TECHNICAL NOTE

MR Virtual Endoscopy for Biliary Tract and Pancreatic Duct

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Developments in magnetic resonance (MR) equipment and techniques have been remarkable. Especially, respiratory-triggered three-dimensional MR cholangiopancreatography (3D-MRCP) has been developed to provide images with high spatial resolution of the biliary tract and pancreatic duct. These 3D data can be employed in MR virtual endoscopy (MRVE) with volume rendering to visualize the lumina of the gallbladder, bile duct, and pancreatic duct. To observe the changes in the lumina with threshold settings on a workstation, we made an original phantom with tubes 2, 3, and 6 mm in internal diameter. We examined the changes in luminal diameter using several threshold settings by comparing the actual internal diameters to determine an appropriate threshold setting, which we then applied in 50 clinical cases, including pancreatic tumors, hepatic tumors, and biliary tract stones. We obtained MRVE images of the gallbladder, bile duct, and pancreatic duct to assess the clinical usefulness of this method. In the phantom study, a value identical to the actual luminal diameter could be obtained with a threshold of less than 20%. In all clinical cases, we obtained MRVE images of the gallbladder, bile duct, and pancreatic duct using the threshold we had determined appropriate and scored the diagnostic usefulness in each region. The MRVE images of the biliary tract provided much supplementary information, including the presence of stones and of duct invasion by the malignancy as well as visualization of the post-stenotic portion. MRVE images of the gall bladder did not significantly improve diagnosis ($P=0.311$), but those of the bile and pancreatic ducts did ($P<0.05$). In addition, MRVE may aid navigation during cholangioscopy. Thus, MRVE is a clinically useful technique for examining lesions of the biliary tract and pancreas.

Keywords: *biliary tract, cholangiopancreatography, magnetic resonance virtual endoscopy, pancreatic duct, threshold*

Introduction

Magnetic resonance cholangiopancreatography (MRCP) with respiratory-triggered three-dimensional fast advanced spin echo (3D-FASE) can provide excellent images with high spatial resolution.¹ These 3D data can be used with MR virtual endoscopy (MRVE) with volume rendering to visualize the lumina of the gallbladder, bile duct, and pancreatic duct.²⁻⁹ In MRVE, it is important to determine the optimum threshold for actual observation of the lumina of the structures of interest. Un-

der suboptimal threshold settings, the internal aspect is disturbed and visualized inappropriately. In this study, we made an original phantom to optimize the threshold settings to perform MRVE, applied the determined optimal setting in a study of 50 clinical cases, and obtained MRVE images of the gallbladder, bile duct, and pancreatic duct. In addition, we discuss the clinical usefulness of MRVE.

Materials and Methods

Phantom study

We made an original phantom with tubes 2, 3, and 6 mm in internal diameter, filled the lumina with distilled water, and covered the phantom with

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chicken liver. The phantom was then placed in a container filled with copper sulphate solution, and MR images were obtained (Fig. 1).

We used the 1.5T Excelart Vantage XGV Power Plus Package (Toshiba Medical Systems, Tokyo, Japan) with a QD torso parallel imaging (SPEEDER) 8-channel coil. The pulse sequence was the T₂ plus (fast recovery) method in which a -90° radio-frequency (RF) pulse was applied after data acquisition of 3D-FASE. Parameters were: 384 × 384; slice thickness 2 mm; field of view (FOV) 35 cm; 2 shots; 1.8 SPEEDER factor; echo train length (ETL) 94; echo time shifting (ETS) 12.5 ms; and 40 partitions. We changed repetition time (TR) within the 3,000- to 8,000-ms range.

The raw data were transferred onto a workstation, and MRVE images were obtained with AZE Virtual Place, Version 3.00 (AZE, Tokyo, Japan). On the MRVE images of the phantom, the threshold was changed from 10 to 60%, with the peak threshold of the signal defined as 100%. The internal diameters of the tubes were measured on the workstation at several threshold settings and compared with the actual internal diameters. We also made and compared MRVE images when TR was changed over the range of 3,000 to 6,000 ms and measured the internal diameter of each tube.

Clinical study

Fifty patients (23 men, 27 women; average age 64.4 ± 13 years old) were examined to investigate the clinical usefulness of the present method. The study population comprised 11 patients with intraductal papillary mucinous neoplasm (IPMN),

seven with pancreatic tumors, seven with cholangiocarcinoma, six with gallstones, four with chronic pancreatitis, two with liver tumors, two with gallbladder cancers, two with common bile duct

Fig. 1. Original phantom
A: The phantom was covered with chicken liver. **B:** Phantom with tubes 2 mm, 3 mm, and 6 mm in internal diameter. **C:** Scheme of the phantom (arrows indicate the lesions in the lumina).

Fig. 2. Appearance of the tube lumen at several threshold settings
A: Distribution of signal values. **B:** Threshold = 100%. **C:** Threshold = 70%. **D:** Threshold = 50%.

stones, three others, and six with no abnormal findings. Endoscopic retrograde cholangiopancreatography (ERCP) was also performed in 23 of the 50 cases. The pulse sequence and parameters were the same as in the phantom study, but TR varied from 2,500 to 6,700 ms as a result of respiratory gating. Imaging time ranged from 2 min 49 s to 5 min 50 s.

The raw data were transferred onto a workstation, and MVRE images were obtained with AZE Virtual Place, Version 3.00. Using the optimum threshold obtained in the phantom study, we obtained MRVE images of 40 gallbladders, 48 bile ducts, and 47 pancreatic ducts. Visualization of the

lumen and the clinical usefulness of the MRVE images in each region were compared with ERCP and/or MIP and coronal MPR images of the MRCP and categorized by 2 radiologists and a surgeon into 5 grades after consultation: excellent (5), good (4), equal (3), poor (2), and very poor (1). In comparison with ERCP and/or MIP and coronal MPR images of MRCP, appropriate visualization of the lumina and more definite identification of lesions were defined as “excellent.” If there was some supplementary information in the region, evaluation of “good” was made. If no supplementary information was obtained, evaluation was

Fig. 3. Measurement of the diameter at each threshold
A: Internal diameter of 3 mm. **B:** Internal diameter of 6 mm.

Fig. 4. Appearance of the tube lumen with a particular threshold (10%) at several repetition times (TR)
A: TR = 3,000 ms. **B:** TR = 4,000 ms. **C:** TR = 5,000 ms. **D:** TR = 6,000 ms.

“equal.” When the MRVE image was poor, it was categorized as “poor.” When the MRVE image was suboptimal and could not be evaluated, it was categorized as “very poor.” Statistical analysis was performed by Wilcoxon’s signed rank test.

Results

Phantom study

The diameters of the tubes 3 and 6 mm in internal diameter were measured with several threshold settings on the workstation (Figs. 2 and 3). In the tubes 3 mm in diameter, the measured internal di-

Fig. 5. Appearance of the tube lumina 2, 3, and 6 mm in internal diameter with particular repetition time (TR) and threshold (TR = 4,000 ms, threshold = 10%). **A:** 2 mm. **B:** 3 mm. **C:** 6 mm.

Fig. 6. A 65-year-old man with gallstones
A: Appearance of the lumen with the threshold setting (60%). **B:** Threshold = 60% in signal distribution. **C:** Appearance of the lumen with optimized threshold setting (10%). **D:** Threshold = 10% in signal distribution.

ameter was almost identical to the actual diameter, with a threshold less than 20% except when TR was 3,000 ms. In the tubes 6 mm in diameter, the measured internal diameter was almost equivalent to the actual diameter at the 10% threshold for every TR. We obtained MRVE images changing the TR over the range of 3,000 to 6,000 ms at the 10% threshold (Fig. 4), and the images were equivalent in quality. In the MRVE images of the tubes 2, 3, and 6 mm in internal diameter, with TR of 4,000 ms and 10% threshold, appropriate visualization of the lumen of the tube 2 mm in internal diameter was possible (Fig. 5).

Clinical study

Although various MRVE images were obtained by changing the threshold setting, appropriate MRVE images were obtained with a 10% threshold (Fig. 6). In evaluation of visualization of the lumen and the clinical usefulness of MRVE images for each region, the MRVE images of the bile ducts provided a great deal of supplementary information. Although there was no significant difference in diagnostic improvement by obtaining MRVE images of the gallbladder ($P=0.311$), there was in images of the bile and pancreatic ducts ($P<0.05$) (Fig. 7) (Table).

Fig. 7. Clinical usefulness of magnetic resonance virtual endoscopy (MRVE) in 50 cases.

Table. Average visual scores

	Number of cases	Rating
Gallbladder	40	3.1 ± 0.8
Bile duct	48	3.2 ± 0.6^a
Pancreatic duct	47	3.4 ± 0.9^a

Two radiologists and a surgeon visually rated the magnetic resonance virtual endoscopy (MRVE) images. Values are means $\pm$ standard deviation (SD).

^a Differences with MRVE were statistically significant ($P<0.05$).

Fig. 8. A 48-year-old man with gallstones

A: Three-dimensional magnetic resonance cholangiopancreatography (3D-MRCP) (MIP image). **B:** MPR image. **C:** Magnetic resonance virtual endoscopy (MRVE) image of the gallbladder neck. **D:** MRVE image of the gallbladder fundus. MRVE images showed gallstones as protruding structures that were not identified on MRCP, but were vaguely visualized on coronal MPR.

Although MRVE images of the gall bladder showed no significant diagnostic usefulness, the localization of gallstones and polyps in the lumen could be visualized well on these images (Fig. 8). In addition, irregular narrowing of the gallbladder lumen by gallbladder cancer was observed in 3 dimensions. MRVE images of the bile ducts allowed intraluminal observation of the local stenosis or occlusion, intraductal solitary or multiple masses, hepatic duct anomaly and confluence of the cystic duct (Fig. 9). In addition, dilatation of the distal hepatic duct and tumor invasion were observed on MRVE images, and retrograde visualization of the post-stenotic duct was possible (Fig. 10). These MRVE findings were compatible with the cholangioscopic findings in some cases in which cholangioscopy was also performed and were useful for navigation during this procedure (Fig. 10).

Intraluminal observation of the local stricture of the pancreatic duct and other elements was possible in MPVR images of the pancreatic duct. Communication between the cystic portion of IPMN and the

pancreatic duct was visualized on MRVE images (Fig. 11).

Discussion

In the present study, we investigated the clinical usefulness of MRVE using volume rendering to depict the lumina of the gallbladder, bile duct, and pancreatic duct using 3D-MRCP data. MRVE is a useful method to visualize the anatomy of the lumina of the gallbladder, bile duct, and pancreatic duct and can also be applied to other clinical procedures, such as visualization of vascular compression of the cranial nerve and navigation for laparoscopic surgery.^{10,11} However, the threshold setting on the workstation is critical to obtain useful MRVE images. Because the appearance of the lumen on the MRVE images depends on the threshold setting, optimized threshold is essential.¹²

We made an original phantom with tubes 2, 3, and 6 mm in internal diameter to optimize the threshold. The measured internal diameter of the

Fig. 9. A 60-year-old man with gallbladder and common bile duct stones
A: Three-dimensional magnetic resonance cholangiopancreatography (3D-MRCP). A common bile duct stone and accessory hepatic duct were seen. The confluence of the accessory hepatic duct is unclear. **B:** Endoscopic retrograde cholangiopancreatography (ERCP). The accessory hepatic duct was seen. **C:** Magnetic resonance virtual endoscopy (MRVE) image. The confluence of the accessory hepatic duct was clearly observed at the proximal cystic duct (arrow). **D:** MRVE image. A stone was also seen in the cystic duct (arrow).

Fig. 10. A 50-year-old woman with mucin-producing cholangiocarcinoma **A:** Endoscopic retrograde cholangiopancreatography (ERCP). **B:** Three-dimensional magnetic resonance cholangiopancreatography (3D-MRCP) (MIP image). **C:** Magnetic resonance virtual endoscopy (MRVE) image at the bifurcation. **D:** Cholangioscopic image. **E:** MRVE image showing the same region as cholangioscopy. Tumor invasion in the common and left hepatic duct was well visualized on the MRVE image (**C**). Cholangioscopy showed the stenotic portion at the left hepatic duct (**D**). The same findings were visualized on MRVE images (**E**).

tube 3 mm in diameter was almost identical to the actual diameter at thresholds less than 20%, except with TR of 3,000 ms. Therefore, it should be noted that the measured diameter may be different from the real value in MRVE obtained with shorter TR and lower signal-to-noise ratio (SNR). The measured internal diameter of the tubes 6 mm in diameter was almost equivalent to the actual diameter at the 10% threshold. Although the measured value of tubes larger than 6 mm in internal diameter tended to be greater than the actual value, the measured internal diameter was almost equivalent to the actual value at the 10% threshold in our preliminary examination with tubes of this size.

The phantom with tubes 2, 3, and 6 mm in internal diameter could be depicted well by MRVE images with 2-mm slice thickness, 384×384 imaging matrix, and 0.9×0.9 mm pixels. Clinical application of MRVE seems practical as the normal lumina of the gallbladder, bile duct, and pancreatic duct are larger than those used in this phantom study.

In the clinical study, MRVE images of 50 cases were available and provided supplementary information. MRVE is less invasive than ERCP and is independent of operator skill. In addition, MRVE provides more distal images to the completely occluded duct and allows simultaneous observation of the bile and pancreatic ducts and repeated obser-

Fig. 11. A 75-year-old man with intraductal papillary mucinous neoplasm (IPMN)

A: Three-dimensional magnetic resonance cholangiopancreatography (3D-MRCP) (MIP image). **B and C:** Magnetic resonance virtual endoscopy (MRVE) images. The MRVE images showed communication between the cystic portion of the IPMN and the pancreatic duct in **B** and the internal appearance of the cystic portion in **C**.

vation if needed. MRVE may be a useful method to assist and navigate invasive ERCP or cholangioscopy. Hirano reported that visualization of aberrant bile ducts and cystic ducts on MR cholangiography was unsatisfactory because of overlap between the duodenum and hepatic ducts.¹³ However, we could clearly determine the anatomical relationship of the accessory hepatic duct using MRVE in one case.

Because it is used for MRVE, obtained 3D data should not be disturbed by blurring. We used a 1.5T machine (Excelart Vantage XGV Power Plus Package; Toshiba Medical Systems Inc.) with a maximum gradient magnetic field of 33 mT/m, 200 mT/m/ms slew rate, and QD Torso parallel imaging (SPEEDER) 8-channel receiving coil. The imaging sequence was a combination of the 3D-FASE and fast recovery methods, in which a -90° RF pulse was applied after acquisition of 3D-FASE. Use of imaging parameters of 2 shots and SPEEDER factor 1.8 improve SNR, reduce blurring and improve the quality of 3D-MRCP images.^{14,15} However, problems in spatial resolution may prevent detection of minute pathological changes.

In clinical practice, MRVE is not always required

for MR diagnosis of biliary tract and pancreatic duct disease because, unlike cholangioscopy, this method does not allow observation of changes in duct color and biopsy. However, our study results indicated that with further development of hardware and software, MRVE may be useful as a new diagnostic technique and for navigation in cholangioscopy.

Conclusions

In this study, we obtained MRVE imaging using 3D-MRCP data and performed a phantom study and investigated its clinical application. The phantom study revealed that the measured internal diameter of the tubes was almost equivalent to the actual value using an optimized threshold (20% or less), and the lumina of tubes at least 2 mm in diameter could be observed. In the clinical study, the MRVE images obtained using the appropriate threshold provided supplementary information, such as anatomical relationships, presence of protruding lesions, and observation of the post-stenotic portion and retrograde observation of the stenotic portion from the distal duct.

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