MR Cholangiography with Volume Rendering: Receiver Operating Characteristic Curve Analysis in Patients with Choledocholithiasis

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OBJECTIVE. The purpose of our study was to compare observer performances for the diagnosis of choledocholithiasis using MR cholangiography with volume-rendered, maximum-intensity-projection, and thick-section half-Fourier rapid acquisition with relaxation enhancement sequences.

MATERIALS AND METHODS. The images from three types of MR cholangiography performed on 43 patients with biliary calculi were retrospectively analyzed. Image review was conducted for two anatomic compartments (upper biliary tract and common bile duct). A total of 86 compartments, including 19 with bile duct calculi, were reviewed by three independent off-site gastrointestinal radiologists. Observer performance was determined by receiver operating characteristic curve analysis. Image quality was subjectively judged by three radiologists.

RESULTS. Sensitivity was higher with volume-rendered MR cholangiography (58%) than with thick-section (54%, not significant) and maximum-intensity-projection MR cholangiography (47%, $p < 0.07$). Specificity was higher with volume-rendered MR cholangiography (92%) than with thick-section (86%, $p < 0.03$) and maximum-intensity-projection MR cholangiography (88%, not significant). Accuracy was higher with volume-rendered MR cholangiography (84%) than with thick-section and maximum-intensity-projection MR cholangiography (79% for both, not significant). Observer performance with volume-rendered MR cholangiography (A_z = 0.791–0.952) was better than that with thick-section (A_z = 0.722–0.834) and maximum-intensity-projection MR cholangiography (A_z = 0.771–0.887). Image quality was better with maximum-intensity-projection MR cholangiography and thick-section MR cholangiography than with volume-rendered MR cholangiography ($p < 0.0001$).

CONCLUSION. Observer performance with volume-rendered MR cholangiography was better than that with maximum-intensity-projection and thick-section MR cholangiography for the diagnosis of choledocholithiasis. Volume rendering may be an efficient technique for the reconstruction of MR cholangiography.

MR cholangiopancreatography has developed as an efficient, noninvasive imaging tool for the diagnosis of pancreaticobiliary diseases. This technique is feasible in patients in whom sufficient endoscopic retrograde cholangiopancreatography (ERCP) has failed, in patients who have undergone gastrectomy or pancreaticoduodenectomy and in whom ERCP cannot be performed, in patients with acute pancreatitis, and in infants or elderly patients. Until now, a variety of pulse sequences such as steady-state free precession [1, 2], two-dimensional fast spin-echo [3–9], three-dimensional fast spin-echo [10, 11], and half-Fourier rapid acquisition with relaxation enhancement (RARE) [12–14] sequences have been described as optimal imaging sequences for MR cholangiopancreatography. Recent studies have described the clinical usefulness of MR cholangiopancreatography performed with half-Fourier RARE sequences with or without image reconstruction using the maximum-intensity-projection technique [15, 16]. MR cholangiopancreatography reconstructed from sequential coronal source images 3–5 mm thick allows complete visualization of the pancreaticobiliary ducts and enables a cinematic observation by spinning the images. Reconstructed MR cholangiopancreatography provides images that can be reviewed in sequence on the computer monitor, which allows viewing the pancreaticobiliary duct system rotating in space and improves the observers' ability to recognize the anatomic architecture and diseased site.

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Researchers have described the usefulness of the volume-rendering technique for reconstructing three-dimensional images of the tracheobronchial tree [17], colorectal polyps [18], and splanchnic vessels [19] with CT images. However, to our knowledge no previous studies have examined the usefulness of volume-rendering techniques for MR cholangiography. We assessed the usefulness of volume-rendered MR cholangiography in patients with choledocholithiasis by comparing observer performance and image quality of MR cholangiography with maximum-intensity-projection, volume-rendered, and thick-section half-Fourier RARE sequences.

Materials and Methods

Patient Study

During the 16-month period between June 1997 and September 1998, 248 consecutive patients who were suspected of having pancreaticobiliary disease on the basis of findings on previously performed transabdominal sonography, CT, or serologic tests underwent MR imaging at our department. All patients understood that the MR examination was primarily for clinical diagnosis and secondarily for radiologic research. Two hundred five patients without proof of the presence of biliary calculi after the radiologic workup with unenhanced helical CT (5- to 7-mm collimation, 120 kVp, 200–220 mAs), transabdominal sonography (3.75-MHz convex transducer), ERCP, or follow-up imaging were excluded from the study population because the purpose of our study was to compare the observer performances among the three types of images. The remaining 43 patients, including 21 men and 22 women (age range, 39–94 years; mean age, 65 years), formed the study population. We included patients with cholecystlithiasis alone because radiologists commonly need to further scrutinize for the presence of bile duct calculi on MR images when gallbladder calculi are seen. Of the 43 patients, 25 who were suspected of having choledocholithiasis underwent ERCP; 17 of these patients were diagnosed as having choledocholithiasis, and eight as having cholecystlithiasis alone. All remaining 18 patients with cholecystlithiasis alone were examined with transabdominal sonography (3.75-MHz convex transducer) and thin-collimation CT (5-mm collimation, 120 kVp, 200–220 mAs), and were determined not to have choledocholithiasis.

MR Imaging Techniques

MR imaging was performed using a 1.5-T MR unit (Signa Horizon; General Electric Medical Systems, Milwaukee, WI) and phased array body multicoil (Torso-array coil; General Electric Medical Systems). The imaging protocol for MR cholangiography comprised T2-weighted imaging with chemical shift selective fat-suppressed respiratory-triggered fast spin-echo imaging (effective TR range/effective TE range, 7500–15,000/252–255; echo train length, 12–18; 2 signals averaged; matrix size, 256 × 192; kHz, ±16; field of view, 24 × 24 cm; 20–28 sections per 3.5–5.5 min) and non–fat-suppressed breath-hold half-Fourier single-shot fast spin-echo imaging (effective TR/effective TE, infinite/81,034; echo train length, 136; half-Fourier acquisition; matrix size, 256 × 256; kHz, ±31.3; field of view, 24 × 24 cm; acquisition time, 1 section per second). Respiratory-triggered fast spin-echo images for the reconstruction of MR cholangiography were obtained in the coronary plane with 3-mm section thickness and no intersection gap. Thick-section MR cholangiography images were obtained in the coronal, oblique, and sagittal planes with a section thickness of 20–50 mm. Six images at every 30° over 180° rotation with the *z*-axis were obtained. Thinner section thickness was used for anterior images to eliminate signals from gastric juice and spinal fluid, and thicker section thickness for oblique images to cover areas as broad as possible.

Reconstruction of MR cholangiography was done with a commercially available workstation (Advantage Windows version 2.0; General Electric Medical Systems) for maximum-intensity-projection reconstruction, and another commercially available workstation (Magic View version 3.1; Siemens, Erlangen, Germany) for volume-rendering reconstruction. The *z*-axis was selected for cinematic three-dimensional observation at every 10° over 180° rotation, resulting in 19 images each for the maximum-intensity-projection and volume-rendering techniques. To generate volume-rendered MR cholangiography, parameter selection was based on our preliminary findings (Kanematsu M, Kondo H, Matsuo M, unpublished data). The position of the trapezoid was determined so that the voxels located at the interface between the bile and calculi were displayed. The trapezoid defined by window width and level was positioned on a histogram of signal intensity of source images displayed on the computer monitor (Fig. 1), in which the *x*-axis represented the signal-intensity value, which ranged from –1000 to 3096 H, and the *y*-axis represented the degree of opacity expressed as a percentage, at which 0% opacity indicates completely transparent and 100% opacity indicates completely opaque. We empirically used four preset points to determine the position of the trapezoid: –980 to –680 H at 0% opacity level, and –900 to –700 H at 100% opacity level (Fig. 1). The window level was always chosen at the midpoint of the window width at the 100% opacity level. For the remaining volume-rendering parameters, the parenchymal opacification was set at 15% and an unshaded algorithm was used. The 19 images each of the maximum-intensity-projection and volume-rendered MR cholangiograms were formatted into two pieces of 4 × 5 formatted film using a laser imager. It typically required 5 min to produce the maximum-intensity-projection or volume-rendered MR cholangiogram for one patient.

Image Analysis

Three off-site radiologists, who had served mainly as gastrointestinal radiologists for 7–17 years (mean, 12.5 years) with experience in interpreting MR images of the pancreaticobiliary system were invited from other institutions to conduct the image review. These radiologists independently reviewed maximum-intensity-projection, volume-rendered, and thick-section MR cholangiograms obtained in the 43 patients. They knew that the patients were referred for assessment of suspected biliary calculi but did not have any other information about the patients' histories.

The image review was conducted for two anatomic compartments: upper biliary tracts (intrahepatic bile ducts, right and left hepatic ducts, and common hepatic duct) and the common bile duct. We performed the image review on a compartment-by-compartment basis because correct localization of biliary calculi is necessary when determining treatment options such as endoscopic lithotripsy, laparoscopic cholecystectomy, laparocystectomy, or laparolithotripsy, and because our objective was to compare observer performance with the three imaging sequences by means of receiver operating characteristic curve analysis.

The three radiologists independently reviewed 86 anatomic compartments in 43 patients, including 19 compartments that harbored bile duct calculi. Images were reviewed in alphabetic order according to the patients' names, but the order in which images obtained with the three imaging sequences were reviewed was randomized. In other words, images from all patients were reviewed at a single session, but only the images obtained with one of the three imaging sequences were reviewed for a given patient at that session. The other types of images were reviewed at subsequent sessions. To minimize learning bias, the name, age, identification number, and imaging parameters were masked.

The radiologists recorded the size and site of the visible area of the signal-intensity defect that was considered to be caused by bile duct calculi, and indicated whether the presence of bile duct calculi could be ascertained for each anatomic compartment. Each radi-

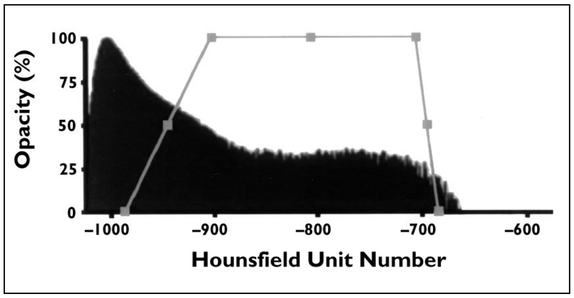


Fig. 1.—Histogram shows opacity percentage plotted against Hounsfield value. Trapezoid was placed so that voxels located at interface between bile and calculi were seen. Four fixed points were used to determine position of trapezoid: –980 to –680 H at 0% opacity level, and –900 to –700 H at 100% opacity level.

ologist allocated one of five confidence levels (1 = definitely absent, 2 = probably absent, 3 = equivocal, 4 = probably present, 5 = definitely present) to each compartment. When a large biliary calculus was located over two compartments, the radiologist was asked to consider only the compartment in which most of the calculus was located and to assess the probability of other bile duct calculi in another compartment. The radiologists were instructed to indicate a score of 1 when no signal-intensity decrease or defect was seen; a score of 3 when the signal-intensity decrease or defect was subtle, ill-defined, or not gravity-dependent; and a score of 5 when the signal-intensity decrease or defect was discrete, well-circumscribed, or gravity-dependent. Scores of 2 and 4 were allocated according to the radiologist's subjective judgment.

Furthermore, each radiologist evaluated image quality in terms of image sharpness, image contrast, depiction of fine structures, and recognition of anatomy using a five-point scale (1 = poor, 2 = fair, 3 = good, 4 = very good, 5 = excellent). A "poor" score was assigned when the image could not be interpreted becuase of image degradation, a "good" score was assigned when the image degradation was present but did not markedly preclude interpretation, and an "excellent" score was assigned when the image was virtually free from image degradation. Scores of "fair" and "very good" were allocated according to the radiologist's subjective judgment.

Statistical Analysis

Sensitivity for detection of bile duct calculi was determined using the number of anatomic compartments assigned a score of 4 or 5 (i.e., probably present or definitely present) of the total number of 19 compartments with bile duct calculi. Specificity was determined using the number of compartments assigned a score of 1 or 2 (i.e., definitely absent or probably absent) of the total number of 67 compartments without bile duct calculi. Sensitivity and specificity were compared using the McNemar test. Accuracy was compared with the chi-square test.

For each imaging sequence, a receiver operating characteristic curve was fitted to each observer's confidence rating using a maximum-likelihood estimation with the ROCKIT 0.9.1B program (Metz, University of Chicago, Chicago, IL) [20]. Observer performance was estimated by calculating the area under the receiver operating characteristic curve (A_z). Differences between the areas under the receiver operating characteristic curves were tested using the area test with univariate *z*-score test.

To assess interobserver variability in interpreting images, kappa statistics for multiple observers were used to measure the degree of agreement among the three observers. We used the nonweighted kappa statistics with binary data defined in terms of the presence (i.e., definitely present, probably present, or equivocal) or absence (i.e., probably absent or definitely absent) of calculi in a compartment. Kappa values of up to 0.40 indicated positive but poor agreement, values of 0.41–0.75 indicated good agreement, and values greater than 0.75 indicated excellent agreement.

Results

In the 43 patients, biliary calculi were located in the gallbladder alone in 26 patients, upper biliary tract alone in one, common bile duct alone in five, gallbladder and upper biliary tract in one, gallbladder and common bile duct in eight, upper biliary tract and common bile duct in one, and all compartments in one.

The sensitivity, specificity, and accuracy for detection of bile duct calculi are listed in Table 1. Sensitivity with volume-rendered MR cholangiography was marginally higher than that with maximum-intensity-projection MR cholangiography in the total data ($p < 0.07$) (Figs. 2–4). Specificity with volume-rendered MR cholangiography was marginally higher than that with thick-section ($p < 0.06$) and maximum-intensity-projection ($p < 0.07$) MR cholangiography for radiologist 2, and was significantly higher than that with thick-section MR cholangiography in the total data ($p < 0.03$). Accuracy with volume-rendered MR cholangiography was significantly higher than that with maximum-intensity-projection MR cholangiography ($p < 0.05$) and marginally higher than that with thick-section MR cholangiography ($p < 0.07$) for radiologist 2, and was marginally higher than that with maximum-intensity-projection and thick-section MR cholangiography in the total data ($p < 0.09$).

The receiver operating characteristic curves for each radiologist are shown in Figures 5–7. Observer performance for detection of bile duct calculi was marginally greater with volume-rendered MR cholangiography than with maximum-intensity-projection MR cholangiography for radiologists 2 and 3 ($p < 0.08$ for both). Observer performance was significantly greater

TABLE 1 Sensitivity, Specificity, and Accuracy for Detection of Bile Duct Calculi

Imaging Sequence	Radiologist 1		Radiologist 2		Radiologist 3		Total	
	No.	%	No.	%	No.	%	No.	%
Sensitivity (19 compartments with calculi)								
Maximum intensity projection	9	47	10	53	8	42	27	47
Volume rendering	10	53	13	68	10	53	33	58[a]
Thick-section RARE	10	53	10	53	11	58	31	54
Specificity (67 compartments without calculi)								
Maximum intensity projection	60	90	60	90	56	84	176	88
Volume rendering	62	93	66	99[b]	57	85	185	92[c]
Thick-section RARE	61	91	61	91	50	75	172	86
Accuracy (all 86 compartments)								
Maximum intensity projection	69	80	70	81	64	74	203	79
Volume rendering	72	84	79	92[d]	67	78	218	84[e]
Thick-section RARE	71	83	71	83	61	71	203	79

Note.—Data are numbers of segments among 19 segments with bile duct calculi assigned a score of 4 or 5 for sensitivity, segments among 67 segments without bile duct calculi assigned a score of 1 or 2 for specificity, and sum of these segments for accuracy. RARE = rapid acquisition with relaxation enhancement.

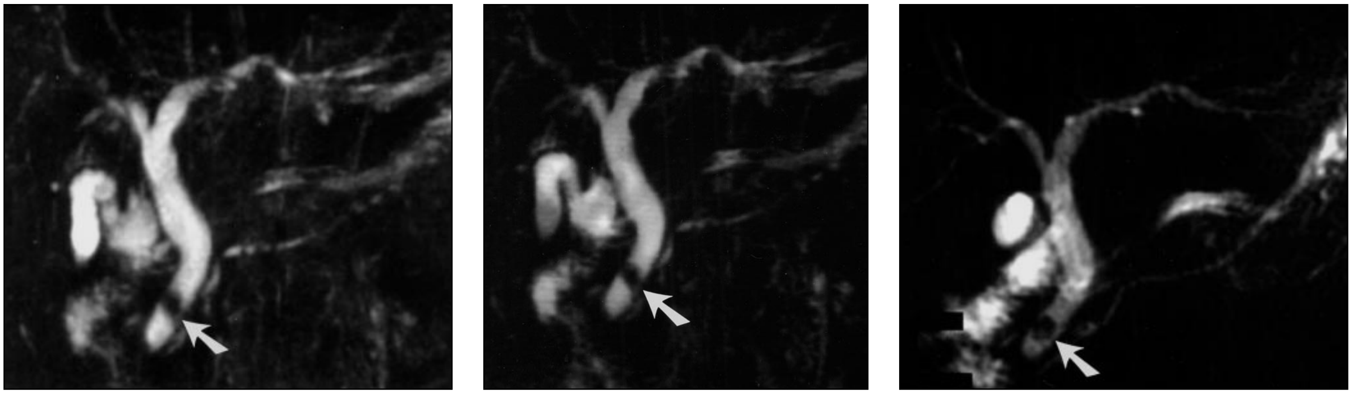
[a] Marginally higher than for maximum intensity projection ($p < 0.07$).

[b] Marginally higher than for maximum intensity projection ($p < 0.07$) and thick-section RARE ($p < 0.06$).

[c] Significantly higher than for thick-section RARE ($p < 0.03$).

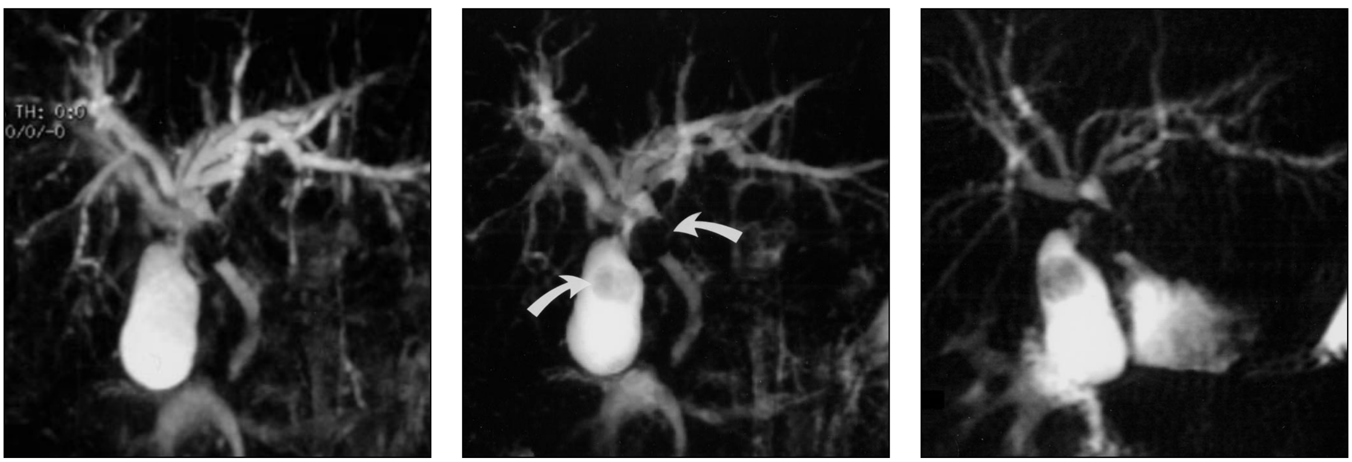
[d] Significantly higher than for maximum intensity projection ($p < 0.05$) and marginally higher than for thick-section RARE ($p < 0.07$).

[e] Marginally higher than for maximum intensity projection ($p < 0.09$) and thick-section RARE ($p < 0.09$).



A B C

Fig. 2.—58-year-old man with common bile duct calculus (*arrows*, **A**–**C**).
A–**C,** Anterior MR cholangiograms with maximum-intensity-projection (**A**), volume-rendered (**B**), and thick-section half-Fourier rapid acquisition with relaxation enhancement (**C**) sequences show that visibility of calculus is comparable for all three types of images. However thick-section MR cholangiography is less blurred as result of 1-sec data acquisition during respiratory suspension.



A B C

Fig. 3.—48-year-old woman with gallbladder and common bile duct calculi (*arrows,* **B**).
A–**C,** Anterior MR cholangiograms with maximum-intensity-projection (**A**), volume-rendered (**B**), and thick-section half-Fourier rapid acquisition with relaxation enhancement (**C**) sequences show that image in **B** shows both calculi more clearly than other types of images.

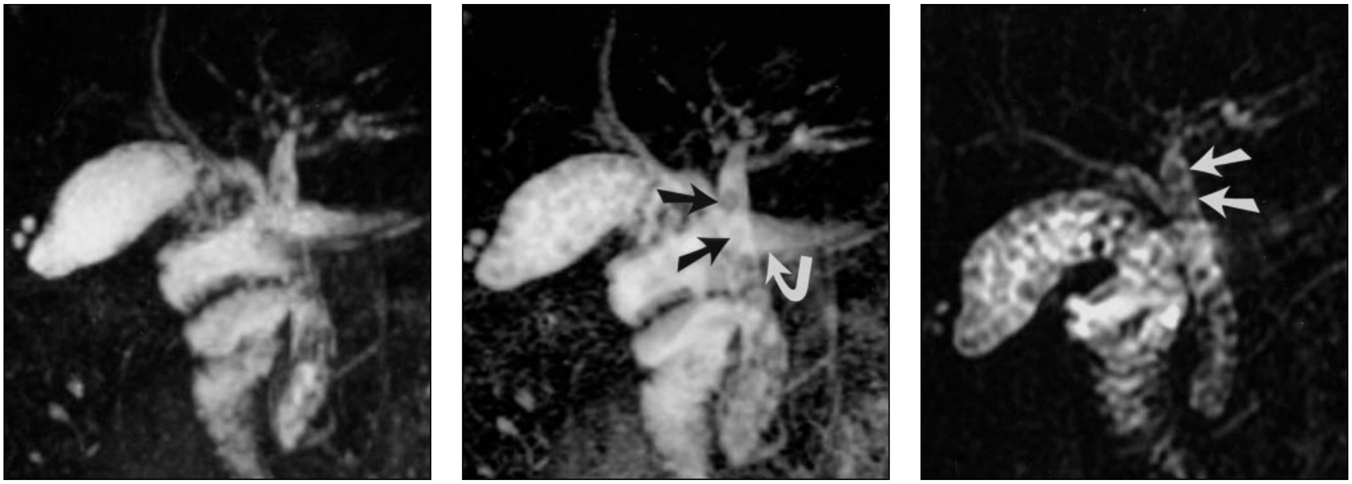
with volume-rendered MR cholangiography than with thick-section MR cholangiography for radiologist 2 ($p < 0.04$). No significant difference in observer performance was found between maximum-intensity-projection and thick-section MR cholangiography. Kappa values were 0.44, 0.60, and 0.58 for maximum-intensity-projection, volume-rendered, and thick-section MR cholangiography, respectively. Good agreement was obtained among the radiologists.

The mean scores for the image quality are shown in Table 2. Image quality was significantly better with maximum-intensity-projection MR cholangiography and thick-section MR cholangiography than with volume-rendered MR cholangiography ($p < 0.0001$) (Figs. 2–4).

Discussion

The maximum-intensity-projection technique is one of the primary means of displaying three-dimensional images and has been used for reconstructing MR cholangiopancreatography. However, the maximum-intensity-projection technique uses only approximately 10% of data [21], and the limitations of the maximum-intensity-projection technique are that overlapping ducts are not depicted as areas of increased density, as occurs with conventional cholangiography, and no information on depth is available. These limitations make evaluation of a single maximum-intensity-projection image difficult. Furthermore, small polyps or calculi are masked if brighter voxels in source images without disease are projected instead of the darker voxels caused by disease. The volume-rendering technique is a novel reconstruction algorithm that is frequently used in clinical practice as a result of recent advances in computer graphics software and hardware. With volume rendering, which uses information from all available voxels not just those at the surface of the objects, some voxels, are rendered opaque whereas others are transparent. Furthermore, the reconstruction algorithm and display technology used in volume rendering yield a number of advantages over maximum-intensity-projection or shaded-surface–display techniques [22].

In our study, analysis of sensitivity showed a trend toward the superiority of vol-



A B C

Fig. 4.—68-year-old man with numerous calculi in upper biliary tract, common bile duct, and gallbladder.
A–C, Anterior MR cholangiograms with maximum-intensity-projection (**A**), volume-rendered, (**B**), and thick-section half-Fourier rapid acquisition with relaxation enhancement (**C**) sequences show that calculi in upper biliary tract (*straight arrows,* **B** and **C**) are better shown in **B** and **C** than in **A**. Note that image in **B** clearly shows calculus in upper biliary tract that is superimposed by signal intensity of gastric juice (*curved arrow,* **B**).

ume-rendered MR cholangiography over maximum-intensity-projection MR cholangiography, although these two types of MR cholangiography were reconstructed from the identical source images. With the maximum-intensity-projection technique, low-signal-intensity voxels caused by calculi were often masked by brighter voxels caused by bile around the lesions. Meanwhile, with the volume-rendering technique, all voxels of source images were transparent to some degree, and the light reflection from voxels inside the structures could be observed, resulting in its superior ability to reveal bile duct calculi (Figs. 3 and 4).

Specificity with volume-rendered MR cholangiography was significantly superior to that with thick-section MR cholangiography. Because thick-section MR cholangiography takes advantage of the partial volume-averaging effect, the thicker the imaging section, the less the image contrast, possibly decreasing the conspicuousness of small calculi. Because the radiologists knew of the low image contrast with thick-section images, they might have recognized the small areas of subtly decreased signal intensity caused by artifacts as areas of disease.

The receiver operating characteristic curve analysis indicated a trend toward the superiority of volume-rendered MR cholangiography over maximum-intensity-projection and thick-section MR cholangiography. The capability of volume-rendered MR cholangiography to show inside structures presumably yielded the

Fig. 5.—Graph shows receiver operating characteristic curves for detection of bile duct calculi by radiologist 1 for maximum-intensity-projection (□) (A_z = 0.771), volume-rendered (◇) (A_z = 0.791), and thick-section (○) (A_z = 0.722) MR cholangiograms. Observer performance with maximum-intensity-projection and volume-rendered MR cholangiography tends to exceed that with thick-section MR cholangiography.

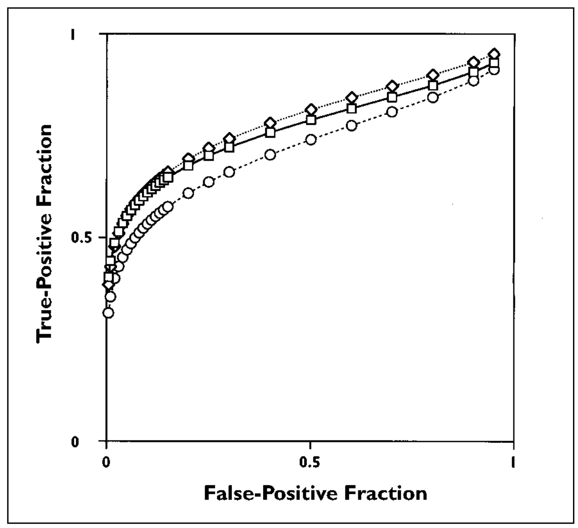


TABLE 2 **Image Quality Subjectively Judged by Three Radiologists**

Imaging Sequence	Image Sharpness[a]	Image Contrast[a]	Depiction of Fine Structures[a]	Recognition of Anatomy[b]	Total[a]
Maximum intensity projection	3.6 ± 0.9	3.6 ± 0.7	3.2 ± 1.0	3.5 ± 0.7	3.5 ± 0.9
Volume rendering	3.3 ± 1.0	3.3 ± 1.0	2.6 ± 1.0	3.3 ± 0.8	3.1 ± 1.0
Thick-section RARE	3.6 ± 0.8	3.6 ± 0.7	3.3 ± 1.0	3.4 ± 0.6	3.5 ± 0.8

Note.—Numbers are mean ± 1 standard deviation. Data are based on radiologists' scores of degree of image quality (1 = poor, 2 = fair, 3 = good, 4 = very good, 5 = excellent). RARE = rapid acquisition with relaxation enhancement.

[a]Mean score was significantly greater with maximum intensity projection ($p < 0.001$) and thick-section RARE ($p < 0.01$) than with volume rendering.

[b]Mean score was significantly greater with maximum intensity projection than with volume rendering ($p < 0.005$).

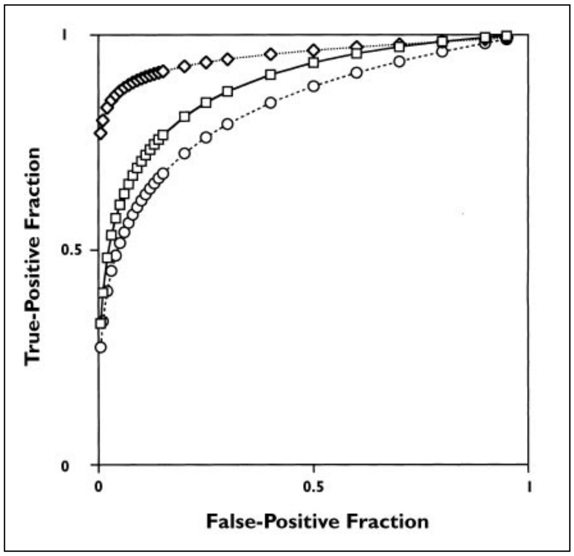


Fig. 6.—Graph shows receiver operating characteristic curves for detection of bile duct calculi by radiologist 2 for maximum-intensity-projection (□) (A_z = 0.887), volume-rendered (◇) (A_z = 0.952), and thick-section (○) (A_z = 0.834) MR cholangiograms. Observer performance with volume-rendered MR cholangiography significantly ($p <$ 0.04) exceeds that with thick-section MR cholangiography, and marginally (p < 0.08) exceeds that with maximum-intensity-projection MR cholangiography.

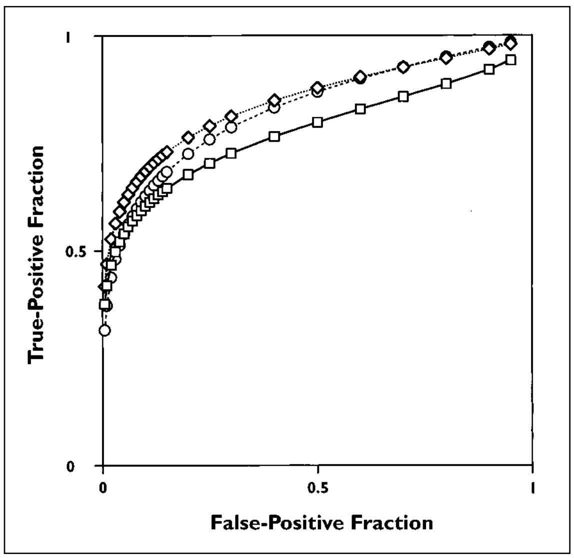


Fig. 7.—Graph shows receiver operating characteristic curves for detection of bile duct calculi by radiologist 3 for maximum-intensity-projection (□) (A_z = 0.777), volume-rendered (◇) (A_z = 0.848), and thick-section (○) (A_z = 0.830) MR cholangiography. Observer performance with volume-rendered MR cholangiography marginally ($p <$ 0.08) exceeds that with maximum-intensity-projection MR cholangiography.

higher observer performance. Observer performance with volume-rendered MR cholangiography was significantly superior to that with thick-section MR cholangiography even though volume-rendered MR cholangiography was interpreted without referring to its source images in this study. Had the volume-rendered MR cholangiography and its source images been reviewed together, the observer performance might have been better than that yielded by volume-rendered MR cholangiography alone.

Image quality was generally inferior with volume-rendered MR cholangiography. Image sharpness deteriorated with volume-rendered and maximum-intensity-projection MR cholangiography, especially in patients whose irregular respiration caused blurring of the source images. To remedy this, the source images may be obtained during breath-hold using a half-Fourier RARE sequence. However, the respiratory-triggered fast spin-echo sequence was preferred because an adequate number of thin sections covering the entire biliary system could be obtained, and the contrast was well preserved even with 3-mm section thickness. We frequently experienced substantial blurring of source images obtained with a breath-hold half-Fourier RARE sequence, which may have been caused by the patient's imperfect respiratory suspension. Image contrast was inferior with volume-rendered MR cholangiography, probably because we set the opacity at 15%; 85% of the light penetrated the voxels, resulting in transparent images that were often ghostlike compared with maximum-intensity-projection MR cholangiograms. Regarding the depiction of fine structures, the peripheral intrahepatic bile ducts were poorly depicted with volume-rendered MR cholangiography compared with maximum-intensity-projection MR cholangiography. The low setting of opacity percentage might be related to the poor depiction of fine anatomic structures with volume-rendered MR cholangiography.

There are some limitations to this study. The 17 patients with choledocholithiasis and eight with cholecystlithiasis alone underwent ERCP for the confirmation of disease, but the remaining 18 patients with cholecystlithiasis alone did not. Ideally, proof of cholelithiasis is obtained at ERCP or intraoperative direct cholangiography. However, noninvasive MR cholangiography is often substituted for diagnostic ERCP, and intraoperative cholangiograms are not obtained in the event that laparoscopic cholecystectomy is performed. Thirty-six of the 43 patients in the current study had cholecystlithiasis; this high prevalence of cholecystlithiasis might have led the radiologists, who were unaware of the patients' histories, to an interpretation bias toward the frequent positive findings of choledocholithiasis. The significance in sensitivity and specificity in our study was limited because of the exclusion of all patients without biliary calculi.

The three radiologists reviewed reconstructed MR cholangiograms alone, without referring to their source images. Although it is common to refer to source images of MR cholangiography or transaxial T2-weighted images in the clinical setting, we deliberately avoided having the radiologists review the source images to achieve a net comparison of volume-rendered and maximum-intensity-projection MR cholangiography. We could not completely blind the off-site radiologists to the types of imaging sequences because each sequence had specific imaging features. The off-site radiologists invited from other institutions did not have any clinical experience with volume-rendered MR cholangiography, whereas they had routinely interpreted maximum-intensity-projection and thick-section MR cholangiography at their institutions. Such unfamiliarity with volume-rendered MR cholangiography might have affected the observer performance and assessment of image quality. However, the diagnostic accuracy with volume-rendered images might have been higher had the radiologists been accustomed to interpreting volume-rendered images. Finally, although we limited our study to the evaluation of MR cholangiography for the detection of choledocholithiasis, the usefulness of volume-rendered MR cholangiopancreatography for the diagnosis of pancreaticobiliary disease caused by malignancy, inflammation, or congenital disorder should be further evaluated.

In conclusion, observer performance for volume-rendered MR cholangiography tended to exceed that of maximum-intensity-projection MR cholangiography in sensitivity and exceeded thick-section MR cholangiography in specificity in the diagnosis of choledocholithiasis. The receiver operating characteristic study showed a trend toward the superiority of volume-rendered MR cholangiography over maximum-intensity-projection and thick-section MR cholangiography. The volume-rendering technique is recommended rather than the maximum-intensity-projection technique for reconstruction of MR cholangiography for the diagnosis of choledocholithiasis.

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