



**Non-invasive investigation of exocrine pancreatic function:  
Feasibility of cine dynamic MRCP with a spatially selective  
inversion-recovery (IR) pulse**

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Non-invasive investigation of exocrine pancreatic function: Feasibility of cine dynamic  
MRCP with a spatially selective inversion-recovery (IR) pulse

**Manuscript Type:** Original Research



### Abstract

**PURPOSE:** To investigate the feasibility of non-contrast-enhanced cine dynamic MRCP with a spatially selective inversion-recovery (IR) pulse for evaluating exocrine pancreatic function in comparison with N-benzoyl-L-tyrosyl-p-aminobenzoic acid (BT-PABA) test as a pancreatic exocrine function test.

**MATERIALS AND METHODS:** Twenty subjects with or without chronic pancreatitis were included. MRCP with a spatially selective IR pulse was repeated every 15 seconds for 5 minutes to acquire a total of 20 images (cine-dynamic MRCP). The median and mean frequency of the observation (the number of times) and the moving distance (mean secretion grading scores) of pancreatic juice inflow on cine-dynamic MRCP were compared with BT-PABA test.

**RESULTS:** The urinary PABA excretion rate (%) had significant positive correlations with both the mean secretion grade ( $r=0.66$ ,  $P=0.002$ ) and frequency of secretory inflow ( $r=0.62$ ,  $P=0.004$ ) in cine dynamic MRCP. Both the mean frequency of observations of pancreatic secretory inflow ( $1.4\pm 1.6$  times versus  $14.3\pm 4.2$  times,  $P<0.001$ ) and the mean secretion grade (grade= $0.16\pm 0.24$  versus grade= $1.81\pm 0.81$ ,  $P<0.001$ ) was significantly lower in chronic pancreatitis group than in normal subject group.

**CONCLUSION:** Cine dynamic MRCP with a spatially selective IR pulse may have a potential for estimating the pancreatic exocrine function noninvasively as a substitute of BT-PABA test.

**Key words:** Cine dynamic MRCP; pancreas; MR imaging; chronic pancreatitis; pancreatic exocrine function

## INTRODUCTION

Assessment of exocrine pancreatic function is important for the diagnosis of chronic pancreatitis as well as for decision-making regarding appropriate treatment. Although several diagnostic techniques have been developed, the secretin test, which has been standardized as a duodenal or pancreatic ductal intubation method that samples and analyzes pancreatic juice directly, is considered the gold standard for evaluating exocrine pancreatic function (1-3). However, the use of this method is restricted to only a few specialized centers because duodenal or pancreatic ductal intubation is invasive and unpleasant for patients, and is methodologically difficult for clinicians to perform. In contrast, there are a number of non-invasive pancreatic exocrine function tests, such as the fecal chymotrypsin (FC) test, the fecal elastase-1 (FE1) test or the N-benzoyl-L-tyrosyl-p-aminobenzoic acid (BT-PABA) test, all of which measure exocrine pancreatic function indirectly either by studying enzyme levels in the stool or enzyme products in the urine (4-6).

Regarding functional assessment with imaging modalities, several studies have reported that secretin-stimulated magnetic resonance cholangiopancreatography (MRCP) may have the potential to assist in evaluating exocrine pancreatic function by monitoring main pancreatic duct size and duodenal filling after pancreatic hormonal stimulation with secretin (7-12). However, this technique is limited to the assessment under non-physiological (secretin-stimulated) conditions, and has some drawbacks including the additional cost of secretin and the potential for adverse events (13). Additionally, it is difficult to obtain secretin products commercially in our country. Recent studies have shown that the secretory flow of pancreatic juice can be directly and noninvasively visualized as a high-signal-intensity inflow within the tagged area at frequent intervals in normal subjects by means of non-pharmacological, non-contrast-enhanced cine-dynamic MRCP with a spatially selective inversion recovery (IR) pulse (14, 15). This simple, physiological and non-invasive method

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3 enables us to evaluate the flow of pancreatic fluid within the main pancreatic duct in a unit of  
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5 time, and may allow estimation of exocrine pancreatic function. The purpose of the present  
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7 study was to investigate the feasibility of non-contrast-enhanced cine-dynamic MRCP with a  
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9 spatially selective IR pulse for evaluating exocrine pancreatic function in subjects with or  
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11 without chronic pancreatitis in comparison with the BT-PABA (6) test as the only currently  
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13 available pancreatic exocrine function test using a synthetic peptide in our country.  
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## 18 **MATERIALS AND METHODS**

### 19 **Study Population**

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22 The protocol of this study was approved by our institutional review board. The study  
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24 was a retrospective analysis that included a subset of subjects (volunteers) who had  
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26 participated in another prospective institutional review board–approved study in which all  
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28 participants had provided informed consent. A waiver of informed consent for the pooled  
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30 analysis in the current retrospective study was approved by our institutional review board.  
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32 From our MR imaging database system, we searched for subjects who underwent abdominal  
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34 MR examination including cine-dynamic MRCP using spatially selective IR pulse between  
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36 August 2011 and August 2014. Among these, we identified 10 patients with clinically  
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38 diagnosed chronic pancreatitis who underwent the BT-PABA test as an exocrine pancreatic  
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40 function test (the chronic pancreatitis group). The diagnosis of chronic pancreatitis was based  
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42 on the Japanese clinical diagnostic criteria for chronic pancreatitis revised in 2010 (16). Nine  
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44 patients had definite chronic pancreatitis with irregular dilatation of the main pancreatic duct  
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46 and irregular dilatation of pancreatic duct branches of variable intensity with scattered  
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48 distribution throughout the entire pancreas, as seen on endoscopic retrograde  
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50 cholangiopancreatography (ERCP). One patient had possible chronic pancreatitis with  
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52 repeated upper abdominal pain, continuous heavy drinking of alcohol equivalent to >80g/day  
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3 of pure ethanol and dilatation of the main pancreatic duct plus pancreatic deformity with  
4 irregular contour, but without characteristic endoscopic ultrasound findings. Additionally, we  
5 identified 10 subjects who underwent the BT-PABA test, and were finally diagnosed as  
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7 having no pancreatic disease (the normal subjects group) in the same period. These subjects  
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9 were volunteers who were recruited as part of other studies during the study period and who  
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11 did not have any symptoms or signs of pancreatic, hepatobiliary, renal, or other diseases.  
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13 Exclusion criteria in the present study were: 1) cannulation in the pancreatic duct, 2) history  
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15 of surgical procedure of the pancreatobiliary system, and 3) unclear main pancreatic duct due  
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17 to motion artifact. Ultimately, the present study included a total of 20 subjects with or without  
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19 chronic pancreatitis (1 woman, 19 men; mean age, 49.9 years; age range 25–76 years) who  
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21 underwent both cine-dynamic MRCP with a spatially selective IR pulse and an exocrine  
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23 pancreatic function test (BT-PABA test).  
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### 32 **MR Imaging Technique**

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34 MR imaging was carried out using a 1.5-T magnet (EXCELART Vantage™ powered  
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36 by Atlas, Toshiba Medical Systems, Tochigi, Japan), equipped with quadrature-detected  
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38 phased array coils (16 channels with 32 elements) (Atlas SPEEDER™ Body combined with  
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40 Atlas SPEEDER Spine; Toshiba). The subjects were required to fast for at least 5 hours  
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42 before the MR examination. At the beginning of the MR examination, each subject orally  
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44 ingested 36 mg of manganese chloride tetrahydrate (MCT) (Bothdel Oral Solution 10 (a  
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46 package of 250 mL); Kyowa Hakko Kirin, Tokyo, Japan) to reduce the signals from the  
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48 bowel.  
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52 Cine-dynamic MRCP with a spatially selective IR pulse was performed as part of our  
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54 pancreatobiliary MR protocol. First, a two-dimensional (2D) thick-slab MRCP image with fat  
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56 suppression technique was obtained during a single breath-hold by using a fast advanced spin  
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3 echo (FASE) sequence to demonstrate the main pancreatic duct in the coronal plane (Fig. 1).  
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5 Imaging parameters of this sequence were as follows; TR/TE=4000/500 msec, echo train  
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7 spacing=6.5 msec, echo train length=172, slice thickness=50 mm, matrix=320x320, field of  
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9 view (FOV)=32x32 cm, bandwidth=488 Hz, parallel imaging factor=2, and number of  
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11 acquisition=1. Using this MRCP as a reference image, a spatially selective IR pulse (inversion  
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13 time=2200 msec) with width of 20 mm was placed on the pancreas head as perpendicularly as  
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15 possible in order to observe the movement of the pancreatic juice in the main pancreatic duct.  
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17 Based on our preliminary experience, an inversion time of 2200 msec was determined to  
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19 nullify the signal of static pancreatic juice. An MRCP image with a spatially selective IR  
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21 pulse using the same MRCP sequence was obtained in 4 seconds during a respiratory  
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23 suspension. All subjects were instructed to start their breath-hold at the end of expiration  
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25 when a scan was begun. With this method, the static pancreatic juice in the area of a spatially  
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27 selective IR pulse appears dark because the signal of static pancreatic juice is nulled (Fig. 2).  
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29 Conversely, when the pancreatic juice is secreted and flows in the pancreatic duct, inflow of  
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31 the pancreatic juice is observed as a high signal within the area of a spatially selective IR  
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33 pulse (Fig. 3) because the fully-magnetized pancreatic juice enters into the area of the IR  
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35 pulse from the caudal side of the pancreatic duct. MRCP with a spatially selective IR pulse  
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37 was repeated every 15 seconds (scanning: 4 seconds, rest: 11 seconds) for 5 minutes to  
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39 acquire a series of single-shot images (a total of 20 images), and the images were  
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41 demonstrated in a cine-dynamic fashion (cine-dynamic MRCP). The 15-second imaging  
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43 interval was designed to allow time for breathing between each acquisition and to wait for  
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45 recovery of longitudinal magnetization.  
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52 In using the BT-PABA test as an exocrine pancreatic function test, the first morning  
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54 urine was collected as control after an overnight fast. Then, subjects were orally given a 500-  
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56 mg dose of BT-PABA reagent (Eizai Co., Ltd., Tokyo, Japan) in about 200 mL of water, and  
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3 the urinary PABA excretion rate (%) was calculated from a 6-hr urine collection. The mean  
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5 time interval between performance of cine-dynamic MRCP and the BT-PABA test was  
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8  $42.3 \pm 74.7$  days (range: 0–213 days).  
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### 10 11 12 **Image Analysis**

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14 Cine-dynamic MRCP images were evaluated independently by two experienced  
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16 radiologists who specialized in abdominal imaging (A.K., K.Y.; 10 and 6 years of experience,  
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18 respectively) on a picture archiving and communication system workstation monitor  
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20 (Rapideye Core; Toshiba Medical Systems, Tochigi, Japan). The image sets on each patient  
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22 were presented to the readers in random order. The readers were blinded to any clinical or  
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24 laboratory information; however, they were aware that the study population included patients  
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26 with chronic pancreatitis. In cases with diagnostic discrepancies (51 of 400 images in 20  
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28 subjects), these discrepancies were resolved during a third analysis session in which a  
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30 decision was reached by consulting with third radiologist (K.I., with 24 years of experience in  
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32 abdominal radiology) as a tie-breaker. The readers were requested to evaluate how frequently  
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34 pancreatic juice flow (secretion) was observed in the pancreatic duct of each patient over the  
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36 5-minute (20 images) observation period (i.e., the number of inflow high signals depicted per  
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38 patient). Additionally, the readers assessed the distance that the pancreatic juice moved in the  
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40 pancreatic duct within the area of a spatially selective IR pulse in each image of the cine-  
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42 dynamic MRCP series, using the following secretion grading scores: grade 0 = no secretion  
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44 (no movement), grade 1 = less than 5 mm, grade 2 = 5–10 mm, grade 3 = 11–15 mm, and  
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46 grade 4 = more than 15 mm (Fig.4). The secretion grade for each subject was defined as:  
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48 (total of grade number)/20. The median and mean frequency of the observation (the number  
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50 of times) and the moving distance (mean secretion grading scores) of pancreatic juice inflow  
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52 on cine-dynamic MRCP were compared with the urinary PABA excretion rate (%) to assess  
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3 the possible role of cine-dynamic MRCP as an alternative exocrine pancreatic function test.  
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5 These cine-dynamic MRCP findings were also compared between the chronic pancreatitis  
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7 group and the normal subjects group to evaluate the difference between groups in the flow  
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9 dynamic pattern of the pancreatic juice in the pancreatic duct.  
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### 11 12 13 14 **Statistical Analysis**

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16 Statistical analyses were performed with commercially available software (SPSS for  
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18 Windows version 19.0, SPSS, Chicago, IL, USA). The relationship between the urinary  
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20 PABA excretion rate and the median and mean frequency (the number of times) of  
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22 observation and the moving distance (median and mean secretion grading score) of the  
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24 pancreatic juice inflow were assessed using Spearman rank correlation coefficient ( $\rho$ ) analysis.  
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26 The nonparametric Mann-Whitney U test was used in the comparison between the chronic  
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28 pancreatitis groups and the normal subjects group. A P value less than .05 was considered to  
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30 indicate a statistically significant difference. Interobserver agreement between the two  
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32 radiologists was evaluated by using weighted kappa statistics. We considered a kappa value  
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34 greater than 0.81 to represent excellent agreement and values of 0.61–0.80, 0.41–0.60, and  
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36 less than 0.41 to represent substantial, moderate, and poor agreement, respectively.  
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### 42 43 **RESULTS**

44  
45 In the exocrine pancreatic function test, the mean urinary PABA excretion rate was  
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47  $52.3 \pm 22.2\%$  with a range of 7.3–81.9% in all subjects. The interobserver agreement for the  
48  
49 detection of the pancreatic juice inflow and the grading of the moving distance of the  
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51 pancreatic juice with cine-dynamic MRCP was excellent (kappa value = 0.966). Hence, the  
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53 results of the final MR consensus review were used for data analysis. In cine-dynamic MRCP  
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55 with a spatially selective IR pulse, the median and mean frequencies of observations of  
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3 pancreatic juice inflow in all subjects were 5.5 and 7.9 times (range; 0–19 times), respectively,  
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5 in a series of 20 images. The median and mean secretion grades in all subjects were 0.70 and  
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7 0.99 (range; 0–3.05), respectively. Regarding the relationship between the urinary PABA  
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9 excretion rate and the secretion grade and frequency of pancreatic secretory inflow, the  
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11 urinary PABA excretion rate (%) had significant positive correlations with both the mean  
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13 secretion grade ( $r=0.66$ ,  $P=0.002$ ) and frequency of secretory inflow ( $r=0.62$ ,  $P=0.004$ ) (Figs.  
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15 5, 6).  
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19 In the comparison between the chronic pancreatitis group and the normal subject  
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21 group, the mean urinary PABA excretion rate in the chronic pancreatitis group ( $35.6 \pm 18.7\%$ )  
22  
23 was significantly lower than that in the normal subject group ( $68.9 \pm 8.6\%$ ) ( $P = 0.001$ ). In  
24  
25 cine-dynamic MRCP findings, the mean frequency of observations of pancreatic secretory  
26  
27 inflow was significantly lower in the chronic pancreatitis group than in the normal subject  
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29 group ( $1.4 \pm 1.6$  times (range; 0–4 times) vs  $14.3 \pm 4.2$  times (range; 7–19 times),  $P < 0.001$ ),  
30  
31 indicating that the pancreatic secretory flow was less frequently observed in patients with  
32  
33 chronic pancreatitis. When the frequency of observations of pancreatic secretory inflow was  
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35 lower than 5 times, chronic pancreatitis could be diagnosed with 100% accuracy. In addition,  
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37 the mean secretion grade was also significantly lower in the chronic pancreatitis group than in  
38  
39 the normal subjects group (grade =  $0.16 \pm 0.24$  (range; 0–0.60) vs grade =  $1.81 \pm 0.81$  (range;  
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41 0.80–3.05),  $P < 0.001$ ) (Table). This indicated that pancreatic juice secretion was significantly  
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43 decreased in the patients with chronic pancreatitis. A cutoff value of 0.7 for the secretion  
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45 grade in patients with chronic pancreatitis had an accuracy of 100%. In one patient with  
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47 possible chronic pancreatitis, the urinary PABA excretion rate was 71.7%, which was above  
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49 the mean value of normal subjects (68.9%), while the secretion grade and frequency of  
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51 pancreatic secretory inflow were low (0.15 and 2 times, respectively).  
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## DISCUSSION

The results of the present study showed that the secretion grade and frequency of pancreatic secretory inflow in cine-dynamic MRCP with a spatially selective IR pulse significantly and positively correlated with the urinary PABA excretion rate in the pancreatic exocrine function test. This result suggests that cine-dynamic MRCP with a spatially selective IR pulse rapidly, and in a noninvasive manner, yields results similar to those of the BT-PABA test, and may have the potential to be an alternative for the pancreatic exocrine function test. These noninvasive tests are physiological function tests designed to assess in vivo chymotrypsin activity in the duodenum (BT-PABA test) (6) or the flow of pancreatic fluid as an index of secretory volume (cine-dynamic MRCP with a spatially selective IR pulse). In the present study, it was interesting that there was a significant correlation between PABA test values and cine-dynamic MRCP findings even though the results of these two tests are independent markers of exocrine pancreatic function.

Cine-dynamic MRCP with a spatially selective IR pulse has some advantages over the BT-PABA test. The BT-PABA test requires 6 hours to collect samples, while cine-dynamic MRCP with a spatially selective IR pulse is simple and convenient, and can be performed repeatedly in the same examination. Therefore, the use of cine-dynamic MRCP with a spatially selective IR pulse may be a clinically valuable approach to assess exocrine pancreatic dysfunction.

The BT-PABA test used as a reference standard does not readily detect slight decreases in exocrine pancreatic function, and has low sensitivity and specificity (46% detection sensitivity, even in moderate exocrine pancreatic dysfunction); therefore, it has the potential to cause false-negative and false-positive results (17–19). In one patient in the present study with possible chronic pancreatitis, the patient's urinary PABA excretion rate was within normal range, while the secretion grade and frequency of pancreatic secretory

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3 inflow were low. This fact suggested that cine-dynamic MRCP with a spatially selective IR  
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5 pulse may be more sensitive to the decrease of pancreatic exocrine function than the BT-  
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7 PABA test, and may have the potential to contribute to the diagnosis of chronic pancreatitis in  
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9 the early stage.

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11 In the present study, both the mean frequency of observation of pancreatic secretory  
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13 inflow and the mean secretion grade were significantly lower in the chronic pancreatitis group  
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15 than in the normal subjects group in cine-dynamic MRCP examinations with a spatially  
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17 selective IR pulse. This fact suggests that cine-dynamic MRCP with a spatially selective IR  
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19 pulse may support the diagnosis of chronic pancreatitis based on exocrine pancreatic  
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21 dysfunction. The standard pancreatic MR examination including static MRCP has provided  
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23 morphologic information on the pancreatic duct and the parenchyma for the assessment of  
24  
25 chronic pancreatitis. This information has included irregular dilatation of the main pancreatic  
26  
27 duct and duct branches, ductal calculi, volume depletion or atrophy of the pancreas and signal  
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29 reduction of pancreatic parenchyma (20, 21). The addition of cine-dynamic MRCP with a  
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31 spatially selective IR pulse to conventional MRI including static MRCP may provide more  
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33 useful information in the diagnosis of chronic pancreatitis by a combination of morphological  
34  
35 and pancreatic exocrine functional evaluation. Further studies will be needed to determine the  
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37 cutoff values of the secretory grading score for the diagnosis and staging of chronic  
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39 pancreatitis.  
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45 In the present study, cine-dynamic MRCP with a spatially selective IR pulse was not  
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47 compared with a duodenal intubation method such as the secretin test, which has been  
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49 considered the gold standard for the evaluation of pancreatic exocrine function. The reason is  
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51 that secretin products are no longer available commercially in our country; therefore, the  
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53 secretin test could not be performed clinically. Exocrine pancreatic function includes 3  
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55 parameters: secretory volume, maximal bicarbonate concentration and amylase output.  
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3 Bicarbonate concentration is the most sensitive and specific parameter for detecting  
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5 dysfunction of the exocrine pancreas in patients with chronic pancreatitis (22). Therefore, the  
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7 disadvantage of cine-dynamic MRCP with a spatially selective IR pulse is that this technique  
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9 evaluates factors (frequency of observation of pancreatic secretory inflow and secretion  
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11 grade) related to secretory volume, not maximal bicarbonate concentrations. However, this  
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13 has not been shown to be a problem because a previous study using 130 subjects  
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15 demonstrated that the urinary PABA excretion rate correlated with the degree of abnormality  
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17 of the secretin test, and was specifically correlated with the pancreatic secretory volume ( $r =$   
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19  $0.276$ ,  $P < 0.005$ ) and maximal bicarbonate concentration ( $r = 0.336$ ,  $P < 0.001$ ) (22).  
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23 The present study was limited by the small number of patients for correlating the  
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25 urinary PABA excretion rate with cine-dynamic MRCP findings. Additionally, most of our  
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27 patients had definite chronic pancreatitis. Further studies with a large patient population  
28  
29 including patients with probable and possible chronic pancreatitis would be necessary to  
30  
31 confirm our data. Second limitation was that assessment of the inflow of the pancreatic duct  
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33 signal into the area of the suppressed signal may be subjective. However, the interobserver  
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35 agreement of the first review between the two reviewers was excellent. Third limitation was  
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37 that cine-dynamic MRCP with a spatially selective IR pulse does not evaluate stimulated  
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39 pancreatic secretion, but rather, basal secretion in the physiological fasting condition.  
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41 However, we believe that the validity of the basic conclusions from the present study is not  
42  
43 reduced by this limitation because the cine-dynamic MRCP findings showed a good  
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45 correlation with the results of the BT-PABA test as an established pancreatic exocrine  
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47 function test. Since the exocrine pancreas has a large reserve capacity, it would be interesting  
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49 in a future study to perform cine-dynamic MRCP with a spatially selective IR pulse after  
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51 secretin loading, if available, to evaluate preserved pancreatic exocrine reserve in patients  
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53 with chronic pancreatitis.  
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3 In conclusion, the results of the present study demonstrated that cine-dynamic MRCP  
4 findings with a spatially selective IR pulse had significant positive correlations with the  
5 urinary PABA excretion rate. Therefore, this technique may have the potential for evaluating  
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7 pancreatic exocrine function noninvasively in patients with chronic pancreatitis.  
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Table. Results of comparison between the normal subjects group and the chronic pancreatitis group

	Normal subjects (n=10)	Chronic pancreatitis (n=10)	P value
The mean urinary PABA excretion rate (%)	$68.9 \pm 8.6$	$35.6 \pm 18.7$	0.001
The mean secretion grade	$1.81 \pm 0.81$	$0.16 \pm 0.24$	< 0.001
The mean frequency of observations of pancreatic secretory inflow	$14.3 \pm 4.2$	$1.4 \pm 1.6$	< 0.001

**FIGURE LEGENDS**

Figure 1. A thick-slab 2D MRCP without a spatially selective IR pulse in a healthy volunteer obtained as a reference image demonstrated the overview of the pancreatobiliary system.

Figure 2. MRCP with a spatially selective IR pulse in a same healthy volunteer as Fig.1 showed the static pancreatic juice within the area of the spatially selective IR pulse (the area of 20mm width between the parallel white lines) as low signal intensity (arrow).

Figure 3. MRCP with a spatially selective IR pulse in a same healthy volunteer as Fig.1 showed the secretory inflow of the pancreatic juice as high signal (arrow) within the area of the spatially selective IR pulse (the area of 20mm width between the parallel white lines). The secretion grade was categorized as grade 2.

Figure 4. a)-d) Categorization of secretory grading score based on the distance that the pancreatic juice moved in the pancreatic duct within the area of the spatially selective IR pulse.

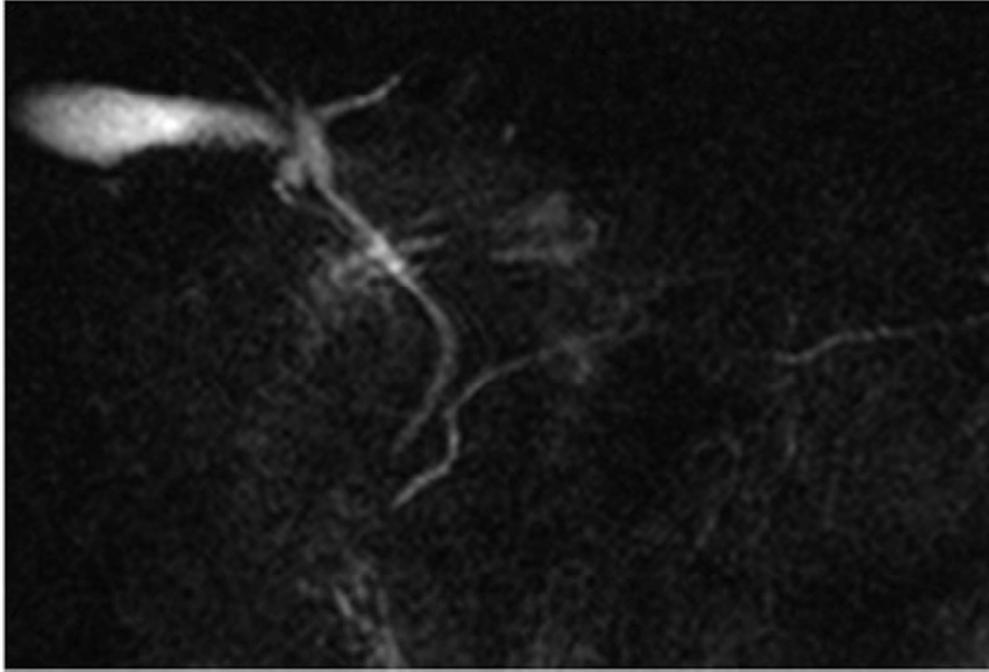
a) Grade1 (less than 5mm), b) Grade2 (5-10mm), c) Grade3 (11-15mm), and d) Grade4 (more than 15mm).

Figure 5. Correlation between the urinary PABA excretion rate (%) and the secretion grade in cine dynamic MRCP with a spatially selective IR pulse.

The urinary PABA excretion rate (%) had significant positive correlations with the mean secretion grade ( $r=0.66$ ,  $P=0.002$ ).

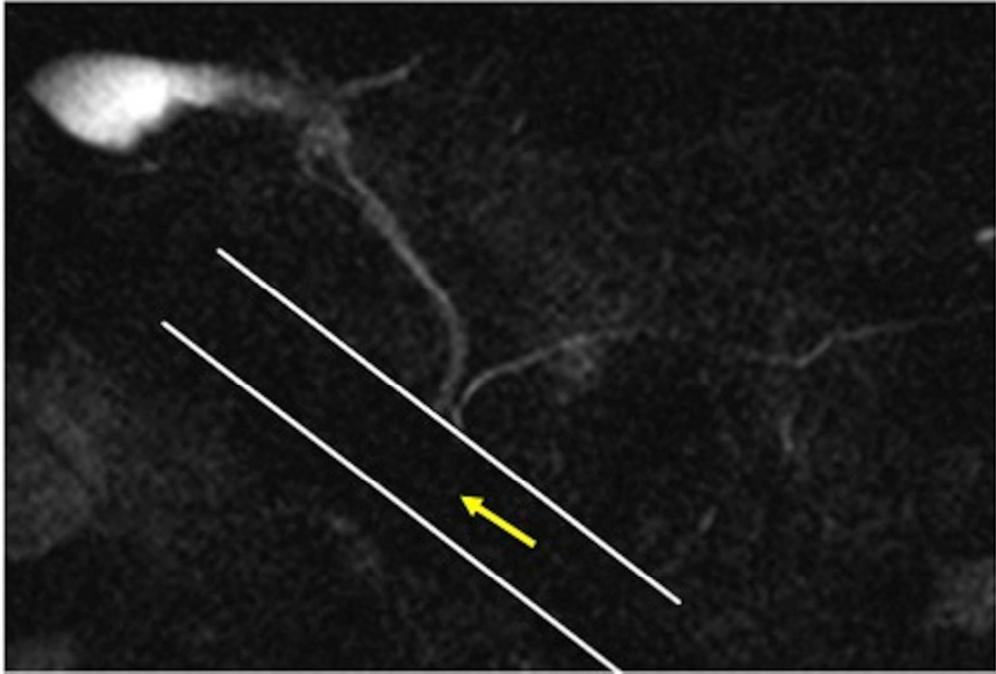
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3 Figure 6. Correlation between the urinary PABA excretion rate (%) and the frequency of the  
4 observation of pancreatic secretory inflow in cine dynamic MRCP with a spatially selective  
5 IR pulse.  
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9 The urinary PABA excretion rate (%) had significant positive correlations with the frequency  
10 of the observation of pancreatic secretory inflow ( $r=0.62$ ,  $P=0.004$ ).  
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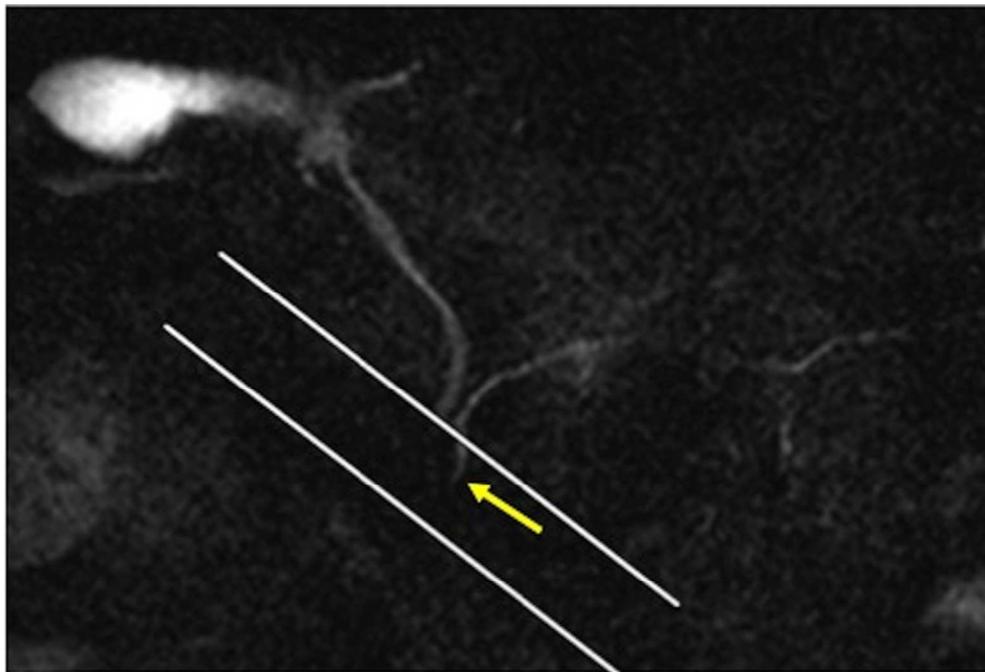
A thick-slab 2D MRCP without a spatially selective IR pulse in a healthy volunteer obtained as a reference image demonstrated the overview of the pancreatobiliary system.  
76x51mm (300 x 300 DPI)

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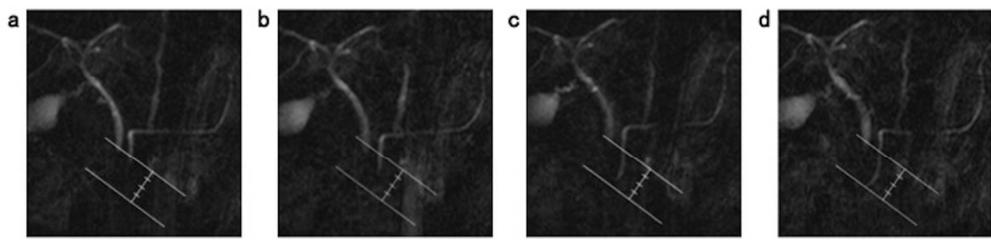
MRCP with a spatially selective IR pulse in a same healthy volunteer as Fig.1 showed the static pancreatic juice within the area of the spatially selective IR pulse (the area of 20mm width between the parallel white lines) as low signal intensity (arrow).  
76x51mm (300 x 300 DPI)

VIEW ONLY



MRCP with a spatially selective IR pulse in a same healthy volunteer as Fig.1 showed the secretory inflow of the pancreatic juice as high signal (arrow) within the area of the spatially selective IR pulse (the area of 20mm width between the parallel white lines). The secretion grade was categorized as grade 2.  
76x51mm (300 x 300 DPI)

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a)-d) Categorization of secretory grading score based on the distance that the pancreatic juice moved in the pancreatic duct within the area of the spatially selective IR pulse.  
a) Grade1 (less than 5mm), b) Grade2 (5-10mm), c) Grade3 (11-15mm), and d) Grade4 (more than 15mm).  
152x36mm (300 x 300 DPI)

PEER REVIEW ONLY

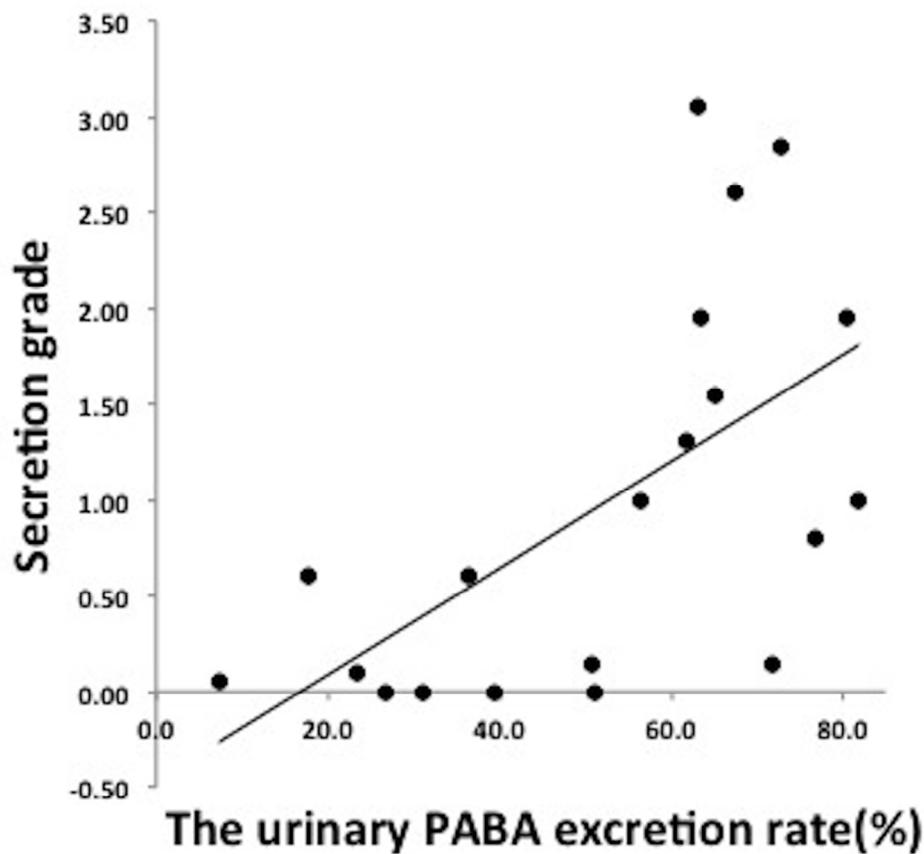


Figure 5. Correlation between the urinary PABA excretion rate (%) and the secretion grade in cine dynamic MRCP with a spatially selective IR pulse.

The urinary PABA excretion rate (%) had significant positive correlations with the mean secretion grade ( $r=0.66$ ,  $P=0.002$ ).

70x64mm (600 x 600 DPI)

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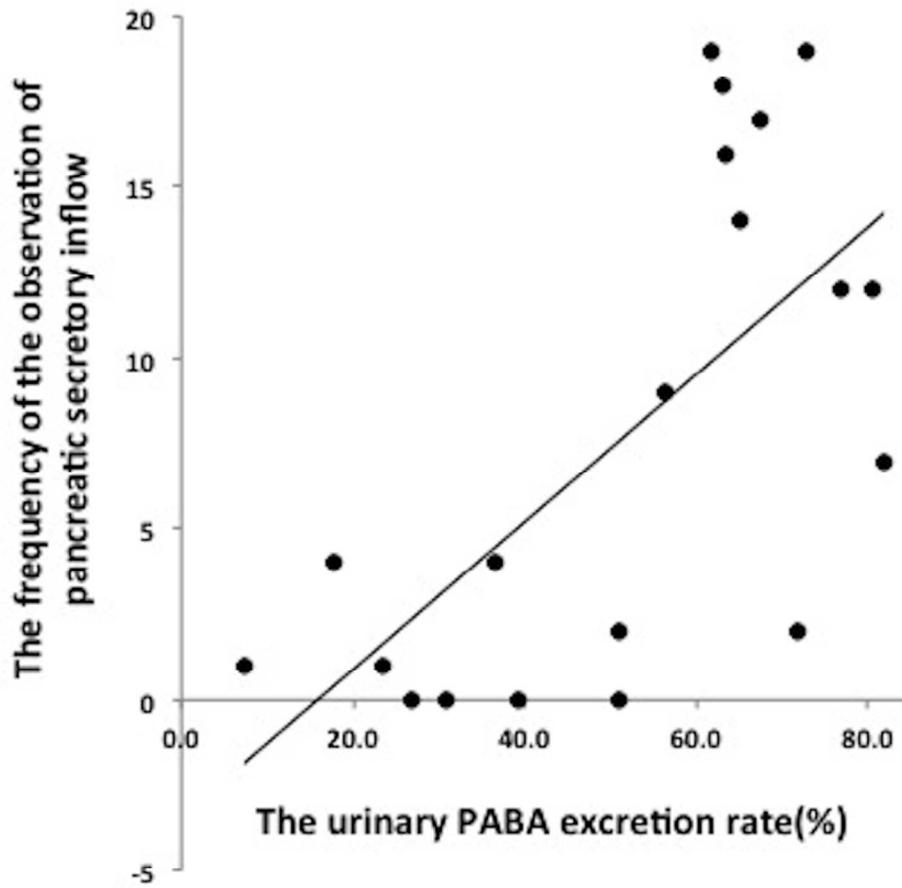


Figure 6. Correlation between the urinary PABA excretion rate (%) and the frequency of the observation of pancreatic secretory inflow in cine dynamic MRCP with a spatially selective IR pulse. The urinary PABA excretion rate (%) had significant positive correlations with the frequency of the observation of pancreatic secretory inflow ( $r=0.62$ ,  $P=0.004$ ). 75x75mm (600 x 600 DPI)