Preoperative evaluation of pancreaticobiliary tumor using MR multi-imaging techniques

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INTRODUCTION
Pancreaticobiliary tumor is a common clinical disease. Currently, the only potential cure for pancreaticobiliary tumor is surgery. Early diagnosis and accurately preoperative assessment of tumor resectability are fundamental to achieve a successful treatment. For a long time, ultrasonography (US), computed tomography (CT), direct cholangiopancreatography, including endoscopic retrograde cholangiopancreatography (ERCP) or percutaneous transhepatic cholangiography (PTC), and conventional angiography are main imaging modalities for diagnosing and staging of pancreaticobiliary tumor. With recent technical advances in the field of MR imaging, such as rapid cross-sectional sequences, MR cholangiopancreatography (MRCP) and 3D dynamic contrast-enhanced MR angiography (3D DCE MRA), MR multi-imaging techniques have provided a non-invasive, safe and simple method in the preoperative diagnosis and evaluation of pancreaticobiliary tumor. The purpose of this study was to establish the MR multi-imaging techniques and to evaluate the clinical value of the synthetical MR imaging protocol.

MATERIALS AND METHODS
Patients
The study subjects included 28 patients (13 men and 15 women, mean age 64.9 years, range 28-83 years). The most common symptoms were abdominal discomfort, loss of weight and obstructive jaundice. All patients underwent US, enhanced or unenhanced CT scan and MR multi-imaging examination. In addition, ERCP was also performed in three patients, but the ERCP imaging did not display the entire pancreaticobiliary duct tree. Sixteen patients had explorative laparotomy from 1 to 30 d (mean 10 d) after MR examination. Twelve patients had intervention or palliative drainage (one endoscopic stent, one percutaneous transhepatic drainage and 10 actinotherapy or chemotherapy) because of the unresectability diagnosed preoperatively by various imaging modalities. Among the 28 patients, the final diagnoses were 17 cases as pancreatic adenocarcinomas, 8 cases of biliary system carcinoma and 3 cases of non-neoplastic lesions (Table 1).

MR multi-imaging protocol
MR imaging was performed with a 1.0T superconductive unit (Philips Gyrosan T10-NT, software version 4.6.2) containing a body coil. MR examination was performed after the patients had fasted for 8-10 h. The patients were examined in the supine position and abdominal band compression. MR multi-imaging protocol included cross-...
sectional imaging, MRCP and 3D DCE MRA. The parameters of MR multi-imaging techniques are shown in Table 2. The total imaging time was approximately 40 min. Cross-sectional scan included T1- and T2-weighted images with spin-echo (SE) or turbo spin-echo (TSE) sequence. Non-breath-hold respiratory trigger (RT) and/or fat suppression (spectral saturation inversion recovery, SPIR) techniques were also used. Upper abdominal axial images were obtained through the liver and pancreas. The axial images served as guides to locate the MRCP examination. MRCP was performed with a coronal, multi-slice, heavily T2-weighted TSE sequence with RT and fat suppression techniques. The source images were 3D reconstructed by using a maximum-intensity-projection (MIP) algorithm to create a rotating radial display. The 3D DCE MRA used a single 22 s breath-hold, coronal, fast field-echo (FFE) sequence. A dose of 30-45 mL contrast agents, gadopentetate dimeglumine (Gd-DTPA), was injected through antecubital vein by hand in a bolus at a rate of 2-3 mL/s, followed by flushing with 20 mL physiologic saline solution. Three imaging sets were consecutively acquired. The images from each scan were viewed both as individual slices and after post-processing with MIP algorithm.

**Imaging analysis**

By careful review of the cross-sectional MR images and of the source and MIP reconstructed images obtained from MRCP and 3D DCE MRA examination, the study contents included the diagnosis of pancreaticobiliary tumor, the definition of the range of tumor infiltration and the prospective assessment of the surgical resectability with MR multi-imaging techniques. According to the tumor staging TNM classification, the signs of unresectability of pancreaticobiliary tumor were as follows: (1) Major abdominal vascular involvement (portal, splenic and superior mesenteric veins, celiac axis, etc), including encasement, occlusion and tumor thrombosis; (2) Tumor adjacent organs or tissues infiltration, but excluding the simply extension into duodenum; (3) The presence of distant metastases or peritoneal carcinomatosis, particularly liver metastasis and ascites; (4) Regional and distant lymph node involvement (larger than 1 cm in diameter) or lymphadenopathy. If none of these criteria were found, the tumor was regarded as resectable.

**Statistical analysis**

When compared the results of resectability assessing of pancreaticobiliary tumor using MR multi-imaging protocol with the outcomes of surgical and US or CT findings, we evaluated the clinical value of MR multi-imaging techniques in diagnosing the pancreaticobiliary tumor and in judging the range of tumor involvement, statistically calculated the sensitivity, specificity, overall accuracy, positive and negative predictive value in assessing the surgical resectability, and analyzed the causes of false-positive and false-negative interpretation. The diagnostic consistency between MR multi-imaging techniques and CT was also calculated by using Kappa test. Using the image fusion software (Analyza 3.0), the MIP reconstructed images of MRCP and 3D DCE MRA were combined in 10 patients.

**RESULTS**

**Tumor diagnosis and analysis**

Of the 28 patients with pancreaticobiliary diseases, MR multi-imaging techniques allowed correct diagnosis of 25 pancreaticobiliary tumors, including 17 cases of pancreatic adenocarcinoma, 6 of cholangiocarcinoma and 2 of gall bladder carcinoma. The overall diagnostic accuracy was 89.3% (25/28). The remaining three cases were misdiagnosed as pancreatic head carcinoma, but the histological diagnoses from explorative laparotomy and surgical biopsy confirmed focal chronic pancreatitis in two cases and one choledocholithiasis with muddy stones.

In all 25 patients with pancreaticobiliary tumors, MRCP demonstrated the dilatation of pancreatic duct and bile duct

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**Table 1** Pancreaticobiliary diseases (n = 28)

| Pancreaticobiliary diseases | Number of cases |
|-----------------------------|-----------------|
| Pancreatic head carcinoma   | 14              |
| Pancreatic body carcinoma   | 3               |
| Gall bladder carcinoma      | 2               |
| Hilar cholangiocarcinoma    | 3               |
| Common bile duct carcinoma | 3               |
| Chronic pancreatitis        | 2               |
| Common bile duct stone      | 1               |

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**Table 2** MR multi-imaging technique parameters

| Protocol angulation | T1WI/SPIR transversal | T2WI/SPIR transversal | T2WI coronal | MRCP coronal | DCE MRA coronal |
|---------------------|-----------------------|-----------------------|--------------|--------------|-----------------|
| Sequence            | TSE/SE                | TSE                   | TSE          | TSE          | FFE             |
| TR (ms)             | 575/500               | 1 800                 | 1 800        | 2 000        | 11              |
| TE (ms)             | 12/15                 | 99/80                 | 100          | 700          | 2.5             |
| FOV (mm)            | 345/375               | 345                   | 435          | 395          | 450             |
| Matrix              | 176×256               | 203×256               | 202×256      | 190×256      | 164×512         |
| No. of slices       | 16                    | 16                    | 18           | 50           | 50              |
| Thickness (mm)      | 10                    | 10                    | 6            | 2            | 2               |
| Gap (mm)            | 1                     | 1                     | 0.6          | 0            | 0               |
| Fast factor         | 4/-                   | 18/14                 | 23           | 101          | –               |
| NSA                 | 5/2                   | 4                     | 4            | 2            | 1               |
| Respiratory         | Trigger               | Trigger               | Trigger      | Trigger      | Breath-hold     |

TR: time of repeat; TE: time of echo; FOV: field of view; NSA: number of signal average.
tree. Mass lesions were identified with MR cross-sectional technique at the location of pancreaticobiliary obstruction. The lesions were hypointense on T1WI and isointense to mildly hyperintense on T2WI. The T2-weighted fat-suppressed imaging was particularly useful for the evaluation of tumor extension, liver metastases and lymph node involvement. In 17 patients with pancreatic adenocarcinoma, the hypointense mass lesions were more conspicuous against a background of hyperintense normal pancreatic tissue on T1-weighted fat-suppressed images. On the source images of 3D DCE MRA, the pancreatic adenocarcinoma appeared more conspicuous on early-phase of the post-contrast images.

**Detection of range of tumor invasion**

MR multi-imaging techniques correctly identified the tumor extension into adjacent organs of liver, stomach and duodenum in 15 patients, 4 liver metastases, 5 peritoneal carcinomatosis and ascites, and 10 lymph node and 8 arterial involvements (Table 3). The portal vein system involvement was clearly visualized on the reconstructed images of 3D DCE MRA in 17 of 20 patients, including 6 cases of venous encasement, 8 of occlusion, 1 of tumor thrombosis and 2 of the formation of lateral circulation (Table 3). Therefore, the accuracy of MR multi-imaging techniques in detecting the range of pancreaticobiliary tumor invasion was 80.3% (57/71) (Table 3).

**Table 3** Detection of range of pancreaticobiliary tumor invasion

| MR finding                  | Final diagnosis | Percentage (%) |
|-----------------------------|----------------|----------------|
| Adjacent organ infiltration | 15             | 17             | 88.2           |
| Liver metastases            | 4              | 5              | 80.0           |
| Lymph node involvement      | 10             | 13             | 76.9           |
| Arterial involvement        | 8              | 13             | 61.5           |
| Portal venous involvement   | 17             | 20             | 85.0           |
| Peritoneal carcinomatosis    | 3              | 3              | 100.0          |
| Total                       | 57             | 71             | 80.3           |

**Tumor resectability assessment**

Of 25 patients with pancreaticobiliary tumor verified by surgical or synthesitical imaging findings, MR multi-imaging techniques correctly diagnosed 5 of 6 resectable tumors with 1 case of false-negative interpretation and 17 of 19 unresectable tumors with 2 of false-positive interpretation. Therefore, the sensitivity, specificity, accuracy, positive and negative predictive value of MR multi-imaging techniques in assessing the resectability of pancreaticobiliary tumors were 83.3%, 89.5%, 88.0%, 71.4%, and 94.4%, respectively (Table 4).

The false-negative case was pancreatic head carcinoma. The enencasement of superior mesenteric vein was detected by 3D DCE MRA, whereas the tumor underwent successful resection because it was only adherence to vessel without invasion. In two false-positive cases (one pancreatic head carcinoma and one cholangiocarcinoma), MR examination underestimated the portal venous and mesenteric vessels involvement by tumors, which were confirmed at surgery. In addition, of 17 cases with unresectability, some lymph node and arterial involvement or small liver metastases were not detected, but the tumors were also considered unresectable by MR assessment because of the presence of other signs of unresectability.

**Table 4** Assessment of resectability of pancreaticobiliary tumor (n)

| MR multi-imaging techniques | Final diagnosis |
|-----------------------------|----------------|
|                            | Resectability | Unresectability |
| Resectability               | 5             | 2             |
| Unresectability             | 1             | 17            |

1True-positive, 2Negative-positive, 3False-negative, 4True-negative.

**Comparison of MR with CT in tumor resectability assessment**

The comparison of MR multi-image techniques with CT examination in assessment of tumor resectability of 25 cases is shown in Table 5. The uniform results of evaluation were found in 21 cases, including 6 of resectability and 15 of unresectability. There was well diagnostic consistency between MR multi-imaging protocol and CT examination (κ = 0.64, U = 7.95, P<0.01).

**Table 5** Comparison between MR and CT in tumor resectability assessment (n)

| MR multi-imaging techniques | CT diagnosis |
|-----------------------------|--------------|
|                            | Resectability | Unresectability |
| Resectability               | 6             | 1              |
| Unresectability             | 3             | 15             |

**Image fusion of MRCP and MRA**

The fusion images were successfully obtained by combining the MIP reconstructed images of MRCP and 3D DCE MRA in 10 patients with pancreaticobiliary tumor. The fusion image intuisionistically exhibited the spatial anatomical relationship between mass lesions and the pertinent surrounding structures and clearly visualized the range of tumor involvement of pancreaticobiliary duct tree and portal venous system, which provided more useful information for the planning of surgical operation.

**DISCUSSION**

US and CT are the first modalities in the field of pancreaticobiliary imaging[4-8]. With recent technical advances, the synthesitical MR multi-imaging protocol, including cross-sectional MR imaging with or without fat-suppressed technique, MRCP and 3D DCE MRA has provided a non-invasive, safe and simple method in the accurate diagnosis and preoperative evaluation of pancreaticobiliary tumor[4-8].

Our study showed that of the 28 patients with pancreaticobiliary tumor, MR multi-image techniques could correctly diagnose 25 cases and the overall accuracy was
89.3%. The mass lesions were hypointense on T1WI and isointense to mildly hyperintense on T2WI. Pancreaticobiliary tumors appeared as slowly continuous enhancement and were best detected on early phase of post-contrast dynamic images, reflecting the fact that the tumor was desmoplastic lesion with sparse vascularity and tends to enhance less than the capillary-rich surrounding parenchyma[8-11]. The T2-weighted fat-suppressed imaging was particularly useful for the evaluation of tumor extension, liver metastases and lymph node involvement. Due to the presence of aqueous protein in the acini of the pancreas, rich endoplasmic reticulum and high manganese content of the pancreatic cells, pancreatic adenocarcinomas were best detected on T1-weighted fat-suppressed images[12-14]. However, the results from our study also suggested that the identification of small pancreatic tumor with focal chronic pancreatitis sometimes might be very difficult even with dynamic MR studies[20-22].

MRCP is the fundamentally new innovation in MR imaging of the pancreaticobiliary diseases. Advocated by German researcher Wallner BK and his group in 1991[23], the imaging quality and the diagnostic ability of MRCP have been improved increasingly with continued technologic advancements. MRCP is a non-invasive, safe, simple method without the ionizing radiation and injection of contrast agents. In most clinical situations, MRCP may replace direct cholangiopancreatography (ERCP or PTC) as a diagnostic tool[8,13,19,20]. In our study of 28 cases, MRCP satisfactorily demonstrated the pancreaticobiliary duct obstruction and dilation with different degree, including three patients in whom ERCP was shown incompletely. Therefore, MRCP may provide an optimal imaging alternative when direct cholangiopancreatography is unsuccessful or inadequate[24-26]. The literature indicates that the overall sensitivity and specificity of MRCP in diagnosing the obstruction of pancreaticobiliary ducts was 95% and 97% respectively[24,25]. The accuracy in diagnosing the location of obstruction was 96%, and the sensitivity and specificity in differentiating malignant from benign pancreaticobiliary obstruction were 88% and 95%, respectively[24-26]. For pancreaticobiliary tumor, MRCP can define the location and morphological characteristics of pancreaticobiliary obstruction as well as evaluate the range of tumor involvement and the surgical resectability. MRCP also helps to provide valuable information to determine the best approach for palliative drainage or endoscopically placed stent in the patients with unresectable tumors.

The MR angiography (MRA) technique has recently become available for non-invasive vascular imaging[26-28]. Non-enhanced MRA, including time-of-flight (TOF) and phase-contrast (PC) technique, is the first means of demonstrating vessels but is limited by its long data acquisition time, motion and flow artifact, and in-plane saturation. Since first reported by Prince et al.[29], contrast enhanced MRA technique has demonstrated that it is more suitable for evaluation of the vascular structures due to the advantages of without flow artifact and saturation effects.

It has been reported that 3D DCE MRA can clearly demonstrate both intra- and extra-hepatic portal venous system and its lateral circulation, and also display portal vein, hepatic vein and inferior vena cava on one same image, which reflects the whole route of tumor metastases through blood circulation[30,31]. Repeated sequences after administration of contrast agents allow separate demonstration of the abdominal arteries and portal veins. In addition, the source images simultaneously demonstrate parenchymal lesion of the liver, pancreas, biliary tract and reflect the dynamic enhancement characteristics of tumor. The evaluation of both MIP reconstructed and source MRA images, as well as the morphological cross-sectional MR images (both T1WI and T2WI, with or without fat-suppressed technique), provided detailed information on vessel anatomy and the relationship of the tumor with vascular wall. Our study showed, the accuracy of 3D DCE MRA in assessing the involvement of portal venous system was 85.0%, but the accuracy in detecting the arterial involvement was only 61.5%. The reason of the low accuracy for 3D DCE MRA is that the involvement of portal venous system was 85.0%, but the accuracy in detecting the arterial involvement was only 61.5%. The reason of the low accuracy for 3D DCE MRA in assessing the arterial involvement might be the long signal acquisition time due to the limit of the MR unit we used, and the demonstration of portal vein interfered the differentiation of arteries system.

Pancreaticobiliary tumors are considered unresectable, if invasion or encasement of any of the vascular structures is present or if there is liver metastasis, peritoneal carcinomatosis, lymphadenopathy or extension into the adjacent organs (excluding the duodenum). By far, the main index of resectability, in the absence of distant metastases, is the patency and absence of infiltration of the major abdominal vessels[32-34]. MR multi-imaging techniques can not only improve the diagnostic ability of pancreaticobiliary tumor, but also assess the surgical resectability[37-41]. In our study, the sensitivity, specificity, accuracy and negative predictive value of the “all-in-one” protocol in assessing the surgical resectability were 83.3%, 89.5%, 88.0%, and 94.4%, respectively. There was also well diagnostic consistency between MR multi-imaging techniques and CT examination (κ=0.64, P<0.01). But our study also showed the positive predictive value of tumor resectability was only 71.4%. The main explanation might be the misestimation of the abdominal vessel involvement by 3D DCE MRA. In addition, the accuracy of MR multi-imaging techniques tend to underestimate the degree in diagnosing the lymph node and arterial involvement, which were 76.9% and 61.5%, respectively. However, it can be believed that with the fast development of MR equipment and software, the clinical value of MR multi-imaging techniques may be improved increasingly.

The image fusion technique could clearly exhibit the source, location and range of tumor lesions, and the spatial relationship between the mass and pertinent surrounding structures. Using special software approaches, the fusion image might even combine the morphological anatomy images, such as CT or MRI, and the metabolic function images, such as positron emission tomography or single photon emission computed tomography, which would provide more valuable information for helping in diagnosing and tumor staging and planning the proposal of surgical operation[42,44].

In summary, MR multi-imaging protocol integrates the advantages of various special imaging techniques. MR cross-sectional images can demonstrate the nature of tumor lesion
and the range of tumor involvement. MRCP can visualize the whole pancreaticobiliary tree and the location and degree of duct obstruction. 3D DCE MRA can exhibit the spatial relationship between the mass lesion and pertinent structures and the range of vessel invasion. Therefore, the non-invasive “all-in-one” MR multi-imaging techniques may provide comprehensive information needed for the preoperative diagnosis and evaluation of pancreaticobiliary tumor, which otherwise can be obtained only by performing three different examinations, including ERCP or PTC, CT and angiography (Figure 1).

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