has resulted in a severity index based on the combination of these two signs (modified Balthasar). However, CT subjects the patient to high levels of radiation when it is repeated often. IV injection of an iodated contrast agent was shown to aggravate the pancreatic microcirculation in animals. These data have not been confirmed in humans (12). MRI may be comparable to CT in the diagnosis of acute pancreatitis and the estimation of its seriousness. Taking the Ranson score as the reference method, Arvanitakis et al. showed that acute pancreatitis was detected with MRI with a sensitivity of 85% and a specificity of 91%, whereas CT had a sensitivity of 78% and a specificity of 96% (13). In this study, pancreatic MRI was done with IV injection of secretin and gadolinium chelates. MRI of the pancreas can also provide functional information, and after IV administration of secretin, a reduction in the distension of the main pancreatic duct was observed, with a Ranson score greater than or equal to 3. This injection is no longer considered a contraindication during acute pancreatitis (3).

Pancreatic MRI therefore has a number of advantages:

- a diagnostic value that is probably equivalent to that of CT.
- better demonstration of solid debris and peripancreatic fluid collection. Taking as the definition of a nondrainable collection the demonstration of debris greater than 1 cm in diameter, the sensitivity and specificity of MRI were 100%, but 25% and 100%, respectively, in the study by Morgan et al. (14).
• detection of duct rupture (8% of the series studied by Arvanitakis et al. (13)), which could have an impact on patient management.
• providing arguments to define the cause of pancreatitis: biliary lithiasis, pancreas divisum; nonetheless, in the acute phase, pancreatic edema results in a clear ductal compression and the diagnosis of pancreas divisum could be less valuable than at a distance.

Although there are good arguments to prefer MRI in acute pancreatitis, CT remains the reference examination: it is more accessible and less expensive than MRI, it can be done in patients in the emergency department, it is more sensitive in detecting calcifications and air bubbles and in topographic mapping of collections, the examination time is faster in CT than in MRI, and finally, if interventional radiology is indicated, it is much simpler with CT.

In conclusion, let us take up the terms of the consensus conference on acute pancreatitis (25 and 26 January 2001): “subject to the greater accessibility of MRI and a standardization of protocol, MRI could be proposed as a replacement to CT. This is particularly true for patients with or at risk for kidney failure because it uses a contrast medium with very low toxicity to assess vascular enhancement.”

Chronic pancreatitis

MRI signs

The morphological signs encountered in chronic pancreatitis visible on MRI are similar to those observed on CT: duct dilatation, a localized increase in the parenchyma, or generally diffuse atrophy and pseudocysts.

Calcifications, one of the specific signs on CT, the most sensitive examination to detect them, are rarely visible on MRI (low sensitivity). They appear as signal voids (fig. 8).

The pancreas can appear abnormal on the T1-weighted fat-saturated sequence after gadolinium chelate injection by reduction of signal intensity before contrast injection and lower than normal or heterogeneous enhancement after contrast injection. The main difficulty lies in early diagnosis of chronic pancreatitis (15). Therefore, some authors have demonstrated that a reduction in enhancement and/or a delay in the enhancement peak of the pancreas had a sensitivity and specificity of 79% and 75%, respectively, for the early diagnosis of chronic pancreatitis.
The advantage of MRI is its ability to rapidly provide reliable imaging of the pancreatic ducts (16). The ductal signs include moderately tortuous dilatation and irregularity of the main pancreatic duct, a moderate and symmetrical fusiform dilatation of the accessory ducts, calculi that appear as lacunae encircled by the duct hyperintensity, and pseudocysts (fig. 9). All these anomalies are clearly identified on heavily T2-weighted sequences in thick and thin slices. Pseudocysts are highly hyperintense in T2-weighted images, unilocular or multilocular. MRI is particularly valuable in demonstrating pseudocysts, determining whether there is communication (even if the endoscopic retrograde cholangiopancreatography [ERCP] is lower), and assessing the internal composition of the pseudocysts for hemorrhage, proteic fluid, or necrotic debris so that treatment of the pseudocysts can be as individualized as possible.

The third advantage of MRI is evaluating pancreatic function and duct morphology after stimulation by IV injection of secretin. The anomalies described during chronic pancreatitis are the following:

- a reduction in duodenal filling, which does not correlate well with morphological abnormalities;
- an increase in the caliber of the main pancreatic duct, with better visualization of this duct and an improvement in visualization of the accessory ducts only in patients who do not have duct stenosis (17);
- a delay in the dilatation of the main pancreatic duct compared to normal subjects, with a lower percentage of variation in subjects with chronic pancreatitis;
- sometimes acinus filling that shows up as a progressive increase in the intensity of the pancreatic parenchyma signal. These anomalies have been observed with CT in patients showing no particularities and could correspond to a sign of early chronic pancreatitis (15).

Finally, the role of imaging is also to attempt to differentiate the pancreatic masses observed in the chronic pancreatitis of adenocarcinoma of the pancreas. These lesions are called focal pancreatitis or inflammatory lesions. Although it seems very difficult to morphologically differentiate a mass associated with chronic pancreatitis from an adenocarcinoma, duct imaging could contribute valuable arguments when it shows a normal aspect or slight stenosis in inflammatory lesions, contrary to the severe stenosis with dilatation upstream, or even the disappearance of the duct that is normally observed in adenocarcinoma. The accessory ducts

**Fig. 8:** Chronic pancreatitis.

*ab* Pre- and postcontrast CT scans show enlargement of the pancreas with multiple calcifications and heterogeneous enhancement of the pancreas after contrast-medium injection.

c T2-weighted sequence demonstrates the pancreatic heterogeneity but not the calcifications.

d Typical MR cholangiography and pancreatography with irregular dilatation of the main pancreatic duct, multiple hypoin signals corresponding to calculi and a tight stenosis of the common bile duct.
**Fig. 9:** Chronic pancreatitis and pseudocyst.

- *a* HASTE sequences showing ductal abnormalities and a cystic and heterogeneous lesion surrounded by a thick wall.
- *b* Ductal irregularities highly suggestive of chronic pancreatitis and pseudocyst.

**Fig. 10:** Ductal disruption.

- *a* T2- and
- *b* Postcontrast T1-weighted sequence showing a cystic lesion as well as a fluid lesion above the body of the pancreas with marked wall enhancement corresponding to a ductal disruption.
- *c* This is seen more clearly on MR pancreatography.
may disappear in adenocarcinoma rather than in the focus of the pancreatitis. Currently, histology remains indispensable.

The role of MRI

CT is the reference examination to demonstrate pancreatic calcifications, one of the specific signs of chronic pancreatitis; however, these calcifications exist in at least 50% of cases. MRI plays an indisputable role in the diagnosis and workup of pseudocysts, pancreatic duct imaging in the search for stenoses, stones, or other anomalies, and biliary duct imaging searching for dilatation, as well as for the etiological workup for nonalcoholic pancreatitis (hereditary, autoimmune, etc.) and the differential diagnosis with intraductal papillary mucinous tumor (IDPMT).

Thoracic fistulae of the pancreas, with the large abdominal cavity (pancreatic ascites) or with chronic collections, are rare subacute or chronic complications of pancreatitis that are manifested by communication between the Wirsung duct and the peritoneal, pleural (pancreaticopleural fistulae), or mediastinal (mediastinal pseudocysts) spaces. MRI is particularly valuable because it can visualize the fistulous trajectory (fig. 10) (9).

Adenocarcinoma

MRI signs

Pancreatic adenocarcinoma is often difficult to differentiate from normal pancreas on T1- and T2-weighted sequences with no fat suppression because this tumor differs little from the rest of the pancreas. Therefore, this is detected and described based on T1-weighted sequences with fat suppression before and after gadolinium injection. Typically, adenocarcinoma is a hypovascular tumor, showing hypointensity on T1-weighted sequence fat suppression before injections and in the arterial phase (fig. 11). Because of the presence of an abundant fibrous stroma within the tumor, a delayed enhancement can usually be observed with secondary isointensity of the lesion. Upstream of the lesion, one can also observe a hypointensity of the pancreas in the T1-weighted image, which is a sign of chronic obstructive pancreatitis, in which fibrous inflammation, parenchymatous atrophy, and the disappearance of the lobulated contours opposite the lesion coexist.

MR cholangiopancreatography searches for typical stenosis at the level of the tumor with duct dilatation upstream, even biductal dilatation for a tumor of the pancreatic head (common bile duct and main pancreatic duct). MRI can also provide vascular staging (identical criteria to those described for CT), lymph node staging, and more distantly, it can search for peritoneal carcinosis or liver metastases. Hepatic metastases of pancreatic cancer are typically hypointense on T1-weighted images and hyperintense on T2-weighted sequences and present peripheral enhancement with halo. MRI with HASTE sequences is very useful in differentiating benign lesions, cysts, and angiomas of liver metastases on long T2-weighted sequences.

Some authors have suggested performing MRI after injection of manganese chelates (Mn-DPDP). This contrast agent has a particular biokinetics, with a large proportion of the manganese at the site of the lesion. Moreover, Mn-DPDP has a long T1 relaxation time, which can be used for differentiating cystic lesions from solid tumors (fig. 12).

Fig. 11: Pancreatic adenocarcinoma.

a) MR cholangiography and pancreatography show a dilatation of both common bile duct and main pancreatic duct with complete stenosis.

b-c) Pre- and postcontrast T1-weighted sequences demonstrate a tumor responsible for the ductal dilatation.
caught in the liver, but also in the pancreas, enhancing the intensity T1-weighted sequences of the pancreatic parenchyma by 98% (18). Using this contrast material could increase the detection of pancreatic tumors, but vascular enhancement cannot be studied and therefore local-regional staging is not possible. The spontaneous hyperintensity in T1-weighted sequences of the pancreas probably provides the same information.

**The role of MRI**

This is a widely debated topic today because although some articles have shown that MRI was equivalent to CT in diagnosis and staging, others have shown the opposite (19-22) (fig. 12). Nishiharu et al. found comparable tumor detection but a benefit with CT, notably for peripancreatic and vascular invasion (22). Comparing CT, echoendoscopy, and MRI, Soriano et al. demonstrated that CT showed the highest level of precision in primary tumor staging, local-regional staging, vascular invasion, distant metastases, TNM staging, and tumor resectability (21).

MRI retains its originality in imaging the parenchyma, the pancreatic and biliary ducts, and vascular structures; however, in many institutions, CT remains the reference imaging choice for diagnosing and staging pancreatic cancer. Other than CT’s advantages for the tumor, its excellent spatial resolution also provides detailed reconstructions in all planes and arterial mapping and therefore makes it possible to search for surgical contraindications such as celiac trunk stenosis. MRI is still used today as a second-intention tool when there is doubt or when CT and echoendoscopy are not sufficiently conclusive; it is not currently recommended to use MRI in first-intention diagnosis of pancreatic cancer (23).

**Other tumors**

**Endocrine system tumors**

These tumors have long T1 and T2 relaxation times, which can be seen in pronounced hypointensity in T1-weighted sequences (good sensitivity) and clear hyperintensity in T2-weighted sequences. They are therefore clearly visible before contrast agent injection and also visible after injection because they are hypervascularized in approximately 80% of cases in the arterial phase. This enhancement can be homogeneous, notably in small tumors, in a peripheral ring, or diffusely heterogeneous in larger tumors. They therefore have features that are very different from adenocarcinoma. In addition, invasion by vascular sheathing is much rarer. However, venous endoluminal obstruction is possible. An effect on the duct is rare, as is upstream dilatation. When metastases are present, they are hypervascularized and MRI could provide the means to better describe the pseudocystic and pseudo-angiomatous metastases than CT (24). Finally, the neighboring pancreatic parenchyma is most often normal (1).

CT and MRI performance seems similar (25). Once again, the T1-weighted fat-saturated sequence before injection and the multiphase analysis after injection including a late sequence are the most useful (late acquisition can demonstrate scirrhou endocrine tumors with abundant fibrosis).

**Cystic lesions and tumors**

With highly T2-weighted sequences, MRI has a very high sensitivity for detecting cystic lesions and tumors of the pancreas. One study (26) showed that the prevalence of asymptomatic cystic lesions of the pancreas discovered incidentally was similar to the prevalence reported by autopsy, i.e., 19.6% of a population of more than 1,000 subjects. These cysts are most often simple (round, thin-walled, with no septa) and single. Patients with multiple cysts are observed particularly in the 70+ age group. These cysts are less than 10 mm in diameter in 84% of cases.
MRI patterns and signs of cystic tumors are quite similar to those described in CT. The mucinous cystadenoma has a variable T1-weighted signal, most often with hypointensity, at times with hyperintensity when there are hemorrhagic changes or a protein-rich content. In T2-weighted sequences, the content is highly hyperintense and the walls are easily discernible when they exist (fig. 13). The wall is thick and takes up contrast material.

Serous cystadenoma is typically hypointense in T1-weighted sequences, the hyperintensity in T2-weighted sequences is related to the fluid content of the many cysts composing the lesion. A central hypointensity can also be observed, corresponding to fibrous tissue that may be calcified (fig. 14). The proportion of cysts and walls is variable (pseudosolid with microcysts, macrocystic, and more rarely unilocular macrocystic, whose diagnosis is difficult).

The solid and pseudopapillary tumor is quite recognizable on MRI: a thick, hypointense capsule on T1-weighted and T2-weighted sequences, with a variable content on often hyperintense T1-weighted images because of the frequent hemorrhage and high level of hyperintensity on T2-weighted sequences, with a variable portion of fleshy material. It is most often discovered in the young female.

MRI is indispensable in describing cystic tumors, with an indisputable advantage in the study of ductal structures and their possible communication with the cystic lesion and the search for multiple lesions. However, the spatial resolution in MRI is less than that in CT and identifying calcifications is much more difficult.

Pancreatic metastases

The most frequently found primary tumors that lead to metastases are cancers of the kidney, the lung, the breast, the digestive tract, and melanoma. Most often, these metastatic lesions are multiple and necrotic. Hypervascularized tumors in the arterial phase simulating endocrine tumors are a particular feature in these tumors, most often observed in patients with a history of kidney cancer.

Papillary intraductal and mucinous tumors of the pancreas

These tumors show a proliferation of the pancreatic duct epithelium that produces mucin. Three types have been described: involving the pancreatic duct alone, the accessory ducts alone, or the combined form associating both the main and accessory ducts. Isolated involvement of the main pancreatic duct can be diffuse or segmental and appears on MRI as a moderate or more or less voluminous dilatation of the main pancreatic duct. This should be differentiated from chronic pancreatitis.

The form located in the accessory ducts appears either as one or several cysts separated from each other by pancreatic parenchyma or a more coalescent form in grape-like clusters. These dilatations have the signal of the ductal structures and appear to branch from the Wirsung duct in MR cholangiopancreatography (fig. 15 and fig. 16).

The combined form that associates both ducts is easy to diagnose. All can be associated with a papillary protrusion that accompanies most particularly the forms of cancer of the main duct that are highly mucous-secreting.

There are three advantages of imaging, and more particularly MRI:
- making a positive diagnosis;
- staging the disease;
- searching for malignant transformation.

The signs that point toward malignity are involvement of the main pancreatic duct, notably when it is greater than 15 mm in diameter, the existence of a mass or parietal nodules, dilatation of the common biliary duct, the presence of calcifications, and diabetes. Apart from calcifications, MRI is particularly advantageous in this duct disease and is also indicated in the follow-up of nonoperated disease (isolated involvement of the accessory ducts in an asymptomatic subject). These subjects have annual MRI monitoring (27).
Fig. 15: IPMT.

- **a-b**  CT shows dilated branch duct dilatation in the head and tail of the pancreas.
- **c-d**  T2- and HASTE sequences identify these abnormalities more clearly.

Fig. 16: Mixed and diffuse IPMT: MR pancreatography depicts dilated branch ducts communicating with the MPD.
Miscellaneous pancreatic diseases

Groove pancreatitis

The groove is a space limited by the head of the pancreas, the duodenum, and the common bile duct. Groove anomalies can be classified into four types: associated with the pancreas, the duodenum, and common bile duct adenopathies. The special feature of this space is that the serous membrane of the second part of the duodenum is closely related to the head of the pancreas, which explains the intricacy of the pathological processes. Groove pancreatitis can be seen in isolation or associated with greater pancreatic involvement. It is observed during perforated peptic ulcer, after gastric surgery, during migration of pseudocysts toward the duodenal wall, and particularly with cystic dystrophy on an aberrant pancreas. MRI demonstrates tissue with an intermediate signal between the head of the pancreas and the second part of the duodenum, T1-weighted hypointensity compared to pancreatic parenchyma, and isointense or slightly hyperintense in T2-weighted sequences. The presence of several small cysts in the thickened wall of the second part of the duodenum associated with the preceding changes is highly characteristic of cystic dystrophy of the aberrant pancreas (28) (fig. 17).

Autoimmune pancreatitis

This is chronic pancreatitis that is isolated or associated with autoimmune diseases (Gougerot-Sjögren disease, sclerosing cholangitis, primary biliary cirrhosis, disseminated lupus erythematosus, etc.). It can still be referred to as lymphoplasmacytic sclerosing pancreatitis. Diagnosis is based on several criteria (Yoshida). On MRI, a diffuse or focal increase in the pancreatic gland with disappearance of the lobular feature can be observed (fig. 18). A fine border of T2-weighted hyperintensity suggests moderate peripancreatic edema, which is frequent. A fibrous peripancreatic capsule was described in a few cases, but has rarely been found again. The absence or rarity of peripancreatic flow, the absence of vascular involvement, calcification, or peripancreatic collection are suggestive. Pancreatic adenopathies are frequently found (29). Heterogeneous enhancement of the pancreas can be seen, sometimes associated with peripheral enhancement. MRI of the pancreatic duct can reveal spindly features or even disappearance of the pancreatic duct, with no dilatation upstream. MR cholangiopancreatography shows frequent, long intrapancreatic stenosis, sometimes with features close to sclerosing cholangitis, with, however, long stenoses, which are not close together and rather central. The signal from all or part of the pancreas is reduced in T1-weighted sequences and increased in T2-weighted sequences. These abnormalities diminish or disappear with corticosteroid treatment, which can be used as a diagnostic test.

The postoperative pancreas

MRI has demonstrated its usefulness in evaluating pancreatic and digestive anastomoses. It can search for complications such as stenosis (very frequent and most often asymptomatic), the formation of stones, and anastomotic leaks. Thus MRI has a number of indications in exploring the pancreas. It is the best noninvasive duct imaging method, if the study includes two series of thick biliopancreatic and corporeocaudal radial slices. It is indispensable in the etiological workup of nonalcoholic, nonbiliary acute pancreatitis, as well as the study of pseudocysts before treatment, pancreatic fistulae, the etiological workup of nonalcoholic chronic pancreatitis, the diagnosis of autoimmune pancreatitis and pancreatic cysts (alone? wall? effect on duct or communication?), and the workup for papillary mucinous tumor (IDPMT) of the pancreas. Given its multiple sequences, it also provides imaging of the parenchyma and vascular structures in a single examination. However, CT without injection of contrast in the search for calcifications is indispensable to correctly interpret the MRI results. Echoendoscopy is most often necessary, particularly in the analysis of a solid tumor (with biopsy), when searching for microcysts of serous cystadenomas and tissue buds of IDPMT degeneration.

Fig. 17: Cystic dystrophy.

HASTE sequence shows cysts within an enlarged duodenal wall. MR cholangiography demonstrates dilatation of the common bile duct above a stenosis due to chronic pancreatitis.
Références


