Imaging of the pancreas

Imaging plays a major role in the investigation and management of pancreatic pathologies. A variety of invasive and non-invasive techniques can be used to characterize abnormalities and provide prognostic information. Diagnostic and therapeutic procedures may also be performed using image guidance.

The pancreas is a glandular organ which has a complex role in digestion and metabolism. The majority of its cells are exocrine and secrete enzymes into the duodenum which complete the digestion of proteins, fats and carbohydrate. Among the exocrine cells are scattered islets of Langerhans which have a complex endocrine role. Specialized cells secrete insulin, glucagon and somatostatin which regulate glucose and lipid metabolism. The two main structural pathologies to affect the gland are pancreatitis and pancreatic cancer, and imaging plays a crucial role in both diagnosis and surveillance of these conditions. Image-guided techniques are also used for obtaining histological samples and for therapeutic interventions. A basic understanding of pancreatic imaging is important for the medical and surgical specialties that manage pancreatic and hepatobiliary diseases.

Anatomy and congenital anomalies

The pancreas is a lobulated retroperitoneal gland that lies in the anterior pararenal space behind the stomach and lesser sac. It measures approximately 15 cm in length and weighs between 60 and 100 g. The head of the pancreas lies in the curvature of the duodenum, the body drapes across the aorta and inferior vena cava, and the tail extends towards the spleen. The pancreatic head has an uncinate process that extends inferiorly behind the superior mesenteric vein. It receives its blood supply from the splenic artery and the pancreaticoduodenal braches of the hepatic and superior mesenteric arteries. Behind the pancreatic head is the confluence of the superior mesenteric and splenic veins with the portal vein. The gastroduodenal artery passes anteriorly between the head and the neck.

Embryologically the pancreas is derived from two separate foregut structures. A larger dorsal bud arises from the duodenum to form the majority of the head, body and tail of the pancreas. A smaller ventral bud arises from the hepatic diverticulum to form the remainder of the pancreatic head and the uncinate process. The ventral pancreas rotates and fuses with the dorsal pancreas, and the ductal systems of each component anastomose to form the main pancreatic duct (of Wirsung). The main duct is joined by the common bile duct which drains into the second part of the duodenum via the ampulla of Vater. The muscular sphincter of Oddi controls the flow of bile and pancreatic enzymes into the small bowel. A smaller accessory duct (of Santorini) may persist within the dorsal component of the pancreatic head and drain proximal to the main duodenal papilla.

The most common anatomical variant is a pancreas divisum in which there is failure of fusion of the dorsal and ventral components. The majority of pancreatic juice then drains via the smaller accessory duct and this may lead to pancreatitis (Klein and Affronti, 2004). The rare annular pancreas is where the duodenum is encircled by pancreatic tissue which may result in bowel stenosis or obstruction (Paraskevas et al, 2001). This condition may be associated with chromosomal abnormalities. Ectopic pancreatic tissue or 'rests' are occasionally present in the submucosa of the stomach or duodenum. These may act as a lead point for intussusception and suffer similar pathological processes to the main pancreatic gland (Rubesin et al, 1997; Jeong et al, 2002).

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Imaging techniques

Plain radiographs do not have a primary role in investigating pancreatic disease; however, some useful clues may be incidentally apparent. Coarse calcifications may be present, characteristically crossing the midline in the epigastrium in chronic pancreatitis (*Figure 1*). Calcified gall-stones may also be seen. Acute pancreatitis may cause a localized duodenal ileus and this may manifest as a C-shape of dilated small bowel to the right of the midline. The colon cut-off sign describes gaseous distension of the transverse colon as far as the splenic flexure.

Figure 1. Coarse midline calcification in alcoholic chronic pancreatitis.

Transabdominal ultrasound has a key role to play in investigating pancreatic pathology. The pancreas is often well-visualized but occasionally overlying gas in the transverse colon or the stomach obscures anatomical detail. Focal pancreatic lesions may be seen as well as peripancreatic fluid collections. Doppler imaging provides information about tissue vascularity as well as assessing flow in the portal venous system and mesenteric arteries. In particular ultrasound is invaluable for excluding gall-stones, both in the gall bladder itself and the bile ducts, the latter predisposing to obstructive jaundice and acute pancreatitis.

A mass in the head of the pancreas or at the ampulla may obstruct the common bile duct and cause biliary dilatation. Transabdominal ultrasound has a high sensitivity for bile duct dilatation. Endoscopic ultrasound (EUS) uses a high frequency probe attached to an endoscope to provide detailed imaging of the bowel mucosa and pancreatic head. It has a developing role in the local staging of malignancies as well as allowing image-guided biopsy and drainage manoeuvres to be performed.

Computed tomography (CT) is performed to stage pancreatic malignancies by assessing tumour size, vascular invasion and the presence of metastases. The other main indication for CT is the evaluation of acute pancreatitis and its complications. A study without intravenous contrast may be performed initially to evaluate the presence of pancreatic calcification in chronic pancreatitis and within tumours. Tissue and vascular enhancement is achieved with an intravenous bolus of iodinated contrast medium. Following contrast administration images may be acquired at different delays depending on the indication. At approximately 20 seconds there is peak arterial enhancement, followed by maximal pancreatic tissue enhancement and then at 60–70 seconds post injection, there is maximal portal venous enhancement. CT cholangiography uses a slow infusion of intravenous contrast that is excreted into the bile ducts. Three-dimensional images of the biliary tree may be reconstructed and, among other applications, this technique is finding a role in evaluating the anatomy of potential liver donors (Wang et al, 2005).

Magnetic resonance cholangiopancreatography (MRCP) is a technique of imaging the pancreas and biliary tree using non-ionizing radiowaves. It uses the intrinsically high contrast between soft tissue and water to produce three-dimensional images of the pancreatic and bile ducts. It may be combined with contrast enhanced images of the liver and pancreas in the investigation of malignant and inflammatory disorders. The invasive technique of endoscopic cholangiopancreatography (ERCP) uses a side-viewing endoscope to aid cannulation of the ampulla and subsequent contrast opacification of the pancreatic and bile ducts. As magnetic resonance imaging (MRI) has the advantage of being non-invasive, ERCP is increasingly reserved for performing therapeutic procedures, such as extracting gall-stones, gaining diagnostic tissue samples and relieving obstructed ducts. Retrograde filling of the pancreatic duct at ERCP may itself lead to iatrogenic pancreatitis.

Catheter angiography is used in selected cases for localizing and characterizing pancreatic neoplasms. Interventional radiology also has a role in peripancreatic abscess drainage, embolization of peripancreatic aneurysms and stent placement. Diagnostic samples may be obtained from suspected tumours using either ultrasound or CT guidance.

Radionuclide techniques have an established role in the identification of islet-cell tumours. In particular, radiolabelled octreotide derivatives have an affinity for somatostatin receptors which are over-expressed in many neuroendocrine tumours (Virgolini et al, 2005). Positron emission tomography (PET) using labelled glucose has a role for revealing distant metastases but is not sensitive enough to distinguish benign from malignant pancreatic masses (Rasmussen et al, 2004).

Pancreatitis

Acute pancreatitis may be caused by a variety of mechanisms (*Table 1*). The process results in the inappropriate activation of enzymes and a severe local inflammatory response sometimes leading to tissue necrosis. The overall mortality rate is approximately 10% and this is frequently as a result of multiorgan failure and sepsis. Initial assessment is generally with transabdominal ultrasound, which will identify gall-stones and may show the presence of fluid collections. Examination may be limited by bowel gas, particularly if there is an ileus. Patients with uncomplicated pancreatitis may not need further imag-

Table 1. Causes of acute pancreatitis

Biliary tract obstruction (most commonly by gall-stones)
Excessive alcohol consumption
Post-endoscopic retrograde cholangiopancreatography
Penetrating or blunt abdominal trauma
Drugs, e.g. azathioprine, steroids
Infections, e.g. mumps, Epstein–Barr virus, tuberculosis, ascaris lumbricoides
Autosomal dominant hereditary pancreatitis
Embryological abnormalities, e.g. annular pancreas and pancreas divisum
Scorpion venom
Hypercalcaemia
Hypertriglyceridaemia
Idiopathic

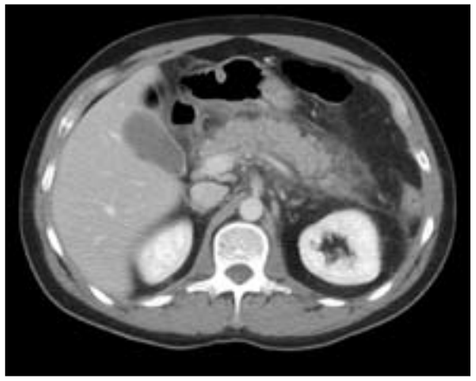
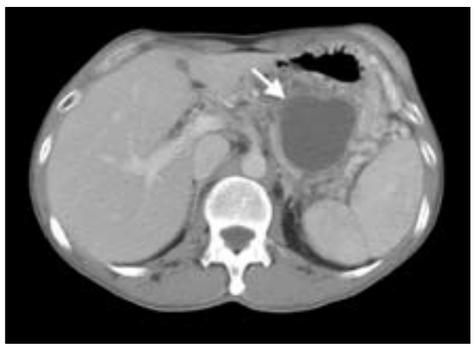


Figure 2. Computed tomogram of acute pancreatitis showing pancreatic swelling as a result of oedema plus inflammation in the surrounding tissues.

ing. However, if the diagnosis is in doubt, or there is clinical evidence to suggest a severe inflammatory episode that could indicate underlying pancreatic necrosis or abscess formation, then CT is performed. Even in mild attacks there is both interstitial and peripancreatic oedema (*Figure 2*). Pseudocysts are a frequent complication of acute pancreatitis and probably result from local extravasation of enzymatic juice. CT is a sensitive method of demonstrating the size and location of pseudocysts (*Figure 3*) and haemorrhage within them.

Symptomatic or infected fluid collections may be drained percutaneously under CT guidance before definitive endoscopic or surgical intervention. Enteral feeding using a nasojejunal tube may be established under fluoroscopic guidance although there may be little advantage over nasogastric feeding (Eatock et al, 2005). Local inflammation can cause vascular complications such as venous thrombosis or peripancreatic pseudoaneurysms, which may be treated with intravascular embolization coils placed during catheter angiography (*Figure 4*). The hallmark of severe pancreatitis is the development of

Figure 3. Computed tomogram of a pancreatic pseudocyst (arrow) complicating acute pancreatitis.



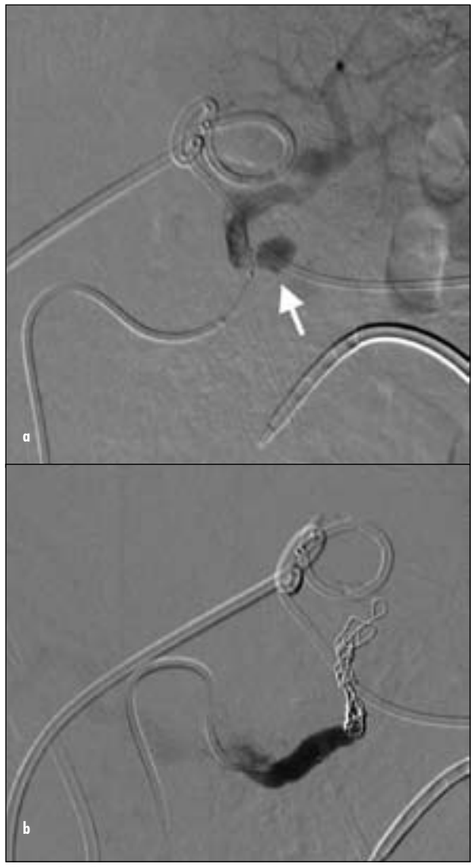


Figure 4. a. Selective splenic artery angiogram demonstrating a pseudoaneurysm (arrow) secondary to acute pancreatitis.
b. Placement of endovascular coils across the neck of the aneurysm.

tissue necrosis, the dead tissue showing no evidence of contrast enhancement compared with normal areas of the gland. The necrosis may be sterile or infected. The latter requires surgical debridement.

MRCP has a role in identifying the underlying cause of pancreatitis if an anatomical variant, gall-stones or a choledochal cyst is suspected. If the cause is an obstructing gall-stone then an early ERCP may be performed with extraction of the calculus following sphincterotomy (*Figure 5*).

Chronic pancreatitis represents a continued inflammatory and fibrosing process that leads to irreversible structural and functional changes. In advanced disease the pancreas becomes atrophic and coarsely calcified especially when associated with chronic alcohol use. The pancreatic duct may develop a 'beaded' appearance as a result of focal dilatations and stenosis. Chronic pseudocysts may also develop which communicate with the pancreatic duct. MRCP is ideally suited to demonstrate

Figure 5. Endoscopic retrograde cholangiopancreatography of the common bile duct. The filling defect (arrow) represents a common duct calculus.

these changes in the pancreatic duct. Additionally, the appearance of the gland on T1- and T2-weighted images reflect the presence of fibrosis and inflammation.

Pancreatic neoplasms

Adenocarcinoma

Pancreatic cancer most commonly arises from the exocrine cells and the majority are adenocarcinomas of ductal cell origin. Overall it is the fifth leading cause of cancer-related mortality with a 5-year survival rate of less than 5%. Typically, a mass is identified within the head of the pancreas with associated findings of biliary and pancreatic duct dilatation and glandular atrophy. Tumours may be locally invasive and typically metastasize to the regional lymph nodes, liver and peritoneal cavity. The majority of tumours arise in the head and neck of the pancreas and hence cause obstructive jaundice relatively early in the course of the illness. More distal neoplasms frequently present at an advanced stage. The aim of imaging is in the initial confirmation of a pancreatic mass and assessment of operability. Surgical resection with venous grafting may necessary if there is invasion of the portal or superior mesenteric veins. However, invasion of the superior mesenteric artery or coeliac axis precludes attempts at a curative resection.

Most patients will initially undergo a transabdominal ultrasound which may identify the mass (*Figure 6*) and demonstrate biliary dilatation and liver metastases. Ultrasound-guided biopsy of the mass or liver metastases confirms the diagnosis and the need for palliative therapy. However, patients with suspected non-metastatic disease proceed to an enhanced thin slice CT. Most tumours demonstrate little contrast enhancement compared to the surrounding glandular tissue. As well as the primary tumour, CT will assess tumour size, local extension, venous and arterial invasion and distant metastases. EUS has become increasingly available and has a high sensitivity for detecting small tumours in the head of the pancreas and in local staging (Maguchi, 2004). Patients in whom tumours are thought to be resectable at CT should proceed to a confirmatory EUS which has greater accuracy in the assessment of tumour size and lymph node involvement (Soriano et al, 2004).

Periampullary tumours are rare but can result in obstructive jaundice and pancreatitis. Papillary adenomas and adenocarcinomas are typically encountered, the malignant tumours having a better prognosis than pancreatic tumours. The mass may be identified by CT, MRI (*Figure 7*) or during ERCP. However, EUS is particularly valuable in the assessment of operability.

Pancreatic neoplasms frequently compress and invade the common bile duct leading to obstructive jaundice and pruritus. As a palliative procedure, a stent may be inserted into the common bile duct, either antegradely during a percutaneous transhepatic cholangiogram or retrogradely during an ERCP. In inoperable cancer pain

Figure 6. A malignant mass in the head of the pancreas on transabdominal ultrasound.

Figure 7. An ampullary mass extending into the duodenal lumen on magnetic resonance imaging (arrow).

relief is often afforded by a neurolytic coeliac axis nerve blockade which is injected transabdominally using CT guidance (*Figure 8*).

Neuroendocrine tumours

Neuroendocrine tumours are a rare group of cancers which derive from the islet cells. Some of these tumours secrete functionally active peptides which may lead to distinctive symptoms and metabolic disturbances. These tumours are associated with the familial syndrome, multiple endocrine neoplasia type 1. Insulinomas and gastrinomas are the tumours most commonly encountered and their small size, frequently 1–2 cm, requires dedicated imaging protocols to visualize them.

Gastrinomas are frequently seen in the 'gastrinoma triangle' which is bounded by the cystic and common bile ducts, the duodenum, and the pancreas. Transabdominal ultrasound has a poor sensitivity and so enhanced CT is often the first-line investigation. The tumours enhance avidly but transiently in the arterial phase (*Figure 9*). Unlike adenocarcinomas they tend not to deform the contour of the pancreas or cause pancreatic duct dilatation. Larger tumours may show central necrosis and calcification, and if greater than 5 cm in diameter are frequently malignant.

MRI is useful for detecting small tumours with T1-weighted fat suppressed sequences offering the greatest sensitivity (Thoeni et al, 2000). EUS has achieved promising results in localizing tumours which appear as well-defined hypoechoic masses, and there are advocates for using this technique as a primary diagnostic tool (Anderson et al, 2000). Alternative approaches include catheter angiography combined with selective arterial calcium stimulation and hepatic venous blood sampling to aid localization of insulinomas. Somatostatin receptor scintigraphy has a complementary role in identifying both the primary tumour and malignant deposits. However,

Figure 8. Coeliac axis nerve blockade. Radio-opaque contrast is injected under computed tomography guidance to check the needle tip position, before injection of the neurolytic. The patient had an inoperable pancreatic tumour and a bile duct stent.

Figure 9. A neuroendocrine tumour in the tail of the pancreas showing increased contrast enhancement relative to the normal pancreas.

despite these techniques a significant number of tumours are not visualized preoperatively. Intraoperative localization with high resolution ultrasonography during surgical exploration may sometimes be required.

Pancreatic cysts

Cystic lesions within the pancreas may have a benign or malignant aetiology. Simple cysts containing serous fluid are benign and do not require treatment. Congenital conditions such as adult polycystic kidney disease and von Hippel–Lindau syndrome may lead to the development of pancreatic cysts. Acquired causes include pseudocysts, hydatid cysts, post-traumatic cysts and cystic neoplasms. The most frequently encountered neoplasms are serous and mucinous tumours, and intra-ductal papillary mucinous tumours (IPMT). Serous cystadenomas are benign and typically appear as a grape-like cluster of small cysts with a central scar (*Figure 10*). These features can be distinguished on CT which may also demonstrate typical sunburst calcification. MRI may confirm the benign appearance of the cysts and show delayed enhancement of the fibrotic central scar. Mucinous cystic tumours show a spectrum of histological appearances from benign to overtly malignant. They typically occur in the body and tail of the pancreas and have a strong female predilection. They may grow into large smooth-bordered fluid-filled cysts up to 20 cm in diameter. CT may demonstrate a mixture of solid and cystic components with focal calcification. Following intravenous contrast they typically show both rim enhancement and enhancement of the septae. The proteinaceous contents of these mucin-filled cysts typically gives rise to hyperintense signal on both T1 and T2 weighted MRI sequences.

IPMTs arise from the main pancreatic duct or its branches. It tends to manifest itself as a multilocuated cyst with papillary projections and is most commonly found in the pancreatic head and uncinate process. Cross-sectional imaging shows pancreatic duct dilatation

and glandular atrophy that may be difficult to distinguish from chronic pancreatitis. MRCP is useful for confirming that the cystic mass communicates with the pancreatic duct.

Lymphoma and metastases

Lymphoma of the pancreas is most commonly of non-Hodgkin's B-cell origin. It manifests as diffuse pancreatic enlargement with peripancreatic and retroperitoneal lymph node enlargement.

Pancreatic metastases should be suspected in the context of a known malignancy with multiple pancreatic masses. The most common primary tumours are lung, breast, kidney and melanoma. Post-contrast cross-sectional imaging demonstrates the typical hypervascularity of these lesions.

Pancreatic trauma

The pancreas is situated in a relatively protected position and is not as vulnerable to blunt injury as the liver and spleen. However, delayed diagnosis carries a significant mortality and it is an important injury to recognise and evaluate (Kao et al, 2003). Pancreatic trauma is seldom an isolated injury and is associated with multiorgan and vascular damage. Penetrating injuries, such as gun shot wounds and stabbings, to the flank or abdomen are a frequent cause of pancreatic trauma. If the patient is haemodynamically stable then CT is the most useful imaging investigation to perform. A severe injury will result in a 'fracture' of the pancreas and this is likely to be associated with duct disruption. Less severe injuries may be evident by pancreatic oedema and retroperitoneal fluid or haematoma. Associated visceral injuries and perforation can also be identified. Both MRCP and ERCP have a role in confirming duct integrity, although may not be appropriate if the patient is in an unstable condition. Intraoperative pancreatography is sometimes performed to assess the integrity of the pancreatic duct during laparotomy.

Figure 10. A large microcystic adenoma with central calcification (arrowhead) arising from the tail of the pancreas.

Conclusions

The pancreas has a complex role in metabolic regulation and digestion. Inflammatory and neoplastic disorders of the pancreas are frequently encountered and imaging plays a pivotal role in their investigation and management. BJHM

Conflict of interest: Dr O'Regan is supported by a grant from Schering Healthcare Ltd.

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KEY POINTS

- Acute pancreatitis is initially investigated with ultrasound (US).
- Computed tomography (CT) is performed if complications are suspected.
- Pancreatic necrosis may require surgical intervention.
- Pancreatic cancer should be suspected in cases of painless jaundice.
- Endoscopic US and CT are used to assess resectability.
- A bile duct stent can relieve symptoms of jaundice.
- Cystic masses may be characterized by CT and magnetic resonance imaging.
- Pancreatic trauma is associated with multi-organ injury.
- Imaging is used to assess duct integrity.