Secretin MRCP (S-MRCP, SS-MRCP) Information

Imaging of the pancreas has always been a challenging procedure. ERCP’s became standard of care until the incidence of Post ERCP pancreatitis and other complications arose from increased procedure rates. This highlighted the need for a simplified and less invasive imaging procedure (Mariani, 2009). Magnetic Resonance Imaging (MRI) and Computed Tomography (CT) has replaced Diagnostic ERCP and has been recommended by the AGA and the ACG as the first line screening test for patients with suspected pancreatic issues.

With the development of synthetic Human Secretin (ChiRhoStim®), gastroenterologists and radiologists are able to order and perform dynamic imaging of the pancreas. SMRCP enables providers to gain a better visualization of the main and side branch ducts of the pancreas and to examine exocrine pancreatic function and ductal extravasation.

Synthetic Human Secretin works as an adjunct to a standard MRCP. The physician is able to assess the endocrine function of the pancreas in real time with Secretin MRCP. It is a valuable tool for imaging the pancreas.

This procedure has been performed and studied extensively in the United States for the past 10 years and at least 15 years in Europe. There are over 100 medical journal articles on Secretin enhanced MRCP. There are clearly identifiable benefits of improving visualization of the pancreas. SMRCP has been mentioned and discussed at various medical conferences, including Digestive Disease Week, ACG Annual Meeting, the Society for Gastrointestinal Radiologist, the Radiology Society of North America, the American Pancreatic Association, and various other regional courses sponsored by the ACG and AGA.

How does Secretin work with imaging modalities?

Secretin is a naturally occurring 27-amino acid polypeptide released by ductal mucosa in response to acid in the lumen. Secretin increases bicarbonate and pancreatic fluid secretion by the exocrine cells. Secretin relaxes the sphincter of Oddi and opens pancreatic duct orifices.

Secretin is injected intravenously at the time of the MRCP. Images are then taken every 30 seconds for 10 minutes. Maximum output of pancreatic fluid is optimal between 6 to 8 minutes. A dynamic image and video is created from a 3-D rendering by the radiologist. This image sequence examines the pancreas response to stimulation. The excess pancreatic fluid/bicarbonate will resonate a sharper image of the pancreas. You are turning static MRCP’s into dynamic images with pancreatic stimulation.

SMRCP protocols are available upon requested from you sales representative or by calling 1-877-272-4888.

Is Synthetic Human Secretin Reimbursable?

Using CPT code 74181 plus 76376, J-Code 2850, JW-code 2850 and 96374 (specify substance; Human Secretin with J-code 2850) will make Secretin enhance MRCP reimbursable.

Consider Secretin enhanced MRCP for dynamic visualization of the pancreatic ducts.
Improve Your MRCP Images with *ChiRhoStim*®
(Human Secretin for Injection)

**Turn Static MRCP’s into Dynamic Images with Pancreatic Stimulation**

*Before ChiRhoStim®*

*After ChiRhoStim®*

Images courtesy of Joseph C. Veniero MD, PhD  Cleveland Clinic Foundation

**Observed pancreatic function and fluid flow in a fasted patient**

**Benefits of ChiRhoStim®:**

- Improves visualization of the pancreas by sharpening images\(^1,2,3,4\)
- Reimbursable with code J-2850
- Superior Stability
- Pure synthetic peptide not manufactured by a recombinant process

For additional information on *S-MRCP*, please visit [www.smrcp.com](http://www.smrcp.com) or call 1-877-272-4888

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**References:**


For highlighted prescribing information using *ChiRhoStim*® (Human Secretin for Injection) please see reverse side.
5.2 Vagotomy or Inflammatory Bowel Disease

Reactions should be immediately available. No allergic reactions were observed after the procedure. Because of a potential allergic reaction to ChiRhoStim®, patients should receive an antihistamine before the test. If an allergic reaction occurs, it should be managed by an adequately trained and qualified individual.

3 WARNINGS AND PRECAUTIONS

3.1 Administration of ChiRhoStim®

Dissolve the contents of the ChiRhoStim® 40 mcg vial in 10 mL of Sodium Chloride injection USP to yield a concentration of 4 mcg/mL. Once reconstituted, the reconstituted solution has a range of 3 to 6.5.

3.2 Stimulation of Gastrin Secretion to Aid in Diagnosis of Gastrinoma:

Stimulation of Gastrin Secretion to Aid in Diagnosis of Gastrinoma:

0.2 mcg/kg body weight by intravenous injection over 1 minute.

Administration of ChiRhoStim® may be given when difficulty is encountered by the endoscopist in identifying the ampulla of Vater for various reasons including: anatomic变异, etc. or in identifying the accessory papilla in patients with pancreas divisum. A test dose of 0.4 mcg/kg by intravenous injection over 1 minute may be used to test for any secretin-induced elevation of the bicarbonate concentration of less than 80 mEq/L, and a bicarbonate output of less than 0.2 mEq/kg/hr for 15 minutes. The values obtained for Figures 1 and 2 were performed by investigators skilled in pancreatic function testing. The PK profile for synthetic human secretin was evaluated in 12 normal subjects. After intravenous bolus administration of 0.4 mcg/kg, synthetic human secretin concentration rapidly reached baseline secretion levels within 90-120 minutes. Half-life of synthetic human secretin is 45 minutes. The clearance of synthetic human secretin is 45 minutes. The clearance of synthetic human secretin is 45 minutes.

3.4 Animal Toxicology and/or Pharmacology

The concomitant use of anticholinergic agents may make patients hyporesponsive to secretin stimulation and may produce a false result. Any results of secretin stimulation test in these studies should therefore be interpreted with caution.

1 USE IN SPECIFIC POPULATIONS

1.7 Pregnancy

Gastrointestinal disorders are occasionally encountered in patients with alcoholic or liver disease. Deveney, et al. established the high sensitivity and specificity of the secretin stimulation test to aid in the diagnosis of gastrinoma and found using discriminant analysis that serum secretin levels were >1 10 pg/mL for all secretin products tested after stimulation with 2.5 mcg synthetic human secretin for intravenous use. The concomitant use of anticholinergic agents may make patients hyporesponsive to secretin stimulation and may produce a false result. Any results of secretin stimulation test in these studies should therefore be interpreted with caution.

1.10 Chronic Pancreatitis

The values obtained for Figures 1 and 2 were performed by investigators skilled in performing secretin stimulation testing and are to be taken only as guidelines. These results should not be generated in studies of secretin stimulation testing conducted in other laboratories. However, a volume response of less than 2 mL/kg/hr, bicarbonate concentrations of less than 80 mEq/L, and a bicarbonate output of less than 0.2 mEq/kg/hr are consistent with impaired pancreatic function.

A physician or institution planning to perform secretin stimulation testing as an aid to the diagnosis of pancreatic disease should begin by assessing normal subjects (>5) to develop proficiency in proper techniques and to generate normal response ranges for the common causes of impaired secretin response, namely alcoholic disease. Deveney, et al. established the high sensitivity and specificity of the secretin stimulation test to aid in the diagnosis of gastrinoma and found using discriminant analysis that serum secretin levels were >1 10 pg/mL for all secretin products tested after stimulation with 2.5 mcg synthetic human secretin for intravenous use. The concomitant use of anticholinergic agents may make patients hyporesponsive to secretin stimulation and may produce a false result. Any results of secretin stimulation test in these studies should therefore be interpreted with caution.

1.13 Facilitation of the identification of the ampulla of Vater during endoscopy.

Ask patients suffering from chronic pancreatitis if they have ever received ChiRhoStim®, as this can be used to detect potential cases of chronic pancreatitis.

ChiRhoStim® is available in two strengths:

3.1.1 Administration of ChiRhoStim®

Dissolve the contents of the ChiRhoStim® 16 mcg vial in 8 mL of Sodium Chloride injection USP to yield a concentration of 2 mcg/mL. Once reconstituted, the reconstituted solution has a range of 3 to 6.5.

Gastrointestinal disorders are occasionally encountered in patients with alcoholic or liver disease. Deveney, et al. established the high sensitivity and specificity of the secretin stimulation test to aid in the diagnosis of gastrinoma and found using discriminant analysis that serum secretin levels were >1 10 pg/mL for all secretin products tested after stimulation with 2.5 mcg synthetic human secretin for intravenous use. The concomitant use of anticholinergic agents may make patients hyporesponsive to secretin stimulation and may produce a false result. Any results of secretin stimulation test in these studies should therefore be interpreted with caution.

3.2.1 Administration of ChiRhoStim®

Dissolve the contents of the ChiRhoStim® 40 mcg vial in 10 mL of Sodium Chloride injection USP to yield a concentration of 4 mcg/mL. Once reconstituted, the reconstituted solution has a range of 3 to 6.5.

2.1 Stimulation of Pancreatic Secretions, Including Bicarbonate to Aid in the Diagnosis of Pancreatic Disease

Hormone concentration was considered positive when a peak bicarbonate concentration for any sample >1 10 pg/mL was the optimal point separating results of positive and negative tests. This gastrin response is the basis for the use of synthetic human secretin stimulation testing in the evaluation of patients in whom gastrinoma is a diagnostic consideration.

In a three way crossover study of patients with tissue diagnosed gastrinoma, there was agreement among synthetic human secretin (ChiRhoStim®), porcine secretin and biologically derived porcine secretin regarding gastrin levels. Serum gastrin levels were reported to be >170 pg/mL for all secretin products tested after stimulation with 0.4 mcg/kg synthetic human secretin. Testing of ChiRhoStim® in 12 healthy volunteers demonstrated completely negative results for gastrin.

1.3.2 Animal Toxicology and/or Pharmacology

The PE profile for synthetic human secretin was evaluated in 12 normal subjects. After intravenous bolus administration of 4 mcg/kg, synthetic human secretin concentration rapidly reached baseline secretion levels within 90-120 minutes. Half-life of synthetic human secretin is 45 minutes. The clearance of synthetic human secretin is 45 minutes.

The PK profile for synthetic human secretin was evaluated in 12 normal subjects. After intravenous bolus administration of 4 mcg/kg, synthetic human secretin concentration rapidly reached baseline secretion levels within 90-120 minutes. Half-life of synthetic human secretin is 45 minutes. The clearance of synthetic human secretin is 45 minutes.
Facilitation of identification of the ampulla of Vater and the accessory papilla during endoscopic retrograde cholangiopancreatography (ERCP) to assist in cannulation of the pancreatic ducts

In a randomized, placebo controlled crossover study in 24 patients with pancreas divisum undergoing ERCP, synthetic human secretin administration at a dose of 0.2 mcg/kg resulted in 16 of 24 successful cannulations of the minor duct compared to 2 of 24 for placebo.

15. REFERENCES


16. HOW SUPPLIED/STORAGE AND HANDLING

ChiRhoStim® 16 mcg vial NDC # 87866-005-01
ChiRhoStim® 40 mcg vial NDC # 87866-007-01

16.1 Supplied

ChiRhoStim® is supplied in two strengths:
As a lyophilized sterile powder in vials containing 16 mcg of human secretin.
As a lyophilized sterile powder in vials containing 40 mcg of human secretin.

16.2 Storage

The unopened product should be stored at -20°C (freezer). Expiration date is marked on the label. Protect from light.

17. PATIENT COUNSELING INFORMATION

Since there is no data on pregnant or nursing mothers, physicians should discuss these matters with the patient before using this product.

ChiRhoStim® is a registered trademark of ChiRhoClin, Inc.
Manufactured for:
ChiRhoClin, Inc.
Burtonsville, MD 20866-6129
0087098
**ChiRhoStim® (Human Secretin for Injection)**

**Imaging protocol for MRCP**

- The patients should fast at least 4-6 hours prior to the study.
- The patients are assessed by the nurse who will administer a test bolus of Secretin (0.2 mcg/Kg). If that goes well, proceed with test.
- All studies will be performed on high field (1.5 Tesla) MR scanners (GE Excite Platform)
- Phased array coil centered over liver.
- Assess the patient’s breath holding capability. If poor, give oxygen.
- All sequences are run with the patient holding their breath in end expiration and in the order listed.

Perform a MRCP first without Secretin enhancement and then with Secretin. Patients will fast for at least 4 hours prior to the scan. Approximately 30 minutes prior to initiating the MRCP, patients will have 300 mL of Ferumoxsil oral suspension (GastroMARK; Mallinckrodt Medical, Raleigh, NC) administered as a negative oral contrast agent or use pineapple juice as a negative oral contrast agent, given at a dose of 3 cups (approximately 500-600 cc) 5-10 minutes before the imaging study. An intravenous line will be inserted into a peripheral vein. (See Appendix A - Standard methodology without Secretin for MRCP). After the non-Secretin enhanced MRCP is completed, a test dose of ChiRhoStim® (0.2 mcg = 0.1 mL) will be administered. If there are no signs of allergic reactions after 1 minute, the full dose of 0.2 mcg/kg will be administered IV over 30 to 60 seconds. (See Appendix A - Standard methodology with Secretin for MRCP is repeated).

**Appendix A**

- Scout
- Cor SSFSE- LIVER and Pancreas 45 mins GT
- AX LAVA (Arterial, Venous, Delayed)
- AX T2 FRFSE with Fat sat-Liver and Pancreas
- Ax SSFSE – liver and pancreas
- AX T1 Dual Echo In/Out of phase- liver and pancreas
- Cor radial 40 mm thick MRCP- 5 radial slices thru ducts
- DWI- liver and pancreas
- Call radiologist
- Radiologist injects Secretin and picks out best single slice from radial that shows pancreatic duct
- Single slice repeated 20 times (every 30 seconds)
- Cor 3D MRCP RTriggered, or 3mm thin- thru ducts
- Ax LAVA Pre with Fat sat- liver and pancreas
- Inject contrast (power injected at 2 cc/sec)
- Ax LAVA Post with Fat sat 3X (Arterial, Venous, Equilibrium) starts 20 sec after injection of CM

**NOTES**

- Secretin injection (0.2 microgram per kilogram max = 16microgram)

For more information on ChiRhoStim® (Human Secretin for Injection)
**ChiRhoStim® (Human Secretin for Injection)**

**Imaging protocol for MRCP**

- The patients should fast at least 4-6 hours prior to the study.
- The patients are assessed by the nurse who will administer a test bolus of Secretin (0.2 mcg/Kg). If that goes well, proceed with test.
- All studies will be performed on high field (1.5 Tesla) MR scanners (Siemens Avanto or Espree)
- Phased array coil centered over liver.
- Assess the patient’s breath holding capability. If poor, give oxygen.
- All sequences are run with the patient holding their breath in end expiration and in the order listed.

Preform an MRCP first without Secretin enhancement and then with Secretin. Patients will fast for at least 4 hours prior to the scan. Approximately 30 minutes prior to initiating the MRCP, patients will have 300 mL of Ferumoxsil oral suspension (GastroMARK; Mallinckrodt Medical, Raleigh, NC) administered as a negative oral contrast agent or use pineapple juice as a negative oral contrast agent, given at a dose of 3 cups (approximately 500-600 cc) 5-10 minutes before the imaging study. An intravenous line will be inserted into a peripheral vein. (See Appendix A - Standard methodology without secretin for MRCP). After the non-Secretin enhanced MRCP is completed, a test dose of ChiRhoStim® (0.2 mcg = 0.1 mL) will be administered. If there are no signs of allergic reactions after 1 minute, the full dose of 0.2 mcg/kg will be administered IV over 30 to 60 seconds. (See Chart below- Standard methodology with Secretin for MRCP is repeated).

<table>
<thead>
<tr>
<th>Sequence</th>
<th>Plane</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>HASTE</td>
<td>Coronal</td>
<td>No fat sat. 4 mm slices. Run sequential packages, skin to skin coverage. TR 1100; TE 71; SL 4mm; Matrix 256x256; FOV 325</td>
</tr>
<tr>
<td>HASTE</td>
<td>Axial</td>
<td>Run concatenated. No fat sat. 4 mm slices. TR 1000; TE 63; SL 4mm; Matrix 256x208; FOV 325</td>
</tr>
<tr>
<td>HASTE</td>
<td>Sagittal</td>
<td>No fat sat. 4 mm slices.</td>
</tr>
<tr>
<td>Thick Slab</td>
<td>Coronal</td>
<td>Straight (Try to get FOV &lt; 250) TR 2380; TE 972; SL 60mm; Matrix 256x256</td>
</tr>
<tr>
<td>Thick Slab</td>
<td>Oblique</td>
<td>30° to the right (Try to get FOV &lt; 250)</td>
</tr>
<tr>
<td>Thick Slab</td>
<td>Oblique</td>
<td>30° to the left (Try to get FOV &lt; 250)</td>
</tr>
<tr>
<td>Thick Slab</td>
<td>Oblique</td>
<td>Pre-Secretin administration Administer ChiRhoStim® Human Secretin (0.2mcg/kg) IV Bolus</td>
</tr>
<tr>
<td>Thick Slab</td>
<td>Oblique</td>
<td>1 measure every 30 sec for 10 min</td>
</tr>
<tr>
<td>HASTE</td>
<td>Coronal</td>
<td>No fat sat. 4 mm slices. Run sequential packages, skin to skin coverage.</td>
</tr>
<tr>
<td>HASTE</td>
<td>Axial</td>
<td>Run concatenated. No fat sat. 4 mm slices.</td>
</tr>
<tr>
<td>STIR</td>
<td>Axial</td>
<td>Run concatenated. If bad ghosting, run Ax HASTE with fat sat (8mm 0.2 gap)</td>
</tr>
<tr>
<td>T1 in/out</td>
<td>Axial</td>
<td>5-6 mm slices TR 167; TE 2.0/4.8; SL 5.5mm; Matrix 256x154; FOV 325</td>
</tr>
<tr>
<td>VIBE</td>
<td>Axial</td>
<td>Try to get effective thickness 2mm. Include pancreas in FOV. Use FOV as small as possible to include entire abdomen. TR 4.3; TE 1.7; SL 2.3mm; Matrix 256x126(estimate); FOV 325</td>
</tr>
</tbody>
</table>


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**ChiRhoStim® (Human Secretin for injection)**

<table>
<thead>
<tr>
<th><strong>Brand Name:</strong></th>
<th>ChiRhoStim®</th>
</tr>
</thead>
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<tr>
<td><strong>Active Ingredient:</strong></td>
<td>Human Secretin</td>
</tr>
<tr>
<td><strong>NDC#</strong></td>
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</tr>
<tr>
<td><strong>Strength(s):</strong></td>
<td>16 Mcg/vial</td>
</tr>
<tr>
<td><strong>Dosage Form(s):</strong></td>
<td>Injection</td>
</tr>
<tr>
<td><strong>Excipients:</strong></td>
<td>L-Cysteine 1.5mg, 20mg of Mannitol, and 9 mg of Sodium Chloride</td>
</tr>
<tr>
<td><strong>Reconstitution</strong></td>
<td>Add 8 ml of Sodium Chloride for injection and use immediately</td>
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<tr>
<td><strong>Storage Conditions:</strong></td>
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<tr>
<td><strong>Shelf Life:</strong></td>
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| **Wholesalers Account#** | Cardinal # 4059184  
McKesson # 2124816  
AmerisourceBergen # 179-150 |
| **Reimbursable Codes#** | J-Code 2850 For CPT Codes, see reverse side of page. |
| **Company Name:** | ChiRhoClin, Inc.  
4000 Blackburn Lane, Suite 270  
Burtonsville, MD 20866  
www.ChiRhoClin.com |
| **Ordering and Information:** | 1-877-272-4888 |
| **Web Site:** | www.ChiRhoStim.com |

**Human Secretin Indications:**

1. Stimulation of pancreatic secretions, including bicarbonate to aid in the diagnosis of exocrine pancreas dysfunction.

2. Stimulation of Gastrin secretion to aid in the diagnosis of Gastrinoma.

3. Stimulation of pancreatic secretions to facilitate the identification of the Ampulla of Vater and accessory Papilla during Endoscopic Retrograde cholangiopancreatography (ERCP).

**Warnings:**

Human Secretin may cause an allergic reaction a test dose should be given to check for allergic reaction.
ChiRhoStim® (Human Secretin for Injection)
MRCP Reimbursement 2013

CPT codes

- 96374 INTRAVENOUS PUSH, SINGLE OR INITIAL SUBSTANCE/DRUG (specify substance; Human Secretin with J-code 2850)
- 74181 MRI imaging, abdomen without contrast material
- 74182 – with contrast material
- 74183 – without contrast material(s) followed by with contrast material(s) and further sequences.
- 76376 3D rendering with interpretation and reporting CT, MRI, EUS not requiring image post processing on an independent workstation
- 76377 – Requiring image post processing on an independent workstation. MRCP studies typically includes 3D MIP cholangiographic images, along with pertinent axial and/or coronal abdominal MR cross-sectional images.

HCPCS J-Code for Reimbursement:

- S8037 Magnetic Resonance Cholangiopancreatography (MRCP)
- J-2850 Injection, Secretin, synthetic, human, 1 microgram
- JW-2850 (Waste) Injection, Secretin, synthetic, human, 1 microgram
  Use this code when you have left over Secretin to seek reimbursement.

ICD-9-CM

- 156.0-156.9 malignant neoplasm of the gallbladder and extrahepatic bile ducts
- 157.0-157.9 malignant neoplasm of the pancreas
- 230.8 Carcinoma in situ of liver and biliary system
- 571.6 biliary cirrhosis
- 574.00-574.91 Cholelithiasis
- 575.0-575.9 other disorders of the gallbladder
- 576.0 – 576.9 other disorders of the biliary tract
- 577.0-577.9 diseases of the pancreas
- 751.60 – 751.69 congenital abnormalities of gallbladder, bile duct, and liver
- 751.7 congenital abnormalities of the pancreas

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Additional Information:

The American College of Radiology has concluded that you can seek reimbursement for Secretin Enhanced MRCP with the following recommendations.

An MRI study of the hepatobiliary region would be appropriately reported using one of the anatomic-specific MRI abdomen CPT codes (74181 – MRI imaging, abdomen without contrast material, 74182 – with contrast material, or 74183 – without contrast material(s) followed by with contrast material(s) and further sequences. The ACR recommends that a typical MRCP study be reported with the appropriate MRI of the abdomen code (74181, 74182, or 74183) and 3D rendering code (76376-3D rendering with interpretation and reporting CT, MRI, EUS not requiring image post processing on an independent workstation or 76377 – Requiring image post processing on an independent workstation. MRCP studies typically includes 3D MIP cholangiographic images, along with pertinent axial and/or coronal abdominal MR cross-sectional images. In various other situations (e.g., adrenal washout CT imaging), quantitative assessment is not separately reported from the imaging interpretation, and ACR believes that that precedent should apply here.

Please note that when an MRCP study is performed with the addition of the pharmacologic agent, Secretin, there is a HCPCS supply code, J-2850 (Injection, Secretin, synthetic, human, 1 microgram), available for use and should be billed as an additional supply for the procedure.
Images of Before, During, and After ChiRhoStim® (Human Secretin) Stimulation. Images were captured every 30 seconds for 10 minutes showing pancreatic fluid flow during a MRCP.
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

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-
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>
<thead>
<tr>
<th>Parameter</th>
<th>Two-Point Dixon Method</th>
<th>Half Single-Shot Fast SE</th>
<th>Half Single-Shot Fast SE</th>
<th>MRCP: 2D Slab</th>
<th>MRCP: 3D (3D Turbo SE)</th>
<th>MRCP: 2D Slab with Secretin</th>
<th>3D GRE with Contrast Material</th>
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<td>Breath hold</td>
<td>Breath hold</td>
<td>Breath hold</td>
<td>Navigator</td>
<td>Breath hold</td>
<td>Breath hold</td>
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<td>None</td>
<td>Fat sat</td>
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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.
Table 2
Parameters for Pancreatic Imaging on 3.0-T MR Imagers

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Two-Point Dixon Method</th>
<th>Half Single-Shot Fast SE</th>
<th>Half Single-Shot Fast SE</th>
<th>MRCP: 3D (3D Turbo SE)</th>
<th>MRCP: 2D Slab with Secretin</th>
<th>3D GRE with Contrast Material</th>
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<tr>
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<td>Axial</td>
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<td>4500/746</td>
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<td>2</td>
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<td>None</td>
<td>Fat sat</td>
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<td>Fat sat</td>
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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.

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.

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,
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 pancreatico-biliary 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-

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

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

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

important 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).
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 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.
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).

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

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Table 4
Cambridge Classification of Chronic Pancreatitis

<table>
<thead>
<tr>
<th>Grade</th>
<th>Main Pancreatic Duct</th>
<th>No. of Abnormal Side Branches</th>
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<td>Normal</td>
<td>None</td>
</tr>
<tr>
<td>Equivocal</td>
<td>Normal</td>
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</tr>
<tr>
<td>Mild changes of chronic pancreatitis</td>
<td>Normal</td>
<td>3 or more</td>
</tr>
<tr>
<td>Moderate changes of chronic pancreatitis</td>
<td>Abnormal</td>
<td>3 or more</td>
</tr>
<tr>
<td>Severe changes of chronic pancreatitis</td>
<td>Abnormal</td>
<td>3 or more</td>
</tr>
</tbody>
</table>

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.
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.

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)
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 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.
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
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).

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).

Mild distention of side branches after the administration of secretin is commonly seen in patients after pancreateicoenteric anastomosis; however, in our experience, progressive distention during the dynamic phase of secretin-enhanced MRCP and a decreased excretory response may indicate anastomotic stenosis (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
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.
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 pancreaticojejunal 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.
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. 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.

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


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.

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).

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.

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.

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.
A patient with abdominal symptoms suggesting pancreaticobiliary disease poses a daunting clinical problem until an accurate diagnosis is made. Determining the cause of the symptoms often requires an invasive diagnostic procedure with sedation, such as ERCP or endoscopic sonography. ERCP has been the most commonly used diagnostic imaging method in the evaluation of these patients and continues to be so at many smaller medical centers. ERCP can also be used to provide therapy, such as sphincterotomy or stent placement, when a structural problem is identified. However, ERCP is associated with substantial morbidity, most commonly pancreatitis; bleeding; duodenal perforations; and in rare instances death [1–3]. Although endoscopic ultrasound is considered a lower-risk procedure, complications are not infrequent. They are more common in association with fine-needle aspiration and endoscopic ultrasound-guided interventions such as pseudocyst drainage and biopsy [4]. In some patients, diagnostic pancreaticobiliary endoscopy may be technically difficult or impossible, as in cases of postoperative anatomic changes. Although imaging of the pancreas and liver is possible with CT and conventional MRI [5], only limited evaluation of the pancreaticobiliary ductal system is possible with these studies, and no functional information about the pancreas is obtained. The introduction

MRCP in Patient Care: A Prospective Survey of Gastroenterologists

OBJECTIVE. MRCP is increasingly used to evaluate pancreaticobiliary disease, yet its effect on patient care is unknown. The purpose of this study was to measure the effect of MRCP on referring physicians’ initial diagnoses, the physicians’ confidence in their diagnoses, and the influence of MRCP results on clinical management.

SUBJECTS AND METHODS. We prospectively surveyed gastroenterologists who referred patients for nonurgent MRCP for pancreaticobiliary evaluation. Before MRCP, gastroenterologists reported the working diagnosis, confidence level (high, moderate, low), and next step in clinical management if MRCP was unavailable. MRCP was performed with standard protocols, including secretin enhancement. After reviewing MRCP findings and without referring to their previous assessment, gastroenterologists reported a revised diagnosis, confidence level, and next step in clinical management. They then compared pre- and post-MRCP management plans and rated the influence of MRCP on changing management from 1 (none) to 5 (major). Diagnostic confidence and frequency of common diagnoses and recommendations for an invasive next-step procedure (e.g., ERCP) or endoscopic ultrasound were compared between pre- and post-MRCP assessments.

RESULTS. Survey data were analyzed on 171 patients (123 women, 48 men; mean age, 50 [SD, 17] years; range, 19–88 years) undergoing MRCP for unexplained abdominal pain (42.9%), suspected pancreaticobiliary neoplasm (20%), recent acute (17.1%) or suspected chronic (14.9%) pancreatitis, and other indications (5.1%). Recommendations of ERCP and endoscopic ultrasound decreased after MRCP (from 49.1% to 35.1%, \( p = 0.03 \), and from 26.9% to 13.5%, \( p \leq 0.01 \)). After MRCP, high confidence in diagnosis increased (from 72/171 to 100/171, \( p < 0.01 \)), as did recommendations for noninvasive therapy (from 18/171 to 56/171, \( p < 0.01 \)). A major or substantial change in clinical management was made in the care of 67 of 171 patients (39.2%).

CONCLUSION. Use of MRCP significantly changes gastroenterologists’ treatment of patients with suspected pancreaticobiliary disease by increasing diagnostic confidence and reducing the frequency of invasive follow-up procedures.
of magnetic resonance cholangiopancreatography (MRCP) has revolutionized the ability to identify ductal anatomy noninvasively [6–9]. Injection of a synthetic secretin, which stimulates pancreatic exocrine function, has further improved MRCP by improving visualization of the pancreatic ductal system and enabling assessment of pancreatic exocrine function [10–12]. Secretin injection improves delineation of the pancreatic ducts and side branches and thus detection of pathologic conditions (e.g., chronic pancreatitis), anatomic variants (e.g., pancreas divisum) [13–15], and pancreatic cystic lesions [16]. MRCP is much less invasive than ERCP and endoscopic ultrasound and has become the front-line imaging technique at our medical center and elsewhere for evaluating patients with unexplained abdominal pain that may be related to pancreaticobiliary disease [17, 18].

Although gastroenterologists and other clinicians have embraced MRCP for initial imaging evaluation, few systematic data are available on the effect of MRCP on clinical decision making [19–21]. The purpose of this study was to measure the effect of MRCP on referring physicians’ initial diagnoses, their confidence in the diagnoses, and the degree to which MRCP results influence clinical management.

**Subjects and Methods**

**Patient Population**

This prospective, single-institution, HIPAA-compliant study was approved by our institutional review board with waiver of the requirement for informed consent. On 95 dates between November 2009 and December 2010, we enrolled all patients who were referred by participating gastroenterologists at our tertiary-care hospital for secretin-enhanced MRCP at our facility is 1 hour.

The proportion of patients with each of several common diagnoses and the proportion with high-confidence diagnoses before and after MRCP were compared by Fisher test. The frequencies of ERCP and endoscopic ultrasound as recommended next-step procedures before and after MRCP were also compared by Fisher test. We divided all next-step procedures into invasive and noninvasive categories and compared their frequency of recommendation before and after MRCP by Fisher test. Invasive procedures included ERCP, endoscopic ultrasound, upper endoscopy, and surgical consultation. Noninvasive measures included outpatient medical therapy, dietary regimen, and follow-up with laboratory or other imaging tests, such as CT, ultrasound, and upper gastrointestinal examinations.

**Results**

At the end of enrollment, 196 patients were identified. Twenty-three patients were excluded from data analysis because of incomplete surveys, and two patients were later found to not meet the inclusion criteria. The other 171 patients (123 women, 48 men; mean age, 50 [SD, 17] years; range, 19–88 years) composed the study group. The reasons for referral were unexplained abdominal pain of suspected pancreaticobiliary origin (42.9%), suspected pancreaticobiliary neoplasm (20%), recent

**MRCP**

All MRCP examinations were performed with a 1.5-T (Magnetom Avanto, Siemens Healthcare) or 3-T (Magnetom Verio, Siemens Healthcare) MRI system with standard MRCP imaging parameters and a multielement phased-array imaging coil. Similar imaging parameters were used for the 1.5-T and 3-T systems. A negative contrast agent consisting of up to 300 mL ferumoxsil oral suspension (GastroMARK, Covidien Pharmaceuticals) was administered orally approximately 30 minutes before the MRCP examination.

Both traditional imaging sequences and fluid-sensitive MRCP sequences designed to depict the pancreatic and biliary ducts were used. Thin-slice, T1- and T2-weighted images were acquired. In addition, the protocol included fluid-sensitive, coronal or coronal oblique 2D, T2-weighted, breath-hold MRCP images obtained with both a thin-slice 3D technique and a thick-slab sequence with a half-Fourier single shot acquisition pulse sequence with a single 40-mm-thick coronal slab positioned over the pancreas. All patients underwent secretin-enhanced MRCP. An image was acquired every 30 seconds over a 10-minute period after IV administration of 16 μg of synthetic human secretin (ChiRhostim, ChiRhoClin) injected over 1 minute. All examinations concluded with a three-phase unenhanced and contrast-enhanced 3D T1-weighted fat-suppressed gradient-echo sequence. A standard of 0.1 mmol/kg gadobenate dimeglumine (MultiHance, Bracco Diagnostics) was administered at 2 mL/s via a power injector and followed by a 20-mL saline flush. The mean imaging time for secretin-enhanced MRCP at our facility is 1 hour.

**Survey Method**

Before MRCP, the requesting gastroenterologist was asked to complete a survey delineating the working diagnosis before MRCP, the level of confidence with this diagnosis (high, moderate, or low), and the next step in clinical management if MRCP were unavailable. The gastroenterologists were aware of all available clinical information, usually including previous imaging studies, as they formed their working diagnoses; this reflects routine clinical practice. After reviewing the results of MRCP and without referring to their pre-MRCP survey responses, the gastroenterologists were asked to provide a revised working diagnosis, level of confidence with this diagnosis, and the next step in clinical management after MRCP was completed. The physician then compared pre- and post-MRCP management plans and rated the influence of MRCP on changing clinical management from 1 (no change) to 5 (major change).

**TABLE 1: Cambridge Criteria for Chronic Pancreatitis**

<table>
<thead>
<tr>
<th>Term</th>
<th>Main Duct</th>
<th>Side Branches</th>
<th>Additional Features</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>Normal</td>
<td>None</td>
<td></td>
</tr>
<tr>
<td>Equivocal</td>
<td>Normal</td>
<td>&lt; 3</td>
<td></td>
</tr>
<tr>
<td>Mild disease</td>
<td>Normal</td>
<td>≥ 3</td>
<td></td>
</tr>
<tr>
<td>Moderate disease</td>
<td>Abnormal</td>
<td>&gt; 3</td>
<td></td>
</tr>
<tr>
<td>Marked disease</td>
<td>Abnormal</td>
<td>&gt; 3</td>
<td>One or more of large cavity, obstruction, filling defect, severe dilatation or irregularity</td>
</tr>
</tbody>
</table>

Note—Modified with permission from [22]. If pathologic changes are limited to one third or less of the gland, they are said to be local and designated as being in the head, body, or tail; if more than one third is affected, the changes are diffuse.
TABLE 4: Proposed Next Step by Referring Gastroenterologists (n = 171)

<table>
<thead>
<tr>
<th>Next Step</th>
<th>Before MRCP</th>
<th>After MRCP</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>ERCP</td>
<td>84 (49.1)</td>
<td>63 (36.8)</td>
<td>0.03</td>
</tr>
<tr>
<td>Endoscopic ultrasound</td>
<td>46 (26.9)</td>
<td>23 (13.5)</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>Conservative therapy*</td>
<td>22 (12.9)</td>
<td>56 (32.7)</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>Further imaging</td>
<td>15 (8.8)</td>
<td>18 (10.5)</td>
<td>0.59</td>
</tr>
<tr>
<td>Surgical consultation</td>
<td>4 (2.3)</td>
<td>5 (3.0)</td>
<td>0.26</td>
</tr>
</tbody>
</table>

Note—Values in parentheses are percentages.

*Medical therapy, diet, laboratory workup, or follow-up.

MRCP has been frequently used to evaluate the pancreaticobiliary ductal system for biliary diseases, such as ductal stones, strictures, and postsurgical complications. In this study, we found that an optimized MRCP examination decreases the need for invasive testing for the diagnosis of pancreatic diseases and that the findings increase the referring physician’s confidence in the working diagnosis.

Few data have been published about how MRCP changes clinical practice. In 1997 in a prospective study that included 40 patients, Sahai et al. [19] evaluated the efficacy of MRCP in supplanting ERCP. The patients had working diagnoses of jaundice, abnormal liver enzyme concentration, abdominal pain, recurrent acute pancreatitis, and suspected complications of chronic pancreatitis. Those investigators concluded that MRCP findings did not significantly affect clinicians’ decision making and that adding results of MRCP to other clinical information would have prevented less than 3% of diagnostic and therapeutic ERCP procedures.

The results of the study by Sahai et al. [19] differ from ours for a number of reasons. The patient selection processes differed substantially. We entered only patients referred for MRCP, whereas Sahai et al. selected patients scheduled for ERCP. This is a crucial methodologic difference, resulting in different patient populations. The technology underlying MRCP has improved substantially in the 15 years between the studies. Modern MRI sys-
tems can generate 3D, high-resolution MRCP images that can show tiny ductal stones, abnormal side branches, and ductal strictures. In addition, visualization of the pancreatic duct can be significantly enhanced with IV secretin [10–15, 18, 23].

In a 2001 study, Parnaby et al. [20] collected data suggesting that in a suitably selected subgroup of patients, MRCP could obviate ERCP, a result similar to ours. In a retrospective study including 1148 patients, Farrell et al. [21] concluded, “initial MRCP in patients referred with abdominal pain would potentially have avoided ERCP in 44% of cases, and significantly reduced patient morbidity and mortality.” These studies approached the problem from different vantage points, yet both concluded that MRCP was useful in reducing the need for ERCP. However, they did not test the clinical value of MRCP in defining the cause of symptoms. Moreover, the MRCP protocols were mainly heavily T2 weighted. In other words, they could be classified as MR ductography. At our institution, we generally incorporate MRCP in a complete MRI study, which includes anatomic soft-tissue imaging and the use of IV gadolinium contrast medium in addition to MRCP with secretin.

Contrast enhancement yields invaluable information about parenchymal organs, including the pancreas. In some cases, high-grade pancreatic ductal strictures can be caused by an obstructive mass, and thus contrast media may be useful for excluding malignancy. Secretin enhancement provides information about pancreatic exocrine function and improves visualization of the main duct, its side branches, and pancreatic cystic lesions and their relation to the main duct in differentiation of side-branch intrapapillary mucinous neoplasms. Use of secretin also facilitates delineation of complete versus incomplete pancreas divisum and pseudoductrices [11–15, 23].

Our results show that in a patient population representative of that seen for evaluation of suspected pancreaticobiliary disease at a tertiary care center, MRCP had a significant effect on clinical decision making. Gastroenterologists would have recommended endoscopic procedures for 76% of patients (ERCP, 49.1%; endoscopic ultrasound, 26.9%) without MRCP findings compared with 48.6% (ERCP, 35.1%; endoscopic ultrasound, 13.5%) when MRCP results were available. Although unproven, preprocedure MRCP may also help in planning for subsequent ERCP in patients in whom it is necessary, as for confirming the presence of complete pancreas divisum and thereby eliminating efforts to cannulate the ventral pancreatic duct.

**TABLE 5: Effect of MRCP Results on Clinical Management by Gastroenterologists (n = 171)**

<table>
<thead>
<tr>
<th>Degree of Change</th>
<th>Clinical Decision</th>
<th>No. of Patients</th>
</tr>
</thead>
<tbody>
<tr>
<td>1, None</td>
<td>No change in management</td>
<td>73 (42.7)</td>
</tr>
<tr>
<td>2, Minor</td>
<td>Nonpharmaceutical, discharge with instructions (e.g., avoid fatty food)</td>
<td>23 (13.5)</td>
</tr>
<tr>
<td>3, Moderate</td>
<td>Additional noninvasive diagnostic procedure (e.g., CT, ultrasound of abdomen) or upper gastrointestinal examination</td>
<td>8 (4.7)</td>
</tr>
<tr>
<td>4, Substantial</td>
<td>Change in pharmaceutical management, invasive procedure (ERCP or endoscopic ultrasound), referral to additional specialist</td>
<td>55 (32.2)</td>
</tr>
<tr>
<td>5, Major</td>
<td>Change in recommendation for surgery, for invasive endoscopic procedure (e.g., sphincterotomy), major change in diagnosis (e.g., benign versus malignant lesion)</td>
<td>12 (7.0)</td>
</tr>
</tbody>
</table>

Note—Values in parentheses are percentages.

Fig. 1—47-year-old woman with constant abdominal pain referred for further evaluation.

A, MRCP image obtained before secretin injection shows normal-caliber main pancreatic duct without obvious abnormal side branches, dilatation, or luminal strictures.

B, MRCP image obtained 4 minutes after secretin injection shows dilated duct with multiple abnormal side branches (arrows) consistent with mild chronic pancreatitis.

C, Axial unenhanced T1-weighted fat-suppressed gradient-recalled echo image shows normal signal intensity of pancreas.

D, Axial contrast-enhanced T1-weighted fat-suppressed gradient-recalled echo image obtained 45 seconds after C shows normal-size pancreatic gland with homogeneous enhancement. Without secretin administration, diagnosis of chronic pancreatitis would not have been possible.
The decreased need for invasive procedures resulted largely from confirmation of suspected chronic pancreatitis and exclusion of structural abnormalities that might have required intervention (Fig. 1). This alone may justify the value of diagnostic MRCP in the evaluation of many abdominal disorders. Another important result is in the increased confidence level of gastroenterologists after MRCP examination.

Chronic abdominal pain related to pancreaticobiliary disease is most commonly due to pancreatitis (acute or chronic), sphincter of Oddi dysfunction, pancreatic cysts and pseudocysts, and mass effect from pancreatic neoplasms, including intraductal pancreatic mucinous neoplasms. In our tertiary care hospital, we currently perform approximately 1200 MRCP examinations each year to evaluate pancreaticobiliary abnormalities. Although ERC and endoscopic ultrasound are still common procedures (∼3000 ERC and 2400 endoscopic ultrasound examinations were performed in 2011), MRCP has reduced the need for purely diagnostic endoscopic ultrasound in many patients.

### References

Magnetic Resonance Cholangiopancreatography in the Diagnosis of Pancreas Divisum

A Systematic Review and Meta-analysis

Tarun Rustagi, MD* and Basile Njei, MD, MPH†

Objective: This study aimed to perform a structured meta-analysis of all eligible studies to assess the overall diagnostic use of magnetic resonance cholangiopancreatography (MRCP) alone or with secretin enhancement (secretin-enhanced MRCP [S-MRCP]) in the detection of pancreas divisum.

Methods: Two authors independently performed a comprehensive search of PubMed, MEDLINE, and the Cochrane Library from inception to September 2013. Studies were included if they allowed construction of 2 × 2 contingency tables of MRCP and/or S-MRCP compared with criterion standard. DerSimonian-Laird random effect models were used to estimate the pooled sensitivity, specificity, and quantitative receiver operating characteristics.

Results: Of 51 citations, 10 studies with 1474 patients were included. Secretin-enhanced MRCP had a higher overall diagnostic performance than MRCP (S-MRCP: pooled sensitivity, 86% [95% confidence interval (CI), 77%–93%]; specificity, 97% [95% CI, 94%–99%]; and area under the curve, 0.93 ± 0.056 compared with MRCP: sensitivity, 52% [95% CI, 45%–59%]; specificity, 97% [95% CI, 94%–99%]; and area under the curve, 0.76 ± 0.104). Pooled diagnostic odds ratios were 72.19 (95% CI, 5.66–938.8) and 23.39 (95% CI, 7.93–69.02) for S-MRCP and MRCP, respectively. Visual inspection of the funnel plot showed low potential for publication bias.

Conclusions: Secretin-enhanced MRCP has a much higher diagnostic accuracy than MRCP and should be preferred for diagnosis of pancreas divisum.

Key Words: pancreas divisum, ERCP, MRCP, secretin

(Pancreas 2014;43: 823–828)

Pancreas divisum, with a reported prevalence of 2.7% to 22%,1,3 is the most common congenital anatomical variant of pancreatic ductal development. The dorsal and ventral pancreatic buds of the foregut fail to fuse during the seventh week of intrauterine life and results in pancreas divisum, in which the duct of Wirsung drains the minor part of the pancreas, that is, the dorsal pancreas, through the minor papilla, whereas the dominant duct of Santorini drains the major part of the pancreas, that is, the dorsal pancreas, through the minor papilla. Because the major part of the pancreatic secretion must flow through the minor papilla, pancreas divisum could predispose to obstructive pancreatopathy, causing both acute pancreatitis and pancreatic type pain, and be implicated in the development of severe chronic pancreatitis.

The best option for the diagnosis of pancreas divisum currently is an endoscopic retrograde cholangiopancreatography (ERCP), which is considered the criterion standard for diagnosing pancreas divisum.11,12 Diagnostic ERCP, however, is associated with significant complications. Magnetic resonance cholangiopancreatography (MRCP) has emerged as a noninvasive imaging modality for the diagnosis of pancreas divisum. Secretin enhancement has been shown to improve visualization of pancreas, particularly pancreatic ductal anatomy. Therefore, secretin-enhanced MRCP (S-MRCP) has been suggested to enhance the detection of congenital pancreaticobiliary malformations, including pancreas divisum. However, despite the recent advances in MRCP pancreas divisum may not be detected in a significant portion of cases, and as such, several studies on the diagnostic accuracy of MRCP and S-MRCP have yielded conflicting results.13–15 The aim of this study was to perform a structured meta-analysis of all eligible studies to assess the overall diagnostic use of MRCP alone or with secretin enhancement (S-MRCP) in the detection of pancreas divisum. This meta-analysis and systematic review was written in accordance with the proposal for reporting by Quality of Reporting of Meta-analyses statement.16

METHODS

Literature Search

A comprehensive search of the literature was performed to identify articles that examined the diagnostic accuracy of MRCP and S-MRCP for the detection of pancreas divisum. We systematically searched PubMed, MEDLINE, and the Cochrane Library for studies published until September 2013. Search terms included “magnetic resonance cholangiopancreatography” and “diagnostic test” in combination with “secretin,” “pancreas divisum,” and/or “endoscopic retrograde cholangiopancreatography.” No language restriction was applied to the search filter. The titles and abstracts of all potentially relevant studies were screened for eligibility. The reference lists of studies of interest were then manually reviewed for additional articles. Two reviewers (T.R. and B.N.) independently screened the titles and abstracts of all the articles according to predefined inclusion and exclusion criteria. Interevaluator discrepancies were resolved by referring to the original article and by mutual agreement.

Study Selection Criteria

Only studies investigating the use of MRCP and/or S-MRCP for the detection of pancreas divisum were included. Only studies with data available for the construction of 2 × 2 contingency tables with true-positive, false-negative, false-positive, and true-negative values were eligible for inclusion.
The exclusion criteria were as follows:
1. studies that did not evaluate MRCP and/or S-MRCP for the detection of pancreas divisum compared with criterion standard;
2. studies with insufficient data;
3. reviews, editorials, and correspondence letters that did not report their own data; and
4. case reports and studies with fewer than 10 patients.

Quality of Studies
Currently, there is no consensus or criteria to evaluate the quality of studies without a control arm.15 The Quality Assessment of Diagnostic Accuracy Studies (QUADAS) questionnaire was used to evaluate the quality of selected studies.18 A total of 14 items were appraised in this study, and items were rated as “yes,” “no,” or “unclear.”

Statistical Analysis
Meta-analysis for the accuracy of MRCP and/or S-MRCP for the detection of pancreas divisum was performed by calculating pooled estimates of sensitivity, specificity, likelihood ratios (LRs), and diagnostic odds ratio (DOR). The DOR was an independent indicator ranging from 0 to infinity, which represented how much greater the odds of having pancreas divisum were for a patient with a positive MRCP and/or S-MRCP result than for a patient with a negative result. The higher the DOR, the better the discriminatory ability of the test was. Pooling was performed using the DerSimonian-Laird method (random effects model), and empty cells were handled using a 0.5 continuity correction. Forest plots were constructed to show the point estimates in each study in relation to the summary pooled estimate. The width of the point estimates in the forest plots corresponded to the assigned weight of the study. Heterogeneity was assessed by using $I^2$ statistics, $I^2$ measure of inconsistency, and Cochran $Q$ test.

A summary receiver operating characteristic (SROC) curve was constructed based on the Moses-Shapiro-Littenberg method as a way to summarize the true-positive and false-positive rates from different studies. The proximity of the area under the curve (AUC) to 1 is a well-validated overall representation of the diagnostic accuracy of a test. The robustness of the meta-analysis to publication bias was assessed by funnel plots and bias indicators, including the Begg-Mazumdar test and the Harbord-Egger test.19,20

Sensitivity Analysis
A sensitivity analysis was conducted for every study to determine whether any single study was incurring undue weight in the analysis. We systematically removed 1 set of study data and checked the pooled results for the remaining studies to see if there was any significant change in test performance.

Combined weighted sensitivity, specificity, positive LR (LR+), negative LR (LR−), DOR, summary receiver operating characteristic curve, and meta-regression were determined by using MetaDiSc version 1.4 (Unit of Clinical Biostatistics, Ramon y Cajal Hospital, Madrid, Spain).

RESULTS

Eligible Studies and Quality Assessment
Fifty-one potentially relevant studies were identified by our primary search of the electronic databases for published work on the subject. Of these studies, 21 were excluded after further review of the title and abstract for irrelevant topics, and an additional 20 were excluded for duplication of the reports, meeting exclusion criteria or lack of data for evaluation. The detailed process of this literature search is shown in Figure 1. After careful review, 10 studies with a total of 1474 subjects were included in this meta-analysis. The characteristics of each included study are shown in Table 1.

The quality of the eligible studies as assessed by the QUADAS criteria is reported in Figure 2. For most QUADAS items (10/14), all studies were classified as high quality.

Magnetic Resonance Cholangiopancreatography
For MRCP (n = 1361; 9 studies), the pooled sensitivity and specificity for diagnosis of pancreas divisum were 52% (95% confidence interval [CI], 45%–59%) and 97% (95% CI, 94%–99%), respectively (Fig. 3). The pooled LR+ was 7.88 (95% CI, 3.03–20.48), and the LR− was 0.47 (95% CI, 0.34–0.64). The positive predictive value was 0.93 (95% CI, 0.86–0.97), and the negative predictive value (NPV) was 0.72 (95% CI, 0.67–0.77). The pooled DOR was 23.39 (95% CI, 7.93–69.02). The results of DOR did not show significant heterogeneity ($P < 0.16$; Cochran $Q$, 11.76; $P^2$=32%). The AUC value was 0.76 ± 0.104 (Supplemental Digital Content 1, Figure 1, http://links.lww.com/MPA/A294).

Secretin-Enhanced MRCP
For MRCP (n = 951; 5 studies), the pooled sensitivity and specificity for diagnosis of pancreas divisum were 86% (95% CI, 77%–93%) and 97% (95% CI, 94%–99%), respectively (Fig. 4). The pooled LR+ was 12.31 (95% CI, 4.33–35.32), and the LR− was 0.19 (95% CI, 0.06–0.62). The positive predictive value was 0.92 (95% CI, 0.84–0.97), and the NPV was 0.94 (95% CI, 0.89–0.97). The pooled DOR was 72.19 (95% CI, 5.66–938.8). The AUC value was 0.93 ± 0.056 (Supplemental Digital Content 2, Figure 2, http://links.lww.com/MPA/A295).

Sensitivity Analysis
We systematically removed 1 data set at a time and recalculated the DOR and AUC values for the remaining studies. The largest change occurred when removing the data set from Kim et al,14 which changed the pooled DOR for MRCP from 23.39 to 21.56 (−7.8%), and the corresponding change in the AUC value was from 0.76 to 0.75 (−1.32%). Similar results were
obtained for S-MRCP. These results indicated that no single data set carried enough weight to significantly influence the pooled test performance reported for MRCP or S-MRCP in the diagnosis of pancreas divisum.

**Publication Bias**

The Begg-Mazumdar indicator for bias gave a Kendall $T_b$ of 0.22 ($P = 0.19$), and Egger test, another indicator for publication bias, was $t_0.59$ (95% CI, $-0.79$ to $0.29$; $P = 0.26$). Both of these values indicated no significant publication bias. Visual inspection of funnel plot further confirms that publication bias is not a major determinant of pooled diagnostic accuracy in this meta-analysis (Fig. 5).

**DISCUSSION**

Pancreas divisum is the most common congenital variant of the pancreas; however, it is of clinical importance in only a small percentage of patients causing recurrent acute pancreatitis, chronic pancreatitis, or pancreatic-type pain. Endoscopic retrograde cholangiopancreatography is currently the criterion standard for diagnosing pancreas divisum but is an invasive test requiring sedation and carries a 10% to 15% complication rate, with up to 10% of patients developing post-ERCP pancreatitis. In addition, the difficulty and the level of expertise required in achieving endoscopic access to the minor papilla makes this a less-than-desirable first-line diagnostic tool. Given these drawbacks of ERCP, several noninvasive or minimally invasive tests such as MRCP, multidetector computed tomography, and endoscopic ultrasound have been considered as alternative options for the detection of pancreas divisum.

Magnetic resonance cholangiopancreatography was first introduced in 1991 as a noninvasive diagnostic technique to illustrate the dilated common bile duct in a way that was similar to what clinicians were accustomed to with ERCP. Over the next few years, the MRCP technique was further developed to not only obtain images in short time of 2 to 20 seconds compared with the original publication, which took 6 minutes, but also to be able to provide images of the pancreatic duct, which is significantly smaller, approximately 3 mm in diameter. In 1995, a Japanese group first described the technology of secretin-stimulated MRCP; however, it was Matos et al from Belgium who presented the first major article making good use of this technology in 1997. They reported enhanced imaging with better delineation of the pancreatic duct using secretin. With continuous improvement in technique, MRCP has been reported to be highly accurate in diagnosing various pancreatic diseases, with accuracy similar to ERCP, and has emerged as noninvasive modality of choice for diagnosing pancreas divisum.

Studies evaluating the accuracy of MRCP in detecting pancreas divisum, however, have yielded varying results. Although earlier studies reported high sensitivity and specificity, approaching 100%, recent studies show a more modest accuracy.
rate. Many explanations have been attributed to the disparities in the results. Exclusion and verification biases with regard to the criterion standard test used and the relatively small number of patients with pancreas divisum in earlier studies might have accounted for a high diagnostic accuracy of MRCP. Various techniques for performing MRCP exist, and thus, there exists a large degree of institutional variability. Performance of MRCP at nonacademic institutions has been shown to have lower overall accuracy.

FIGURE 3. Forest plot of sensitivity and specificity of MRCP in diagnosing pancreas divisum.

FIGURE 4. Forest plot of sensitivity and specificity of S-MRCP in diagnosing pancreas divisum.
Another important factor that might account for variation is the presence of stones and strictures in either the ventral or dorsal pancreatic ducts.34,37 The difficulty in the detection of pancreas divisum in patients with chronic pancreatitis has been attributed to a poorer-than-average secretin response and the presence of stones and strictures in either the ventral or dorsal pancreatic ducts.34,37

In conclusion, this study is the first meta-analysis, to the best of our knowledge, to summarize all the available evidence regarding the diagnostic performance of MRCP and S-MRCP in the detection of pancreas divisum. Secretin-enhanced MRCP has a much higher diagnostic accuracy than MRCP and should be preferred for diagnosis of pancreas divisum. Magnetic resonance cholangiopancreatography without secretin should be obsolete if the detection of pancreas divisum is desired.

REFERENCES


Dynamic Secretin-enhanced MR Cholangiopancreatography¹

M. Fatih Akisik, MD • Kumaresan Sandrasegaran, MD • Alex A. Aisen, MD • Dean D. T. Maglinte, MD • Stuart Sherman, MD • Glen A. Lehman, MD

Secretin causes temporary dilatation of pancreatic ducts, principally by increasing pancreatic exocrine secretions, and thus allows better visualization of the ducts at magnetic resonance (MR) cholangiopancreatography. Secretin-enhanced MR cholangiopancreatography is useful for detection and diagnosis of a variety of congenital, inflammatory, and neoplastic conditions of the pancreas. Although MR cholangiopancreatography without secretin is a reliable method for evaluating the pancreaticobiliary ductal system, the authors believe that secretin-enhanced MR cholangiopancreatography gives additional valuable functional and anatomic information about the pancreatic duct and pancreatic excretory capacity.

¹RSNA, 2006

Abbreviations: ERCP = endoscopic retrograde cholangiopancreatography, IPMT = intraductal papillary mucinous tumor

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Introduction

Magnetic resonance (MR) cholangiopancreatography is a noninvasive technique for evaluation of the pancreatic ducts and biliary tree. The method has been available for more than a decade and is based on the use of heavily T2-weighted MR sequences to suppress the signal from most soft tissues and allow the stationary fluid in the ducts to be visualized. Use of a contrast agent is not necessary at MR cholangiopancreatography, and the imaging examination is often performed without it. However, we have found that the use of secretin, a hormone that stimulates pancreatic secretion, improves our ability to assess the pancreatic duct system. In this article, we discuss and illustrate the utility of secretin-enhanced MR cholangiopancreatography in the detection of various pancreatic diseases.

Secretin is a 27–amino acid polypeptide hormone secreted by the duodenal mucosa in response to luminal acid, typically after a meal (1). It has numerous physiologic effects, including actions on the sphincter of Oddi, the biliary tree, and the pancreas. An important action is its stimulation of the pancreatic secretion of bicarbonate-rich fluid; the agent also transiently increases tone in the sphincter of Oddi. The effects on biliary flow are less pronounced than those on the pancreas. As a result, secretin usually produces distention of the pancreatic duct that is most visible 4–10 minutes after administration.

Prior to 1999, secretin was available commercially in the United States in a form purified from porcine duodenum. The porcine form of the hormone differs from the human form in two amino acid residues; however, the biologic properties are believed to be identical. In 1999, the biologic porcine form became unavailable in the United States, and a synthetic form was developed. Synthetic porcine secretin is now approved by the Food and Drug Administration and is commercially available in the United States (Secreflo; Repligen, Waltham, Mass), as is a synthetic form of human secretin (Chirhostim; ChiRhoClin, Burtonsville, Md).

Most MR cholangiopancreatographic studies are probably still performed without secretin because of the cost and inconvenience of using the hormone. However, secretin is safe to use, with a very small incidence of serious side effects, and is easy to administer. Most important, it can significantly enhance the depiction of pancreatic ducts on MR cholangiopancreatographic images. While the agent produces little change in the appearance of the biliary tree, visualization of pancreatic ductal anatomy is often substantially improved, and use of the hormone is recommended in cases in which a detailed evaluation of the pancreatic duct is desired or when it is important to obtain a qualitative indication of the exocrine function of the pancreas.

In our routine practice, secretin-enhanced MR cholangiopancreatography is performed in all patients whose symptoms might be related to the pancreas and in whom visualization of pancreatic ducts is important, especially in those with unexplained abdominal pain that continues after noncontributory conventional examinations. In this article, we review our experience with 295 dynamic secretin-enhanced MR cholangiopancreatographic examinations. The MR cholangiopancreatography–based diagnoses included acute pancreatitis (n = 19), chronic pancreatitis (n = 49), pancreas divisum (n = 33), intraductal papillary mucinous tumor (IPMT) (n = 12), other pancreatic cancers (n = 14), and various conditions after Whipple surgery (n = 14).

Secretin-enhanced MR Imaging Technique

Fasting by the patient for 4–6 hours prior to the examination, along with the administration of 300 mL of ferumoxsil oral suspension as a negative oral contrast agent (Gastromark; Mallinckrodt Medical, Raleigh, NC), helps to avoid obscuration of the pancreatic ducts by high signal
intensity in the overlying stomach and duodenum (Fig 1). We give the oral contrast medium approximately 30 minutes before initiating the MR cholangiopancreatographic acquisitions. Secretin is given intravenously over 1 minute to avoid abdominal pain that may occur with a bolus injection. An adult dose of 2 μg per kilogram of body weight is used. At the commencement of the injection, a baseline image is obtained, followed by acquisition of a coronal single-shot turbo spin-echo image (acquisition time, 2 seconds) every 30 seconds for 15 minutes.

After the acquisition of axial locator images, the pancreatic duct is imaged by applying a single-shot fast spin-echo pulse sequence within a single 40-mm-thick coronal slab positioned over the pancreas. The matrix size for most patients is 256 × 256; the field of view varies from patient to patient but is generally 22 × 22 cm. Echo time is typically more than 750 msec. Fat saturation is used in all patients. Acquisition times are approximately 1–2 seconds per section, and images are acquired during breath holding. The examination parameters are listed in Table 1. The

Table 1
Parameters for T2-weighted Single-Shot MR Imaging with Secretin

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>Echo time (msec)</td>
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</tr>
<tr>
<td>Echo train (no. of echoes)</td>
<td>128–256</td>
</tr>
<tr>
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<tr>
<td>Slab thickness (mm)</td>
<td>40</td>
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</table>

Figure 1. A comparison of MR cholangiopancreatographic images shows the value of oral ferumoxsil. (a) Image obtained without secretin and ferumoxsil shows high signal intensity in the fluid-distended stomach (arrow) and small bowel (arrowhead) that obscures the pancreatic ducts. (b) Image obtained with the use of oral ferumoxsil (Gastromark; Mallinckrodt) as a negative contrast material shows a near absence of signal from the stomach and duodenum, a condition that allows better visualization of the pancreatic (arrow) and biliary ducts.
The maximal effect of intravenous secretin is observed at 5–7 minutes after the start of the injection (Fig 2). The caliber of the main pancreatic duct increases by at least 1 mm, and high signal intensity is seen in the descending and transverse duodenum in normal individuals after secretin injection.

The most common adverse effects of secretin are abdominal cramps, abdominal discomfort, nausea, vomiting, bloating, bradycardia, decreased blood pressure, diaphoresis, and diarrhea. However, in our experience, adverse effects occur infrequently. Only one (0.3%) of our patients developed severe abdominal pain requiring 4 hours of observation.
Pancreas Divisum

The pancreas derives from dorsal and ventral buds that develop from the embryonic foregut. The ventral system also gives rise to the hepatobiliary system. At approximately 6–8 weeks of gestation, the ventral pancreas rotates posterior to the duodenum and comes to rest inferior and slightly posterior to the head portion of the dorsal pancreas. Fusion of the ductal system occurs in more than 90% of individuals, but variations occur that may affect the patency of the accessory duct (Santorini duct). Figure 3 shows variations of the ductal anatomy (2).

Pancreas divisum occurs if there is a lack of fusion of the dorsal and ventral anlagen. Between 5% and 10% of the general population have this anatomic variant (3). Endoscopic retrograde
Figures 4, 5. (4) Incomplete pancreas divisum. Secretin-enhanced MR image shows the continuity of the main duct (curved white arrow) with the dorsal duct (black arrowhead) and of the ventral duct (black arrow) with the distal common bile duct (straight white arrow), features suggestive of pancreas divisum. However, a tenuous connection (white arrowhead) between the ventral and dorsal duct systems indicates incomplete division. (5) Complete pancreas divisum. (a) Presecretin MR image does not clearly depict the main pancreatic duct. (b) MR image obtained 5 minutes after secretin injection clearly shows the main duct in the body of the pancreas (white arrow) and the dorsal duct (arrowhead) in continuity with the main duct. Note that the main duct does not join with the distal common bile duct (black arrow), a finding that indicates complete pancreas divisum. (c) Corresponding ERCP image obtained after injection via the minor papilla helps confirm pancreas divisum and shows a santorinicele (arrow) at the minor papilla.
cholangiopancreatographic (ERCP) studies have shown that in 10%–15% of patients, pancreas divisum is incomplete; that is, there is a minor communication between the dorsal and ventral ducts (Fig 3, C) (2,4). This percentage may be an underestimate, as a vigorous injection of contrast material into the ventral duct would be required to show the connection. The significance of a bifid pancreas has been debated. The small diameter of the minor papilla orifice results in increased dorsal and main duct pressures that may cause pain or pancreatitis. About 15%–20% of patients with unexplained pancreatitis have pancreas divisum. Minor papilla sphincterotomy is the usual treatment for recurrent pancreatitis or disabling abdominal pain in patients with a divided pancreas. Traditionally, incomplete pancreas divisum was thought less likely than complete divisum to be associated with pancreatitis, since high pressure in the dorsal pancreatic duct system could be decreased via a connection to the ventral duct (Fig 4); however, this notion has been challenged by some investigators (5). The sensitivity of MR cholangiopancreatography for detection of pancreas divisum is considerably increased with the use of secretin (3,6,7) (Fig 5). Dynamic MR cholangiopancreatography also can depict a cystic distention of the distal accessory duct or Santorini duct (a so-called santorinicele) (Fig 6), probably as a result of impaired flow through the minor papilla. It has been suggested that patients with a pancreas divisum and a santorinicele have a higher risk of pancreatitis (8).

**Acute Pancreatitis**

Computed tomography (CT) is the principal method for evaluating the severity of pancreatitis and determining whether complications are present. MR cholangiopancreatography with or
without secretin for contrast enhancement is an excellent alternative method of evaluating the pancreatobiliary system in patients with an elevated creatinine level or a severe allergy to iodinated contrast material. It is also superior to CT for the detection of choledocholithiasis. The use of secretin in patients with acute pancreatitis has caused concern in the past; however, we encountered only one instance of abdominal pain and no exacerbations of pancreatitis after secretin injection in 295 examinations. Secretin enhancement is occasionally useful for determining whether the main pancreatic duct is completely disconnected or only stenosed in patients with necrotizing pancreatitis, an important distinction when surgical intervention is being considered (9) (Figs 7, 8).

### Chronic Pancreatitis
Pancreatologists use the Cambridge criteria for grading chronic pancreatitis at ERCP (Table 2). The use of secretin improves visualization of the main pancreatic duct and its side branches to such a degree at MR cholangiopancreatography that it is possible to use the same criteria for disease severity (Figs 9, 10). While parenchymal calculi are not seen as clearly at MR cholangiopancreatography as they are at CT, intraductal calculi are well demonstrated as filling defects at secretin-enhanced MR cholangiopancreatography. In

<table>
<thead>
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<th>Grade</th>
<th>ERCP Findings</th>
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<tbody>
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</tr>
<tr>
<td>2</td>
<td>Equivocal</td>
</tr>
<tr>
<td>3</td>
<td>Mild chronic pancreatitis</td>
</tr>
<tr>
<td>4</td>
<td>Moderate chronic pancreatitis</td>
</tr>
<tr>
<td>5</td>
<td>Marked chronic pancreatitis</td>
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Note.—Adapted, with permission, from reference 10.

**Figures 7, 8.** (7) Disconnected pancreatic duct syndrome. (a) Presecretin MR image shows a lack of continuity of the main pancreatic duct (arrow) in the region of the pancreatic neck and proximal body. (b) Postsecretin MR image demonstrates the absence of duct connection (arrowhead) and lack of stenosis. Note the curved drain catheter at the site of a peripancreatic fluid collection (arrow). (c) ERCP image helps confirm disruption of the main duct in the pancreatic head (arrowhead). The patient subsequently underwent pancreaticojejunostomy and percutaneous drain placement. (8) Pancreatic duct stenosis following acute pancreatitis. (a) Presecretin MR image shows discontinuity of the main duct at the level of the pancreatic neck (white arrowhead), an adjacent high-signal-intensity fluid collection (black arrowhead), and diffuse ascites (arrow). (b) MR image obtained 7 minutes after secretin injection shows stenosis of the main pancreatic duct in the pancreatic neck (white arrowhead) and diffuse ascites (arrow). The fluid collection adjacent to the pancreatic neck (black arrowhead) appears brighter than on the presecretin image, a feature suggestive of a connection to the duct. (c) ERCP image helps confirm the presence of stenosis (white arrowhead) and absence of disconnection of the duct. The fluid collection (black arrowhead) is filled with injected contrast material, which indicates disruption of the duct. The patient underwent percutaneous placement of a pancreatic stent (not shown) and did not need open surgery.
addition to depicting the ductal anatomy, secretin-enhanced MR cholangiopancreatography is useful also for qualitatively evaluating the exocrine secretory function in patients with intraductal calculi (11,12).

**Pancreatic Adenocarcinoma**

Pancreatic adenocarcinoma is the fourth most common cause of death due to cancer in the United States. MR imaging with gadolinium can be used for problem solving and for staging of the tumor in patients for whom contrast-enhanced CT is contraindicated. MR cholangiopancreatography with secretin is not usually required for diagnosis of a tumor or detection of tumor growth. In our experience, MR cholangiopancreatography with secretin is not accurate for differentiating between benign and malignant strictures of the main pancreatic duct. Occasionally, the etiology of ductal stricture in the pancreatic head is not determined preoperatively, and a Whipple procedure, which involves radical resection of the pancreatic head, duodenum, common bile duct, right half of the omentum, and local nodes, is performed.

**Intraductal Papillary Mucinous Tumor**

IPMTs originate from the main pancreatic duct or side branches and can mimic chronic pancreatitis–related changes such as dilated ducts or filling defects. The tumor produces thick mucin, which is usually visible at ductal cannulation during ERCP. About 90% of these tumors are benign or are carcinomas in situ. The prognosis, however, is considerably worse if the tumor becomes invasive. MR imaging is as sensitive as CT, if not more sensitive, for the diagnosis and staging of IPMT (13). Unfortunately, neither CT nor MR imaging enable differentiation of thin mucin from pancreatic juices. Such differentiation is possible with ERCP and endoscopic ultrasonographically guided fine-needle aspiration. However, in our experience, thick mucin balls may have decreased signal intensity on T2-weighted images and may appear as 1–3-mm filling defects.
in affected ducts (Fig 11). By definition, IPMTs communicate with the main pancreatic duct. Theoretically, small tumors should increase in size after secretin injection, as they fill with exocrine secretions. However, in 21 cases of side branch IPMT that we reviewed, no significant change in tumor size followed secretin injection. In these cases, a mucous plug may have impeded the filling of the cystic tumor by secreted juices.

Chronic pancreatitis is a frequent complication of IPMT because of long-term obstruction of

Figure 10. Severe chronic pancreatitis. (a) MR image obtained 7 minutes after secretin injection shows severe cystic dilatation of side branches in the pancreatic head and irregular dilatation of the main pancreatic duct, with low-signal-intensity filling defects (arrows). The exocrine response to secretin was poor, as demonstrated by the lack of high signal intensity in the duodenum. (b) Corresponding ERCP image helps confirm the presence of main duct filling defects consistent with calculi (arrows), findings indicative of grade 5 chronic pancreatitis. MR cholangiopancreatography has lower sensitivity than does ECRP for depicting pancreatic ductal calculi.

Figure 11. IPMT with diffuse duct disease. (a) Postsecretin MR image shows severe dilatation of the main duct in the pancreatic body and tail. The appearance of the duct resembles that in chronic pancreatitis, but dilatation is diffuse, and there is no stricture. Cystic dilatation of the main duct is visible in the head of the pancreas (white arrow). Small low-signal-intensity filling defects in the duct (arrowheads) are likely to be mucous concretions. The ventral duct (black arrow) appears normal. (b) ERCP image shows an extrusion of mucus from a bulging major papilla. There is marked dilatation of the proximal main pancreatic duct (arrowhead). The ventral duct (black arrow) appears normal. The cystic dilatation of the main duct in the pancreatic head is not as well depicted as at MR cholangiopancreatography, but a mucin-related filling defect (white arrow) that was not visible on the MR images is shown. Thin mucin is indistinguishable from pancreatic juices at MR imaging.
Figure 12. Recurrence of IPMT. (a) Postsecretin MR image, obtained 3 years after surgery with the Whipple procedure for IPMT, shows cystic dilatation of the duct in the remnant pancreatic tail (arrow). Low-signal-intensity foci with diameters of 2–3 mm (arrowheads), features likely due to viscid mucus, are seen within the duct. (b) Axial T2-weighted MR image shows a distended duct in the pancreatic tail (arrowheads) and the postsurgical site of pancreatojejunostomy (arrow). IPMT recurrence was found at pathologic analysis of a resected specimen. Right-sided hydronephrosis due to a ureteropelvic junction obstruction (not shown) was an incidental finding.

Figure 13. Whipple procedure. (a) Presecretin MR image obtained after Whipple surgery does not show any residual pancreatic duct. (b) MR image obtained 7 minutes after secretin injection clearly depicts the pancreatic duct in the body and tail (white arrow), mild stenosis at the junction with the roux limb of the jejunum (black arrow), and dilatation of a side branch (arrowhead). (c) ERCP image obtained with cannulation of the pancreatojejunostomy helps confirm mild distention of the main pancreatic duct and side branch.
pancreatic ducts by viscous secretions. MR features that support a finding of IPMT more than that of chronic pancreatitis include diffuse dilatation without stricture; septation; and a mural nodule within a dilated ductal side branch. Features associated with a higher risk of malignancy in IPMT include the presence of diabetes, age of more than 70 years, a tumor larger than 3 cm, a mural nodule larger than 1 cm, a bulging papilla, or main pancreatic duct dilatation of more than 1 cm (14–16). MR imaging is useful for postoperative follow-up of IPMT. Features suggestive of tumor recurrence include a recurrent cystic pancreatic mass, increased dilatation of ducts in the pancreas, and a solid extrapancreatic lesion (17) (Fig 12).

### Postsurgical Anatomy

After a pancreatic surgical resection (eg, the Whipple procedure, or pancreaticojejunostomy with the Puestow or Frey procedures for chronic pancreatitis), ERCP is more difficult to perform. MR cholangiopancreatography is the predominant method of investigating disease in the residual pancreas. Mild distention of the main pancreatic duct, a finding that becomes more obvious after the administration of secretin, is commonly seen following Whipple surgery and is attributed to the near-universal presence of anastomotic stenosis (Fig 13). The volume of fluid seen in the efferent jejunal limb may be an indirect measure of remnant pancreatic exocrine function after the Whipple procedure (18). The current practice among surgeons at our institution is to insert a stent at the anastomotic site. Following the Puestow operation, the main pancreatic duct may be invisible unless there is a recurrence of chronic pancreatitis.

### Conclusions

Secretin is a safe, albeit costly, agent that improves visualization of the main and side pancreatic ducts in normal and pathologic states during MR cholangiopancreatography. Dynamic MR cholangiopancreatography after secretin administration also provides valuable information about the secretory reserve capacity of the pancreas. Yet, a lack of awareness of the value of secretin-enhanced MR cholangiopancreatography among radiologists and referring clinicians has limited the use of this technique.

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MR cholangiopancreatography in children: feasibility, safety, and initial experience

Lisa Delaney · Kimberly E. Applegate · Boaz Karmazyn · M. Fatih Akisik · S. Gregory Jennings

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Abstract
Background The indications for MR cholangiopancreatography (MRCP) in children, and its safety and findings, might differ from those in adults and are not well described. Objective To investigate the safety, feasibility, and accuracy of MRCP in children. Materials and methods We reviewed all prospective MRCP reports, noting the indication, the use of secretin, endoscopic retrograde cholangiopancreatography (ERCP) findings, and patient outcomes. Two readers reviewed each MRCP study by consensus to rate duct visualization and compare pancreatic duct sizes before and after secretin administration (paired t-test). The likelihood of a normal versus an abnormal MRCP study was compared by gender, pancreatitis as the primary indication, secretin use, and whether ERCP was performed (Fisher’s exact test), as well as age (t-test).
Results A total of 85 MRCP studies were performed in children (mean age 10.3 years), most commonly for evaluation of pancreatitis (n=47, 55%); 41 (48%) used secretin and 39 (46%) used a negative oral contrast agent. Of the 85 studies, 72 (85%) had excellent image quality and 43 were normal. ERCP was performed after 16 of the 85 MRCP studies (19%); the diagnoses were concordant with those of MRCP in 13 (81%). There were 42 abnormal MRCP studies, and these were more likely to be in girls (P=0.03) and in children who had undergone ERCP (P<0.01). Secretin and the negative oral contrast agent were well-tolerated. Secretin improved duct visualization (P<0.001).
Conclusion MRCP safely and accurately depicted pancreaticobiliary anatomy in children. The use of secretin improved visualization of the pancreatic duct.

Keywords Magnetic resonance cholangiopancreatography · Secretin · Pancreatitis · Children

Introduction
Pancreatitis is often considered an adult disease, so when it occurs in children it is often not initially considered in the differential diagnosis of abdominal pain. The incidence of pancreatitis in children is not well described, although it is perhaps more common than previously suspected [1]. The etiology of pancreatitis in children is more often related to congenital anomalies than in adults, and tumors are rare. According to one meta-analysis, the top three causes of pediatric pancreatitis are idiopathic anomalies (23%), trauma (22%), and structural anomalies (15%) [2].

Imaging evaluation of the pediatric pancreaticobiliary system includes US, radionuclide studies, endoscopic retrograde cholangiopancreatography (ERCP), and percutaneous transhepatic cholangiography, and more recently endoscopic US (EUS). However, ERCP is difficult to perform in young children because it requires special equipment and expertise that are not available in many institutions [3]. Magnetic resonance cholangiopancreatography (MRCP) was introduced in the early 1990s as a noninvasive examination that does not expose the patient to ionizing radiation and requires no intravenous contrast
agent [4]. It can demonstrate congenital anomalies and pathology of the pancreaticobiliary system, and is useful in determining the need for ERCP and medical or surgical management. The addition of a hormone, secretin, that stimulates pancreatic exocrine function has been shown to improve visualization of pancreatic ductal anatomy and function [5, 6].

Unfortunately, evaluating pediatric pancreatic pathology is often challenging because of smaller duct sizes and the need for sedation to decrease motion artefacts. The efficacy of MRCP in evaluating pancreatic pathology might thus differ from that in adults. While the advantages and pitfalls of MRCP in adults have been extensively reported, only a few studies of MRCP in children have been published [7–11]. All but one of these studies are case reports or very small series of children and were mostly focused on one abnormality (e.g., choledochal cyst). Moreover, none of the groups reported an extensive experience with the use of secretin. Secretin might be even more useful in children than in adults because it enhances the ability to view the normally smaller pancreatic ducts. In the study reported here we investigated the feasibility, safety, and results in a large series of pediatric patients who underwent MRCP at our institution, including the effects of secretin and a negative oral contrast agent, and compare MRCP and ERCP findings in patients who underwent both studies.

Materials and methods

This retrospective study was approved by our institutional review board with an informed consent waiver. From our radiology information system, we identified each MRCP study performed on any patient age 18 years or younger between March 2002 and June 2005. One author who was not involved in image analysis prospectively reviewed each report. This coauthor also identified all ERCP studies performed in these patients within 2 months of MRCP and without surgical intervention. All patient medical records were reviewed for demographic information and clinical and surgical follow-up.

MRCP technique

All MRCP examinations were performed using a 1.5-T scanner (Signa Horizon LX, General Electric Medical Systems, Milwaukee, WI). MRCP was performed using a body phased-array coil and a single-shot fast spin-echo sequence of 20- to 30-mm slabs, depending on patient size (Table 1).

MRCP examination time was approximately 45 min. If a child was unable to lie still for that length of time (generally those younger than 6 years and those with cognitive disabilities), conscious sedation was used. If the child was less than 12 kg and younger than 2 years, chloral hydrate (50–100 mg/kg) was given orally. In other children age 5 years and younger, midazolam (0.1 mg/kg, maximum 2.5 mg) and pentobarbital (2–6 mg/kg, maximum 100 mg) were administered intravenously. Sedation was administered by a radiology nurse following the American Academy of Pediatrics guidelines [12]. For those children who did not meet the guideline criteria, sedation or general anesthesia was performed by an anesthesiologist.

In examinations performed on nonsedated children, a negative oral contrast agent consisting of 150–300 ml of ferumoxsil oral suspension (Gastromark, Mallinckrodt Medical, Raleigh, NC) was given immediately before the examination. If the patient refused to drink the negative oral contrast agent and was not diabetic, pineapple juice, which contains a high level of iron, was offered as an alternative. The negative bowel contrast agent decreases bright signal from the stomach and proximal duodenum that could obscure visualization of the pancreatic duct.

Secretin was routinely used in our studies from early 2005. Secretin (0.2 μg/kg body weight, up to 16 μg maximum dose) was slowly injected intravenously over 1 min. Slab MRCP images were obtained.

Data collection and analysis

Pertinent findings from the clinical and surgical history prior to and after the MRCP study were recorded, including patient age, sex, pertinent prior medical diagnoses, results of endoscopy, amylase, lipase and liver function values, and action taken after the MRCP study (including ERCP, biopsy, or surgery). The specialty of the referring physician, the clinical indication for the MRCP study stated on the requisition, whether conscious sedation, intravenous contrast agent, secretin, and/or negative oral contrast agent (or pineapple juice) was used during the MRCP study (and any associated complications), whether image quality was suboptimal and why (e.g., motion, inability to drink contrast agent), and the MRCP findings were also recorded.

When both nonsecretin and secretin MRCP sequences were performed in a patient, we subjectively compared the quality of the images before and after secretin that included partial or complete visualization of the pancreatic duct. Two radiologists independently measured the pancreatic duct size in the pancreatic head, body, and tail regions on the PACS images. When the raters differed, the final rating was reached by consensus review. The radiologists also rated the visualization of the entire pancreatic duct using a four-point scale (0 no change in visualization of the duct after secretin administration, 1 mild improvement in visualiza-
Table 1  MRCP technique (using a 1.5-T scanner)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Scan 1</th>
<th>Scan 2</th>
<th>Scan 3</th>
<th>Scan 4</th>
<th>Scan 5*</th>
<th>Scan 6*</th>
<th>Scan 7*</th>
<th>Scan 8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coil Plane</td>
<td>Cardiac or torso phased array</td>
<td>Axial</td>
<td>Coronal</td>
<td>Axial</td>
<td>Coronal oblique</td>
<td>Coronal oblique</td>
<td>Coronal oblique</td>
<td>Axial</td>
</tr>
<tr>
<td></td>
<td>Three-plane</td>
<td>Fast multiphase</td>
<td>Single-shot</td>
<td>Fast spin echo</td>
<td>Single-shot</td>
<td>Fast spin echo</td>
<td>3-D fast recovery</td>
<td>Fast recovery</td>
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<tr>
<td></td>
<td>localizer</td>
<td>Fast spin echo</td>
<td>Single-shot</td>
<td>Fast spin echo</td>
<td>Single-shot</td>
<td>Fast spin echo</td>
<td>recovery fast spin echo T2-W</td>
<td>recovery fast spin echo XL</td>
</tr>
<tr>
<td>Pulse sequence</td>
<td>Three-plane</td>
<td>Fast multiphase</td>
<td>Single-shot</td>
<td>Fast spin echo</td>
<td>Single-shot</td>
<td>Fast spin echo</td>
<td>127 (4 ET/slice)</td>
<td>102</td>
</tr>
<tr>
<td>Echo time (ms)</td>
<td>4.76</td>
<td>2.81</td>
<td>1,450–1,800</td>
<td>4,000</td>
<td>4,000</td>
<td>1,500</td>
<td>1,500</td>
<td>13</td>
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<tr>
<td>Echo train length</td>
<td>In phase</td>
<td>230</td>
<td>230</td>
<td>256</td>
<td>256</td>
<td>127 (4 ET/slice)</td>
<td>102</td>
<td>102</td>
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<tr>
<td>Repetition time (ms)</td>
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<td>230</td>
<td>230</td>
<td>256</td>
<td>256</td>
<td>127 (4 ET/slice)</td>
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<td>102</td>
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<tr>
<td>Flip angle</td>
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<td>100–200</td>
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<td>180</td>
<td>180</td>
<td>180</td>
<td>13</td>
</tr>
<tr>
<td>Receiver bandwidth (kHz)</td>
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<td>62.5</td>
<td>62.5</td>
<td>62.5</td>
<td>62.5</td>
<td>32.25</td>
<td>31.25</td>
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<tr>
<td>Field of view</td>
<td>Determined by size of child</td>
<td>Determined by size of child</td>
<td>Determined by size of child</td>
<td>Determined by size of child</td>
<td>Determined by size of child</td>
<td>Determined by size of child</td>
<td>Determined by size of child</td>
<td>Determined by size of child</td>
</tr>
<tr>
<td>Slice thickness (mm)</td>
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<td>6–7</td>
<td>4</td>
<td>4</td>
<td>20–30</td>
<td>20–30</td>
<td>1.8</td>
<td>1.8</td>
</tr>
<tr>
<td>Slice spacing (mm)</td>
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<td>1</td>
<td>0</td>
<td>0</td>
<td>3.5–8</td>
<td>3.5–8</td>
<td>3.5–8</td>
<td>1.5</td>
</tr>
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<td>256</td>
</tr>
<tr>
<td>Matrix phase (pixels)</td>
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<td>160</td>
<td>160</td>
<td>160</td>
<td>160</td>
<td>160</td>
<td>128</td>
<td>224</td>
</tr>
<tr>
<td>Frequency direction</td>
<td>R/L</td>
<td>L/R</td>
<td>S/I</td>
<td>L/R</td>
<td>S/I</td>
<td>A/P</td>
<td>L/R</td>
<td>R/L</td>
</tr>
<tr>
<td>No. of excitations</td>
<td>1</td>
<td>1</td>
<td>1.25</td>
<td>1</td>
<td>1.5</td>
<td>1.5</td>
<td>1.5</td>
<td>4</td>
</tr>
<tr>
<td>Secretin</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Fat saturation</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Gating</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>None</td>
</tr>
</tbody>
</table>

* Scan 5: SSFSE radial oblique; radial slabs every 10°.

** Scan 6 (secretin slabs): SSFSE parallel to pancreatic duct; slabs every 30 s for 10 min. Scan 7: only necessary in children who cannot hold their breath.

tion of the duct, 2 moderate improvement in visualization of the duct, 3 marked improvement in visualization of the duct). The changes in duct size and visualization from before to after secretin were analyzed using a paired t-test.

When available, the prospective reports for each MRCP and ERCP were used and compared. We documented any additional MRCP findings that could not have been demonstrated by ERCP, as well as any interventions performed during ERCP.

In patients with a normal MRCP examination, we reviewed all available follow-up imaging, ERCP, and clinical records to determine whether a diagnosis was later determined. For those with an abnormal MRCP examination, we performed a similar review to determine whether follow-up information was consistent with the MRCP diagnosis.

The likelihood of normal versus abnormal MRCP examinations was compared for sex, pancreatitis as the primary indication, secretin use, contrast agent use, and whether ERCP was performed (Fisher's exact test), and for age (t-test). The average age of patients with examinations limited by motion was compared with the overall average (two-tailed unpaired t-test). For all statistical analyses, P values <0.05 were considered significant.
Results

Patient population

We identified 85 MRCP examinations during the study period that met the entry criteria. These examinations were performed in 78 different patients with a mean age of 10.3 years at the time of examination (range 0.2–17.9 years). Of the 85 MRCP examinations, 35 were performed in boys (41%) and 50 in girls (Table 2). Most MRCP examinations (48/85, 57%) followed referral by a pediatric gastroenterologist. The most frequent clinical indications for MRCP were pancreatitis (47/85, 55%) and elevated liver function tests (29/85, 34%; Table 3). Secretin was administered in 41 of 85 MRCP studies (48%) and in 39 studies (46%) the child drank a negative contrast agent. None had any complications from these medications and none of the children who were sedated had complications.

Referring physicians

Most patients (55/85, 65%) were referred by gastroenterologists, 48 by pediatric gastroenterologists and 7 by adult gastroenterologists. Of the MRCP studies requested by gastroenterologists, 42% (23/55) were abnormal. Pediatric surgeons requested the second highest number of MRCPs (14/85, 16%), and 86% (12/14) of these were abnormal. The remainder (16/85, 19%) were requested by a variety of other specialties (general pediatricians, hematologists/oncologists, etc.) and 50% (8/16) of these were abnormal.

Image quality

Image quality was considered optimal when the entire pancreaticobiliary system could be visualized and was not obscured by patient motion, overlying lines, tubes, or bowel fluid. Image quality was diagnostic in 72 of the 85 MRCP examinations performed (85%). Image quality in 13 of 85 MRCP examinations (15%) was suboptimal. Of these 13 examinations, 9 (69%) were suboptimal because of potentially controllable factors such as patient motion. Patients whose examinations were limited by motion were not significantly younger than the average patient (8.2 years vs. 10.3 years, \( P=0.32 \)). Other studies had limitations because of patient findings (e.g., overlying fluid in bowel that obscured pancreaticobiliary ductal anatomy; Table 4). Another study was limited by suboptimal choice of MRCP slab placement. Three patients with suboptimal MRCP examinations underwent ERCP. In one of these patients the MRCP study had a common bile duct filling defect interpreted as calculus or artefact; ERCP did not demonstrate a calculus. In another of these patients, ERCP was performed for stent placement, and in the third patient whom the slab placement was suboptimal on MRCP, ERCP was performed to better visualize the bile ducts in an unusual case of biliary stasis.

Only five patients in our study received an intravenous contrast agent. For three of the five, the indication was a mass (liver or pancreas). In the other two, the reason for administration of intravenous contrast material was not

### Table 2: Demographics of the patients with normal and abnormal MRCP examinations

<table>
<thead>
<tr>
<th>Patients</th>
<th>Number</th>
<th>Mean</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>43</td>
<td>9.6</td>
<td>0.2–17.9</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>MRCP examinations</th>
<th>Normal MRCP</th>
<th>Abnormal MRCP</th>
<th>All MRCPs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total number</td>
<td>43</td>
<td>42</td>
<td>85</td>
</tr>
<tr>
<td>In boys</td>
<td>23 (27%)</td>
<td>12 (14%)</td>
<td>35 (41%)</td>
</tr>
<tr>
<td>In girls</td>
<td>20 (24%)</td>
<td>30 (35%)</td>
<td>50 (59%)</td>
</tr>
<tr>
<td>With secretin</td>
<td>24 (28%)</td>
<td>17 (20%)</td>
<td>41 (48%)</td>
</tr>
<tr>
<td>With oral contrast agent</td>
<td>23 (27%)</td>
<td>16 (19%)</td>
<td>39 (46%)</td>
</tr>
</tbody>
</table>

### Table 3: Clinical indications for MRCP examinations (multiple indications were present in 29 patients)

<table>
<thead>
<tr>
<th>Indication</th>
<th>Normal MRCP (n=43)</th>
<th>Abnormal MRCP (n=42)</th>
<th>All MRCPs (n=85)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pancreatitis</td>
<td>24 (55%)</td>
<td>23 (52%)</td>
<td>47 (55%)</td>
</tr>
<tr>
<td>Elevated liver function tests</td>
<td>14 (34%)</td>
<td>15 (36%)</td>
<td>29 (34%)</td>
</tr>
<tr>
<td>Occult abdominal pain</td>
<td>9 (21%)</td>
<td>2 (5%)</td>
<td>11 (13%)</td>
</tr>
<tr>
<td>Evaluate choledochal cyst</td>
<td>0</td>
<td>6 (14%)</td>
<td>6 (7%)</td>
</tr>
<tr>
<td>Rule out common bile duct calculi</td>
<td>6 (14%)</td>
<td>6 (14%)</td>
<td>12 (14%)</td>
</tr>
<tr>
<td>Rule out primary sclerosing cholangitis</td>
<td>1</td>
<td>3</td>
<td>4 (5%)</td>
</tr>
<tr>
<td>Evaluate liver or pancreas mass</td>
<td>0</td>
<td>4 (9%)</td>
<td>4 (5%)</td>
</tr>
<tr>
<td>Trauma</td>
<td>1</td>
<td>2</td>
<td>3 (4%)</td>
</tr>
<tr>
<td>Abscess</td>
<td>0</td>
<td>1 (2%)</td>
<td>1 (1%)</td>
</tr>
<tr>
<td>Pre-liver transplant evaluation</td>
<td>0</td>
<td>1 (2%)</td>
<td>1 (1%)</td>
</tr>
<tr>
<td>Evaluate liver transplant</td>
<td>0</td>
<td>1 (2%)</td>
<td>1 (1%)</td>
</tr>
</tbody>
</table>
stated. There were no complications associated with intravenous contrast agent administration.

In 41 of 85 MRCP examinations (48%) the patient received secretin; none of them experienced any adverse reaction. Of these 41 patients who received secretin, 18 (44%) had pancreatitis at the time of examination (as defined by elevated amylase or lipase values within 2 weeks prior to examination). Secretin allowed better delineation of the pancreatic duct as well as qualitative evaluation of the exocrine function of the pancreas (Fig. 1). In one patient who received secretin, there was improved visualization of an intraduodenal bile duct stricture after secretin administration (Fig. 2).

Of 85 MRCP examinations, 39 (46%) included the use of a negative oral contrast agent. No complications were associated with its use. Pineapple juice did not appear to suppress the high signal from gastric secretions as well as the negative oral contrast solution.

Normal MRCP

Of the 85 MRCP examinations, 43 (51%) were prospectively interpreted as normal (Fig. 1). Of these 43 children (mean age 9.6 years), 23 (53%) were male, 23 (53%) received secretin, 25 (58%) ingested a negative oral contrast agent, 24 (56%) were imaged for pancreatitis, 9 (21%) had abdominal pain with or without nausea and vomiting but with normal laboratory values, 14 (33%) had abnormal liver function tests, and 6 (14%) had a suspected common bile duct calculus (Table 3). Multiple clinical indications were given for some MRCP examinations.

Only two of the children with a normal MRCP study had ERCP within 2 months. In both children ERCP demonstrated normal pancreatic ducts and therefore MRCP and ERCP were concordant. In both patients a stent was placed in the pancreatic duct, in one child because of recurrent pancreatitis and in the other because of sphincter of Oddi dysfunction. In the latter child, a sphincterotomy was also performed.

Further clinical investigations revealed a cause for pancreatitis in seven children (16%) (medications, familial, cystic fibrosis, inflammatory bowel disease). Nine (21%) of the 43 children with normal MRCP examinations had no further episodes of pancreatitis. Eight children (19%) had no follow-up imaging or laboratory data at our institution. Four children (9%) had at least one further episode of pancreatitis with undetermined etiology. Three different children (7%) had at least one further episode of pancreatitis with undetermined etiology and had stents placed at ERCP performed more than 2 months after the MRCP. One of these patients underwent five subsequent ERCP examinations during the following 4 years and had serial

| Table 4 Reasons for suboptimal MRCP examinations (n=13) |
|----------------------------------|------------------|
| Limitation                       | Number (%)       |
| Patient motion                   | 5 (42%)          |
| Nausea and/or vomiting (could not complete study) | 3 (25%) |
| Duct visualization obscured by nearby fluid | 2 (17%) |
| Duct visualization obscured by supporting lines and tubes | 2 (17%) |
| Suboptimal choice of MRCP slab placement | 1 (8%) |

*aThe average age of children with examinations limited by motion was 8.2 years.*
pancreatic duct stenting for increasing duct size. ERCP 8 months after the MRCP showed changes consistent with mild chronic pancreatitis; however, the child had two episodes of pancreatitis between the MRCP and ERCP. He subsequently underwent a pancreateicojejunostomy (Paestow procedure) for pain control. The other two children's later ERCP examinations did not add clinical information.

In six children (14%) a nonpancreatic pathology that could have explained the abdominal pain was found. Two children (5%) had chronic hepatitis and two (5%) had cholelithiasis and chronic inflammation; one (2%) had eosinophilic gastritis, and one (2%) had ulcerative colitis. Two children (5%) had subsequent cholecystectomies for biliary dyskinesia that demonstrated normal pathology and no common bile duct calculi. No further work-up after the cholecystectomies was found in our electronic database.

Abnormal MRCP

Of the 85 MRCP examinations, 42 (49%) were prospectively interpreted as abnormal (Table 5). Of the 42 patients (mean age 11.1 years), 12 (29%) were male, 8 (43%) received secretin, 14 (33%) ingested a negative oral contrast agent, and 23 (55%) had pancreatitis (the most common indication; Table 3). Some patients had multiple indications and diagnoses.

Subjectively, in two of five patients (40%) with pancreas divisum, the abnormal insertion of the pancreatic duct was better seen after secretin administration. In two of seven patients (29%) with anomalous pancreatico-biliary ductal junctions (long common channel), the anomalous junction was better visualized after the administration of secretin.

Of the 42 abnormal studies, 12 (29%) demonstrated congenital anomalies of the pancreatico-biliary tree. The most common congenital anomaly was pancreas divisum, seen in five children (Figs. 3 and 4). The second most common was choledochal cyst, seen in three children on seven different studies (Fig. 5). One patient with heterotaxy syndrome had an annular pancreas (Fig. 6). Of the 42 abnormal studies, 11 (26%) showed acute or chronic pancreatitis (Figs. 4 and 7).

Two studies demonstrated gallbladder calculi and three studies showed calculi in the common bile duct or

Fig. 2 Bile duct stricture in a 9-month-old boy with jaundice after liver transplantation. a The common hepatic duct stricture is not well seen prior to secretin administration. There is a difference in size of the donor and recipient common bile duct (arrow). b The dilated left hepatic duct and stricture (arrow) is better visualized after the administration of secretin. c An ERCP image obtained 7 days later again demonstrates a stricture of the left dilated hepatic duct (arrow) and a discrepancy in the sizes of the donor and recipient ducts. A biliary duct stent was placed
Table 5 Diagnoses in abnormal MRCP examinations (n=42)

<table>
<thead>
<tr>
<th>Diagnosis</th>
<th>Examinations</th>
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<tbody>
<tr>
<td>Biliary duct dilation</td>
<td>9</td>
</tr>
<tr>
<td>Choledochal cyst</td>
<td>7</td>
</tr>
<tr>
<td>Pancreatitis (chronic)</td>
<td>6</td>
</tr>
<tr>
<td>Pancreatitis (acute)</td>
<td>5</td>
</tr>
<tr>
<td>Pancreas divisum</td>
<td>5</td>
</tr>
<tr>
<td>Choledocholithiasis</td>
<td>3</td>
</tr>
<tr>
<td>Pancreatic mass (hemangioma, pseudocyst)</td>
<td>3</td>
</tr>
<tr>
<td>Stricture of common bile duct</td>
<td>2</td>
</tr>
<tr>
<td>Cholelithiasis</td>
<td>2</td>
</tr>
<tr>
<td>Hepatic mass (hepatocellular carcinoma)</td>
<td>1</td>
</tr>
<tr>
<td>Annular pancreas</td>
<td>1</td>
</tr>
<tr>
<td>Non-accidental trauma with duct disruption</td>
<td>1</td>
</tr>
<tr>
<td>Primary sclerosing cholangitis</td>
<td>1</td>
</tr>
<tr>
<td>Caroli disease</td>
<td>1</td>
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</tbody>
</table>

*Multiple diagnoses were present in five patients.

pancreatic duct (Figs. 4, 5 and 8). Two studies (5%) showed strictures (Fig. 2) or narrowing of the common bile duct. One patient had findings consistent with Caroli disease (Fig. 8) and one patient had primary sclerosing cholangitis (Fig. 9). One study demonstrated transection of the pancreatic duct (Fig. 10).

Additional diagnoses on MRI

Of 85 MRCP examinations, 35 had findings that could not have been visualized by ERCP alone. These included liver lacerations (Fig. 10), adrenal hemorrhage, multicycstic dysplastic kidney, hepatosplenomegaly, varices, hepatic tumors, ascites, lung consolidation, omental and mesenteric tumor metastases, and pancreatic masses. Three studies (7%) showed pancreatic masses—pseudocysts in two and hemangioma in one (Fig. 11).

Fig. 4 Pancreas divisum, chronic pancreatitis and calculi in a 9-year-old girl with chronic pancreatitis. a There is pancreas divisum with a filling defect in the minor papilla consistent with a calculus (arrow). There is a dilated side branch also containing a calculus (curved arrow). The pancreatic duct is dilated, consistent with chronic pancreatitis. b This ERCP image obtained the following day again demonstrates filling defects consistent with pancreatic duct calculi (arrows) that were removed endoscopically. The divisum is again seen on the ERCP image (note that the minor papilla is cannulated). At ERCP the patient had a dorsal pancreatic sphincterotomy.

Fig. 3 Pancreas divisum in a 10-year-old boy with a history of Crohn disease and acute pancreatitis. The main pancreatic duct empties into the minor papilla (arrow). The common bile duct empties into the major papilla (curved arrow). There is no ductal dilation and the gallbladder has normal fluid signal.
Fig. 5 Choledochal cyst. a A 7-year-old girl with pancreatitis. There is fusiform dilation of the extrahepatic bile duct consistent with a type 1 choledochal cyst. The pancreatic duct joins the common bile duct (arrow) approximately 1.5 cm proximal to the ampulla, known as a long common channel (distal to arrow). Also notice the filling defect in the dilated portion of the common bile duct just proximal to the pancreatic duct insertion, consistent with a calculus (curved arrow). b A 4-year-old girl with pancreatitis. There is fusiform dilation of the extrahepatic bile duct with multiple areas of cystic dilation of the intrahepatic bile ducts consistent with a type IV choledochal cyst. Also note that there is a long common channel and a filling defect in the distal common bile duct consistent with a calculus (arrow). c This ERCP image was obtained 2 days later and demonstrates the type IV choledochal cyst. A calculus was removed from the distal common bile duct (not shown).

ERCP correlation

Of the 85 MRCP studies, 16 (19%) were followed within two months by ERCP (mean interval 10 days, range 1 to 33 days), and of these 16 MRCP studies 14 showed an abnormality and two were normal. At ERCP, 4 of the 14 patients with an abnormal MRCP had calculi removed from either the common bile duct or the pancreatic duct, two had strictures dilated, three had pancreatic stents placed, one had a stent removed, and four had sphincterotomies (Table 6). Another patient, with a normal MRCP but elevated lipase, had a sphincterotomy and pancreatic stent placement, despite having normal-appearing pancreatic and bile ducts.

The MRCP and ERCP diagnoses were concordant in 13 of 16 patients (81%). Among the three patients with discordant diagnoses, strictures of anomalous pancreaticobiliary ductal junctions were not seen on MRCP in two patients. In one of

Fig. 6 A 5-year-old girl with annular pancreas and a history of protein-losing enteropathy, double outlet right ventricle and AV canal, now being evaluated for an abscess. MR image demonstrates the pancreas partially wrapping around the second portion of the duodenum (annular pancreas, arrows) and complex ascites.
these patients, the MRCP findings in retrospect were suspicious for stricture, but a stricture was not fully described in the report. In the other patient, the stricture was visible in retrospect, but it was attributed to being part of the lobulated contour of a choledochal cyst rather than a discrete stricture. In the remaining patient, pancreatic ductal calculi were not visualized. Even in retrospect, the calculi were not well visualized on the MRCP image and were difficult to visualize on the ERCP image. All three of these patients with discrepancies received secretin and none of the MRCP examinations was considered limited by image quality. Neither patient with stricture drank a negative oral contrast agent; however, interpretation of the studies was not limited by overlying fluid in the bowel. The patient with the pancreatic duct calculi did drink a negative oral contrast agent.

Statistical correlations

Girls were more likely than boys to have an abnormal MRCP examination (30 of 50 versus 12 of 35 abnormal studies, respectively; P=0.03). As expected, patients who had an abnormal MRCP study were also more likely to undergo ERCP: 14 of 42 patients with an abnormal MRCP study had ERCP, while only 2 of 43 patients with a normal MRCP study had ERCP (P=0.01). There was no significant association between an abnormal MRCP examination and age (P=0.15), pancreatitis as the indication for MRCP (P=1.00), use of secretin (P=0.19), or use of a negative oral contrast agent (P=0.19).

Comparison of pancreatic duct visualization before and after secretin administration

There were 37 children who had MRCP slabs available from both before and after secretin administration for
comparison. The mean change in duct visibility rating was 2.6. The duct was significantly better visualized with the use of secretin, with a mean rating of 2.6 versus 1.0 without secretin ($P<0.001$).

The average change in pancreatic duct size after secretin administration in the head of the pancreas was 0.6 mm, in the body 0.4 mm and in the tail 0.5 mm. These changes were statistically significant (all three $P<0.001$). When comparing the 21 normal MRCP studies with the 16 abnormal ones, there were no significant differences in the change in pancreatic duct sizes (head 0.7 mm vs. 0.6 mm, body 0.4 mm vs. 0.4 mm, and tail 0.5 mm vs. 0.3 mm).

Fig. 9 Primary sclerosing cholangitis in a 14-year-old boy with ulcerative colitis. a There is mild, diffuse irregularity and dilation of the intra- and extrahepatic bile ducts. The pancreatic duct is normal. b This coronal T2-weighted MR image demonstrates wall thickening in the bile ducts (arrow).

Fig. 10 Non-accidental trauma in a 3-year-old boy who had idiopathic pancreatitis and the endoscopist requested MRCP prior to ERCP. The axial T2-weighted MR image demonstrates a transected pancreatic neck with fluid signal (arrow). He also had two liver lacerations (one shown curved arrow) and ascites, neither of which would have been seen on ERCP alone. He also had bilateral adrenal hemorrhages and anterior right rib fractures (not shown).

Fig. 11 Pancreatic hemangioma in a 7-month-old girl with a history of obstructive jaundice and a distal common bile duct stricture. She underwent percutaneous biliary stent placement. Her abdominal CT scan was unrevealing and her biopsy at laparotomy was unsuccessful. This heavily T2-weighted axial MR image demonstrates a hemangioma in the head of the pancreas that later involuted with steroid treatment. The girl received an intravenous contrast agent during the study.
**Table 6 Interventions during ERCP (n=15)**

<table>
<thead>
<tr>
<th>Intervention</th>
<th>ERCP examinations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sphincterotomy</td>
<td>5</td>
</tr>
<tr>
<td>None</td>
<td>4</td>
</tr>
<tr>
<td>Removal of calculi</td>
<td>4</td>
</tr>
<tr>
<td>Stent placement</td>
<td>4</td>
</tr>
<tr>
<td>Dilatation of stricture</td>
<td>2</td>
</tr>
<tr>
<td>Stent removal</td>
<td>1</td>
</tr>
</tbody>
</table>

*Multiple procedures were performed during four ERCP examinations.*

**Discussion**

Recent technical advances in MR hardware and software have made MRCP a practical modality for imaging the pancreaticobiliary system in children [11, 13]. The results of our study confirm that MRCP can be used safely and effectively in children. While common clinical indications for MRCP in children are similar to those in adults, in our study children had more frequent congenital anomalies than reported in adults who undergo MRCP [14].

The use of heavily T2-weighted sequences with the fast single-shot technique is an easy, quick, and noninvasive test to evaluate the pancreatic and biliary ducts. The protocol uses coronal oblique slabs of single-shot fast spin-echo sequences with fat saturation, each acquired in approximately 2 s. Although this sequence was originally developed as a breath-hold technique, we also perform the technique in sedated and anesthetized children without breath-holding.

High signal from normal gastric and duodenal fluid can obscure visualization of the pancreaticobiliary ducts, particularly in the pancreatic tail. At our institution, we use a negative oral contrast agent when the child is not sedated to suppress this high signal in the overlying stomach and proximal duodenum [15]. Reported side effects of the negative oral contrast agent (nausea, vomiting, diarrhea, and abdominal cramping) were not reported in our patients. When children refused to drink the negative oral contrast agent because of its taste, pineapple juice was used as a mild negative oral contrast agent, although it is less effective in suppressing the high signal of gastric fluid.

The pancreatic duct is smaller than the biliary ducts, which can make it more challenging to evaluate by MRCP when it is normal in caliber or only minimally dilated [16]. Secretin is a polypeptide hormone secreted by duodenal mucosa in response to luminal acid [17]. Its onset of action is 5–7 min (and lasts only 15 min); it induces pancreatic secretion of water and bicarbonate and increases the tone of the sphincter of Oddi [7, 17]. Consequently, a normal response to secretin is increased fluid signal in the pancreatic duct and fluid excretion into the duodenum. Thus, the intravenous injection of secretin during MRCP enhances visualization of the pancreatic ducts and also can be used to evaluate the exocrine function of the pancreas [6, 16, 18, 19]. In our study, the pancreatic duct did enlarge after the administration of secretin. We found the addition of secretin and subsequent enlargement of the duct to be the most useful in patients in whom the pancreatic duct was difficult to visualize before the administration of secretin and/or when the ductal findings were subtle. In patients in whom the pancreatic duct was already dilated, the administration of secretin had limited value.

Reported side effects of secretin (transient abdominal cramping and nausea) are uncommon and were not reported in our patients. Cramping and nausea are more likely to occur in patients with pancreatitis because the effects of secretin on the pancreas mimic a meal; however, in our study no side effects were noted, even in children with active pancreatitis at the time of secretin administration. One disadvantage of secretin is its cost, although both ERCP and EUS are more costly procedures and they also use secretin to visualize the major papilla in children.

At present, the need for an intravenous contrast agent during MRCP in children is limited because of the low incidence of pancreatic tumors, although in some centers secretin with or without gadolinium is used to quantitate pancreatic exocrine function [5, 6, 16, 19]. At our institution, we do not routinely administer an intravenous contrast agent unless a tumor or vascular malformation is suspected.

MRCP is capable of demonstrating normal and anomalous pancreaticobiliary systems. Of our patients, 51% had normal MRCP examinations. Patients with abnormal MRCPs were significantly more likely to undergo ERCP. Further research might prove that having a normal MRCP examination could save the patient the risk, discomfort, and cost of ERCP. The NIH consensus statement on the use of ERCP states that MRCP, ERCP, and endoscopic US examinations provide comparable sensitivity for the diagnosis of choledocholithiasis and suggests that ERCP is not necessary if MRCP is negative [14]. Manfredi et al. [16] reported improved MRCP diagnosis of pancreas divisum with secretin administration (14% versus 7%). Furthermore, Shannugam et al. [20] reported that a normal MRCP examination avoids the need for ERCP in patients with clinically suspected calculi with a sensitivity of 98% and specificity of 84%.

The NIH consensus statement on the use of ERCP states that "with newer diagnostic imaging technologies emerging, ERCP is evolving into a predominantly therapeutic procedure." Thus, in some patients with an abnormal MRCP examination, ERCP might be necessary for therapeutic reasons. ERCP with endoscopic sphincterotomy (ES) and calculi removal is therapeutically valuable in patients with choledocholithiasis with jaundice, dilated common bile duct, acute pancreatitis and cholangitis. Other patients in whom ERCP can be useful include those in whom biopsy is necessary for definitive diagnosis, those in whom
stent placement would palliate nonoperative obstruction (such as tumors), and those with sphincter of Oddi dysfunction where sphincterotomy might be beneficial [14]. Additionally, in our study, only 16 patients had ERCP within 2 months of MRCP; 81% of these demonstrated concordant results. A larger series should be obtained to better determine the frequency and significance of discordant results between MRCP and ERCP. Furthermore, every effort should be made to optimize MRCP images. This might include encouraging patients to drink the negative oral contrast agent despite its taste, repeating motion-degraded sequences, and making children as comfortable as possible in the MRI bore.

The role of multidetector row CT (MDCT) in the diagnosis and assessment of pancreatitis in adults and children is well recognized. Thin reconstruction MDCT imaging is the reference standard for assessing complications from pancreatitis and for the detection of calcifications in chronic pancreatitis [21]. However, its role in detecting pancreaticobiliary anatomic variants such as pancreas divisum is less well recognized, and therefore MRCP is the modality of choice in these clinical situations [22].

This study was retrospective and therefore has the potential biases of all retrospective research. We do not know how much the MRCP results influenced the management decisions of the referring clinicians, how many ERCP examinations might have been avoided, nor how the study improved the health of these children.

Additionally, one of the methods of evaluating the added diagnostic information from the administration of secretin is subjective. A 0–3 rating scale was used, but bias could have been introduced by the reviewers. A more objective method to evaluate the effect of secretin included measuring the change in pancreatic duct size at three different locations within the pancreas. The measurements were difficult, however, as the changes in pancreatic duct size were often only fractions of millimeters.

Conclusion

MRCP is technically feasible and safe in children, and the use of both secretin enhancement and a negative oral contrast agent appears to improve both image quality and the diagnostic confidence of the radiologist. MRCP gives additional information, compared to ERCP alone, on a variety of pathologies in the pancreaticobiliary systems and abdomen and it might obviate the need for ERCP in some children.

References

ACR PRACTICE GUIDELINE FOR THE PERFORMANCE OF MAGNETIC RESONANCE IMAGING (MRI) OF THE ABDOMEN
(Excluding the Liver)

PREAMBLE

These guidelines are an educational tool designed to assist practitioners in providing appropriate radiologic care for patients. They are not inflexible rules or requirements of practice and are not intended, nor should they be used, to establish a legal standard of care. For these reasons and those set forth below, the American College of Radiology cautions against the use of these guidelines in litigation in which the clinical decisions of a practitioner are called into question.

The ultimate judgment regarding the propriety of any specific procedure or course of action must be made by the physician or medical physicist in light of all the circumstances presented. Thus, an approach that differs from the guidelines, standing alone, does not necessarily imply that the approach was below the standard of care. To the contrary, a conscientious practitioner may responsibly adopt a course of action different from that set forth in the guidelines when, in the reasonable judgment of the practitioner, such course of action is indicated by the condition of the patient, limitations of available resources, or advances in knowledge or technology subsequent to publication of the guidelines. However, a practitioner who employs an approach substantially different from these guidelines is advised to document in the patient record information sufficient to explain the approach taken.

The practice of medicine involves not only the science, but also the art of dealing with the prevention, diagnosis, alleviation, and treatment of disease. The variety and complexity of human conditions make it impossible to always reach the most appropriate diagnosis or to predict with certainty a particular response to treatment.

Therefore, it should be recognized that adherence to these guidelines will not assure an accurate diagnosis or a successful outcome. All that should be expected is that the practitioner will follow a reasonable course of action based on current knowledge, available resources, and the needs of the patient to deliver effective and safe medical care. The sole purpose of these guidelines is to assist practitioners in achieving this objective.

I. INTRODUCTION

Magnetic resonance imaging (MRI) of the abdomen is a proven and useful tool for the evaluation, assessment of severity, and follow-up of diseases of the abdomen. It should be performed only for a valid medical reason. MRI of the abdomen is an evolving technology involving a variety of pulse sequences and protocols that are continuously being modified and improved. Detailed imaging protocols have been omitted here to avoid promoting obsolete methodology. This document pertains to the MRI assessment of the abdomen excluding the liver. For practice guidelines pertaining to the liver, see the ACR Practice Guideline for the Performance of Magnetic Resonance Imaging (MRI) of the Liver.

The choice of MRI of the abdomen requires an analysis of the strengths of MRI as well as its suitability for the particular patient and particular clinical situation. For suspected lesions requiring a technique to detect subtle soft-tissue contrast (lesion characterization), to provide a three-dimensional depiction of a lesion, and to image other than with ionizing radiation or in a patient with an allergy to iodinated contrast and a need for intravenous contrast enhancement, MRI might be the procedure of
choice provided that the patient does not have a contraindication to MRI (see section IV below).

II. INDICATIONS

Indications for MRI of the abdomen (excluding the liver) include, but are not limited to:

A. Pancreas
   1. Detection of pancreatic tumors.
   2. Characterization of indeterminate lesions and/or unexplained enlargement detected with other imaging modalities.
   3. Evaluation of pancreatic duct obstruction or dilatation.
   4. Detection of pancreatic duct anomalies.
   5. Evaluation of pancreatic or peripancreatic fluid collections or fistulae.
   6. Evaluation of chronic pancreatitis to include estimating pancreatic exocrine function.

B. Spleen
   1. Characterization of indeterminate lesions detected with other imaging modalities.
   2. Detection and characterization of suspected diffuse abnormalities of the spleen.
   3. Evaluation of suspected accessory splenic tissue.

C. Kidneys, Ureters, and Retroperitoneum
   1. Detection of renal tumors.
   2. Characterization of indeterminate lesions detected with other imaging modalities.
   3. Preoperative assessment of renal neoplasms to include evaluation of the renal vein and inferior vena cava.
   4. Evaluation of the urinary tract for abnormalities of anatomy or physiology (MR urography).
   5. Postprocedure surveillance after renal tumor ablation or surgical extirpation via partial or complete nephrectomy.
   7. Evaluation of suspected retroperitoneal fibrosis.

D. Adrenal Glands
   1. Detection of suspected pheochromocytoma and functioning adrenal adenoma.
   2. Characterization of indeterminate lesions detected with other imaging modalities.

E. Vascular (See the ACR–ASNR–SNIS–SPR Practice Guideline for the Performance of Cerebrocerebral Magnetic Resonance Angiography [MRA]).

F. Bile Ducts and Gallbladder
   1. Detection and post treatment follow-up of bile duct and gallbladder cancer.
   2. Detection of bile duct or gallbladder stones.
   3. Evaluation of dilated bile duct.
   4. Preoperative staging of cholangiocarcinoma.
   5. Evaluation of suspected congenital abnormalities of the gallbladder or bile ducts.

G. Gastrointestinal Tract and Peritoneum
   1. Preoperative assessment of gastric neoplasms.
   2. Preoperative staging of rectal carcinoma.
   3. Assessment of inflammatory disorders of the small or large bowel and mesenteries.
   4. Assessment of acute abdominal pain (e.g., appendicitis) in pregnant patients.
   5. Detection and evaluation of primary and metastatic peritoneal or mesenteric neoplasms.

H. Other
   1. Imaging follow-up of abnormalities of the abdomen deemed indeterminate on initial MRI and for which surgery is not advised.
   2. Detection and characterization of extraperitoneal neoplasms other than above.
   3. Evaluation of the abdomen as an alternative to computed tomography (CT) when radiation exposure is an overriding concern in susceptible patients such as pregnant or pediatric patients, or in patients with a contraindication to iodinated contrast agents.

III. QUALIFICATIONS AND RESPONSIBILITIES OF PERSONNEL

See the ACR Practice Guideline for Performing and Interpreting Magnetic Resonance Imaging (MRI).

IV. SAFETY GUIDELINES AND POSSIBLE CONTRAINDICATIONS


Peer-reviewed literature pertaining to MR safety should be reviewed on a regular basis [1,3].

V. SPECIFICATIONS OF THE EXAMINATION

The supervising physician must have complete understanding of the indications, risks, and benefits of the examination, as well as alternative imaging procedures. The physician must be familiar with potential hazards
associated with MRI, including potential adverse reactions to contrast media. The physician should be familiar with relevant ancillary studies that the patient may have undergone. The physician performing MRI interpretation must have a clear understanding and knowledge of the anatomy and pathophysiology relevant to the MRI examination.

The written or electronic request for MRI of the abdomen should provide sufficient information to demonstrate the medical necessity of the examination and allow for its proper performance and interpretation.

Documentation that satisfies medical necessity includes 1) signs and symptoms and/or 2) relevant history (including known diagnoses). Additional information regarding the specific reason for the examination or a provisional diagnosis would be helpful and may at times be needed to allow for the proper performance and interpretation of the examination.

The request for the examination must be originated by a physician or other appropriately licensed health care provider. The accompanying clinical information should be provided by a physician or other appropriately licensed health care provider familiar with the patient’s clinical problem or question and consistent with the state’s scope of practice requirements. (ACR Resolution 35, adopted in 2006)

The supervising physician must also understand the pulse sequences to be used and their effect on the appearance of the images, including the potential generation of image artifacts. Standard imaging protocols may be established and varied on a case-by-case basis when necessary. These protocols should be reviewed and updated periodically.

A. Patient Selection

The physician responsible for the examination should supervise patient selection and preparation, and be available in person or by phone for consultation. Patients must be screened and interviewed prior to the examination to exclude individuals who may be at risk by exposure to the MR environment.

Certain indications require administration of intravenous (IV) contrast media. IV contrast enhancement should be performed using appropriate injection protocols and in accordance with the institution’s policy on IV contrast use. (See the ACR–SPR Practice Guideline for the Use of Intravascular Contrast Media.)

Patients suffering from anxiety or claustrophobia, or who are unable to cooperate or suspend respiration may require sedation or additional assistance. Administration of sedation may be necessary to achieve a successful examination. If sedation is necessary, refer to the ACR–SIR Practice Guideline for Sedation/Analgesia.

B. Facility Requirements

Appropriate emergency equipment and medications must be immediately available to treat adverse reactions associated with administered medications. The equipment and medications should be monitored for inventory and drug expiration dates on a regular basis. The equipment, medications, and other emergency support must also be appropriate for the range of ages and sizes in the patient population.

C. Examination Technique

A phased array surface coil should be used unless precluded by patient body habitus or condition [4]. The field of view should be selected to provide the highest resolution possible that includes the entire region or organ of interest and allows for an adequate signal-to-noise ratio (SNR). Multiple acquisitions with repositioning of the surface coil may be necessary when the region of interest exceeds the potential field of view of the surface coil. For most applications, evaluation of the abdomen should include T1-weighted and T2-weighted images. Acquisitions in multiple imaging planes may be beneficial in defining anatomic relationships. For most applications, slice thickness for acquisitions should not exceed 1 cm with the interslice gap not exceeding 3 mm, although thinner slices and gaps are desirable.

T1-weighted imaging may be performed using a conventional spin echo, echo train spin echo (TSE) or fast spin echo (FSE), or gradient echo sequence. T2-weighted images may be accomplished using one of the fast spin echo sequences (TSE or FSE) or a hybrid gradient and spin echo (GRASE) technique [5]. Fat suppression is frequently beneficial during T2-weighted imaging and may be accomplished using short tau inversion recovery (STIR), chemically selective fat saturation or spectral presaturation inversion recovery (SPIR), or other forms of fat suppression such as water excitation and Dixon-based techniques.

While fast gradient echo T1-weighted images can usually be acquired during breath-holding, conventional and fast spin echo T2-weighted imaging is often complicated by motion. Breath-hold techniques can be used for T2-weighted imaging if the scan time is reduced by (a) long echo trains, (b) half-Fourier imaging, and/or (c) use of parallel imaging techniques. Other strategies include respiratory compensation (respiratory ordered phase encoding), respiratory triggering with respiratory bellows [6], or the use of navigator pulses [7,8] to correct for motion during free breathing. A recent advance in motion correction is the acquisition of k-space data in concentric
rectangular strips [9] rotated about central k-space, which has recently shown promise in reducing motion artifact in the abdomen [10,11].

Three-dimensional (3D) techniques are available for both T1-weighted and T2-weighted imaging. Numerous advantages over 2D sequences include higher inherent SNR, higher in-plane and through-plane resolution, and homogenous fat suppression [12], most of which are better realized in T1-weighted imaging. Isotropic voxel dimensions allow multiplanar reconstructions that may obviate the need for additional acquisition in other planes. Limited early data have shown varying degrees of diagnostic performance but have illustrated the value of T2 3D imaging for the depiction of complex anatomy [13-15].

Intravenous contrast enhancement with gadolinium chelates is beneficial to detect and characterize many intra-abdominal neoplasms, vascular abnormalities, and inflammatory processes. However, the use of gadolinium may be omitted when noncontrast images are sufficiently diagnostic if in the opinion of the supervising physician, the administration of intravenous contrast is unlikely to be of further benefit to the patient. Intravenous contrast may also be omitted when there is (a) no intravenous access, (b) a history of prior allergic-type reaction to gadolinium chelates and the patient has not been premedicated, (c) a relative contraindication to gadolinium chelates (such as pregnancy), (d) severe renal insufficiency estimated glomerular filtration rate (eGFR) <30 mL/min or acute renal insufficiency of any severity in the setting of hepatorenal syndrome or in the perioperative transplantation period [16], or (e) known or suspected diagnosis of nephrogenic systemic fibrosis. Contrast-enhanced images in dynamic fashion (including precontrast, arterial, venous, and equilibrium phase images) are beneficial for evaluating blood vessels and tumors of the solid organs [17-20]. Subtraction images may also be generated, which can be helpful in identifying tumor enhancement [21]. Postcontrast enhanced imaging may be performed with a 2D or 3D technique. 3D imaging allows isotropic or near isotropic resolution and facilitates multiplanar reconstructions [22]. The use of fat suppression during dynamic contrast-enhanced, T1-weighted imaging is encouraged, as it improves the conspicuity of enhancing structures and abnormalities. Fat suppression can be accomplished using chemically selective fat saturation techniques, water excitation, or Dixon technique. STIR should be avoided for gadolinium-enhanced T1-weighted imaging, as enhancement due to gadolinium can be suppressed with this technique.

Delayed postcontrast T1-weighted imaging can be useful in detecting pathology in the urinary tract (excretory MR urography) [23-25]. Intravenous hydration and/or diuretic administration has been shown to improve visualization of the nondilated collecting system [26,27] and ureters [28] during excretory MR urography. Delayed imaging may also be useful in diagnosing cancer of the biliary system [29].

The use of an oral contrast agent for MRI of the abdomen is considered optional but may occasionally be beneficial for gastrointestinal imaging [30]. Negative oral contrast agents may be helpful in selected cases to suppress signal and reduce artifact from bowel contents when imaging other organs or structures such as the peritoneum, pancreatic biliary tree, or urinary system. When using oral contrast media for assessing the small bowel (MR enterography), an agent that produces a dark enteric lumen on T1-weighted images is recommended to allow detection of mural enhancement after intravenous administration of a gadolinium images is recommended to allow detection of mural enhancement after intravenous administration of a gadolinium chelate. Administration of spasmolytic agents, such as glucagon [31] can reduce peristalsis and its resultant motion artifact. This can be particularly helpful for contrast enhanced fast gradient echo T1-weighted imaging of the bowel (MR enterography) [32] or for evaluating the mesentery and peritoneal surfaces [33].

Inclusion of at least one in-phase and out-of-phase gradient echo sequence is useful for detecting intracellular lipid within certain adrenal (e.g., adenoma) and renal (e.g., clear cell carcinoma) tumors and to confirm fatty infiltration of organs such as the pancreas [4,34-40]. Either a single dual echo gradient echo sequence or separate gradient echo sequences that differ in echo times may be performed, although breath-held dual echo sequences are generally preferable.

The addition of a heavily T2-weighted magnetic resonance cholangiopancreatography (MRCP) sequence may be beneficial for evaluating the biliary and pancreatic ducts [41-44]. The use of secretin has been shown to significantly improve visualization of the pancreatic duct during MRCP, which can aid in the diagnosis of anatomic variants [45-47], chronic pancreatitis [48,49], and side-branch intraductal papillary mucinous neoplasms [50], and in quantifying pancreatic exocrine function [51,52]. T2-weighted imaging is usually performed using a rapid acquisition relaxation enhance (RARE) or half-Fourier single-shot echo train spin echo sequence. These sequences can be performed as a thick slab acquisition in multiple projections or as multiple thin (less than 5 mm) slices in at least one imaging plane during breath holding. Three-dimensional respiratory triggered T2-weighted FSE techniques can also be used, potentially offering improved SNR and spatial resolution [53]. Such heavily T2-weighted sequences may also serve to evaluate dilated renal collecting systems (static-fluid MR urography) [24,54]. The addition of an additional sequence, such as dynamic T1-weighted or FSE T2-weighted imaging, can aid in the assessment of periductal tissues, in the
evaluation for causes of extrinsic ductal compression, and in the staging of cholangiocarcinoma [55,56].

In recent years, 3 T imaging systems have become widely available. While experience in the abdomen remains relatively limited, potential advantages include increased SNR [57] and increased conspicuity of enhancement after administration of a gadolinium chelate [58]. Potential disadvantages include decreased image contrast on T1-weighted images, increased susceptibility artifact, increased chemical shift artifact, increased specific absorption rate (SAR), and signal inhomogeneity [59]. The latter can be partially compensated for by the use of radiofrequency cushions [60]. In short, 3 T imaging can offer substantial improvements in SNR and spatial resolution, and/or decreases in imaging times, but sequence modifications are often required to maintain desired image contrast and reduce artifacts.

Parallel imaging (PI) techniques take advantage of spatial sensitivity information from multiple independent receiver coil elements in order to reduce the number of phase encoding steps, therefore reducing scan times [61]. The two strategies currently used include sensitivity encoding (SENSE), which works in the “image” domain, and simultaneous acquisition of spatial harmonics (SMASH), which works in the “k-space” domain. Parallel imaging techniques can not only shorten overall examination duration, but they can also expand the options for breath-hold imaging and result in decreased blurring on echo train sequences such as single shot FSE. The primary penalty for this time savings is modestly reduced SNR [62]. There is a potentially synergistic effect between PI and imaging at 3T: (1) the decreased SNR inherent to PI is partially offset by the increased SNR of 3T, and (2) the SAR issues inherent to 3T can be offset by a reduced number of phase encoding steps [63].

Diffusion weighted imaging (DWI) has recently been investigated for abdominal application [64]. Most research to date has centered on oncologic applications, either for staging disease or monitoring response to therapy [65-71]. The most common technique uses single shot echo planar imaging (SS-EPI). Breath-held, free breathing multiple-averaging, and respiratory gated SS-EPI techniques have been described [72,73]. PI can be used to decrease imaging time, and has been shown to result in accurate Apparent diffusion coefficient (ADC) values [74]. DWI has shown promising results in early research and at least appears to be a value-added adjunct sequence capable of revealing additional sites of disease in the abdomen [69]. ADC maps can be generated to help differentiate between restricted diffusion and T2 shine-through. At least two b-values are obtained, including b = 0 s/mm² and b = 500 to 1,000 s/mm².

VI. DOCUMENTATION

Reporting should be in accordance with the ACR Practice Guideline for Communication of Diagnostic Imaging Findings.

VII. EQUIPMENT SPECIFICATIONS

The MRI equipment specifications and performance must meet all state and federal requirements. The requirements include, but are not limited to, specifications of maximum static magnetic strength, maximum rate of change of magnetic field strength (dB/dt), maximum radiofrequency power deposition (specific absorption rate), and maximum acoustic noise levels.

VIII. QUALITY CONTROL AND IMPROVEMENT, SAFETY, INFECTION CONTROL, AND PATIENT EDUCATION

Policies and procedures related to quality, patient education, infection control, and safety should be developed and implemented in accordance with the ACR Policy on Quality Control and Improvement, Safety, Infection Control, and Patient Education appearing under the heading Position Statement on QC & Improvement, Safety, Infection Control, and Patient Education on the ACR web page (http://www.acr.org/guidelines).

Specific policies and procedures related to safety should be in place with documentation that is updated annually and compiled under the supervision and direction of the supervising MRI physician. Guidelines should be provided that deal with potential hazards associated with MRI examinations to the patient as well as to others in the immediate area [1,3-7]. Screening forms must also be provided to detect those patients who may be at risk for adverse events associated with the MRI examination [1,3,6,7].

Equipment performance monitoring should be in accordance with the ACR Technical Standard for Diagnostic Medical Physics Performance Monitoring of Magnetic Resonance Imaging (MRI) Equipment.

ACKNOWLEDGEMENTS

This guideline was revised according to the process described under the heading The Process for Developing ACR Practice Guidelines and Technical Standards on the ACR web page (http://www.acr.org/guidelines) by the Committee on Abdominal Imaging of the Commission on Body Imaging.

Principal Reviewers: John R. Leyendecker, MD David D. Childs, MD
REFERENCES


