Insulinoma is the most common islet cell tumor of the pancreas, although it is a rare tumor. The diagnosis is usually made on the basis of the classical clinical symptomatology and laboratory investigation, described as Whipple’s triad (symptoms of hypoglycemia, concomitant plasma glucose of <45 mg/dl (<2.2 mmol/liter), and relief of symptoms with sugar intake). In past, the pre-operative localization is not needed because of relatively poor sensitivities of non-invasive imaging technologies and the sensitivity for localization using intraoperative US with palpation can approach nearly 100%. However, potential curative treatment of insulinomas can be achieved only with surgical resection, and most surgeons attempt to localize the tumor pre-operatively. Until now, the utility of pre-operative localization of insulinomas continues to be debated about what localization procedure or combination of localization procedures should be used. Dynamic magnetic resonance (MR) imaging is one of the common non-invasive pre-operative radiologic techniques used in the evaluation of islet cell tumors including insulinoma. Nevertheless, pre-operative MR detection of insulinoma is not highly sensitive (45-77%) because of the smallness of the tumour. The development of MR techniques now allows high-resolution images to be obtained during multiphase enhanced-gadolinium technique, especially with a Sensitive Encoding (SENSE) coil. The sensitivity and specificity of insulinoma detection by the newer MR technique could be greater, but few publications reported them. The purpose of our study was to determine the efficacy of advanced MR with SENSE coil to localize insulinoma and describe the MR features of insulinoma.

MATERIALS AND METHODS

Our institutional review board approved this retrospective study without requiring informed consent. Over a 3-year period (March 2003-July 2006), 13 consecutive patients (5 men, 8 women) suspected of having insulinomas on the basis of clinical symptoms and laboratory
data underwent surgery (n = 2, distal pancreatectomy; n = 8, enucleation; n = 1, partial pancreatic resection; n = 2, biopsy on liver metastases) were enrolled in this study. Histologic proof was obtained in all cases. The patient’s age at the time of diagnosis ranged 19 to 76 years.

All MR examinations were performed with commercially available 1.5 T MR imagers (Philips, ACS-NT, maximum gradient performance, 30-mT/m amplitude; slew rate, 150 T/m/sec). All patients underwent T1-weighted in-phase gradient recalled echo (GRE), T2-weighted with short taut inversion recovery (STIR). After T1-weighted (T1W) and T2-weighted (T2W) images were obtained, the pre-, dynamic post-gadolinium (Gd) 3-dimension (3D) T1-weighted gradient-echo MR images were performed during an intravenous bolus administration of 0.1 mmol/kg of gadolinium-based contrast material (Magnevist; Schering, Berlin). Delayed enhanced T1-weighted GRE images with fat suppression (FS) were obtained 20, 70 and 120 sec after the administration of contrast material.

Detailed parameters for the MR imaging sequences were the following: (a) T1-weighted GRE sequence, (TR/TE = 100/4.6, Flip angle = 80 degree, matrix = 224 x 512, FOV = 375, slice thickness = 5 mm, no gap, and 10-second acquisition time) (b) T2-weighted inversion recovery sequence, (TR/TE = 1,600/100, NSA = 1, TSE factor = 24, FOV = 375, slice thickness = 5 mm, gap = 1 mm, matrix = 249 x 512, inversion time = 160-180 sec, and 20-35-second acquisition time) (c) Pre- and post-3D dynamic breath-hold enhanced gradient-echo T1-weighted sequence, 4.7/2.3, 10° flip angle, 213 x 512 matrix, 4 mm section thickness, -2 mm intersection gap, one signal acquired, and 18-27-second acquisition time.

Image interpretation in tumor detection was performed in both primary pancreatic lesions and assessment of distant metastases (especially hepatic metastases) which is important in the evaluation of islet cell tumors. On the basis of findings in the surgical pathology reports, we attempted to determine the true number and location of all tumors in all patients. We also attempted to correlate the anatomic and imaging findings of the histopathologically proved tumors as accurately as possible to allow detection of false-positive readings.

On all the MR images, one of the investigators (P.F.) read out as the presence or absence of a tumor. If tumors were considered to be present in the pancreas on any sequences of MR image, the number and location of tumors were recorded. In addition, the signal intensity of the tumors was described as hypo-, iso-, or hyperintense relative to that of the adjacent normal pancreatic parenchyma in all sequences. The sensitivity, positive predictive value (PPV), and false positive (FP) of detecting tumor on each pulse sequence were calculated.

RESULTS

At surgery, 13 insulinomas between 5.6 and 30 mm. in maximal diameter (mean 13.7 mm) were found, 7 were smaller than or equal to 1 cm and 6 were larger than 1 cm in maximal diameter. Two were located at the head, two at the uncinate process, one at the neck, 2 at the body, and 6 at the tail. All lesions were detected by surgeons with intraoperative US combined palpation, based on preoperative imaging.

Regarding tumor detection with MR images, 12 of 13 were prospectively identified and only one cannot be confidently detected, located at the uncinate process on surgery. The false negative rate of tumor detection is 7.7%. The sensitivity of the complete set of MR imaging in detecting insulinoma was 92.3% with a 100% positive predictive value (Fig 1).

Regarding tumor detection on different MR techniques, Table 1 showed the distribution of MR findings and sensitivity of each MRI sequence. On dynamic 3D-GRE Gd images, six insulinomas (3: homogenous arterially enhancing, 2: heterogenous arterially enhancing, and 1: homogenous portal enhancing) were identified. The sensitivities in tumor detection on different MR techniques were 30.7% on in-phase T1-weighted images, 61.5% on T2-weight images with fat suppression technique (Fig 2.3), 76.9% on pre-contrast 3D-GRE T1-weighted images (Fig 4), and 46.1% on dynamic 3D-GRE Gd images.

Table 2 shows the sensitivity of lesion detection in each sequence. The sensitivity of tumor detection obtained by both T2-weight images with fat suppression technique and pre-contrast 3D-GRE T1-weighted images were the highest ones (91.7%) with the same detecting sensitivity by the complete set of MR images.

Two patients had evidence of liver metastases at presentation (Fig 5).

DISCUSSION

Previously, no imaging modalities were recommended because of their unreliable results when intraoperative ultrasonography was available for the pre-operative localization of insulinoma. Currently technical advance of imaging modalities are challenging the radiologists to depict more and smaller lesions. And also the pre-operative localization of insulinoma becomes necessary

![Fig 1. Typical MR findings of insulinoma: (a) Transverse T1-weighted GRE image shows a 8-mm lesion (arrow) at the tail of pancreas (p). (b) Transverse breath-hold T2-weight FSE with STIR image also demonstrates small insulinoma (arrow) as high signal intensity. (c) Transverse pre-contrast 3D-GRE image shows the lesion as low signal intensity (arrow). (d) Transverse pre-contrast 3D-GRE image with gadopentetate dimeglumine enhancement shows the enhancing mass (arrow) of high signal intensity than adjacent normal enhancing pancreatic parenchyma (p).](image-url)
for many surgeons because 10-20% of cases were missed during surgical exploration. However, until now the most effective imaging modality of detecting insulinoma in the exact location are under discussion because of a great variety in success rates for localization of the tumor in each modality depending on tumor size, position, vascularity, and imaging protocol as well as experience of radiologists.

Regarding MR insulinoma localization, the exact role of MR imaging in detection of insulinomas has still to be determined because of varying sensitivities on different MR sequences and machines. MRI is considered the most accurate non-invasive technique for demonstrating insulinomas and we have proposed this diagnostic modality as the first choice for preoperative imaging.

The sensitivity of MR imaging in the detection of pancreatic insulinoma has been reported to range widely, from 24% to 100%, depending on the variable techniques used. Our overall sensitivity reported nearly 100% on lesions greater than 1 cm. in diameter and 90% on lesions less than 1 cm. in diameter with 100% of positive predictive value. The excellent MR results in our study might be from the better MR techniques by using a SENSE coil that enables a faster imaging sequence, higher signal-to-noise ratios, thinner slice thicknesses and superior imaging of gadopentetate dimeglumine enhancement. The thinner slice thickness with SENSE has become possible to facilitate visualization of smaller lesions by improving spatial resolution and minimizing volume averaging.

In our study, we presumed that the causes of one missed lesion could be its smallness and having iso-signal intensity with the normal pancreatic parenchyma which is definitely hard to detect on MR images. Generally, tendency of the false-negative interpretation might be from a tumor which lies close to enhancing vessels, and having signal intensity similar to normal pancreatic parenchyma in all sequences. Therefore, we suggest that the MR interpretations are used with care for false-positive and false-negative findings. Overall they have improved the rate of lesion detection.

As we know, different MR techniques can show the different sensitivities of tumor localization. Some investigators reported the different sensitivity of each MR sequence. T1-weighted SE sequence with fat suppression was reported as the best sequence for depicting small islet cell tumors including insulinoma. In our study, we found that each MR technique

### TABLE 1. MR imaging features and sensitivity of each MRI sequence of 13 insulinomas.

<table>
<thead>
<tr>
<th>Sequence</th>
<th>MR Imaging Features</th>
<th>Seen</th>
<th>Signal intensity</th>
<th>Not seen</th>
</tr>
</thead>
<tbody>
<tr>
<td>In-phase T1-weighted images</td>
<td></td>
<td>4 (30.7%)</td>
<td>0</td>
<td>9 (69.3%)</td>
</tr>
<tr>
<td>T2-weight images with fat suppression technique</td>
<td></td>
<td>2 (15.4%)</td>
<td>6 (46.2%)</td>
<td>5 (38.5%)</td>
</tr>
<tr>
<td>Pre-contrast 3D-GRE T1-weighted images</td>
<td></td>
<td>10 (76.9%)</td>
<td>0</td>
<td>3 (23.1%)</td>
</tr>
<tr>
<td>Dynamic 3D-GRE Gd images</td>
<td></td>
<td>6 (46.1%)</td>
<td>7 (55.9%)</td>
<td></td>
</tr>
</tbody>
</table>
shows the different results of sensitivity for tumor detection. All sequences can demonstrate all large lesions (>20 mm) in contrary to the smaller lesions can be demonstrated on only some sequences or even only on one sequence. However, currently we use T1-weighted in-phase GRE images replaced with T1-weighted SE sequence with fat suppression to reduce breathing artifact with faster imaging time. Also our T1-weighted in-phase GRE images showed low sensitivity because of low conspicuity and thick slices. Recently, Thoeni et al., found pre-contrast spoiled GRE sequences are the accurate sequences which had the ability of islet cell tumor detection as the same number of lesions detected with T1-weighted SE sequence with fat suppression, but using the shorter acquisition time. Similar to our results using SENSE coil, our pre-Gd 3D-GRE technique for masking images, with using thinner slices and the shorter acquisition time, showed the good sensitivity (75%) for depicting insulinoma the same as T2W with fat suppression sequence and much greater than the sensitivity of the T1-weighted GRE sequence. It is thought that high conspicuity of the lesion compared to the normal part of the pancreas in this sequence could be an advantage of the 3D GRE sequence which allows thinner images with good spatial resolution.

**TABLE 2.** Sensitivity of combined MRI sequences.

<table>
<thead>
<tr>
<th>MR technique</th>
<th>Seen</th>
<th>Not seen</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-contrast 3D-GRE T1-weighted images and dynamic 3D-GRE Gd images</td>
<td>10 (76.9%)</td>
<td>3 (23%)</td>
</tr>
<tr>
<td>In-phase T1-weighted images and dynamic 3D-GRE Gd images</td>
<td>6 (46.1%)</td>
<td>7 (53.8%)</td>
</tr>
<tr>
<td>In-phase T1-weighted images and T2-weighted images with fat suppression technique</td>
<td>8 (61.5%)</td>
<td>5 (38.5%)</td>
</tr>
<tr>
<td>In-phase T1-weighted images and pre-contrast 3D-GRE T1-weighted images</td>
<td>10 (76.9%)</td>
<td>3 (23.1%)</td>
</tr>
<tr>
<td>T2-weighted images with fat suppression technique and pre-contrast 3D-GRE T1-weighted images</td>
<td>12 (92.3%)</td>
<td>1 (7.7%)</td>
</tr>
</tbody>
</table>
the complete set of MR images with Gd enhancement which confirmed the prior study16 which showed the gadolinium-enhanced sequences are needed only on equivocal or negative MR imaging results.

This study has some limitations. We had a small group of insulinomas because of their rarity.

CONCLUSION

Recent advanced MR imaging is one of the sensitive imaging modalities for detecting the presence of insulinoma. Combined pre-contrast 3D GRE sequence and T2-weighted images with fat suppression are the essential recent MRI protocol. Dynamic Gd-enhanced protocol is required to confirm the lesion in the case of equivocal pre-contrast MR.

REFERENCES