RadioGraphics

Secretin-enhanced MR Cholangiopancreatography: Spectrum of Findings[1]

Temel Tirkes, MD • Kumaresan Sandrasegaran, MD • Rupan Sanyal, MD Stuart Sherman, MD • C. Max Schmidt, MD, PhD, MBA • Gregory A. Cote, MD, MSc • Fatih Akisik, MD

SA-CME

See www.rsna.org/education/search/RG

LEARNING OBJECTIVES FOR TEST 2

After completing this journal-based SA-CME activity, participants will be able to:

- Describe the physiologic action of secretin and its usefulness in MRCP studies.
- Identify congenital and acquired malformations of the pancreatic ducts.
- Identify postoperative complications after pancreatectomy.

TEACHING POINTS

See last page

Magnetic resonance cholangiopancreatography (MRCP) is the most effective, safe, noninvasive magnetic resonance (MR) imaging technique for the evaluation of the pancreaticobiliary ductal system. The MRCP imaging technique has substantially improved during the past 2 decades and is based mainly on the acquisition of heavily T2-weighted MR images, with variants of fast spin-echo sequences. MRCP can also be performed by utilizing the hormone secretin, which stimulates a normal pancreas to secrete a significant amount of fluid while transiently increasing the tone of the sphincter of Oddi. The transient increase in the diameter of the pancreatic duct improves the depiction of the ductal anatomy, which can be useful in patients in whom detailed evaluation of the pancreatic duct is most desired because of a suspicion of pancreatic disease. Improved depiction of the ductal anatomy can be important in *(a)* the differentiation of side-branch intraductal papillary mucinous neoplasms from other cystic neoplasms and *(b)* the diagnosis and classification of chronic pancreatitis, the disconnected pancreatic duct syndrome, and ductal anomalies such as anomalous pancreaticobiliary junction and pancreas divisum. In patients examined after pancreatectomy, stimulation with secretin can give information about the patency of the pancreaticoenteric anastomosis. Duodenal filling during the secretin-enhanced phase of the MRCP examination can be used to estimate the excretory reserve of the pancreas. Secretin is well tolerated, and complications are rarely seen. Secretin-enhanced MRCP is most useful in *(a)* the evaluation of acute and chronic pancreatitis, congenital variants of the pancreaticoduodenal junction, and intraductal papillary mucinous neoplasms and *(b)* follow-up of patients after pancreatectomy.

Introduction

Magnetic resonance cholangiopancreatography (MRCP) of the pancreas emerged almost 2 decades ago as an accurate noninvasive technique for imaging the pancreatic and biliary ductal system. MRCP is based mainly on the acquisition of heavily T2-weighted magnetic resonance (MR) images, with variants of fast spin-echo (SE) sequences; however, the examination also includes T1-weighted MR images and dy-

Abbreviations: ERCP = endoscopic retrograde cholangiopancreatography, IPMN = intraductal papillary mucinous neoplasm, MRCP = MR cholangiopancreatography, SE = spin-echo, 3D = three-dimensional

RadioGraphics 2013; 33:1889–1906 • **Published online** 10.1148/rg.337125014 • **Content Codes:** GI MR

[1]From the Department of Radiology and Clinical Sciences (T.T., K.S., F.A.), Division of Gastroenterology (S.S., G.A.C.), and Department of Surgery (C.M.S.), Indiana University School of Medicine, 550 N University Blvd, UH0663, Indianapolis, IN 46202; and the Department of Radiology, University of Alabama at Birmingham, Birmingham, Ala (R.S.). Recipient of a Certificate of Merit award for an education exhibit at the 2010 RSNA Annual Meeting. Received February 29, 2012; revision requested April 4 and received April 17, 2013; accepted May 20. For this journal-based SA-CME activity, the authors K.S., S.S., C.M.S., and G.A.C. have disclosed financial relationships (see p 1904); all other authors, the editor, and reviewers have no relevant relationships to disclose. **Address correspondence to** T.T. (e-mail: *atirkes@iupui.edu*).

Table 1
Parameters for Pancreatic Imaging on 1.5-T MR Imagers

Parameter	Two-Point Dixon Method	Half Single-Shot Fast SE	Half Single-Shot Fast SE	MRCP: 2D Slab	MRCP: 3D (3D Turbo SE)	MRCP: 2D Slab with Secretin	3D GRE with Contrast Material
Imaging plane	Axial	Axial	Coronal	Coronal	Coronal	Coronal	Axial
TR/TE (msec)	7.47/4.76 (in), 2.38 (out)	1100/90	1100/90	2000/755	2500/691	2000/756	5.17/2.52
Flip angle (degrees)	10	130–150	130	180	Variable	1	12
Section thickness (mm)*	3.4	4.0	4.0	40	1.0	40	3.0
Number of signals acquired	1	1	1	1	2	1	1
Receiver bandwidth (Hz/pixel)	290	475	476	300	372	300	300
Matrix	256 × 120	256 × 192	256 × 192	256 × 256	384 × 346	256 × 256	256 × 144
Respiration	Breath hold	Breath hold	Breath hold	Breath hold	Navigator	Breath hold	Breath hold
Fat saturation	None	None	None	Fat sat	Fat sat	Fat sat	Fat sat

Note.—Fat sat = spectral selective fat saturation, GRE = gradient-recalled echo, TR/TE = repetition time (msec)/echo time (msec), 2D = two-dimensional.
*2D MRCP and secretin-enhanced MRCP slabs are single slabs 40 mm thick. 3D sequences do not have a section gap.

namic contrast material–enhanced MR images for a complete evaluation. Since its first clinical application, this technique has undergone a number of refinements to improve the spatial resolution, contrast-to-noise ratio, and image acquisition times. The concurrent use of secretin improved the diagnostic yield of MRCP in the evaluation of the pancreatic duct for structural abnormalities and the diagnosis and follow-up of cystic pancreatic neoplasms (1,2). These refinements in the MRCP examination, together with an increasing awareness of its value by clinicians, established MRCP as a widely accepted and noninvasive imaging modality for the assessment of the pancreaticobiliary ductal system and cystic pancreatic lesions.

The purpose of this article is to review the MRCP imaging examination and the clinical scenarios in which the use of secretin-enhanced MRCP is most useful. First, the MRCP imaging technique is covered, along with the administration of secretin to enhance the technique. Then the use of secretin-enhanced MRCP is discussed in the evaluation of acute and chronic pancreatitis, congenital variants of the pancreaticoduodenal junction, and intraductal papillary mucinous neoplasms and for postoperative imaging after pancreatectomy.

Imaging Technique

To fully evaluate the pancreaticobiliary ductal system and pancreatic parenchyma, the following sequences are used in our institution: T1-weighted gradient-echo; T2-weighted axial and coronal sequences; turbo SE or one of its variants; two-dimensional and three-dimensional (3D) MRCP; and T1-weighted 3D gradient-echo before and after administration of gadolinium-based contrast material (Tables 1, 2) (3). To adequately assess the exocrine response to secretin, patients should be fasting for at least 4 hours before the MR imaging examination. We recommend administration of a negative oral contrast agent to remove high signal intensity from the fluid within the stomach and duodenum on MRCP images (Fig 1). If a commercial product is not available, pineapple juice and blueberry juice can be used as alternative negative MR contrast material (4,5). A total of 320 mL of pineapple juice at 100% concentration is given as a replacement at our institution.

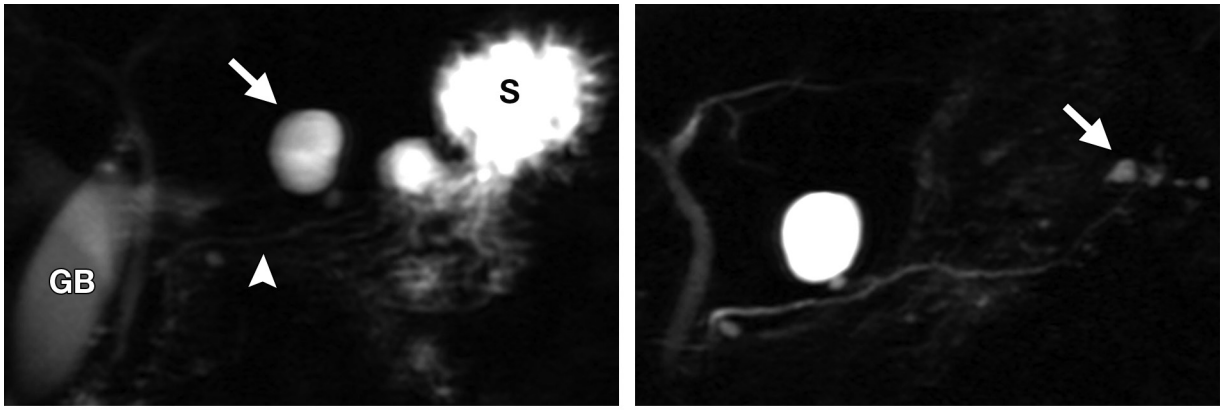
Secretin

Secretin is a 27–amino acid polypeptide hormone secreted by the duodenal mucosa in response to increased intraluminal acidity, typically after a meal (6). Synthetic human secretin

Table 2
Parameters for Pancreatic Imaging on 3.0-T MR Imagers

Parameter	Two-Point Dixon Method	Half Single-Shot Fast SE	Half Single-Shot Fast SE	MRCP: 2D slab	MRCP: 3D (3D Turbo SE)	MRCP: 2D Slab with Secretin	3D GRE with Contrast Material
Imaging plane	Axial	Axial	Coronal	Coronal	Coronal	Coronal	Axial
TR/TE (msec)	5.45/2.45 (in), 3.68 (out)	2000/96	2000/97	4500/622	2400/719	4500/746	4.19/1.47
Flip angle (degrees)	9	150	150	160	Variable	180	9
Section thickness (mm)*	4.0	5.0	4.0	40	1.2	40	2.6
Number of signals acquired	1	1	1	1	2	1	1
Receiver bandwidth (Hz/pixel)	500 or 780	780	780	383	318	161	350
Matrix	320 × 224	320 × 224	320 × 256	384 × 306	380 × 380	384 × 306	308 × 210
Respiration	Breath hold	Breath hold	Navigator	Breath hold	Navigator	Breath hold	Breath hold
Fat saturation	None	SPAIR	None	Fat sat	SPAIR	Fat sat	SPAIR

Note.—Fat sat = spectral selective fat saturation, GRE = gradient-recalled echo, SPAIR = spectral adiabatic inversion-recovery, TR/TE = repetition time (msec)/echo time (msec), 2D = two-dimensional.
*2D MRCP and secretin-enhanced MRCP slabs are single slabs 40 mm thick. 3D sequences do not have a section gap.



a. **b.**

Figure 1. Fluid within the stomach can markedly degrade the findings from MRCP studies. **(a)** Coronal MRCP image from a follow-up secretin-enhanced MRCP study of a 65-year-old woman with a history of side-branch intraductal papillary mucinous neoplasm (IPMN). This image was obtained without a negative contrast agent within the stomach. The T2 signal hyperintensity of the fluid within the fundus and body of the stomach *(S)* obscures the entire pancreatic duct within the tail (arrowhead) and limits the evaluation. Multiple cystic lesions are shown, with a dominant cyst (arrow) depicted within the pancreatic body. *GB* = gallbladder. **(b)** MRCP image from a repeat study performed after the same patient was given oral suspension ferumoxsil to null the fluid signal intensity shows the entire pancreatic duct and additional parenchymal cysts (arrow) within the tail of the pancreas.

for injection (ChiRhoStim; ChiRhoClin, Burtonsville, Md) is a purified synthetic peptide with an amino acid sequence identical to the naturally occurring hormone and is approved by the Food and Drug Administration for stimulation of the pancreas during endoscopic retrograde cholangiopancreatography (ERCP).

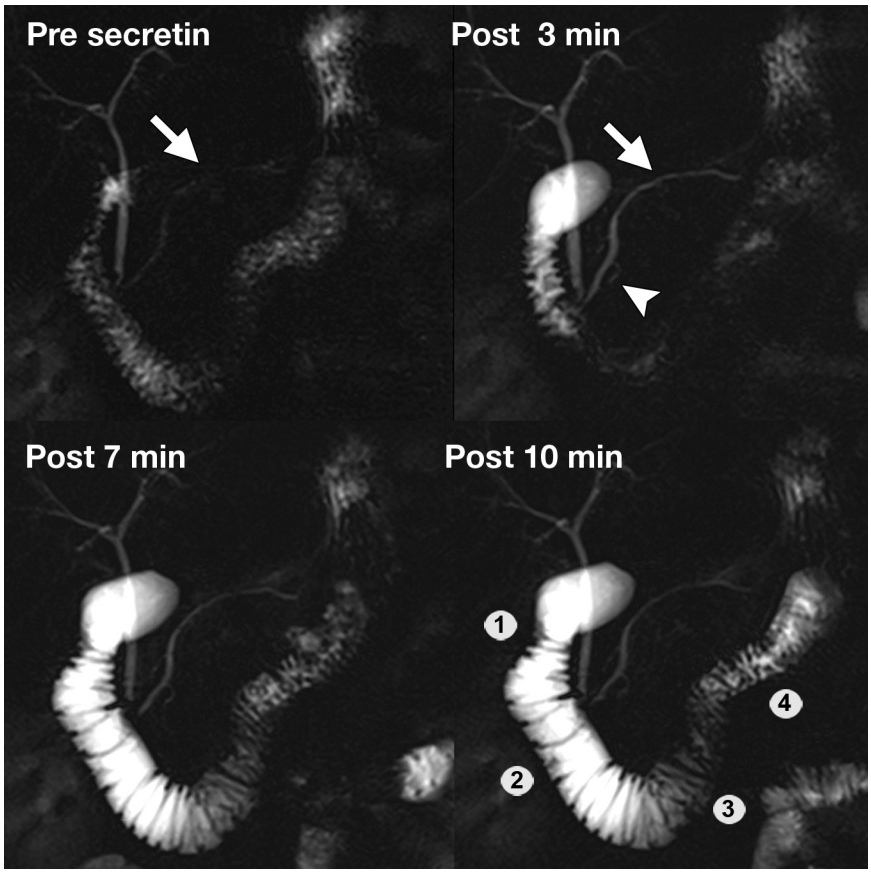


Figure 2. Duodenal filling as a response to secretin stimulation can be used to assess the excretory reserve of the pancreas. Sequential MRCP images obtained before and after the administration of secretin in a 37-year-old woman with right upper quadrant abdominal pain of suspected pancreaticobiliary origin show a brisk excretory response to secretin stimulation. Approximately a 1-mm dilatation of the main pancreatic duct (arrows) is shown as a result of secretin stimulation. The 3-minute image shows a side-branch duct (arrowhead), which was not depicted previously. The T2 signal hyperintensity within the duodenum is from the excreted fluid, which is continuously filling and even distending the lumen. Filling of the duodenum is graded according to duodenal anatomic imaging findings and is used to estimate the pancreatic excretory reserve: grade 1, when pancreatic fluid excretion is confined to the duodenal bulb *(1);* grade 2, when fluid is seen as far as the second portion of the duodenum *(2);* and grade 3, when duodenal filling reaches the third portion of the duodenum *(3)*. The presence of normal duodenal filling does not exclude impairment of pancreatic exocrine function. *4* = fourth portion of the duodenum.

Teaching Point

The physiologic effects of secretin include the secretion of bicarbonate-rich fluid from pancreatic ductal cells and a transient increase in the tone of the sphincter of Oddi, which improves the depiction of the pancreatic duct. The manufacturer's recommended dose of secretin is 0.2 μg/kg of body weight. A test dose is injected intravenously to test for possible allergies. If there are no signs of allergic reaction, approximately 16 μg of secretin (for adults) is given as a slow intravenous injection during a period of 1 minute, to avoid abdominal pain as a potential side effect, which may occur with a bolus injection. After intravenous injection, the pancreaticobiliary ductal system is imaged with a coronal single-shot turbo SE sequence, which takes only 2 seconds and is repeated every 30 seconds for 10 minutes. After this pulse sequence, a respiratory synchronized 3D turbo SE sequence (3D PACE; Siemens Medical Solutions, Malvern, Pa) is used.

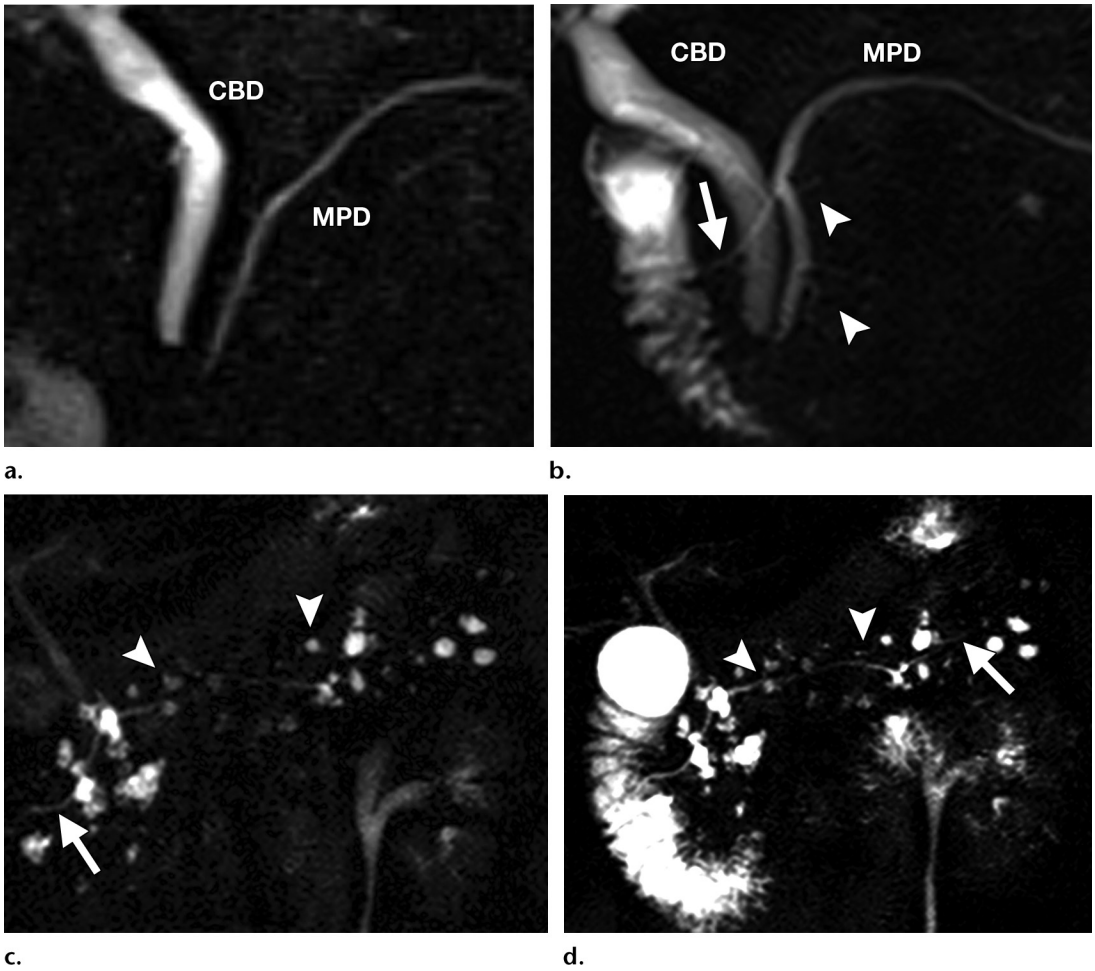


Figure 3. Secretin provides better detail of the pancreatic ductal anatomy. **(a, b)** Coronal MRCP images of a 63-year-old woman with abdominal pain. **(a)** Image obtained before the administration of secretin shows the main pancreatic duct *(MPD)* and the common bile duct *(CBD)*. **(b)** Image acquired 5 minutes after secretin administration shows that the main pancreatic duct *(MPD)* drains via the major papilla, together with the common bile duct *(CBD);* and a patent accessory duct (arrow) drains via the minor papilla. The accessory pancreatic duct is depicted because of the effect of secretin on the pancreas. The diameter of the downstream portion of the main pancreatic duct increased by 0.5 mm. The high signal intensity within the duodenum indicates the fluid excreted by the pancreas. This patient has ectatic side branches (arrowheads). **(c, d)** Coronal MRCP images of a 68-year-old woman with multiple pancreatic cysts. **(c)** Image obtained before the administration of secretin shows multiple parenchymal cystic lesions (arrowheads). It is not clear whether these cysts communicate with the main pancreatic duct. The main pancreatic duct (arrow) is depicted in the head of the pancreas; however, the duct is imperceptible in the tail. **(d)** Image obtained after secretin administration shows the entire pancreatic duct, including the portion in the tail (arrow). Depiction of the duct is improved, even though there is no noticeable difference in the diameter. The benefit of secretin administration in this case was that some of the side branches (arrowheads) were depicted connecting the cystic lesions to the main pancreatic duct. This finding is crucial in the diagnosis of side-branch IPMN, which has a lower malignant potential than main duct IPMN or other cystic pancreatic neoplasms.

The peak effect of intravenous secretin administration is usually observed at 3–5 minutes after the injection (Fig 2) (7,8). At this time, the caliber of the main pancreatic duct can increase by 1 mm or more, compared with the baseline measurement and the side branches, which may become visible and be helpful in the diagnosis (Fig 3a, 3b) (9). Common indications for the use of secretin are summarized in Table 3. Depiction of the side branches is important in certain cases,

Table 3
Common Indications for the Use of Secretin during MRCP

Clinical Scenario	Indication
Acute recurrent pancreatitis or recent severe necrotizing pancreatitis	Evaluate integrity of the pancreatic duct*
Chronic pancreatitis	Evaluate ductal stricture or stones, estimate pancreatic excretory volume
Pancreatic cystic neoplasm	Differentiate side-branch IPMN from other cystic neoplasms or pseudocyst
Postoperative pancreas	Evaluate patency of the pancreaticoenteric anastomosis, estimate pancreatic exocrine reserve, ductal dilatation, filling defects, or leak
Suspected ductal anomaly	Depict pancreas divisum with variants and anomalous pancreaticobiliary junction

*The pancreatic duct can be difficult to visualize if there are multiple large peripancreatic fluid collections.

such as differentiating the side-branch IPMN from other pancreatic cysts with a higher confidence (Fig 3c, 3d). Another potentially useful finding observed with the administration of secretin is the high T2 signal intensity in the duodenum, a finding that is secondary to the excretion of pancreatic fluid. This topic will be discussed in detail in the section on "Chronic Pancreatitis."

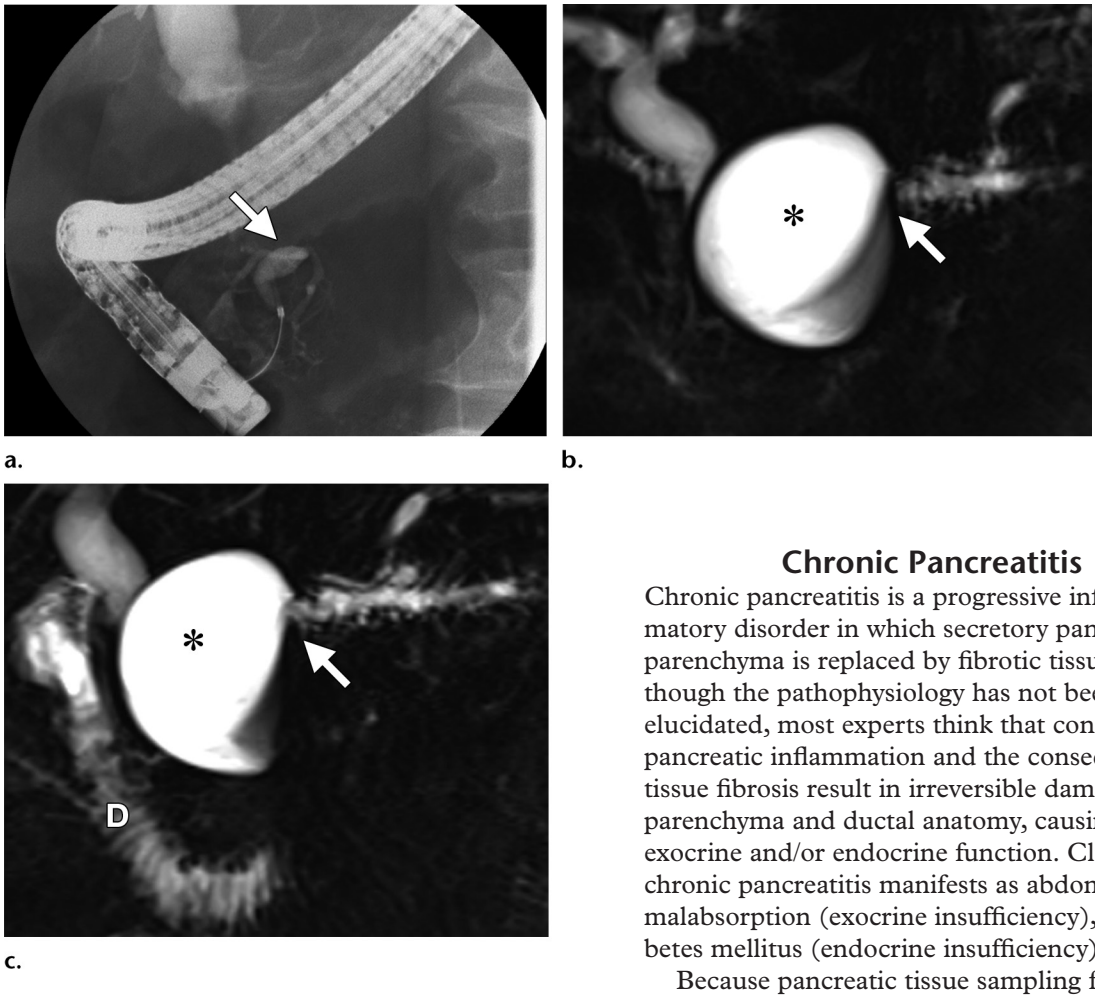
The most common adverse effects of secretin administration are nausea, flushing, abdominal pain, and vomiting, side effects that are observed in 0.5% of the patients (10). We have performed more than 10,000 secretin-enhanced MRCP examinations during the past 10 years and are aware of only two documented cases of mild acute pancreatitis as a result of secretin administration. The only contraindication to the use of synthetic secretin documented by the manufacturer is acute pancreatitis. In our institution, secretin is used in patients with mild acute pancreatitis, but its use is avoided in patients with severe pancreatitis because of the possibility of ductal obstruction.

Acute Pancreatitis

Acute pancreatitis is diagnosed when two or more of the following three conditions are present: *(a)* abdominal pain consistent with pancreatic origin, usually in the epigastrium, often radiating to the back or flanks; *(b)* elevation of the serum amylase or lipase enzyme level to more than three times the upper limit of the reference range; or *(c)* radiologic findings (computed tomography [CT], MR imaging, or ultrasonography [US]) demonstrating changes consistent with acute pancreatitis (11). CT has been widely used as the radiologic imaging modality of choice for evaluating the severity of pancreatitis and the presence of complications (12); however, compared with MRCP, CT has a lower sensitivity for depicting abnormalities of the pancreaticobiliary tree (eg, pancreas divisum, choledocholithiasis) and for ruling out choledocholithiasis (13).

A discrete intrapancreatic fluid collection along the expected course of the main pancreatic duct, with viable upstream pancreatic parenchyma, is suggestive of the diagnosis of the disconnected pancreatic duct syndrome. Diagnosis of the disconnected pancreatic duct syndrome is important in the determination of the optimal approach (surgical, endoscopic, and percutaneous) for patients with organizing pancreatic necrosis or fluid collections (14). The treatment of the disconnected pancreatic duct is surgical and requires either internal drainage or distal pancreatic resection for complete resolution. The exact incidence of this syndrome remains unknown; however, pancreatic duct disruption has been observed in as many as 50% of patients after an episode of severe acute necrotizing pancreatitis (14). Despite the severity of this complication, the average delay before diagnosis can be as long as 9.3 months (15). The morbidity associated with ERCP in the setting of recent acute pancreatitis is high, and the procedure is often technically challenging because of *(a)* ongoing edema that involves the duodenum or *(b)* complete disruption of the main pancreatic duct. Therefore, cross-sectional imaging with both CT and MR imaging plays an im-

Figure 4. Secretin-enhanced MRCP can help find a disconnected or disrupted pancreatic duct, as shown in a 78-year-old woman with gallstone pancreatitis complicated by necrosis and pseudocyst, who had been followed up with serial CT imaging for 7 months but eventually was readmitted with fever and an unresolving pseudocyst. **(a)** Initial ERCP image shows that the entire duct could not be depicted, secondary to obstruction in the pancreatic head (arrow), which the endoscopist presumed was secondary to extrinsic compression. MRCP was performed after the inconclusive findings at ERCP. **(b)** Coronal MRCP image obtained before the administration of secretin shows a centrally located fluid collection (*) within the head and neck of the pancreas, a finding consistent with a pseudocyst. Dilatation of the upstream portion of the pancreatic duct is shown, a finding that was not depicted at ERCP. The dilated upstream duct shows abrupt termination (arrow) a few millimeters from the cyst. The findings on this image help confirm obstruction of the duct secondary to extrinsic compression. **(c)** Secretin-enhanced MRCP image shows that stimulation of the pancreatic excretion function dilated the obstructed pancreatic duct, including the side branches. With the help of the increased amount of ductal fluid, the communication (arrow) of the duct with the collection (*) is depicted. This finding helped make the diagnosis of a disconnected or disrupted pancreatic duct. Part of the fluid was also excreted into the duodenum *(D)*.



a. **b.** **c.**

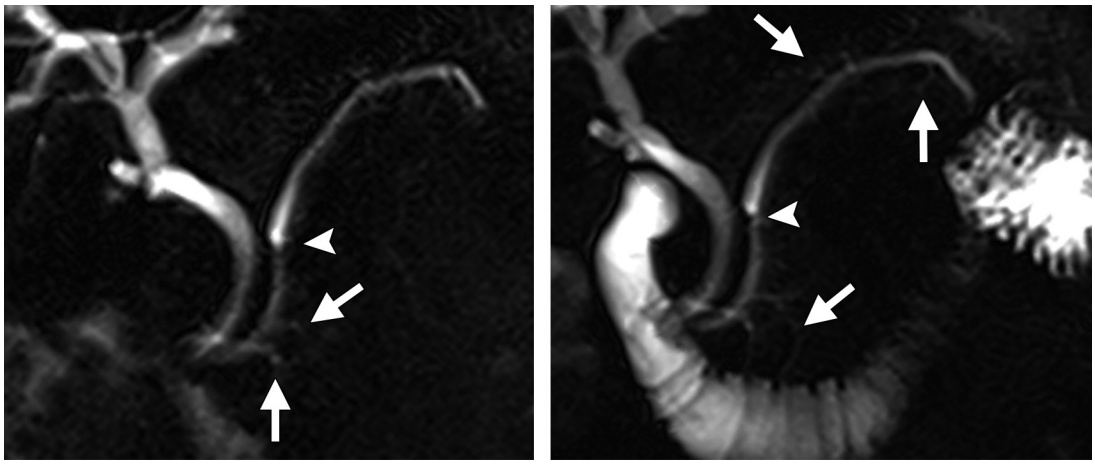
portant role. ERCP findings of ductal obstruction at the level of this fluid collection, with or without extravasation of contrast material, help confirm this diagnosis. Although ERCP is still considered the reference standard for evaluation of the disconnected pancreatic duct syndrome, secretin-enhanced MRCP can be useful in determining whether the main pancreatic duct is disrupted or disconnected in patients with necrotizing pancreatitis (Fig 4) (1,11,16,17).

Chronic Pancreatitis

Chronic pancreatitis is a progressive inflammatory disorder in which secretory pancreatic parenchyma is replaced by fibrotic tissue. Although the pathophysiology has not been fully elucidated, most experts think that continued pancreatic inflammation and the consequential tissue fibrosis result in irreversible damage to the parenchyma and ductal anatomy, causing loss of exocrine and/or endocrine function. Clinically, chronic pancreatitis manifests as abdominal pain, malabsorption (exocrine insufficiency), and diabetes mellitus (endocrine insufficiency).

Because pancreatic tissue sampling for histopathologic analysis and diagnosis is often impractical, establishing the diagnosis of chronic pancreatitis is a common challenge for the clinician. It is especially challenging to diagnose early chronic pancreatitis. One of the earliest findings of chronic pancreatitis is abnormal side-branch dilatation (Fig 5a). Administration of secretin during MRCP enhances the ductal morphologic features and increases the sensitivity of the diagnosis of chronic pancreatitis, compared with MRCP performed without secretin (7,8). ERCP

Teaching Point



a. b.

Figure 5. Chronic pancreatitis in an 80-year-old man with a history of recurrent pancreatitis. **(a)** Thick-slab MRCP image shows a focal dilatation (arrowhead) of the main pancreatic duct in the region of the head of the pancreas. Two ectatic side branches are depicted in the uncinate process (arrows). **(b)** Coronal MRCP image from the same study obtained after the administration of secretin. There is an increase in the diameter of the upstream duct, which shows a caliber change secondary to the pancreatic ductal stricture (arrowhead). The number of depicted ectatic side-branch ducts (arrows) is also increased. These findings are compatible with moderate chronic pancreatitis on the basis of the Cambridge classification. Filling of the duodenum and jejunum represents a grade 4 excretory response to secretin stimulation.

helps delineate the ductal changes of chronic pancreatitis, but ERCP is invasive and can itself cause acute pancreatitis (18).

The normal pancreas has a smooth contour of the main pancreatic duct, which measures as much as 3 mm in the head and tapers gradually in the tail. The presence of main pancreatic duct irregularity, loss of tapering in the tail, main duct strictures, abnormally dilated side branches, or main pancreatic duct dilatation is consistent with chronic pancreatitis. Secretin administration during the MRCP examination stimulates the exocrine glands to secrete fluid and causes distention of the main pancreatic duct. Loss of main pancreatic duct distensibility (a surrogate for reduced compliance) is used as a marker for chronic pancreatitis (19). The use of ductal distention to assess for chronic pancreatitis has potential pitfalls. Any stricture or obstruction in the distal duct or ampulla can increase the distention of the upstream portion of the duct in response to secretin. Because strictures are often found in patients with chronic pancreatitis, ductal distention in such cases can be falsely reassuring. On the other hand, ductal distention in response to secretin administration is not seen in normal patients who have undergone prior pancreatic sphincterotomy, because of the lack of pressure at the orifice.

Distention of the main pancreatic duct during secretin-enhanced MRCP helps in the identification of ductal strictures (8). MRCP can be used to delineate the length of tight strictures, as well as the upstream ductal anatomy (toward the tail), in cases of complete or nearly complete obstruction; and ERCP can fail to opacify the upstream duct. Ductal calcifications are common in chronic pancreatitis and cause obstruction, which leads to stasis and recurrent attacks of pancreatitis. Although CT demonstrates calcifications better than MR imaging does, ductal calculi can be depicted as filling defects during secretin-enhanced MRCP (Fig 6). The presence of ductal calculi or ductal obstruction is not a contraindication for secretin administration, unless the finding is causing severe acute pancreatitis.

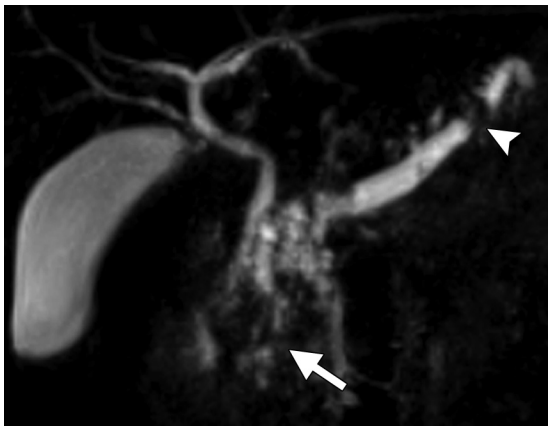


Figure 6. Established chronic pancreatitis in a 38-year-old woman who presented with abdominal pain. Coronal secretin-enhanced MRCP image shows severe dilatation of the main pancreatic duct, which measured as much as 8 mm in diameter, and several dilated side branches, particularly within the head of the pancreas. The pancreatic duct in the region of the head is not depicted (arrow), and no fluid is excreted into the duodenum. These findings are highly suggestive of a ductal stricture. Multiple filling defects within the main pancreatic duct are suggestive of ductal calculi, and the largest calculus (arrowhead) is located in the pancreatic tail. ERCP was performed; however, the upstream pancreatic duct could not be depicted because of the complete obstruction of the duct in the head. The patient eventually underwent duodenum-preserving pancreatic head resection (Frey procedure).

Table 4
Cambridge Classification of Chronic Pancreatitis

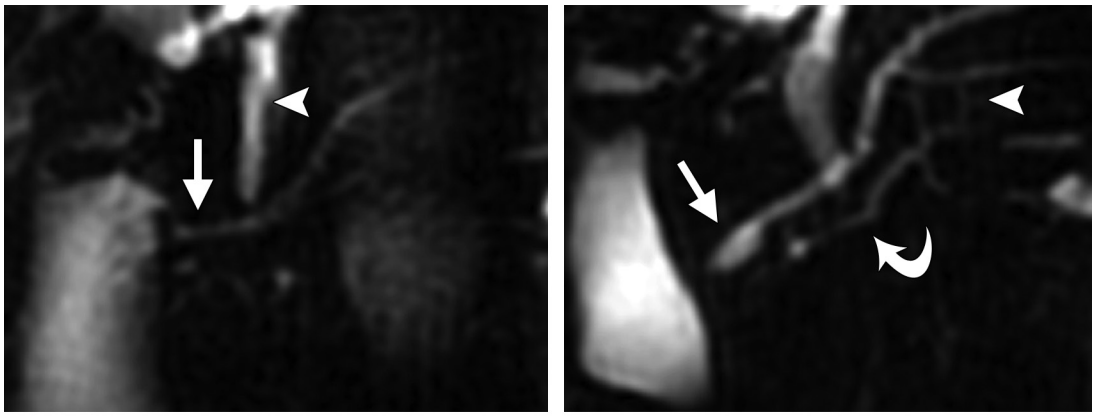
Grade	Main Pancreatic Duct	No. of Abnormal Side Branches
Normal	Normal	None
Equivocal	Normal	Less than 3
Mild changes of chronic pancreatitis	Normal	3 or more
Moderate changes of chronic pancreatitis	Abnormal	3 or more
Severe changes of chronic pancreatitis*	Abnormal	3 or more

Note.—The Cambridge classification considers structural changes on pancreatograms, and the classification grade does not necessarily coincide with the severity of pathology or the functional status. Patients with normal pancreatograms may have chronic pancreatitis, and asymptomatic patients may have marked pancreatographic changes.
*Additional features include a large cavity, obstruction, a filling defect, severe dilatation, or irregularity.

Several classification systems are used to define and characterize the severity of chronic pancreatitis. The Cambridge classification, which is the most commonly used grading system for chronic pancreatitis, was established in 1984 for ERCP (20). This system classifies pancreatograms into normal or equivocal, mild, moderate, and severe changes of chronic pancreatitis on the basis of the main pancreatic duct dilatation, side-branch dilatation, and additional features (Table 4). The new MR imaging techniques and the addition of secretin improved depiction of the main pancreatic duct and its side branches to such a degree that it is possible to use the Cambridge classification by MRCP (13,21,22).

Teaching Point

Secretin-enhanced MRCP is an imaging modality that not only helps identify the characteristic ductal changes of chronic pancreatitis but also provides an estimate of pancreatic excretory volume. It is important to remember that the presence of normal duodenal filling does not exclude impairment of pancreatic exocrine function, which is measured by determining the fluid bicarbonate level (19). Excretory function is graded according to the duodenal anatomic imaging findings: *(a)* grade 1, when pancreatic fluid is confined to the duodenal bulb; *(b)* grade 2, when fluid is seen as far as the second portion of the duodenum; and *(c)* grade 3, when duodenal filling reaches the third portion of the duodenum (Fig 2). Diminished estimated pancreatic exocrine function is suspected with grade



a. b.

Figure 7. Pancreas divisum in a 51-year-old man referred to our institution because of recurrent upper abdominal pain. **(a)** Coronal MRCP image obtained before the administration of secretin shows that the common bile duct (arrowhead) and the main pancreatic duct (arrow) appear to intersect with each other. The most distal portion of the common bile duct is not depicted. Findings are suggestive of, but not definitive for, pancreas divisum. **(b)** Coronal MRCP image acquired 3 minutes after secretin administration shows that the diameter of the main pancreatic duct is increased, with improved delineation of the ductal anatomy. The ventral pancreatic duct (curved arrow) and the dorsal pancreatic duct (straight arrow) are depicted after secretin injection. The dorsal pancreatic duct drains more superiorly into the minor papilla (duct of Santorini). Depiction of the ventral pancreatic duct helps confirm the diagnosis of pancreas divisum. Also shown after secretin stimulation are the ectatic side branches (arrowhead), which are suggestive of chronic pancreatitis.

1 duodenal filling, or in the absence of duodenal fluid accumulation in the duodenal lumen (19). This grading does not differentiate between early and established pancreatitis. Other methods of quantification have been proposed, which involve measuring the volume of fluid excreted in the duodenum or the peak flow rate (23,24). These newer techniques may be able to be used to differentiate among the grades of pancreatitis, and the techniques hold promise but are new and not yet used widely.

Congenital Variants of the Pancreaticoduodenal Junction

Pancreas Divisum

About 15%–20% of patients with unexplained pancreatitis have been found to have the anatomic variant of pancreas divisum, whereas only 5%–10% of the general population has this anatomic variant (25,26) (Fig 7). The results of ERCP studies suggest that in 10%–15% of patients, the divisum is incomplete, meaning that there is a diminutive communication between the dorsal and ventral ducts (25,27)

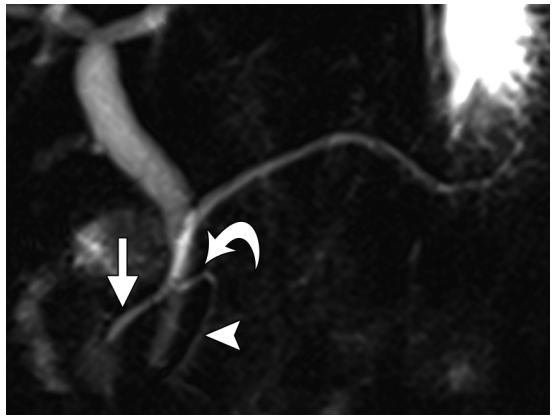


Figure 8. Incomplete pancreas divisum in a 50-year-old man. Coronal secretin-enhanced MRCP image shows incomplete pancreas divisum. The main drainage of the pancreas is from the dominant dorsal pancreatic duct (straight arrow), which is larger in diameter than the ventral duct (arrowhead). However, the pancreas divisum is not complete because there is also a communication (curved arrow) between the ventral and dorsal pancreatic ducts.

(Fig 8). It has been suggested that incomplete pancreas divisum (also known as "dominant dorsal duct") may have similar implications to those of complete pancreas divisum (28). The

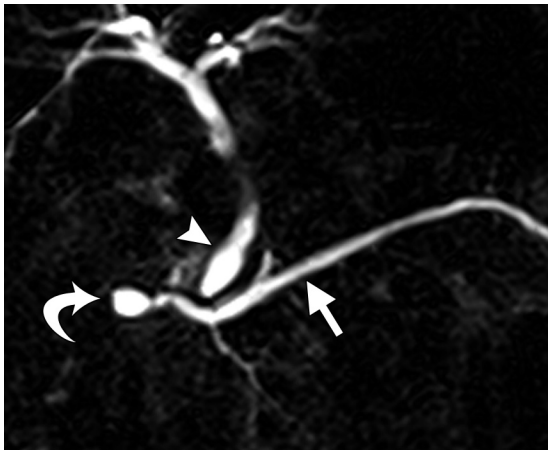


Figure 9. Santorinicele in a 59-year-old woman. Coronal MRCP image shows the common bile duct (arrowhead) crossing the main pancreatic duct (straight arrow), which is draining through the minor papilla, consistent with the anatomic variant of pancreas divisum. Also depicted is a santorinicele (curved arrow), which is a term used for saccular dilatation of the distal portion of the dorsal duct, a finding suggestive of increased pressure that is due to limited flow capacity in the minor papilla.

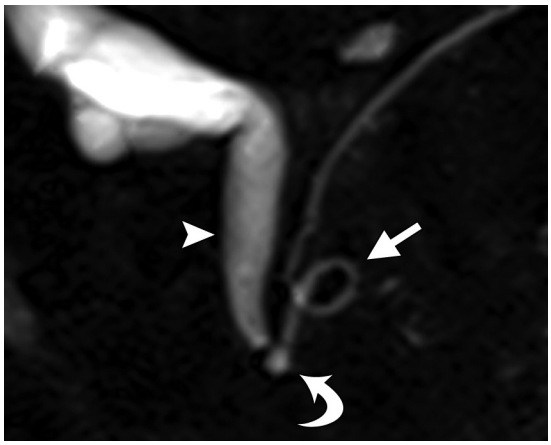


Figure 10. Wirsungocele in a 72-year-old woman with recurrent right upper quadrant pain. Coronal MRCP image shows that the common bile duct (arrowhead) is dilated. Also depicted is a wirsungocele (curved arrow), which is a saccular dilatation of the terminal portion of the ventral pancreatic duct. The loop configuration (straight arrow) of the ventral pancreatic duct is a normal variant.

accuracy of diagnosing pancreas divisum with MRCP is noticeably increased with the use of secretin (26,29,30), with values for the sensitivity of secretin-enhanced MRCP reported between 73% (31) and 100% (32) and specificities of 97%–100%. Lower sensitivity was attributed to the presence of chronic pancreatitis (31).

Santorinicele and Wirsungocele

MRCP can also detect the presence of a santorinicele, which is a focal distention of the dorsal (Santorini) duct as it enters the duodenal wall, presumably as a result of impaired flow across the minor papilla (Fig 9). There is an increased risk of recurrent acute pancreatitis in patients with pancreas divisum who also have a santorinicele (33). Focal saccular dilatation of the terminal part of the main (ventral) pancreatic duct has also been described as an incidental finding and is termed a wirsungocele (Fig 10).

Anomalous Pancreaticobiliary Junction

Anomalous pancreaticobiliary junction is a congenital anomaly defined as a malunion of the pancreatic and biliary ducts that is located outside the duodenal wall (Fig 11a). Conventional MRCP is a useful noninvasive examination for diagnosing congenital pancreaticobiliary malformations, and the diagnostic accuracy can be increased with secretin stimulation (16) (Fig 11b, 11c). Bidirectional regurgitations may occur, secondary to the lack of the sphincter muscle (sphincter of Oddi) function at the union. The anomalous junction is linked with several complications, including cholangitis, pancreatitis, and formation of biliary and pancreatic calculi. Prophylactic surgical interventions are recommended because of an increased risk of biliary tract or gallbladder cancer (34). Diagnosis of an anomalous pancreaticobiliary junction may also be possible by demonstrating distention of the gallbladder during secretin-enhanced MRCP (35).

Annular Pancreas

Annular pancreas is a congenital anomaly that arises from failed or incomplete rotation of a portion of the ventral pancreas during embryologic development. A part of the ventral pancreas passes posterior to the descending duodenum and partially or completely encircles the second portion of the duodenum. Annular pancreas typically produces ringlike narrowing of the descending duodenum between the major papilla and the minor papilla. Although children with annular pancreas tend to present with gastric outlet obstruction, this manifestation is less common in

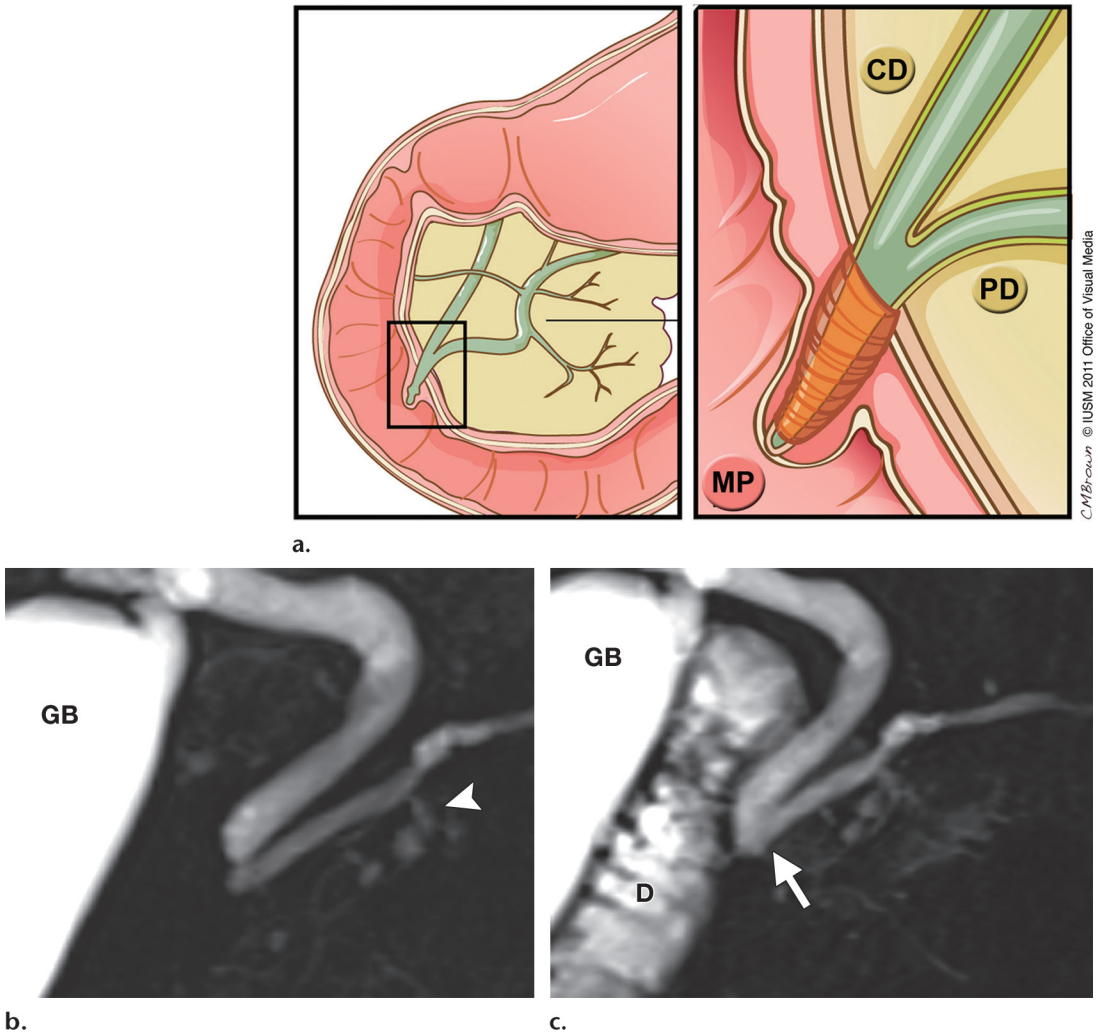
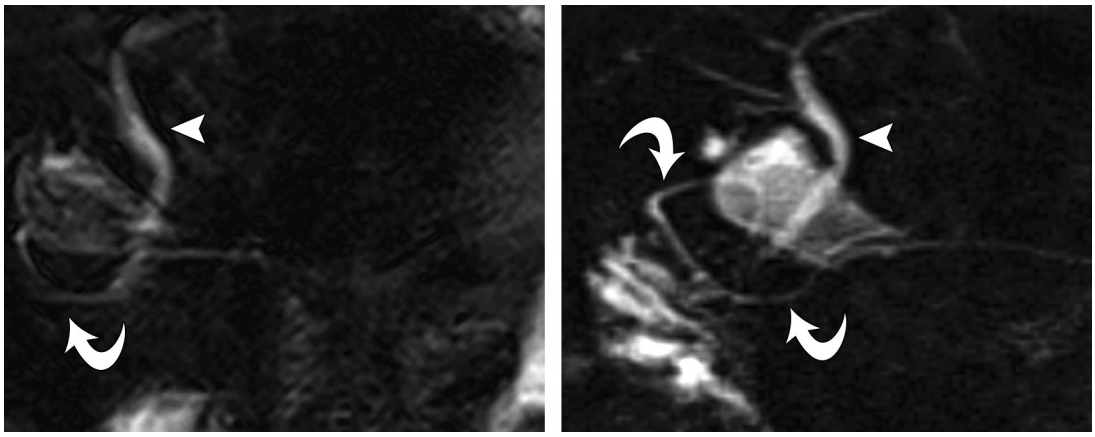


Figure 11. Anomalous pancreaticobiliary junction. **(a)** Drawing (left) and enlarged view (right) show an abnormal junction of the distal bile duct *(CD)* and the pancreatic duct *(PD)*. A common channel that is not covered by the sphincter muscle is proximal to the sphincter muscle at the major papilla *(MP)*. This anomalous communication is responsible for bidirectional regurgitation of the pancreatic and biliary secretions. An anomalous pancreaticobiliary junction predisposes patients to several complications, including cholangitis, pancreatitis, calculus formation, and malignancy. **(b, c)** Coronal MRCP images of a 74-year-old woman with a 13-year history of intermittent liver enzyme elevations and cholangitis. **(b)** Image obtained before the administration of secretin shows main and side-branch ductal ectasia (arrowhead) of the pancreas. The findings on this image do not raise a suspicion of anomalous pancreaticobiliary junction. *GB* = gallbladder. **(c)** Secretin-enhanced image acquired 10 minutes after secretin administration shows a common channel (arrow) between the common bile duct and the pancreatic duct, a finding that was not depicted on **a**. Demonstration of an anomalous pancreaticobiliary junction markedly changes patient management, including surgical intervention to prevent future complications. *D* = fluid excreted in the duodenum, *GB* = gallbladder. (Fig 11a used with permission from Indiana University School of Medicine, Office of Visual Media.)

the adult population. Annular pancreas can be diagnosed on the basis of CT and MR imaging findings that show pancreatic tissue and an annular duct encircling the descending duodenum (36,37) (Fig 12).

Intraductal Papillary Mucinous Neoplasm

The increased utilization of *(a)* cross-sectional imaging and *(b)* advances in MR imaging has resulted in an increased incidence of pancreatic cystic lesions. According to one study, the prevalence of incidentally detected pancreatic



a. b.

Figure 12. Annular pancreas in a 53-year-old woman who presented with nausea and vomiting. **(a)** Coronal MRCP image obtained before the administration of secretin shows an unusual semicircular course of the main pancreatic duct (arrow) traversing lateral to the expected location of the ampulla, a finding suspicious for annular pancreas. However, the insertion point of the main pancreatic duct is not depicted. The common bile duct (arrowhead) is shown. **(b)** Coronal secretin-enhanced MRCP image allows tracing of the entire course of the main pancreatic duct (arrows). The distal main pancreatic duct makes a full circle around the duodenal lumen before joining the common bile duct (arrowhead) at the major papilla, a finding that helped confirm the diagnosis of annular pancreas. High signal intensity within the duodenum is secondary to the excretion of pancreatic juice.

cysts at MR imaging is 13.5% (38). IPMN is the most common cystic neoplasm of the pancreas, with the following rates reported: IPMN, 36%; mucinous cystic neoplasms, 20%; serous cystadenoma; 12%; pseudocyst, 14%; and ductal adenocarcinoma, 7% (39). IPMNs are considered to be more common in men, although an equal prevalence in men and women has also been reported (40), and the mean age is reported to be 65 years (41). These tumors are characterized by intraductal proliferation of neoplastic mucinous cells forming papillary projections into the pancreatic ductal system, which is typically dilated and contains globules of mucus (Fig 13a).

Teaching Point

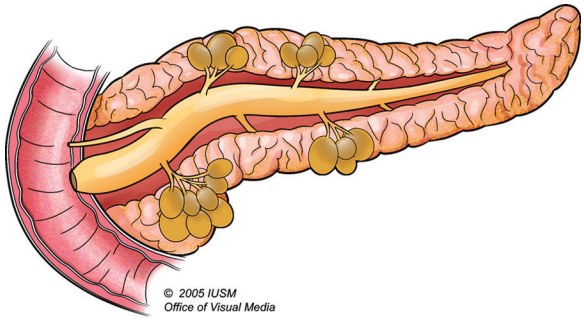
Pancreatic ductal imaging is essential not only in establishing the diagnosis of IPMN but also in differentiating among the subtypes of IPMN (42), such as main duct IPMN (either diffuse or segmental) and mixed or side-branch IPMN (43). The reported risk of in situ or invasive malignancy in postoperative patients with main duct IPMN ranges from 57% to 92% but is less than 20% in side-branch IPMN (44). Isolated side-branch IPMNs can be difficult to distinguish from other cystic lesions, such as serous or mucinous cystic neoplasms or a pseudocyst. The presence or absence of direct communication with the main pancreatic duct is important to distinguish side-branch IPMNs from mucinous cystic neoplasms (with relatively high malignant potential) (45) (Fig 13b, 13c). Surgical resection is recommended for all of the mucinous cystic neoplasms, whereas side-branch IPMN can be managed with observation if the patient is asymptomatic and the lesion is smaller than 3 cm (42).

Imaging of the Pancreas in the Postoperative Patient

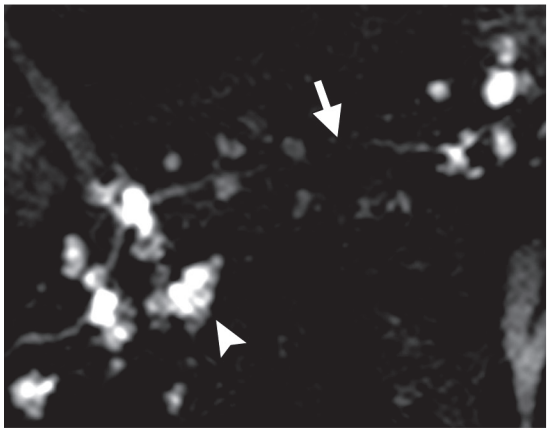
ERCP is difficult to perform in patients after a pancreatic surgical procedure, and secretin-enhanced MRCP is the noninvasive modality of choice for follow-up (1). MRCP is able to image the pancreatic duct after most common pancreatic surgical procedures, including the Whipple procedure, distal pancreatectomy, and central pancreatectomy with pancreaticojejunostomy (Figs 14–18).

Teaching Point

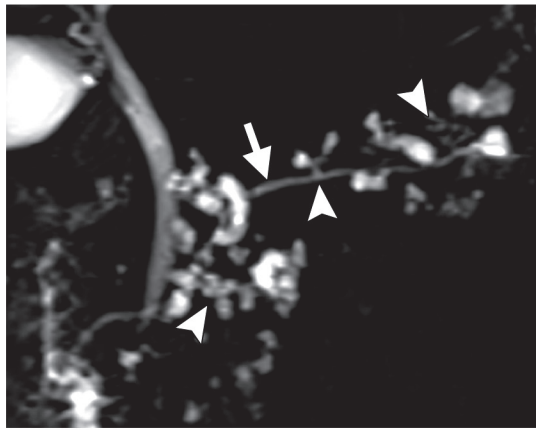
Mild distention of side branches after the administration of secretin is commonly seen in patients after pancreaticoenteric anastomosis; however, in our experience, progressive distention during the dynamic phase of secretin-enhanced MRCP and a decreased excretory response may indicate anastomotic stricture (Fig 14). Anastomotic strictures may predispose patients to develop inspissated secretions or a calculus (Fig 15). Accumulation of fluid near the pancreas during the dynamic phase may indicate a pancreatic



a.



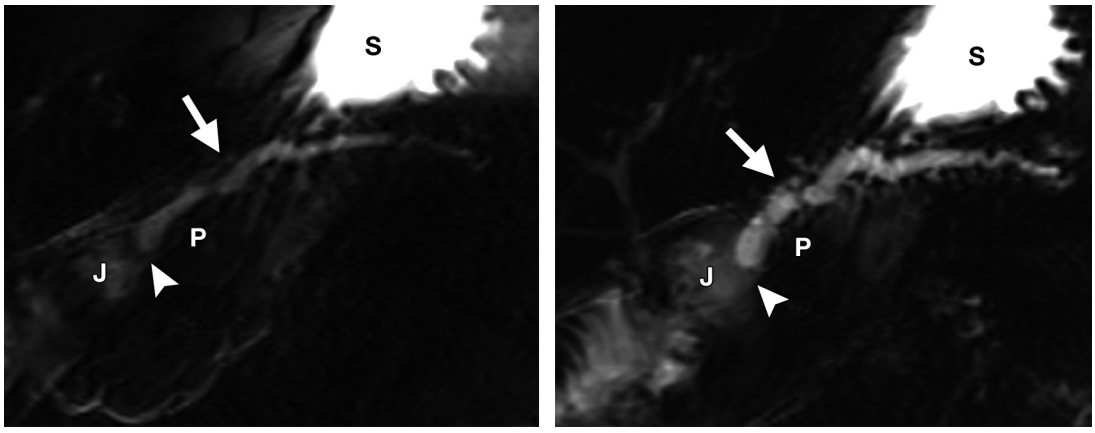
b.



c.

Figure 13. Secretin can help the depiction of side-branch ducts in patients with IPMN. **(a)** Drawing of a side-branch IPMN. The cysts of the side-branch IPMN are formed by neoplastic mucinous cells and are usually multiple. Depiction of a side-branch duct between the cyst and the main pancreatic duct is a key finding that distinguishes side-branch IPMNs from other cystic pancreatic neoplasms. **(b, c)** Coronal MRCP images of a 68-year-old woman with a history of abdominal pain but no history of pancreatitis who was referred for evaluation of pancreatic cysts. **(b)** Image obtained before the administration of secretin shows multiple cystic lesions (arrowhead) within the parenchyma. The main pancreatic duct (arrow) is faintly depicted within the body. **(c)** Image obtained after secretin administration shows that these cysts (arrowheads) are arising from the side branches of the pancreatic duct, which was not apparent on **a**. The main duct (arrow) is now depicted throughout its entire course and is not dilated. These findings favor the diagnosis of a side-branch IPMN, which has a substantially lower malignant potential than the more worrisome mucinous neoplasms. Findings from endoscopic aspiration of the pancreatic fluid disclosed that tumor markers were negative for malignancy. These cysts were stable for 5 years of follow-up with MRCP, and the patient did not require surgery. (Fig 13a used with permission from Indiana University School of Medicine, Office of Visual Media.)

Figure 16. Pancreatic ductal leak in a 30-year-old woman who had undergone distal pancreatectomy secondary to chronic pancreatitis. **(a)** Coronal MRCP image acquired immediately after the administration of secretin shows that the remaining pancreatic duct (arrow) is faintly depicted. The biliary tree is also dilated secondary to a distal common bile duct stricture as a sequela of chronic pancreatitis. **(b)** Coronal MRCP image obtained 10 minutes after secretin administration shows that an increased diameter of the pancreatic duct (arrow) allows improved depiction. The secretin-stimulated dynamic phase shows progressive accumulation of the fluid (arrowhead) near the distal pancreatic stump, a finding suspicious for pancreatic ductal leak. ▶



a. b.

Figure 14. Postoperative anastomotic stricture in a 36-year-old man who had undergone pancreaticoduodenectomy for IPMN. *J* = jejunal loop, *P* = pancreas, *S* = fluid in the stomach. **(a)** Selected coronal MRCP image was acquired 3 minutes after the administration of secretin. The main pancreatic duct (arrow) appears dilated. The pancreaticojejunal anastomosis (arrowhead) is depicted. **(b)** Coronal MRCP image obtained 10 minutes after secretin administration. The pancreatic duct (arrow), including the side branches, shows an increase in diameter during the secretin-stimulated dynamic phase, and jejunal filling is less than expected. These findings are suspicious for a stricture at the pancreaticojejunal anastomosis (arrowhead).

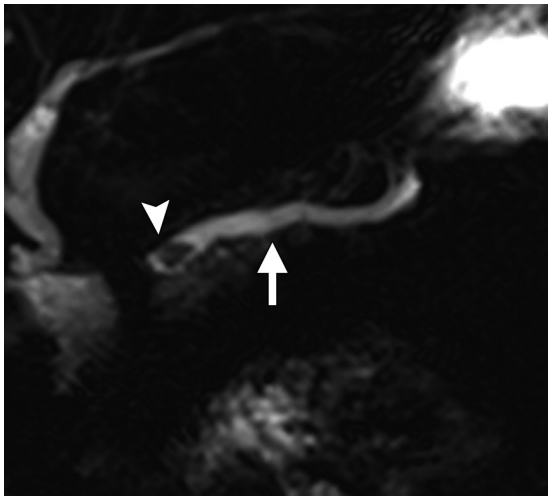
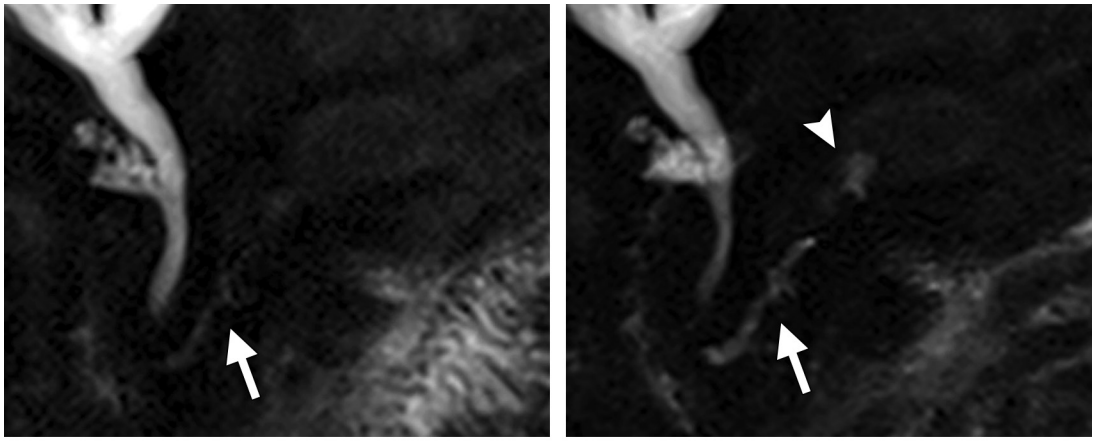
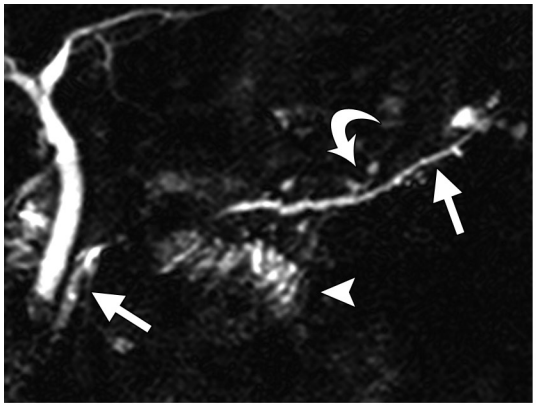


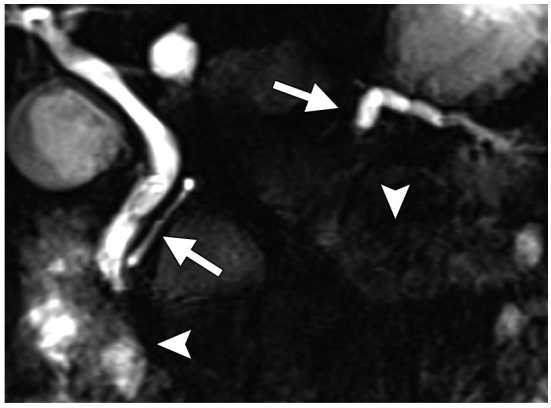
Figure 15. Pancreatic ductal dilatation and a ductal filling defect in a 51-year-old woman who had undergone pancreaticoduodenectomy secondary to IPMN. Coronal MRCP image from a follow-up examination performed years after the surgery shows dilatation of the main pancreatic duct (arrow), together with a ductal filling defect (arrowhead) near the pancreaticojejunostomy anastomosis. These findings raised a suspicion of a recurrence of IPMN. The findings from endoscopic aspiration of the main pancreatic duct with a transgastric approach disclosed mucin but could not confirm the presence of recurrent tumor. Nevertheless, this patient underwent a second surgery, and the report from pathologic examination specified that the filling defect was an inspissated secretion.



a. b.



17.



18.

Figures 17, 18. **(17)** Multifocal IPMN in a 65-year-old symptomatic man who had undergone central pancreatectomy with pancreaticojejunostomy. Coronal MRCP image obtained 7 minutes after the administration of secretin shows that the pancreatic duct is depicted in the region of the pancreatic head (straight arrow at left) and tail (straight arrow at right). Excreted pancreatic juice (arrowhead) is shown within the jejunum, a finding that indicates a patent pancreaticojejunal anastomosis. Multiple residual small cystic lesions (curved arrow) are depicted. **(18)** Postoperative follow-up imaging of a 44-year-old woman who had undergone central pancreatectomy and pancreaticojejunostomy. Coronal MRCP image acquired 10 minutes after the administration of secretin shows the main pancreatic duct in the region of the pancreatic head (arrow at left) and tail (arrow at right). The duct is dilated in the tail. A satisfactory amount of pancreatic fluid is shown to be excreted into the duodenum (arrowhead at left), but almost no fluid is excreted from the tail into the jejunum (arrowhead at right). These findings were suspicious for either poor excretory reserve or a stricture at the pancreaticojejunostomy. MRCP is the preferred modality for follow-up of these patients because it would be difficult to assess the tail portion of the duct with ERCP.

ductal leak (Fig 16). In the absence of stricture, the amount of excreted fluid seen in the efferent jejunal limb may reflect the exocrine reserve in the remaining pancreas (46).

Long-term prospective studies are required to achieve a consensus about the duration and time interval for follow-up of patients who have undergone segmental pancreatectomy for IPMN. Yearly follow-ups have been proposed in cases with resected IPMNs, as well as follow-ups every 6 months if an invasive carcinoma was found (42). New outcome data have suggested that patients with high-grade dysplasia, positive main pancreatic duct margin, and development of new lesions at follow-up imaging are at higher risk for subsequent development of cancer. Thus, these groups of patients should be followed up at even shorter intervals than 6 months (47).

Conclusions

MRCP performed with secretin and with new 3D fast SE techniques has markedly improved, providing detailed anatomy of the pancreatic duct and its relationship with other structures. In selected cases, secretin-enhanced MRCP has proved itself to be a valuable noninvasive complementary procedure to endoscopic US and ERCP, accurately characterizing pancreatic duct abnormalities while sparing patients the need for an invasive procedure.

***Disclosures of Conflicts of Interest.*—C.M.S.:** *Related financial activities:* none. *Other financial activities:* board member and speaker for Asuragen, consultant and speaker for Redpath, and patents; **G.A.C.:** *Related financial activities:* none. *Other financial activities:* consultant for Boston Scientific and Olympus America; **K.S.:** *Related financial activities:* none. *Other financial activities:* consultant for and research grant from Repligen; **S.S.:** *Related financial activities:* none. *Other financial activities:* board member of American Board of Internal Medicine, consultant for Repligen, and speaker for Cook, Olympus, and Boston Scientific.

References

1. Akisik MF, Sandrasegaran K, Aisen AA, Maglinte DDT, Sherman S, Lehman GA. Dynamic secretin-enhanced MR cholangiopancreatography. RadioGraphics 2006;26(3):665–677.
2. Carbognin G, Pinali L, Girardi V, Casarin A, Mansueto G, Mucelli RP. Collateral branches IPMTs: secretin-enhanced MRCP. Abdom Imaging 2007;32(3):374–380.

3. Tirkes T, Menias CO, Sandrasegaran K. MR imaging techniques for pancreas. Radiol Clin North Am 2012;50(3):379–393.
4. Coppens E, Metens T, Winant C, Matos C. Pineapple juice labeled with gadolinium: a convenient oral contrast for magnetic resonance cholangiopancreatography. Eur Radiol 2005;15(10):2122–2129.
5. Papanikolaou N, Karantanas A, Maris T, Gourtsoyiannis N. MR cholangiopancreatography before and after oral blueberry juice administration. J Comput Assist Tomogr 2000;24(2):229–234.
6. Chey WY, Chang TM. Secretin, 100 years later. J Gastroenterol 2003;38(11):1025–1035.
7. Matos C, Metens T, Devière J, et al. Pancreatic duct: morphologic and functional evaluation with dynamic MR pancreatography after secretin stimulation. Radiology 1997;203(2):435–441.
8. Manfredi R, Costamagna G, Brizi MG, et al. Severe chronic pancreatitis versus suspected pancreatic disease: dynamic MR cholangiopancreatography after secretin stimulation. Radiology 2000;214(3):849–855.
9. Punwani S, Gillams AR, Lees WR. Non-invasive quantification of pancreatic exocrine function using secretin-stimulated MRCP. Eur Radiol 2003;13(2):273–276.
10. Ng SYL, Cheng CYY, Chow BKC. Secretin. In: Kastin AJ, ed. Handbook of biologically active peptides. 2nd ed. Waltham, Mass: Academic Press/Elsevier, 2013; 924–932.
11. Gillams AR, Kurzawinski T, Lees WR. Diagnosis of duct disruption and assessment of pancreatic leak with dynamic secretin-stimulated MR cholangiopancreatography. AJR Am J Roentgenol 2006;186(2):499–506.
12. Arvanitakis M, Koustiani G, Gantzarou A, et al. Staging of severity and prognosis of acute pancreatitis by computed tomography and magnetic resonance imaging: a comparative study. Dig Liver Dis 2007;39(5):473–482.
13. Sugiyama M, Haradome H, Atomi Y. Magnetic resonance imaging for diagnosing chronic pancreatitis. J Gastroenterol 2007;42(suppl 17):108–112.
14. Neoptolemos JP, London NJ, Carr-Locke DL. Assessment of main pancreatic duct integrity by endoscopic retrograde pancreatography in patients with acute pancreatitis. Br J Surg 1993;80(1):94–99.
15. Tann M, Maglinte D, Howard TJ, et al. Disconnected pancreatic duct syndrome: imaging findings and therapeutic implications in 26 surgically corrected patients. J Comput Assist Tomogr 2003;27(4):577–582.
16. Arvanitakis M, Delhaye M, De Maertelaere V, et al. Computed tomography and magnetic resonance imaging in the assessment of acute pancreatitis. Gastroenterology 2004;126(3):715–723.
17. Khalid A, Peterson M, Slivka A. Secretin-stimulated magnetic resonance pancreaticogram to assess pancreatic duct outflow obstruction in evaluation of idiopathic acute recurrent pancreatitis: a pilot study. Dig Dis Sci 2003;48(8):1475–1481.
18. Christensen M, Matzen P, Schulze S, Rosenberg J. Complications of ERCP: a prospective study. Gastrointest Endosc 2004;60(5):721–731.
19. Cappeliez O, Delhaye M, Devière J, et al. Chronic pancreatitis: evaluation of pancreatic exocrine function with MR pancreatography after secretin stimulation. Radiology 2000;215(2):358–364.
20. Sarner M, Cotton PB. Classification of pancreatitis. Gut 1984;25(7):756–759.
21. Sai JK, Suyama M, Kubokawa Y, Watanabe S. Diagnosis of mild chronic pancreatitis (Cambridge classification): comparative study using secretin injection-magnetic resonance cholangiopancreatography and endoscopic retrograde pancreatography. World J Gastroenterol 2008;14(8):1218–1221.
22. Testoni PA, Mariani A, Curioni S, Giussani A, Masci E. Pancreatic ductal abnormalities documented by secretin-enhanced MRCP in asymptomatic subjects with chronic pancreatic hyperenzymemia. Am J Gastroenterol 2009;104(7):1780–1786.
23. Gillams AR, Lees WR. Quantitative secretin MRCP (MRCPQ): results in 215 patients with known or suspected pancreatic pathology. Eur Radiol 2007;17(11):2984–2990.
24. Sanyal R, Stevens T, Novak E, Veniero JC. Secretin-enhanced MRCP: review of technique and application with proposal for quantification of exocrine function. AJR Am J Roentgenol 2012;198(1):124–132.
25. Lehman GA, Sherman S. Pancreas divisum: diagnosis, clinical significance, and management alternatives. Gastrointest Endosc Clin N Am 1995;5(1):145–170.
26. Matos C, Metens T, Devière J, Delhaye M, Le Moine O, Cremer M. Pancreas divisum: evaluation with secretin-enhanced magnetic resonance cholangiopancreatography. Gastrointest Endosc 2001;53(7):728–733.
27. Jacob L, Geenen JE, Catalano MF, Johnson GK, Geenen DJ, Hogan WJ. Clinical presentation and short-term outcome of endoscopic therapy of patients with symptomatic incomplete pancreas divisum. Gastrointest Endosc 1999;49(1):53–57.
28. Kim MH, Lee SS, Kim CD, et al. Incomplete pancreas divisum: is it merely a normal anatomic variant without clinical implications? Endoscopy 2001;33(9):778–785.
29. Hellerhoff KJ, Helmberger H 3rd, Rösch T, Settles MR, Link TM, Rummeny EJ. Dynamic MR pancreatography after secretin administration: image quality and diagnostic accuracy. AJR Am J Roentgenol 2002;179(1):121–129.
30. Manfredi R, Costamagna G, Brizi MG, et al. Pancreas divisum and "santorinicele": diagnosis with dynamic MR cholangiopancreatography with secretin stimulation. Radiology 2000;217(2):403–408.
31. Mosler P, Akisik F, Sandrasegaran K, et al. Accuracy of magnetic resonance cholangiopancreatography in the diagnosis of pancreas divisum. Dig Dis Sci 2012;57(1):170–174.
32. Bret PM, Reinhold C, Taourel P, Guibaud L, Atri M, Barkun AN. Pancreas divisum: evaluation with MR cholangiopancreatography. Radiology 1996;199(1):99–103.

33. Seibert DG, Matulis SR. Santorinicele as a cause of chronic pancreatic pain. Am J Gastroenterol 1995; 90(1):121–123.
34. Miyazaki M, Takada T, Miyakawa S, et al. Risk factors for biliary tract and ampullary carcinomas and prophylactic surgery for these factors. J Hepatobiliary Pancreat Surg 2008;15(1):15–24.
35. McMahon CJ, Vollmer CM Jr, Goldsmith J, Brown A, Pleskow D, Pedrosa I. An unusual variant of anomalous pancreaticobiliary junction in a patient with pancreas divisum diagnosed with secretin-magnetic resonance cholangiopancreatography. Pancreas 2010;39(1):101–104.
36. Mammone JF, Siegelman ES, Outwater EK. Magnetic resonance imaging of the pancreas and biliary tree. Semin Ultrasound CT MR 1998;19(1):35–52.
37. Soto JA, Barish MA, Yucel EK, Ferrucci JT. MR cholangiopancreatography: findings on 3D fast spin-echo imaging. AJR Am J Roentgenol 1995;165(6): 1397–1401.
38. Lee KS, Sekhar A, Rofsky NM, Pedrosa I. Prevalence of incidental pancreatic cysts in the adult population on MR imaging. Am J Gastroenterol 2010; 105(9):2079–2084.
39. Fernández-del Castillo C, Targarona J, Thayer SP, Rattner DW, Brugge WR, Warshaw AL. Incidental pancreatic cysts: clinicopathologic characteristics and comparison with symptomatic patients. Arch Surg 2003;138(4):427–433; discussion 433–434.
40. Hwang DW, Jang JY, Lee SE, Lim CS, Lee KU, Kim SW. Clinicopathologic analysis of surgically proven intraductal papillary mucinous neoplasms of the pancreas in SNUH: a 15-year experience at a single academic institution. Langenbecks Arch Surg 2012;397(1):93–102.
41. Salvia R, Fernández-del Castillo C, Bassi C, et al. Main-duct intraductal papillary mucinous neoplasms of the pancreas: clinical predictors of malignancy and long-term survival following resection. Ann Surg 2004;239(5):678–685; discussion 685–687.
42. Tanaka M, Chari S, Adsay V, et al. International consensus guidelines for management of intraductal papillary mucinous neoplasms and mucinous cystic neoplasms of the pancreas. Pancreatology 2006;6 (1-2):17–32.
43. Procacci C, Megibow AJ, Carbognin G, et al. Intraductal papillary mucinous tumor of the pancreas: a pictorial essay. RadioGraphics 1999;19(6): 1447–1463.
44. Schmidt CM, White PB, Waters JA, et al. Intraductal papillary mucinous neoplasms: predictors of malignant and invasive pathology. Ann Surg 2007;246(4): 644–651; discussion 651–654.
45. Sahani DV, Kadavigere R, Blake M, Fernandez-del Castillo C, Lauwers GY, Hahn PF. Intraductal papillary mucinous neoplasm of pancreas: multi–detector row CT with 2D curved reformations—correlation with MRCP. Radiology 2006;238(2):560–569.
46. Monill J, Pernas J, Clavero J, et al. Pancreatic duct after pancreatoduodenectomy: morphologic and functional evaluation with secretin-stimulated MR pancreatography. AJR Am J Roentgenol 2004;183 (5):1267–1274.
47. Cauley CE, Waters JA, Dumas RP, et al. Outcomes of primary surveillance for intraductal papillary mucinous neoplasm. J Gastrointest Surg 2012;16(2): 258–266; discussion 266.

Secretin-enhanced MR Cholangiopancreatography: Spectrum of Findings

Temel Tirkes, MD • Kumaresan Sandrasegaran, MD • Rupan Sanyal, MD • Stuart Sherman, MD • C. Max Schmidt, MD, PhD, MBA • Gregory A. Cote, MD, MSc • Fatih Akisik, MD

RadioGraphics 2013; 33:1889–1906 • **Published online** 10.1148/rg.337125014 • **Content Codes:** GI MR

Pages 1892
The physiologic effects of secretin include the secretion of bicarbonate-rich fluid from pancreatic ductal cells and a transient increase in the tone of the sphincter of Oddi, which improves the depiction of the pancreatic duct.

Pages 1895
Administration of secretin during MRCP enhances the ductal morphologic features and increases the sensitivity of the diagnosis of chronic pancreatitis, compared with MRCP performed without secretin (7,8).

Page 1897
The new MR imaging techniques and the addition of secretin improved depiction of the main pancreatic duct and its side branches to such a degree that it is possible to use the Cambridge classification by MRCP.

Page 1901
Pancreatic ductal imaging is essential not only in establishing the diagnosis of IPMN but also in differentiating among the subtypes of IPMN (42), such as main duct IPMN (either diffuse or segmental) and mixed or side-branch IPMN.

Page 1901
MRCP is able to image the pancreatic duct after most common pancreatic surgical procedures, including the Whipple procedure, distal pancreatectomy, and central pancreatectomy with pancreaticojejunostomy.