Clinical application of Mn-DPDP-enhanced 3D-T1W MR cholangiography: Additional information to the conventional T2W MR cholangiography

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Clinical application of Mn-DPDP-enhanced 3D-T1W MR cholangiography: Additional information to the conventional T2W MR cholangiography

The Doctoral Dissertation submitted to the Department of Medicine, the Graduate School of Yonsei University in partial fulfillment of the requirements for the degree of Doctor of Medicine

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December 2004
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Mi-Suk Park
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</tr>
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<table>
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<tr>
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<table>
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Abstract

Clinical application of Mn-DPDP-enhanced 3D-T1W MR cholangiography: Additional information to the conventional T2W MR cholangiography

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(Directed by Professor Ki Whang Kim)

Purpose: To determine prospectively the additional information and clinical application of manganese-enhanced 3D-T1W MR cholangiography combined with conventional T2W MR cholangiography in the various biliary diseases

Materials and Methods: Conventional heavily T2W MR cholangiography with manganese-enhanced T1W and T2W MR cholangiography were performed in 64 patients with high
clinical suspicion of acute cholecystitis (n=30), biliary complications after laparoscopic cholecystectomy (n=10), and intrahepatic choledocholithiasis (n=14), and normal population (n=10). The image analysis in the patients with acute cholecystitis were focused on the presence of outflow obstruction of gallbladder, those of biliary complications were the presence and degree of the bile duct injury, bile leakage, and retained stones, and those of intrahepatic choledocholithiasis were the function of the diseased intrahepatic segmental ducts.

RESULTS: The sensitivity, specificity, and accuracy for the outflow obstruction of gallbladder in the patients with acute cholecystitis on pre-contrast T2W MR cholangiography were 82%, 88%, and 83%, respectively. On the other hand, all of them on manganese-enhanced MR cholangiography were 100%. The diagnoses on MR cholangiography in the patients with biliary complications were as follows: a) complete transection and occlusion of the common bile duct (CBD) with bile leakage (n=4); b) partial strictures of the CBD with bile leakage...
(n=2); c) cystic duct leakage (n=2); d) partial ligation of aberrant right hepatic duct (n=1), and hemorrhage without biliary complication (n=1). MR cholangiography accurately yielded the same findings as the final diagnoses on surgery or ERCP, except one case with partial stricture of the bile duct with bile leakage (over-diagnosed as complete occlusion on MR cholangiography). Of 22 diseased segmental ducts in the patients with intrahepatic choledocholithiasis on conventional T2W MR cholangiography, eight segmental ducts were filled with contrast at manganese-enhanced T1W MR cholangiography, indicating that they were functioning bile ducts. The remaining 14 segmental ducts were not filled with contrast at manganese-enhanced T1W MR cholangiography, hence they were non-functioning bile ducts.

CONCLUSION: T2W MR cholangiography combined with manganese-enhanced T1W MR cholangiography provided not only the anatomic detail, but also the functional detail. Therefore, manganese-enhanced MR cholangiography is a useful supplement to conventional heavily T2W MR cholangiography in the evaluation...
of acute cholecystitis, biliary complications after laparoscopic cholecystectomy, and intrahepatic choledocholithiasis

**Key words:** bile ducts, calculi, cholangiography, magnetic resonance, contrast
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I. INTRODUCTION

Since its introduction in 1991, technical advances in heavily T2W MR cholangiopancreatography have made it possible to generate high-quality images of the bile ducts \(^{1-3}\). With a breath-hold half-Fourier rapid acquisition with relaxation enhancement (RARE) sequence and a phased-array body coil, we obtained high-quality images that show both the dilated and non-dilated biliary system without motion artifact \(^{1-3}\). Sequential acquisition of multiple 3-mm-thick sections improved spatial resolution and allowed calculi as small as 2-
3 mm to be depicted. For the accuracy in the diagnosis of various biliary diseases, heavily T2W MR cholangiopancreatography has proven to be comparable or superior to that of direct cholangiography. Moreover MR cholangiography has no complications or contraindications, is able to depict the entire biliary tree including both the proximal and distal part of the obstruction, and shows coexistent parenchymal lesions. MR cholangiography is now replacing purely diagnostic direct cholangiography in the various biliary diseases. However, heavily T2W MR cholangiopancreatography without contrast material is not able to reflect the dynamics of biliary system.

Mangafodipir trisodium (Mn-DPDP, manganese) is a paramagnetic contrast agent originally designed for liver imaging. This contrast agent consists of manganese bound to \( N, N' \)-dipryidoxyethylene-diamine-\( N, N' \)-diacetate 5, 5'-bis (phosphate), or DPDP, is taken up by functioning hepatocytes, and is primarily excreted in bile into the feces. Because manganese is a paramagnetic metal ion, it primarily acts on T1 resulting in T1 shortening, although it also acts on T2
resulting in T2 shortening. Enhanced liver and functioning bile ducts therefore have higher signal intensity on T1-weighted images and lower signal intensity on T2-weighted images. The signal intensity of the bile ducts that are obstructed or otherwise not functioning due to stasis, however, may not be affected because biliary stasis in the setting of strictures or stones reduces the excretion of biliary manganese. Theoretically, this characteristic property of Mn-DPDP-enhanced MR cholangiography could allow noninvasive imaging in the evaluation of biliary dynamics.

There have been a few reports about manganese-enhanced T1W MR cholangiography in the evaluation of intrahepatic biliary anatomy and in the detection of bile duct leaks. To our knowledge, however, there are no studies in which conventional heavily T2W MR cholangiography and manganese-enhanced T1W and T2W MR cholangiography have been compared. To define the usefulness of manganese-enhanced T1W MR cholangiography in the evaluation of biliary ductal system, we performed manganese-enhanced T1W and T2W MR cholangiography in addition to conventional heavily T2W MR cholangiography. We then sought to
determine the influence of this technique on clinical management decisions in a variety of disease process.
II. MATERIALS AND METHODS

1. Study Population

Between September 2001 and August 2004, manganese-enhanced T1W and T2W MR cholangiography in addition to conventional heavily T2W MR cholangiography were performed in 64 patients at two institutions. This prospective study population consists of the patients with acute cholecystitis, biliary complications after laparoscopic cholecystectomy, and intrahepatic choledocholithiasis. The patients with jaundice were excluded from our study.

Ten control patients who had no symptoms referable to the biliary tract were examined to establish the secretion time of the manganese into the extrahepatic bile duct, gallbladder, and duodenum.

Thirty patients with a high index of suspicion of acute cholecystitis clinically (sudden onset of right upper quadrant tenderness, low-grade fever, and leukocytosis without jaundice) and at ultrasonography (visualization of impacted stones in the gallbladder neck or cystic duct or positive US Murphy sign with gallbladder wall thickening or distention)
were examined by MR cholangiography and hepatobiliary scintigraphy.

Ten patients with high clinical suspicion of biliary complications (abdominal pain, nausea, or vomiting accompanied by leukocytosis, or low-grade fever) after laparoscopic cholecystectomy were examined. All of the patients underwent sonography or CT scans before MR cholangiography and ERCP.

Fourteen patients with a high index of suspicion of intrahepatic choledocholithiasis clinically (recurrent attacks of abdominal pain and fever without jaundice) and at US (segmental intrahepatic duct dilatation with or without stones) were examined by MR cholangiography.

2. Imaging Technique

Patients were asked to fast for a minimum of six hours.

MR cholangiography was performed with a 1.5-T superconducting unit (Magnetom Vision; Siemens Medical Systems, Erlangen, Germany) and a phased-array torso coil. Two MR cholangiographic techniques were applied: single-shot RARE and multislice half-Fourier RARE sequence (HASTE; Siemens). The
slab of a single-shot RARE sequence was obtained at various angles to allow optimal visualization of the bile ducts. The multislice half-Fourier RARE images were obtained at an angle of 20°-35° to the coronal plane to simulate a right anterior oblique projection on direct cholangiography. The imaging parameters for a single-shot RARE sequence were TR/effective TE, infinite/1200; echo-train length, 240; flip angle, 150°; slab thickness, 50-70 mm; field of view, 300-350 mm; matrix, 240 x 256; and an acquisition time, 2.32 sec. The imaging parameters for multislice half-Fourier RARE sequence were TR/effective TE, infinite/95; echo-train length, 128; flip angle, 150°; slab thickness, 3-5 mm with no gap; number of slice, 13-15 (range of coverage, 52-60 mm); field of view, 300-350 mm; matrix, 240 x 256; and an acquisition time, 18 sec. Postprocessing of the multislice half-Fourier RARE images was performed.

After the patients were removed from the magnet, an IV injection of mangafodipir trisodium (Mn DPDP; Teslascan, Nycomed Amersham, Oslo, Norway) at a standard dose of 5 μmole/kg (0.1 mL/kg; maximum dose, 15 mL) was administered
via a slow injection over 2-3 ml/min followed by a 10 ml saline flush. Contrast-related adverse events, only flushing, occurred in one patient. Twenty-five to forty-five min after injection, we obtained 3D T1-weighted fat-saturated volumetric interpolated breath-hold images (TR/TE, 4.2/1.6; flip angle, 12°; matrix 205x256; field of view, 300-350 mm; and 24 partitions interpolated to 48 slices with a thickness of 1.3 mm). Routine heavily T2-weighted MR cholangiography using the same half-Fourier RARE sequence was repeatedly performed. Because mangafodipir trisodium is a negative contrast agent on T2-weighted images, we obtained post-contrast heavily T2-weighted MR cholangiography to compare pre-contrast T2-weighted MR cholangiography images. All MR cholangiograms were reviewed at the console by an abdominal radiologist before the patient was removed from the magnet, as a standard protocol.

Additional examinations were obtained with a delay of 1 and 4 hours if the radiologist deemed it necessary.

3. Image Analysis

The MR cholangiograms were interpreted prospectively by the
consensus of two abdominal radiologists, who were blinded to the patients’ clinical information and the other image findings. The source images as well as the three-dimensional reconstruction images of conventional heavily T2-weighted MR cholangiography and manganese-enhanced T1-, and T2-weighted MR cholangiography were reviewed on a Picture Archiving Communicating System (PACS) workstation monitor.

Image analysis in the patients with suspicion of acute cholecystitis focused on the presence and location of calculi in the gallbladder, and the associated findings, such as gallbladder wall thickening, fluid collection around the gallbladder, or common bile duct calculi on conventional heavily T2W MR cholangiography. Outflow obstruction of the gallbladder on conventional heavily T2W MR cholangiography was definitively defined when a signal void was identified within the cystic duct or gallbladder neck on images obtained in at least two different projections. On manganese-enhanced T1W MR cholangiography, the presence and time of visualization of the gallbladder and bile duct were evaluated. Outflow obstruction of the gallbladder was defined as no-contrast filling in
gallbladder until one hour. Outflow obstruction of the
gallbladder on conventional heavily T2W and manganese-enhanced
T1W MR cholangiography was compared with the hepatobiliary
scans.

Image analysis in the patients with suspicion of biliary
complications after laparoscopic cholecystectomy focused on
the presence and location of bile duct leaks, complete bile
duct transection or occlusion, partial stricture of bile duct,
or retained bile duct stones. Bile duct leakage was defined as
contrast agent extravasation adjacent to a bile duct or
contrast agent opacification of a peritoneal drain on
manganese-enhanced T1W MR cholangiography with abnormal
peritoneal fluid collection on conventional heavily T2W MR
cholangiography and signal loss of abnormal peritoneal fluid
collection on manganese-enhanced T2W MR cholangiography. A
complete transection or occlusion of the bile duct was defined
as an absence of opacification of the extrahepatic bile duct
on manganese-enhanced T1W MR cholangiography and persistence
of signal of that on manganese-enhanced T2W MR cholangiography
with disconnection of extrahepatic bile duct on conventional
heavily T2W MR cholangiography. Stricture of the bile duct was defined as the opacification of the extrahepatic bile duct on manganese-enhanced MR cholangiography and signal loss of that on manganese-enhanced T2W MR cholangiography, despite the presence of a narrowing or disconnected segment of the bile duct on conventional heavily T2W MR cholangiography. The diagnosis of complications were classified as described in previous publications:  

8,9: a) complete transections and occlusions of the bile duct with or without bile leakage; b) partial strictures of the bile duct with or without bile leakage; c) cystic duct leakage and accessory bile duct leakage; d) occlusion of part of the intrahepatic duct; e) residual stones. The same investigators reviewed the ERCP images using the same method as for the MR cholangiographic images. The diagnoses on the MR cholangiography were compared with the final diagnoses on surgery or ERCP.

Image analysis in the patients with suspicion of intrahepatic choledocholithiasis focused to identify intrahepatic ductal dilatation and stricture, intrahepatic duct calculi and common duct calculi on conventional heavily
T2W MR cholangiograms and to verify bile duct enhancement on manganese-enhanced T1W MR cholangiograms. The final diagnosis of diseased bile ducts was divided into two categories - functioning or non-functioning bile duct - depending on the combined findings of conventional heavily T2W and manganese-enhanced T1W MR cholangiograms. Functioning bile ducts were the bile ducts that were filled with contrast agent at manganese-enhanced T1W MR cholangiography despite the presence of intrahepatic ductal dilatation with stricture or calculi at conventional T2W MR cholangiography. Non-functioning bile ducts were the diseased segmental ducts on T2W MR cholangiography in which contrast agent filling did not occur at manganese-enhanced T1W MR cholangiography. The distribution of the intrahepatic abnormalities was interpreted based on the classification of the internal lobation and segmentation of the liver (four segments: left lateral, left medial, right anterior, and right posterior). Intrahepatic ductal dilatation was diagnosed when the diameter of a duct was greater than 3mm, and stricture was diagnosed when focal caliber change was present at any segment. Calculi were considered present on MR
cholangiographic images when a signal void was identified within the bile duct in at least two different projections.

4. Statistical Analysis

In the cases of acute cholecystitis, sensitivity, specificity, accuracy, positive predictive value (PPV), and negative predictive value (NPV) were calculated as follows:

- sensitivity = true positive / (true positive + false negative);
- specificity = true negative / (true negative + false positive);
- accuracy = (true positive + true negative) / (true positive + true negative + false positive + false negative);
- positive predictive value (PPV) = true positive / (true positive + false positive);
- negative predictive value (NPV) = true negative / (true negative + false negative).

The differences between conventional T2W MR cholangiography and manganese-enhanced MR cholangiography were tested for statistical significance by using the McNemar’s test.

A five-point scale was used to assign a confidence level in the evaluation of the cystic duct obstruction: 1, definitely patent; 2, probably patent; 3, indeterminate; 4, probably
obstruct; 5, definitely obstruct. Receiver operating characteristic (ROC) curve analysis was performed to compare the results of readings of conventional T2W MR cholangiography versus the results of readings of manganese-enhanced MR cholangiography. Nonparametric receiver operating characteristic (ROC) curves were fitted by using a computer software package (Analyse-it, version 1.63; Analyse-it-Software, Leeds, England). The diagnostic capability was determined by calculating the area under the ROC curve ($A_z$) for each reader. For all tests, $P < .05$ was considered to indicate a statistically significant difference.
III. RESULTS

1. Control group

The secretion time of the manganese into the extrahepatic bile duct, gallbladder, and duodenum in ten control patients was summarized in Table 1.

Table 1. Secretion time of manganese in control group

<table>
<thead>
<tr>
<th>Extrahepatic duct</th>
<th>Gallbladder</th>
<th>Bowel</th>
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</thead>
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<tr>
<td>10 min</td>
<td>8</td>
<td>3</td>
</tr>
<tr>
<td>20 min</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>30 min</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>60 min</td>
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<td>1</td>
</tr>
<tr>
<td>Total</td>
<td>10</td>
<td>10</td>
</tr>
</tbody>
</table>

2. Acute cholecystitis

Among the 30 patients with suspicion of acute cholecystitis, outflow obstruction of gallbladder on hepatobiliary scintigraphy was seen in 21 patients. The sensitivity, specificity, accuracy, PPV, and NPV for the outflow obstruction of gallbladder on pre-contrast T2-weighted MR cholangiography were 82%, 88%, 83%, 95%, and 64%,
respectively. On the other hand, all of them on manganese-enhanced MR cholangiography were 100% (Table 2). Statistically, however, there is no significant difference between pre-contrast T2-weighted MR cholangiography and manganese-enhanced MR cholangiography (\(P = 0.375\)).

ROC curve (Fig 1) shows that the \(A_z\) for pre-contrast T2-weighted MR cholangiography is 0.943 and that for manganese-enhanced MR cholangiography is 1.0. There is no statistically significant difference between them (\(P = 0.057\)).

In 18 of 30 cases, conventional heavily T2-weighted MR cholangiography demonstrated cystic duct or gallbladder neck calculi clearly, and the morphologic evidence of outflow obstruction was definitive. Manganese-enhanced T1W MR cholangiography depicted an enhanced common bile duct and hepatic duct, but not the gallbladder, suggesting a flow obstruction of the gallbladder. DISIDA scan failed to visualize the gallbladder for up to four hours after IDA injection for all of the 18 patients (Fig 2).

In eleven of 30 cases, heavily T2W MR cholangiography demonstrated only floating calculi in the gallbladder lumen
without cystic duct or gallbladder neck calculus and there was no evidence of outflow obstruction of the gallbladder. After the administration of manganese, T1W MR cholangiography depicted contrast enhancement of the gallbladder in seven cases suggesting a patent cystic duct. In these cases, DISIDA scan showed the gallbladder within 45 minutes after IDA injection. In four cases, however, the gallbladder was not visualized up to four hours on manganese enhanced T1W MR cholangiography and DISIDA scan failed to visualize the gallbladder for up to four hours after IDA injection. In those cases the findings on heavily T2W MR cholangiography was mismatched with that on manganese enhanced T1W MR cholangiography and DISIDA scan (Fig 3).
Table 2. Out-flow obstruction of gallbladder in clinically suspected acute cholecystitis patients

<table>
<thead>
<tr>
<th></th>
<th>Conventional T2W MRC</th>
<th>Mn-enhanced T1W MRC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensitivity</td>
<td>82%</td>
<td>100%</td>
</tr>
<tr>
<td>Specificity</td>
<td>88%</td>
<td>100%</td>
</tr>
<tr>
<td>Accuracy</td>
<td>83%</td>
<td>100%</td>
</tr>
<tr>
<td>PPV</td>
<td>95%</td>
<td>100%</td>
</tr>
<tr>
<td>NPV</td>
<td>64%</td>
<td>100%</td>
</tr>
</tbody>
</table>
**Figure 1.** Receiver operating characteristic curves illustrate the increase in diagnostic confidence after manganese-enhanced T1W MR cholangiography. Graphs are plotted to discriminate between obstruct and patent cystic duct on conventional heavily T2W MR cholangiography (continuous line) and on manganese-enhanced T1W MR cholangiography (dotted line). The curves are shown against a diagonal (right) line, which represents a review method with which obstruct and patent ducts cannot be differentiated.
Figure 2. A 48-year-old man with acute cholecystitis.

(a) Conventional heavily T2W MR cholangiography (thin-slab half-Fourier RARE sequence) shows three cystic duct stones (arrows), suggesting outflow obstruction of gallbladder.

(b) Manganese-enhanced 3D volumetric interpolated T1W MR cholangiography (maximum intensity projection image) shows enhanced extrahepatic duct and small bowel with nonvisualization of gallbladder, suggesting outflow obstruction of gallbladder.
(c) Manganese-enhanced T2W MR cholangiography (thin-slab half-Fourier RARE sequence) shows three cystic duct stones (arrows). The bile duct is not visualized due to T2 shortening effect of excreted manganese.

(d) Hepatobiliary scintigraphic image shows visualization of extrahepatic duct and small bowel, but fail to depict gallbladder.
Figure 3. A 49-year-old woman with suspicious acute cholecystitis.

(a and b) Serial images of conventional heavily T2W MR cholangiography (thin-slab half-Fourier RARE sequence) show suspicious signal void lesions (arrow in b) in the cystic duct. However, they cannot be differentiated from a tortuous normal cystic duct.
(c) Manganese-enhanced 3D volumetric interpolated T1W MR cholangiography (maximum intensity projection image) shows enhanced extrahepatic duct and small bowel with nonvisualization of gallbladder, suggesting outflow obstruction of gallbladder.

(d) Hepatobiliary scintigraphic image shows visualization of extrahepatic duct (arrow) and small bowel, but fail to depict gallbladder, compatible with acute cholecystitis.
3. Biliary complications after laparoscopic cholecystectomy

The clinical and radiological results were summarized in Table 3.

The diagnoses on MR cholangiography were as follows: a) complete transection and occlusion of the common bile duct (CBD) with bile leakage (n=4) (Fig 4); b) partial strictures of the CBD with bile leakage (n=2) (Fig 5); c) cystic duct leakage (n=2); d) partial ligation of aberrant right hepatic duct (n=1) (Fig 6), and hemorrhage without biliary complication (n=1).

The final diagnoses on surgery and ERCP were as follows: a) complete transection and occlusion of the CBD with bile leakage (n=3); b) partial strictures of the CBD with bile leakage (n=3); c) cystic duct leakage (n=2); d) partial ligation of aberrant right hepatic duct (n=1), and hemorrhage without biliary complication (n=1).

MR cholangiography accurately yielded the same findings as the final diagnoses, except one case with partial stricture of the bile duct with bile leakage (over-diagnosed as complete occlusion on MR cholangiography).
MR cholangiography was diagnostic in the cases with complete transection and occlusion of the bile duct with bile leakage. T2-weighted conventional MR cholangiography showed not only the distal, but also the proximal part of the disconnected site of the bile duct with abnormal peritoneal fluid collection. Manganese-enhanced T1-weighted MR cholangiography was able to demonstrate the presence and the exact site of bile leakage by showing contrast agent extravasation adjacent to the bile duct. Moreover, it was able to prove complete disconnection of the bile duct by showing the absence of opacification of the CBD. These patients underwent operations, which confirmed the MR cholangiographic findings.

In the patient with partial strictures of the CBD with bile leakage, T2W conventional MR cholangiography showed abnormal fluid collection with narrowing of the extrahepatic bile duct. Manganese-enhanced T1W MR cholangiography showed contrast agent extravasation adjacent to clipping site with opacification of the extrahepatic bile duct, suggesting partial stricture. The patient underwent ERCP with internal
stent, which confirmed the MR cholangiographic finding.

One patient with partial strictures of the CBD with bile leakage was over-diagnosed on MR cholangiography. T2W conventional MR cholangiography showed abnormal fluid collection with narrowing of the extrahepatic bile duct. Manganese enhanced T1W MR cholangiography showed contrast agent opacification of the peritoneal drain without opacification of the CBD. This case was interpreted as complete obstruction of the bile duct with bile leakage on MR cholangiography. The patient underwent ERCP with internal stent, showing the communication of the extrahepatic bile duct with bile leakage, suggesting partial stricture of the CBD.

In the patients with cystic duct leakage, T2W conventional MR cholangiography showed abnormal fluid collection without narrowing of the extrahepatic bile duct. Manganese-enhanced T1W MR cholangiography showed contrast agent extravasation adjacent to the clipping site with normal opacification of the extrahepatic bile duct. The patients underwent ERCP with internal stent, which confirmed the MR cholangiographic finding.
In a patient with aberrant right hepatic duct ligation, T2W conventional MR cholangiography showed a dilated right posterior duct without abnormal fluid collection. Manganese–enhanced T1W MR cholangiography showed opacification of the right posterior duct without connection to the remaining hepatic duct. We interpreted the findings on MR cholangiography as partial ligation of the aberrant right posterior duct. ERCP did not show the right posterior duct. After two months, the patient underwent hepatobiliary scintigraphy, showing a photon defect area of the right posterior segment, which confirmed the MR cholangiographic finding.
<table>
<thead>
<tr>
<th>No./Age</th>
<th>Findings at T2-MRI</th>
<th>Findings at 5th-T1-MRI</th>
<th>Diagnosis on pre- &amp; post MRI</th>
<th>Findings at ERCP</th>
<th>Final Diagnosis</th>
<th>Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>106/1/9</td>
<td>Disconnected CBD</td>
<td>No speciation of CBD</td>
<td>Complete transection of CBD</td>
<td>Obstruction of CBD</td>
<td>Complete transection of CBD</td>
<td>Operation</td>
</tr>
<tr>
<td>273/1/9</td>
<td>Fluid collection</td>
<td>Disconnected CBD</td>
<td>Complete transection of CBD</td>
<td>Structure CBD</td>
<td>Partial structure of CBD due to bile leakage</td>
<td>Internal stent</td>
</tr>
<tr>
<td>2/4/1/9</td>
<td>Disconnected CBD</td>
<td>No speciation of CBD</td>
<td>Complete transection of CBD</td>
<td>Obstruction of CBD</td>
<td>Complete transection of CBD</td>
<td>Operation</td>
</tr>
<tr>
<td>401/1/9</td>
<td>Fluid collection</td>
<td>Normal bile duct</td>
<td>Hemorrhage without biliary complication</td>
<td>Normal bile duct</td>
<td>Hemorrhage without biliary complication</td>
<td>Observation</td>
</tr>
<tr>
<td>332/1/10</td>
<td>Narrowing of CBD</td>
<td>No speciation of CBD</td>
<td>Partial structure of CBD</td>
<td>Structure of CBD</td>
<td>Partial structure of CBD</td>
<td>Internal stent</td>
</tr>
<tr>
<td>660/1/7</td>
<td>Fluid collection</td>
<td>Normal bile duct</td>
<td>Bile leak at cystic duct stump</td>
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<td>Bile leak at cystic duct stump</td>
<td>Internal stent</td>
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<tr>
<td>793/1/21</td>
<td>Fluid collection</td>
<td>Normal bile duct</td>
<td>Bile leak at stump</td>
<td>Bile leak at stump</td>
<td>Bile leak at stump</td>
<td>Observation</td>
</tr>
<tr>
<td>846/1/9</td>
<td>No fluid collection</td>
<td>No speciation of CBD</td>
<td>Complete transection of CBD</td>
<td>Obstruction of CBD</td>
<td>Complete transection of CBD</td>
<td>Operation</td>
</tr>
<tr>
<td>930/1/9</td>
<td>Narrowing of CBD</td>
<td>No speciation of CBD</td>
<td>Partial structure of CBD</td>
<td>Structure of CBD</td>
<td>Partial structure of CBD</td>
<td>Internal stent</td>
</tr>
<tr>
<td>1063/1/0</td>
<td>Normal bile duct</td>
<td>No speciation of CBD</td>
<td>Bile leak at cystic duct stump</td>
<td>Normal bile duct</td>
<td>Bile leak at cystic duct stump</td>
<td>Internal stent</td>
</tr>
</tbody>
</table>
**Figure 4.** A 56-year-old man with complete transection of CBD with bile leakage.

(a) Conventional heavily T2W MR cholangiography (thin-slab half-Fourier RARE sequence) shows disconnected CBD (arrows), with abnormal fluid collection (short arrow).

(b) Manganese-enhanced 3D volumetric interpolated T1W MR cholangiography shows extravasation of contrast material (short arrow) from EHD (arrow). Distal CBD is not visualized.
(c) Manganese-enhanced T2W MR cholangiography (thin-slab half-Fourier RARE sequence) shows only disconnected distal CBD (arrow).

(d) ERCP image shows CBD (arrow) with complete obstruction. The proximal portion of the obstruction site is not opacified.
**Figure 4.** A 35-year-old man with partial stricture of CBD with bile leakage.

(a) Conventional heavily T2W MR cholangiography (thin-slab half-Fourier RARE sequence) shows disconnected CBD (arrows), with abnormal fluid collection (short arrow).

(b) Manganese-enhanced 3D volumetric interpolated T1W MR cholangiography shows enhanced EHD, in spite of the presence of narrowing segment (arrow), with extravasation of contrast material (short arrow) from EHD.
ERCP image shows partial stricture of CBD (arrow) with bile leakage (short arrow).
Figure 6. A 57-year-old man with ligation of aberrant right posterior duct.

(a) Conventional heavily T2W MR cholangiography (thick-slab half-Fourier RARE sequence) shows mild diluted and disconnected right posterior duct (arrow).

(b) Manganese-enhanced 3D volumetric interpolated T1W MR cholangiography shows opacification of right posterior duct (arrow).
(c) ERCP image did not show right posterior duct.

(d) Hepatobiliary scintigraphy, two months after (a)(b)(c), shows a photon defect area (arrows) in the right lobe of liver.
4. Intreheptic choledocholithiasis

The findings of intrahepatic choledocholithiasis on MR cholangiography are summarized in Table 4.

According to the findings on conventional T2W MR cholangiography, 14 patients had 22 diseased segments. Intrahepatic bile ductal dilatation with calculi with or without stricture was present in eight segments. Among them, three segmental ducts were filled with contrast at manganese-enhanced T1W MR cholangiography. Intrahepatic bile ductal dilatation with stricture without calculi was present in seven segments. Among them, four segmental ducts were filled with contrast at manganese-enhanced T1W MR cholangiography. Impacted calculi without bile juice were present in six segmental ducts. None of them was filled with contrast at manganese-enhanced T1W MR cholangiography. Only one segmental duct was dilated without calculi or stricture. That was filled with contrast at manganese-enhanced T1W MR cholangiography.

Of 22 diseased segmental ducts on conventional T2W MR cholangiography, 14 segmental ducts were not filled with
contrast at manganese-enhanced T1W MR cholangiography, indicating that they were non-functioning bile ducts (Fig 7). The remaining eight segmental ducts were filled with contrast at manganese-enhanced T1W MR cholangiography, hence they were functioning bile ducts (Fig 8).

Table 4. Findings of intrahepatic choledocholithiasis at MR cholangiography.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Conventional T2W MRC</th>
<th>Contrast filling at T1W MRC</th>
<th>Total</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>No (5)</td>
<td>Yes (3)</td>
<td>8</td>
</tr>
<tr>
<td>Dil c stone c/s stricture</td>
<td>5</td>
<td>3</td>
<td>8</td>
</tr>
<tr>
<td>Dil c stricture s stone</td>
<td>3</td>
<td>4</td>
<td>7</td>
</tr>
<tr>
<td>Dilatation</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Impacted stones</td>
<td>6</td>
<td>0</td>
<td>6</td>
</tr>
</tbody>
</table>
Figure 7. A 47-year-old man with intrahepatic choledocholithiasis.

(a) Conventional heavily T2W MR cholangiography (thin-slab half-Fourier RARE sequence) shows markedly dilated left duct with stone (long arrows) and impacted multiple stones in right posterior duct (short arrows).

(b) Manganese-enhanced 3D volumetric interpolated T1W MR cholangiography shows the enhanced right anterior duct and common bile duct. Contrast was not filled in left (long arrows) and right posterior duct (short arrows).
Manganese-enhanced T2W MR cholangiography (thin-slab half-Fourier RARE sequence) still demonstrates markedly dilated left duct with stone (long arrow) and impacted multiple stones in right posterior duct (short arrows), suggesting no contrast filling. The right anterior duct and common bile duct was not visualized.
Figure 8. A 47-year-old man with intrahepatic choledocholithiasis

(a) and (b) Serial conventional heavily T2W MR cholangiography (thin-slab half-Fourier RARE sequence) shows dilatation with stone of left and right anterior duct (long arrows) and dilatation with stricture of right posterior duct without stone (short arrow)
(c) and (d) Serial manganese-enhanced 3D volumetric interpolated T1W MR cholangiography shows that contrast filling in all of the three ducts in spite of stones and stricture, suggesting functioning bile duct.
IV. DISCUSSION

Mangafodipir trisodium is a paramagnetic contrast agent originally designed for liver imaging. This contrast agent consisting of manganese bound to DPDP is taken up by functioning hepatocytes, and is primarily excreted via bile into the feces \(^4\text{-}^7\). Therefore contrast-enhanced MR cholangiography with mangafodipir trisodium provides information about biliary dynamics similar to that obtained on hepatobiliary scintigraphy or direct cholangiography \(^4\text{-}^7\).

Because manganese is a paramagnetic metal ion, it acts primarily on T1, resulting in T1 shortening, although it also acts on T2, resulting in T2 shortening \(^4\text{-}^7\). Enhanced liver and functioning bile ducts, therefore, have higher signal intensity on T1-weighted images and lower signal intensity on T2W images \(^4\text{-}^7\). Therefore mangafodipir trisodium is primarily used as a positive contrast agent of T1W MR cholangiography. Additionally it acts as a negative contrast agent on conventional heavily T2W MR cholangiography. On T2W MR cholangiography after manganese administration, signal
intensity is lost in the functioning bile duct, but persists in the non-functioning bile duct. This characteristic property of combined T1W and T2W MR cholangiography before and after administration of mangafodipir trisodium could be used as an excellent imaging tool in the evaluation of biliary dynamics 4-7.

We used 3D fat-saturated volumetric interpolated breath-hold examination (VIBE) as a T1W MR cholangiographic sequence. It is well known that properly structured 3D gradient echo sequence provides higher signal to noise ratio, thinner sections, no gaps, and comparable image contrast than 2D gradient echo sequence 10. Moreover, VIBE sequence provides isotropic or nearly isotropic spatial resolution, which allows multiplanar reconstruction images to be generated in any desired plane 10. Lee et al. 7 reported that manganese-enhanced T1W MR cholangiography using 3D VIBE sequence provided the definition of intrahepatic bile duct anatomy in non-obstructed biliary systems with excellent image quality. In our study, the slice thickness of manganese-enhanced 3D T1W MR cholangiography was 1.3 mm with no gap and there was hardly
any partial volume artifact on maximum intensity projection images. Therefore, the image quality of coronal 3D T1W MR cholangiography was excellent in evaluating the various biliary diseases.

Acute cholecystitis is an acute inflammation of the gallbladder, consisting of leukocytic infiltration, edema, vascular congestion, frank abscess formation, or gangrenous necrosis \(^\text{11}\). Most of these cases result from chemical irritation and inflammation of the obstructed gallbladder due to cystic duct obstruction by impacted calculi \(^\text{11,12}\). In this context, the key diagnostic question in acute cholecystitis is whether or not the cystic duct is patent.

Ultrasonography has been most frequently used to assess suspected acute cholecystitis. It is, however, rarely able to depict the impacted cystic duct calculi because of the lack of the landmark of the cystic duct and too small amount of surrounding bile to create an acoustic contrast \(^\text{13}\). The ultrasonographic diagnosis of acute cholecystitis, therefore, rests on imaging gallstones in association with secondary signs, such as “the sonographic Murphy sign, changes in the
gallbladder wall, pericholecystic fluid collection, and intraluminal changes” rather than a direct depiction of cystic duct obstruction. Cholescintigraphy has proven to be the most sensitive method available for documenting cystic duct patency or obstruction. Nonvisualization of the gallbladder with visualization of the normal common bile duct and bowel accurately confirms the diagnosis of acute cholecysitis in most cases (95.2%), while visualization of the gallbladder accurately excludes it (99.4%). However, nonvisualization of the gallbladder is the only sign of cystic duct obstruction. The site and cause of obstruction are not demonstrable. Furthermore, it cannot depict associated findings, such as common bile duct calculi, pericholecystic fluid collection or changes in the gallbladder wall and it is not able to provide anatomic information about the organs outside of the liver or biliary tree.

In our study, results as to the presence of cystic duct patency on manganese-enhanced T1W MR cholangiography completely agreed with the hepatobiliary scintigraphy. In the cases with a patent cystic duct, this imaging demonstrated
both the bile duct and gallbladder as an area of high signal intensity reflecting the normal flow of biliary system without obstruction or stasis. In the cases of cystic duct obstruction, however, the gallbladder was not enhanced. Therefore MR cholangiography enhanced with manganese reflects the biliary dynamics just like cholescintigraphy and is able to provide functional information of the biliary system. Furthermore T1W MR cholangiography enhanced with manganese shows the calculi in the cystic duct or gallbladder neck, proximal to the obstruction site, and thus it can depict the cause of obstruction anatomically.

Conventional heavily T2W MR cholangiography is able to detect small stones less than 3mm and to show both the proximal and distal parts of the obstruction site in spite of a complete obstruction. Therefore it can provide accurate information concerning the site and cause of the obstruction. Recently, MR cholangiography has been used to examine the gallbladder and cystic duct in the setting of acute cholecystitis, demonstrating a high sensitivity in detecting an impacted cystic duct or gallbladder neck stones. In
this study, the impacted cystic duct or gallbladder neck calculi were accurately demonstrated, to a resolution as small as 3mm. In some cases, however, we were unable to differentiate the calculus from part of the normal cystic duct. Following manganese injection, however, MR cholangiography depicts the cystic duct obstruction clearly, with nonvisualization of the gallbladder on T1W images. MR cholangiography in conjunction with conventional heavily T2W and manganese-enhanced T1W imaging is superior to conventional heavily T2W MR cholangiography without manganese, in the diagnosis of acute cholecystitis, particularly when evidence of cystic duct obstruction is equivocal.

Compared with calculus cholecystitis, acute acalculus cholecystitis has increased the incidence of gangrene and perforation, resulting in increased morbidity and mortality. In the cases of the acalculus form, a delay in diagnosis and definitive treatment is frequent because a demonstrable cause of obstruction is not present. In such cases, therefore, other imaging modalities (ultrasonography and CT) are less sensitive than cholescintigraphy because they cannot provide functional
information concerning biliary dynamics. The case of acalculus cholecystitis in our study was a more complicated one. The cholescintigraphy of this case was interpreted as a visualization of the gallbladder. However, the visualized gallbladder was proven to be only a portion of the neck and not the entire gallbladder. In contrast with cholescintigraphy, MR cholangiography, T1- and T2W imaging combined with pre- and post-manganese injection, was able to depict the contrast-filling portion in connection with the remaining portion of the gallbladder. Therefore it was easier for us to accurately approach this case with MR cholangiography than cholescintigraphy.

It would be of great value if one imaging modality could combine the anatomic detail of cross-sectional imaging with the functional detail of cholescintigraphy, particularly in cases of acalculus cholecystitis or calculus cholecystitis with stones too small to detect in the cystic duct. We are convinced that MR cholangiography, T1- and T2-weighted combined with pre- and post-manganese injection, provides this very imaging modality because it is superior to
ultrasonography in the depiction of the causes of cystic duct obstruction \textsuperscript{16} and it completely agrees with hepatobiliary scintigraphy in the evaluation of cystic duct patency in this study. It could replace both the cross-sectional imaging and cholecintigraphy all at once with a higher degree of confidence in patients with acute cholecystitis.

Leakage of the bile, bile duct injury, and retained bile duct calculi are the main biliary complications of laparoscopic cholecystectomy \textsuperscript{8-9, 18-20}. They may occur separately, but complex biliary complications, such as bile duct injury combined with bile leakage, may occur rather frequently \textsuperscript{8-9, 18-20}. Although, there is no accepted classification of biliary complications and no standard protocol for the management of them, it is generally accepted that the treatment modalities depend on the type, cause, location, and extent of complications \textsuperscript{9, 20}. Prat et al \textsuperscript{9} suggested that endoscopic sphincterotomy was sufficient for the treatment of simple bile leakage without duct injury, clip migration, and retained stones. They \textsuperscript{9} also recommended endoscopic stenting as a primary option in partial CBD strictures, and surgery as a
definite treatment of choice in major injuries, including complete transection and complex injury.

Most patients with complications after laparoscopic cholecystectomy usually undergo a multitude of imaging tests—sonography, CT, hepatobiliary scintigraphy, percutaneous aspiration, endoscopic retrograde cholangiography, and/or percutaneous cholangiography—because no single test is able to provide complete and final diagnosis and some of them are too invasive to perform for the first time. The main roles of CT or sonography with or without percutaneous aspiration are to establish the presence of bile in the peritoneal cavity and to drain it. However, they cannot establish the combined bile duct injury and the exact location of the bile leak. The main roles of hepatobiliary scintigraphy are to establish the presence of a continuing bile leak. However, it cannot provide the anatomical information. ERCP and percutaneous cholangiography are able to establish the presence of a continuing bile leak, provide exact anatomical diagnosis, and treat injury by decompressing the biliary tree or by dilating it. However they are invasive and they could
miss the proximal or distal part of the complete obstruction site, and, in this case, they are not diagnostic.

Differentiating complete obstruction from partial stricture of the bile duct is important because the former is a definite indication of surgical treatment whereas the latter is an indication of endoscopic stenting rather than surgery. In our study, manganese-enhanced T1W MR cholangiography differentiated complete obstruction from partial stricture. Manganese-enhanced T1W MR cholangiography clearly demonstrated the two cases of complete obstruction with bile leakage, by showing extravasation of the contrast from the bile duct without opacification of the distal part of the extrahepatic bile duct. On the other hand, because ERCP could not evaluate the proximal portion of the disconnected site of the bile duct, it was not able to evaluate the presence of bile leakage and the distance of the injured bile duct from the confluence level, which is an important factor for operation plan. ERCP has limitations in evaluating the completely obstructed cases.

In our study, manganese-enhanced T1W MR cholangiography
clearly demonstrated the partial stricture with bile leakage, by showing extravasation of the contrast from the bile duct with opacification of the extrahepatic bile duct, despite the presence of an abnormal narrowing segment of the bile duct at conventional T2W MR cholangiography. In this case, the patient did not have a peritoneal drain. However in a patient with a peritoneal drain, contrast opacification of the extrahepatic duct was absent at manganese-enhanced T1W MR cholangiography, suggesting the complete occlusion or transection of the bile duct. However, ERCP showed a partial stricture of the bile duct and not complete obstruction. It may be because the main bile flow was into the peritoneal drain rather than the extrahepatic duct, causing the degree of obstruction to be overestimated with manganese-enhanced T1W MR cholangiography in the patient with a peritoneal drain.

In our study, manganese-enhanced T1W MR cholangiography differentiated abnormal fluid collection of biliary origin from that of non-biliary origin. Manganese-enhanced T1W MR cholangiography showed normal contrast filling of the biliary system without leakage or obstruction in a patient with a
large amount of fluid collection at sonography and conventional T2W MR cholangiography, suggesting a non-biliary origin of fluid collection. It was diagnosed as hemorrhage.

The traditional algorithm for the imaging of postcholecystectomy biliary complications has been sonography, CT and/or hepatobiliary scintigraphy, followed by diagnostic and/or therapeutic ERCP or percutaneous cholangiography, and some of them underwent surgery. We think that combined conventional T2-weighted and Mn-enhanced T1-weighted MR cholangiography can differentiate biliary complications from non-biliary complications, simple leakage without bile duct injury from that with bile duct injury, and complete obstruction of the bile duct from partial stricture of the bile duct. Moreover, they are non-invasive. Therefore, they could be used as the first-line study for postcholecystectomy biliary complications. After diagnosing simple leakage without bile duct injury on combined MR cholangiography, ERCP with sphincterotomy with or without internal stent may be performed. After diagnosing partial stricture of the bile duct with or without bile leakage on combined MR cholangiography, ERCP with
internal stent may also be performed. Furthermore, after diagnosing complete transection or occlusion of the bile duct with or without bile leakage on combined MR cholangiography, prompt surgical repair should be performed. ERCP or PTC is not necessary in those cases. Therefore, this series suggest that combined conventional T2-weighted and Mn-enhanced 3D T1-weighted MR cholangiography may eliminate the need for other studies for the imaging of postcholecystectomy biliary complications.

The management of symptomatic intrahepatic choledochalithiasis is difficult and remains far from satisfactory. In the last decade, however, the management of this condition has been improved by a systemic approach, advances in hepatobiliary imaging, availability of flexible choledochoscopy, application of stone-fragmentation technology, and innovative surgical approaches to the biliary tract. A combination of all the various treatment modalities is required, on a selective basis, to achieve optimal results. The treatment modalities depend on identifying the exact location and level of stones or stricture, the degree of
stenosis or obstruction, the degree of destruction of the involved liver segment, and the presence of combined hepatic abscess or cholangiocellular carcinoma. Recently, reports have suggested MR cholangiography to be superior to direct cholangiography in the accurate topographic evaluation of intrahepatic choledocholithiasis because of its ability to depict all parts of the biliary tree, regardless of obstruction or stenosis. However, conventional heavily T2W MR cholangiography has some limitations in evaluating the degree of stenosis or obstruction and the function of the involved bile duct and liver parenchyma. In our study, manganese-enhanced T1W MR cholangiography provided the functional information of the bile ducts and indicated the degree of stricture and the function of the involved duct. Therefore, rather than conventional T2W MR cholangiography alone, manganese-enhanced MR cholangiography combined with conventional T2W MR cholangiography could provide further information that is necessary for treatment decision-making in the patients with intrahepatic choledocholithiasis.

Several limitations exist in this study. One limitation is
that mangafodipir-trisodium cannot be used for the patients with jaundice because the biliary systems are not opacified and therefore the patient population in our study was very restricted. However, the incidence of adverse events was comparable between the group of patients with jaundice or cirrhosis and the group of patients without jaundice or cirrhosis. The most commonly reported adverse events were nausea (7%) and headache (4%), and they were mild to moderate in intensity, not requiring treatment. A second limitation is that there was no standard reference to the diseased segmental ducts in the patients with intrahepatic choledochalithiasis. A third limitation is the cost-effectiveness manganese-enhanced MR cholangiography, especially in the patients with acute cholecystitis. In our country, DISIDA scan and US are far more cheaper than MR cholangiography and more their diagnostic accuracies in the evaluation of acute cholecystitis are not so much inferior to MR cholangiography. Therefore manganese-enhanced MR cholangiography cannot be the first line diagnostic modality in the evaluation of the patients with suspected acute cholecystitis. The clinical application may be
restricted to the cases that the evidence of cystic duct obstruction is equivocal.
V. CONCLUSION

Conventional heavily T2W MR cholangiography combined with manganese-enhanced MR cholangiography provided not only the anatomic detail, but also the functional detail. Therefore, manganese-enhanced MR cholangiography is a useful supplement to conventional heavily T2W MR cholangiography in the evaluation of acute cholecystitis, biliary complications after laparoscopic cholecystectomy, and intrahepatic choledocholithiasis.
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목적: 다양한 담도계 질환에서, 고식적 T2 강조 자기공명 담관 조영술과 망간 조영 증강 삼차원 T1 강조 자기공명 담관 조영술을 함께 시행하였을 때, 그 부가적인 정보 유무를 분석한 후, 망간 조영 증강 자기공명 담관 조영술의 임상 활용에 대하여 연구하고자 함.

대상 및 방법: 임상적으로 급성 담낭염 (n=30), 복강경 유도 하 담낭 절제술 후의 담도계 합병증 (n=10), 간내 담석증 (n=14), 대조군 (n=10), 모두 64명의 환자에서, 고식적 T2 강조 자기공명 담관 조영술과 망간 조영 증강 삼차원 T1과 T2 강조 자기공명
담관 조영술을 함께 시행하였다. 급성 담낭염의 경우 담낭유출로의 폐쇄 유무에 초점을 두고 영상을 분석하였으며, 복강경유도 하 담낭 절체술 후의 담도계 합병증의 경우 담관 손상, 담즙유출, 전류 담석 유무, 그리고 간내 담석증의 경우 병변이 있는 간내 담도의 기능 유무에 초점을 두고 영상 분석을 하였다.

결과: 급성 담낭염 환자에서 담낭 유출로의 폐쇄 유무에 대한, 고식적 T2 강조 자기 공명 담관 조영술의 예민도, 특이도, 정확도는 각각 82%, 88%, 83%이었으나, 담낭 절체술 후의 담도계 합병증이 의심되는 환자에서 자기 공명 담관 조영술의 진단은 모두 100%이었다. 담낭 절체술 후의 담도계 합병증의 진단은, 총담관의 완전 혈착과 담즙 유출 (n=4), 총담관의 부분 혈착과 담즙 유출 (n=2), 전류 담낭관에서의 담즙 유출 (n=2), 변이 우담관 결찰 (n=1), 그리고 출혈 (n=1)이었다. 자기 공명 담관 조영술의 진단은, 완전 혈착으로 과 진단한 부분 혈착 한 예를 제외하고는 모두 수술 혹은 역행성 담도 조영술 소견과 일치하였다. 간내 담석증의 경우 고식적 T2 강조 자기 공명 담관 조영술에서는 22 분절의 담도에 병변이 있었다. 담낭 절체술 후의 담도계 합병증이 의심되는 환자에서 자기 공명 담관 조영술에서는, 8 분절의 담도는 조영 증강이 되어 아직 기능을 하고 있었으며 나머지 14 분절의 담도는 기능이 없었다.
결론: 고식적 T2 강조 자기 공명 담관 조영술과 망간 조영 증강 삼차원 T1 강조 자기 공명 담관 조영술을 함께 시행하였을 때, 병변에 대한 해부학적인 정보 뿐만이 아니라 그 역동적, 기능적인 정보까지 얻을 수 있다. 따라서 망간 조영 증강 자기 공명 담관 조영술은, 급성 담낭염, 복강경 유도 하 담낭 절제술 후의 담도계 합병증, 그리고 간내 담석증의 진단에 있어서, 이제까지의 고식적 T2 강조 자기 공명 담관 조영술에 대한 추가 진단 방법으로써 매우 유용하다.

핵심 되는 말: 담관, 결석, 자기공명영상, 담도조영술, 자기공명영상 조영제