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**Abbreviation:**

ROI = region of interest

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# Pancreatic Transplants: Noninvasive Evaluation with Secretin-augmented MR Pancreatography and MR Perfusion Measurements— Preliminary Results<sup>1</sup>

Feasibility of secretin-augmented magnetic resonance (MR) pancreatography and dynamic contrast material-enhanced MR measurements for evaluation of functional status of pancreatic allografts was determined by quantifying the excretion and perfusion of the grafts. Ten patients were included prospectively before pancreatic transplantation. Dynamic T2-weighted sequences after secretin stimulation and dynamic contrast-enhanced T1-weighted gradient-echo sequences were performed. Area under the curve and maximum signal intensity-to-time ratio were determined in selected regions of interest. Biochemical parameters, Doppler ultrasonography, and/or surgery were standards for final diagnosis. Patients with normal outcome ( $n = 7$ ) produced  $236 \text{ mL} \pm 104$  (standard deviation) of pancreatic juice, and patients with dysfunctional grafts ( $n = 3$ ) produced  $42 \text{ mL} \pm 25$ . Area under the curve and maximum signal intensity-to-time ratio provided thresholds of 0.5 and 0.3, respectively, for distinction between functional and dysfunctional grafts. Secretin-augmented MR pancreatography combined with MR perfusion measurements may aid in differentiation between patients with and those without graft dysfunction.

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Simultaneous pancreas-kidney transplantation is a currently accepted valid therapeutic option for patients with insulin-dependent diabetes mellitus and end-stage

nephropathy. According to the International Pancreas Transplant Registry published in June 2002 (available at [www.iptr.umn.edu](http://www.iptr.umn.edu) and accessed August 2003), 1800 transplantations were performed in 2001. This procedure may restore normoglycemia, and restoration of normoglycemia results in the prevention of the secondary complications of diabetes and in an improvement in the quality of life (1). Despite advances in both surgical technique and postoperative management, acute rejection episodes occur in up to 60% of transplanted grafts (2). The following methods are unreliable in the detection of acute rejection: clinical and biochemical analysis, which includes blood levels of pancreatic enzymes; ultrasonography (US), with a sensitivity of 18%–58% and a specificity of 73%–100% (3–5); and computed tomography (6,7).

In patients who underwent simultaneous pancreas-kidney transplantation, the functional status of the kidney may also serve as an indicator of pancreatic rejection (8). For patients with pancreatic transplantation alone or pancreatic transplantation after kidney transplantation, however, this option does not exist. Moreover, the diagnosis of pancreatic rejection is especially difficult in the absence of kidney rejection. Therefore, pancreatic allograft biopsy is the preferred technique for evaluation of pancreatic allograft rejection or dysfunction. At percutaneous biopsy guided with US, adequate tissue samples are obtained in 89% of patients (9), but this procedure is accompanied by complications that include inflammation and abdominal bleeding (8).

Krebs et al (10) showed that dynamic contrast material-enhanced magnetic resonance (MR) imaging for evaluation of

**MR Pancreatographic Results, MR Perfusion Values, and Clinical Findings in Patients**

Patient No.	Pancreatic Output after 10 Minutes (mL)	AC*	MITR†	Amylase Level (U/L)	Lipase Level (U/L)	Creatinine Level (mg/dL)‡	Blood Glucose Level (mg/dL)§	Insulin Replacement	US Results	Histologic Findings
1	128	2.86	1.32	53	97	1.38	85	No	Homogeneous parenchyma, well perfused	Not performed
2	198	1.62	0.83	35	23	0.92	87	No	Homogeneous parenchyma, well perfused	Not performed
3	314	1.06	0.33	19	11	1.25	91	No	Homogeneous parenchyma, well perfused	Not performed
4	387	4.06	1.67	66	46	0.96	92	No	Homogeneous parenchyma, well perfused	Not performed
5	102	1.88	0.81	59	27	1.29	89	No	Not performed	Not performed
6	308	2.28	0.96	194	183	1.08	86	No	Homogeneous parenchyma, well perfused	Not performed
7	213	3.69	1.56	86	52	0.93	74	No	Homogeneous parenchyma, well perfused	Not performed
8	64	0.07	0.11	32	45	2.19	68	No	Inflammation	Chronic rejection
9	46	0.30	0.19	158	215	6.63	101	Yes	Not performed	Necrotizing pancreatitis
10	15	0.44	0.13	466	475	6.91	56	Yes	Enlarged, not well perfused	Necrotizing pancreatitis

\* AC = area under the curve.

† MITR = maximum signal intensity-to-time ratio.

‡ To convert to Système International unit (micromol per liter), multiply by 88.4.

§ To convert to Système International unit (millimol per liter), multiply by 0.05551.

graft enhancement is highly sensitive for the detection of acute pancreatic graft rejection. They calculated the mean percentage of pancreatic enhancement and demonstrated that this value is correlated with the severity of the pancreatic rejection. In some cases, however, they demonstrated an overlap in mean percentage of pancreatic enhancement between functioning and nonfunctioning grafts. Secretin-augmented MR hydrometry has been shown to be a reliable diagnostic tool in the assessment of exocrine organ function in patients with chronic pancreatitis (11, 12). Thus, the purpose of our study was to prospectively explore the feasibility of secretin-augmented MR pancreatography in combination with dynamic contrast-enhanced MR measurements for evaluation of the functional status of pancreatic allografts by quantifying the excretion and perfusion of the grafts.

**I Materials and Methods**

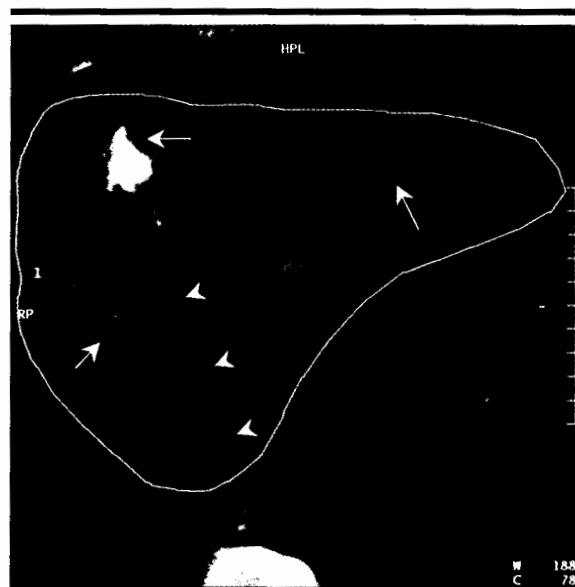
**Patients**

Among 12 patients who were undergoing simultaneous pancreas-kidney transplantation in the Department of General Surgery at the University Hospital of Philipps University, Marburg, Germany, 10 patients (four men, six women; mean age, 36.4 years ± 9.7 [standard deviation]; range, 20–54 years) were selected to be prospectively included in this preliminary study from August 2000 to July 2002. Two patients refused to take part in the study. The study protocol was approved by the institutional review board,

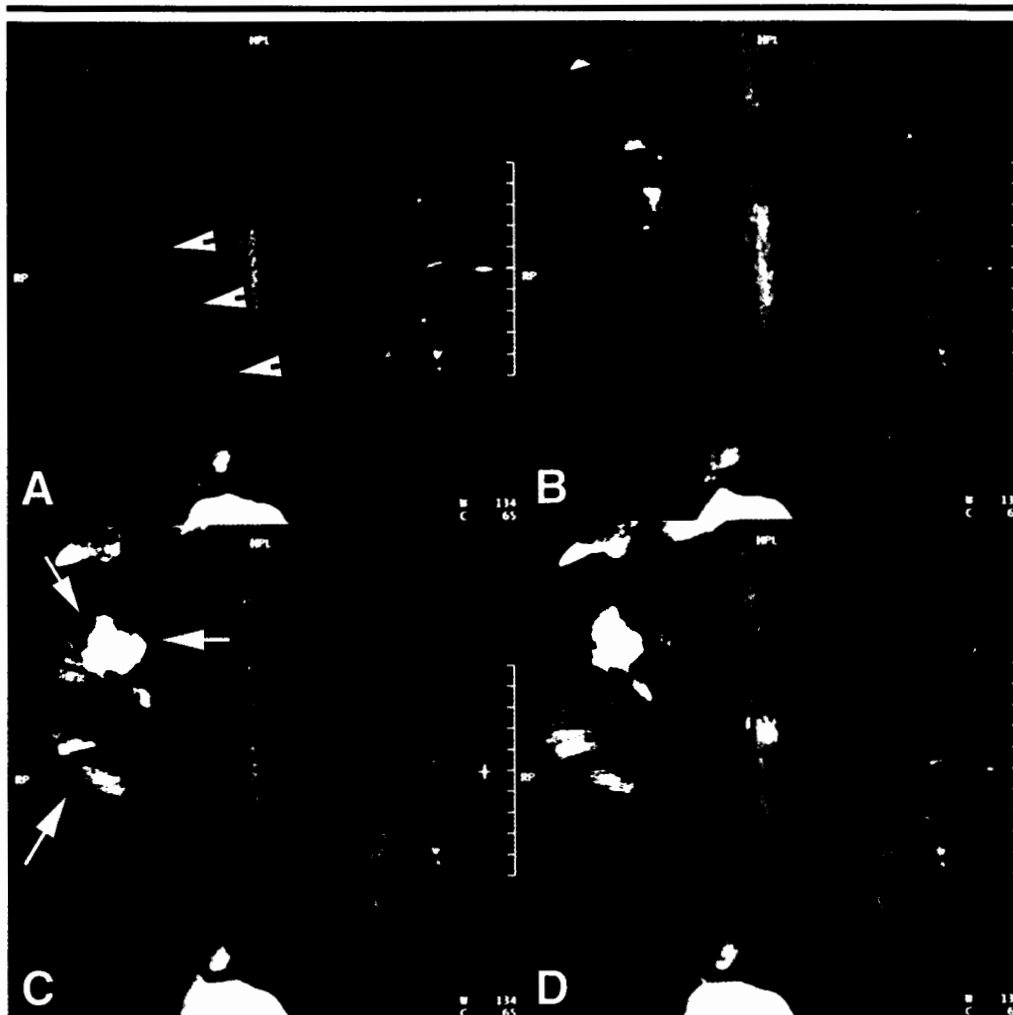
and written informed consent was obtained from all patients prior to inclusion in the study during the eligibility screening for transplantation.

All grafts were transplanted with systemic venous (inferior vena cava) and enteric (jejunal loop) drainage. All patients received standard immunosuppressive therapy. Pancreatic graft rejection was indicated by an increase in circulating blood levels of creatinine, glucose (fast-

ing), lipase, and amylase; Doppler US findings; and/or histologic findings (1). Blood analysis and Doppler US were performed within 1 day prior to or after the MR imaging measurements. Transplant parenchyma and perfusion were evaluated with US (Sonoace SA 9900; Kretz Technik, Zipf, Austria) by one investigator with 14 years of experience. Patients who did not show any signs of graft rejection were followed up clinically by a



**Figure 1.** Dynamic coronal thick-section T2-weighted fast spin-echo MR image ( $\infty/1100$  [effective]; flip angle, 150°) in 31-year-old woman (same patient as in Fig 2) shows ROI (outlined area). ROI includes graft, with pancreatic duct (arrowheads), and anastomosed small bowel (arrows).



**Figure 2.** Dynamic coronal fast spin-echo MR images ( $\infty/1100$  [effective]; flip angle,  $150^\circ$ ) obtained before and after secretin stimulation in 31-year-old woman (same patient as in Fig 1). Images were acquired every 30 seconds. Graft showed no clinical or laboratory signs of rejection. Pancreatic duct of the graft (arrowheads) was visible throughout the entire investigation. Visibility of the duct improved markedly after secretin injection. Fluid signal intensity from the draining small bowel (arrows) increased. *A*, Image obtained before secretin injection. *B*, Image obtained 180 seconds after injection. *C*, Image obtained 480 seconds after injection. *D*, Image obtained 570 seconds after injection.

nephrologist (H.E.) for at least 1 year (mean; 22 months; range, 12–33 months), and this follow-up included quarterly blood analysis of creatinine, lipase, and amylase levels. The need for insulin replacement therapy was determined with blood levels of glucose. Biopsy was not performed in any of the patients without signs of graft rejection or failure. All measured values were tabulated, and mean values with standard deviations were calculated when appropriate.

### MR Imaging

Patients were examined by using MR imaging to evaluate exocrine pancreatic function and the perfusion of the transplant between posttransplantation days

14 and 17. All examinations were performed in a 1.0-T clinical magnet (Magnetom Expert; Siemens, Erlangen, Germany) with a quadrature phased-array body coil and commercially available gradients capable of a 1200- $\mu$ sec rise time and 20 mT/m maximum gradient strength. A negative oral contrast agent was not applied in order to prevent interference between the contrast agent and secreted fluid.

After the acquisition of scout images, a fluid-sensitive fast spin-echo MR imaging sequence was selected to depict all fluid in the examination volume. A dynamic breath-hold T2-weighted single-shot fast spin-echo sequence (repetition time msec/echo time msec,  $\infty/1100$  [effective]; flip angle,  $150^\circ$ ) with a 7-second acquisi-

tion time was used. The echo train consisted of 240 echoes with an echo spacing of 9.2 msec. Single slabs with an in-plane resolution of  $1.00 \times 0.94$  mm and a voxel depth of 65 mm were acquired. The slabs were angled in a coronal oblique plane to cover the graft and adjacent small bowel. This positioning provided a summation of all fluids in the imaging volume.

After the acquisition of the first image, 1 clinical unit per kilogram body weight of secretin (Secrelux; Goldham, Neuss, Germany) was injected intravenously in order to stimulate the transplanted pancreas to produce the exocrine secretion. Then, measurements were repeated every 30 seconds for a total imaging time of 10 minutes. Similar to the protocol pro-

posed by Krebs et al (10), a protocol with a fat-suppressed contrast-enhanced dynamic T1-weighted gradient-echo sequence (153.4/6.0; flip angle, 70°; field of view, 30 cm; matrix, 256 × 256; acquisition time, 24 seconds) was performed in a breath-hold phase. Images were acquired in a coronal oblique plane, similar to the way they were acquired with the T2-weighted sequence. A nonenhanced measurement was conducted. After the injection of 0.1 mmol/kg of gadopentetate dimeglumine (Magnevist; Schering, Berlin, Germany), measurements were repeated every minute for a total investigation time of 5 minutes.

Between measurements, the patients were allowed to catch their breath. The contrast agent was administered with a power injector (Spectris; Medrad, Pittsburgh, Pa) at an injection rate of 2 mL/sec. Total examination time, which included patient positioning, was approximately 60 minutes. Patients were questioned by one author (J.T.H.) about secretin or contrast agent side effects and the tolerability of the MR imaging investigation.

### Image Evaluation

Evaluation of the MR images and region of interest (ROI) placement were performed by one investigator (J.T.H., with 7 years of experience in MR imaging) who was blinded to all clinical and laboratory results.

MR pancreatographic images were evaluated according to the protocol derived by Heverhagen and colleagues (13). In brief, the mean signal intensity of the ROI was provided by a histogram algorithm. The mean ROI size was 250 cm<sup>2</sup> ± 52. The increase in mean signal intensity over 10 minutes was divided by a calibration factor of 0.043, which was derived from data in a previously performed volunteer study (13). The ROI included only the transplanted pancreas and the associated small bowel; therefore, the native pancreas and the draining duodenum and small bowel were excluded (Fig 1).

The calculated volume changes compared with the baseline values were plotted against the MR examination time, and a regression line was calculated. This regression line was used to derive the volume at the end of the examination. The values obtained in each patient were tabulated, and the mean values with standard deviations were calculated for the patient groups. Excretion of pancreatic fluids less than a threshold of 100 mL within 10 minutes after stimulation was considered a sign of graft dysfunction

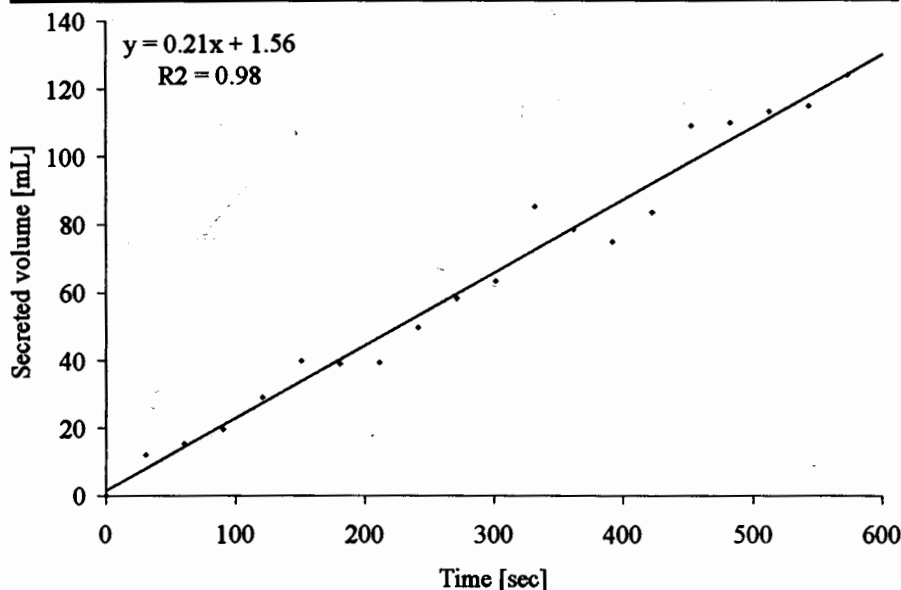


Figure 3. Graph shows results of quantitative evaluation of secretin-augmented graft excretion in same patient as in Figure 1. Graph demonstrates a linear increase in excreted fluid volume during the entire examination time. A total of 128 mL of pancreatic juice had been secreted by the end of the examination time of 10 minutes.

(11). Additionally, the images were evaluated by one author (J.T.H.) visually for possible superposition of fluid excreted from the native pancreas. Static fluid in the images (eg, cerebrospinal fluid, gallbladder fluid, fluid in adjacent bowel loops) did not influence the measurements because only increases in fluid volume from the baseline level were measured.

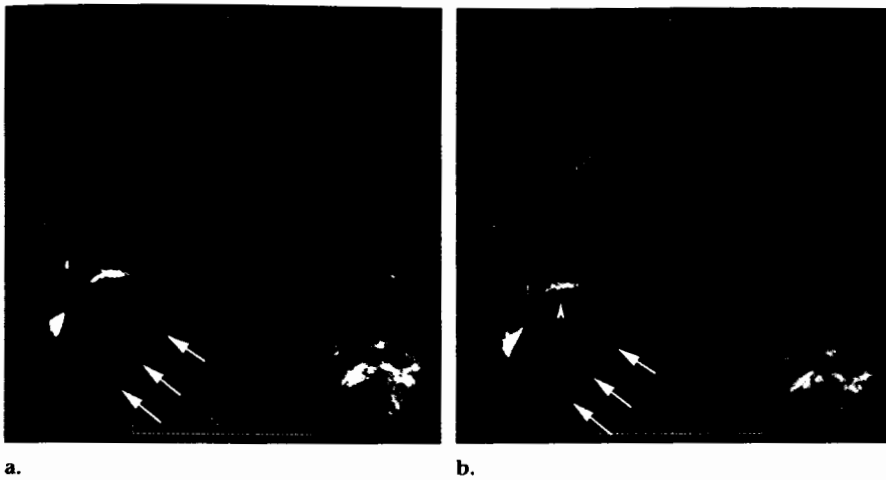
The enhancement pattern of the transplant in one selected ROI per patient was evaluated. The mean ROI size was 56 mm<sup>2</sup> ± 16. The percentage enhancement in each ROI was calculated as the difference of the signal intensity of each measurement time point and the signal intensity of the first measurement divided by this initial signal intensity. The maximum signal intensity-to-time ratio and the area under the curve were determined. The slope of the curve from the first measurement to peak enhancement represents the maximum signal intensity-to-time ratio.

### Results

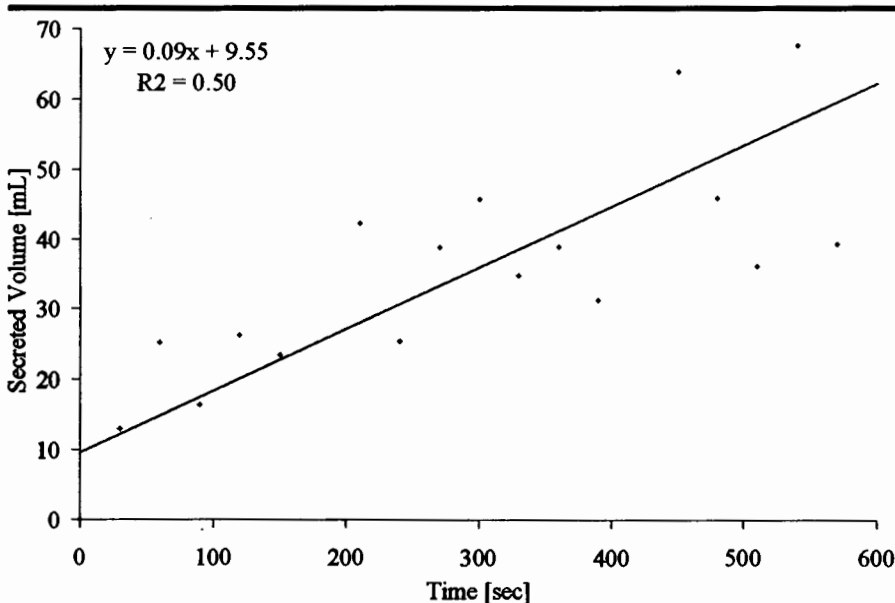
No side effects of the intravenous secretin or contrast medium injection were observed. Of the 10 patients included in the study, seven showed no signs of rejection or graft failure (Figs 2, 3). One patient had chronic graft rejection of both allografts (Figs 4, 5), which was proved with laboratory data and kidney

biopsy results. He recovered after tacrolimus (Prograf; Fujisawa Healthcare, Deerfield, Ill) rescue therapy. The remaining two patients developed necrotizing graft pancreatitis in the initial postoperative period, and their grafts had to be removed within 2 weeks after transplantation. Pathologic examination of the explanted pancreatic grafts validated the diagnosis of acute necrotizing pancreatitis. The MR imaging examination was tolerated well by all patients. The Table includes a complete summary of results in the patients.

All patients had normal blood glucose levels. The seven patients with normal graft function (patients 1–7) and the patient with chronic rejection of the graft (patient 8) did not require insulin treatment, whereas the two patients with necrotizing pancreatitis (patients 9 and 10) were insulin dependent. The blood levels of lipase, amylase, and creatinine were strongly increased (Table) in both patients with necrotizing pancreatitis and in one patient with a functioning graft (patient 6). All other patients demonstrated only slight increases in as many as two of these parameters. Mean values and standard deviations for these parameters were as follows: lipase, 43 U/L ± 28; amylase, 50 U/L ± 23; and creatinine, 1.27 mg/dL (112.27 μmol/L) ± 0.45. Clinical follow-up revealed no further signs of late rejection, especially no increase in creatinine, lipase, or amylase



**Figure 4.** Coronal secretin-augmented dynamic fast spin-echo MR images ( $\infty/1100$  [effective]; flip angle,  $150^\circ$ ) in 40-year-old man with histologic evidence of chronic graft rejection. (a) Image obtained before secretin administration. (b) Image obtained after secretin administration. Duct of transplant (arrows) is visible in both images. In the anastomosed jejunum (arrowhead), only a small fluid increase is recognized.



**Figure 5.** Graph shows results of quantitative evaluation of fluid excretion in patient in Figure 4. Graph reveals a linear increase in fluid volume during the entire examination time. After 10 minutes, only 64 mL of pancreatic juice had been secreted.

levels, and no insulin replacement was required.

US was not able to depict the graft in two cases because of gas overlay. Six functional grafts were demonstrated at US, with homogeneous parenchyma and good perfusion. The chronically rejected graft showed signs of inflammation. One graft with necrotizing pancreatitis was enlarged and showed decreased perfusion at color-coded Doppler US.

Histologic analysis was performed in

only those patients with abnormal graft function, and results confirmed the diagnoses of chronic rejection (patient 8, Table) and necrotizing pancreatitis (patients 9 and 10, Table).

MR perfusion measurements (Fig 6) used to plot curves produced area under the curve values that were greater than the threshold value of 0.5 for functional grafts and less than 0.5 for dysfunctional grafts. Maximum signal intensity-to-time ratio values provided a similar

threshold value of 0.3 (Fig 7). With secretin-augmented MR pancreatography, a mean excreted volume of  $236 \text{ mL} \pm 104$  was calculated in functioning grafts, compared with that of  $42 \text{ mL} \pm 25$  calculated in dysfunctional grafts. No superposition of fluids secreted from the native pancreas was observed. The graph displayed in Figure 7c summarizes the maximum signal intensity-to-time ratio for MR pancreatographic results.

## Discussion

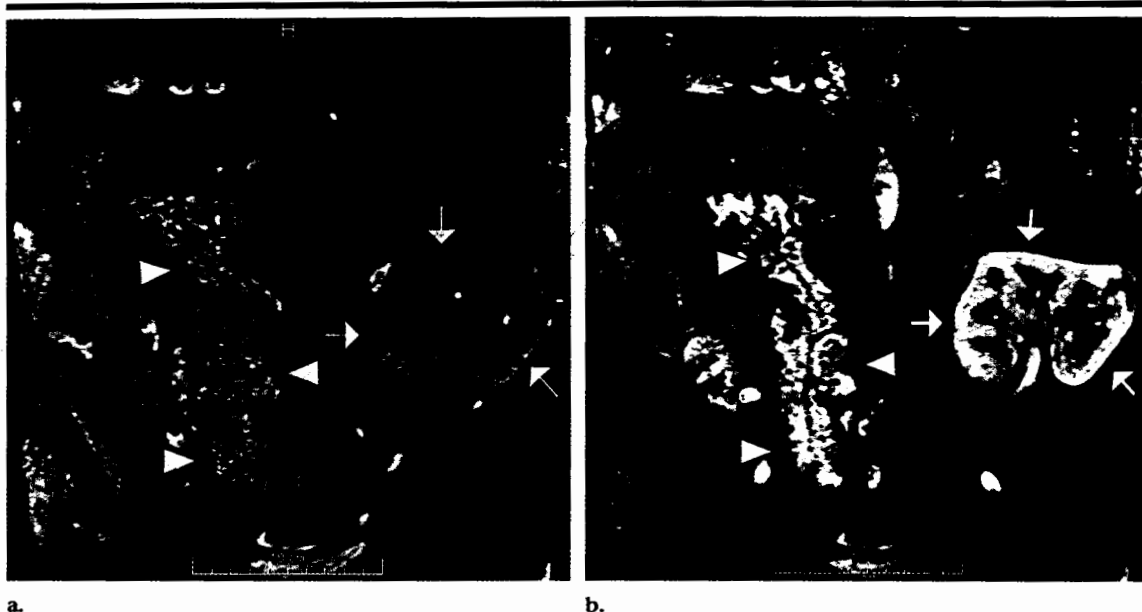
Although pancreatic transplantation is usually performed to substitute endocrine pancreatic function, the exocrine properties of the graft can be used to assess graft function (14). Currently, enteral drainage of the exocrine function is used in the majority of cases (15,16). Compared with bladder drainage, however, this technique prevents easy access to pancreatic enzyme secretions. Analysis of pancreatic enzyme concentration was a reliable tool to diagnose pancreatic graft rejection (14).

Therefore, some noninvasive approaches have been developed to investigate the functional status of the graft, but none of them have been adopted for broad clinical use.

At US, the radiologist uses the variation of the size and the echogenicity of the graft as indicators of disease. US examinations of pancreatic grafts include Doppler imaging of the vascular supply (arteries and veins) and morphologic study of the parenchyma. With US, one can identify arteriovenous fistulas, vascular thrombosis, pseudoaneurysms, and vascular anastomotic stenoses (17). US, however, is investigator dependent, and a sensitivity between 18% and 58% and a specificity between 73% and 100% can be achieved for graft failure (3-5). At percutaneous biopsy guided with US, adequate tissue samples have been obtained in 89% of cases (9).

Laboratory parameters for estimation of graft function, such as enzyme concentrations in the blood, are sensitive but not specific in regard to graft dysfunction (6,7).

Various authors have addressed the problems of pancreatic transplant rejection by using MR imaging. The use of unenhanced T1- and T2-weighted MR images provided varying results. Some groups (18,19) have not been able to show differences in the signal intensity behavior of rejected pancreatic allografts compared with that of grafts without rejection. On the other hand, Yuh et al (20) evaluated signal intensity of the graft in



**Figure 6.** Coronal T1-weighted gradient-echo MR images (153.4/6.0; flip angle, 70°) obtained in 54-year-old man with normally functioning pancreatic allograft (arrowheads) and neighboring renal graft (arrows). Area under the curve was 1.81 and maximum signal intensity-to-time ratio was 0.81. (a) Unenhanced image. (b) Image acquired 1 minute after administration of contrast medium demonstrates strong enhancement throughout pancreatic allograft. Renal graft shows similar enhancement.

comparison with that of muscle tissue (T1) and of urine (T2), which resulted in a 100% sensitivity and a 76% specificity. In a quantitative approach, Vahey et al (21) measured a higher T2 value for rejected organs than was measured for that of nonrejected grafts. Contrast-enhanced MR imaging revealed differences between the two groups in signal intensity enhancement 1 minute after application of contrast medium (10,19). These results, however, have limited clinical value because of a marked overlap in results between both groups of patients.

Matos et al (22) proposed a semiquantitative visual grading of the duodenal filling after secretin stimulation to diagnose exocrine pancreatic insufficiency. The authors proposed to classify the duodenal filling into four grades, which ranged from 0 when no fluid was secreted to 3 when the duodenum was largely filled beyond the genu inferius. A grade of less than 3 was considered to be indicative of reduced exocrine function. Matos et al showed a significant difference between control subjects and patients with a reduced exocrine secretion. This method has been refined into a fully quantitative analysis of pancreatic output (13).

In a recent study, Krebs et al (10) showed that dynamic contrast-enhanced MR imaging for evaluation of graft enhancement is

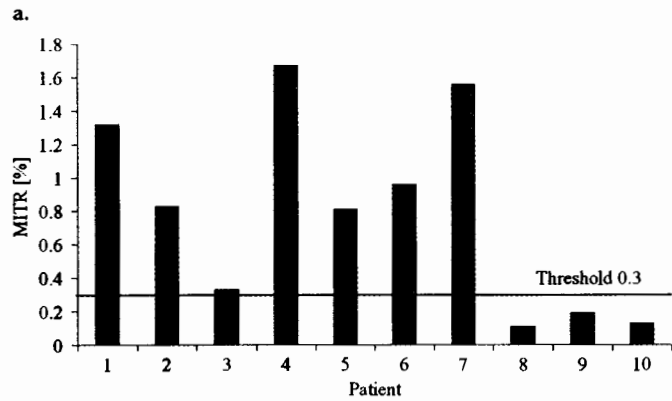
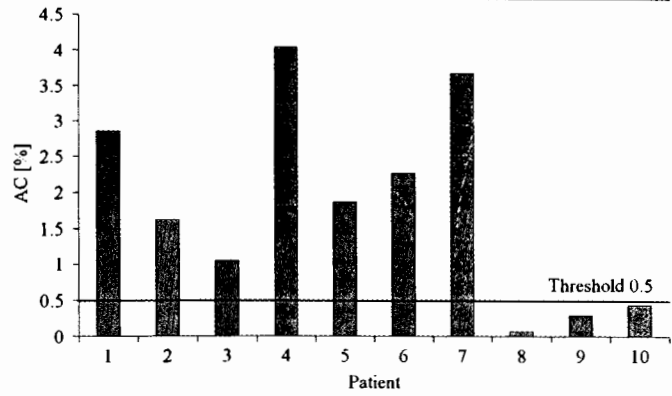
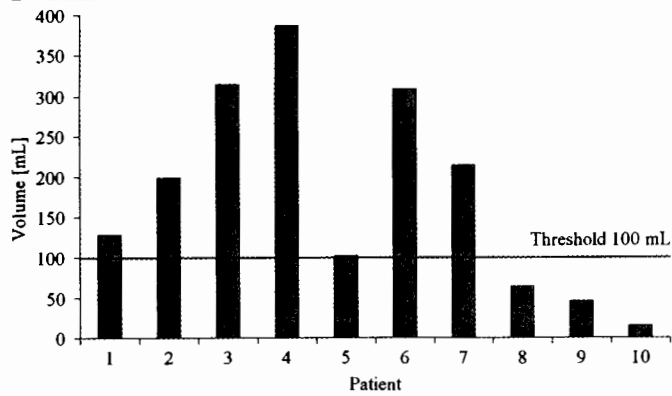
highly sensitive for the detection of acute pancreatic graft rejection. They calculated the mean percentage of pancreatic enhancement and demonstrated that it was correlated with the severity of the pancreatic rejection. In some cases, however, they demonstrated an overlap in mean percentage of pancreatic enhancement between functioning and nonfunctioning grafts.

In our study, MR imaging of the graft and the anastomosed small bowel was performed with fluid-sensitive T2-weighted sequences after secretin stimulation of the exocrine pancreatic function and with dynamic breath-hold contrast-enhanced T1-weighted sequences. Secretin stimulation was used to demonstrate exocrine function that correlated with pancreatic rejection, and dynamic contrast-enhanced MR imaging was used to provide information about graft perfusion. The results of these investigations were compared with the clinical diagnosis of the patients as assessed with biochemical parameters, biopsy results, and surgical findings.

Normally functioning grafts produced more fluid after secretin stimulation and had stronger enhancement after contrast medium injection. Ten minutes after secretin stimulation, the fluid production in the normal group was always greater than the threshold of 100 mL, whereas the dysfunctional allografts secreted less than 100 mL. Also, there were differences in both of the

obtained perfusion parameters, area under the curve and maximum signal intensity-to-time ratio, between groups. In accordance with the results of Krebs et al (10), our area-under-the-curve measurements were always greater than 0.5 and maximum signal intensity-to-time ratio was greater than 0.3 in the functional transplant group, whereas the dysfunctional transplant group consistently had values less than these thresholds. Because of the larger patient population evaluated by Krebs et al, however, an overlap in values between healthy and dysfunctional grafts was found, thus limiting the clinical application of MR imaging perfusion studies in evaluation of graft function.

To overcome this diagnostic problem, we added the measurement of transplant fluid output after secretin stimulation to our study, and this additional measurement enabled us to further discriminate well-functioning from dysfunctioning allografts. Therefore, benefits are expected from the combination of both perfusion and secretion measurements in larger patient groups, especially in providing differentiation between early stages of graft rejection and regular graft function. The method of secretion quantification, however, is a relatively new method that needs to be further evaluated. The suggested thresholds adopted from studies



**Figure 7.** Graphs show results in 10 patients. Patients 1-7 showed no signs of rejection, whereas patients 8-10 had signs of graft rejection. (a) Fluid output (volume) at the end of the examination. (b) Area under the curve (AC). (c) Maximum signal intensity-to-time ratio (MITR).

**a.**

**b.**

**c.**

about chronic pancreatitis could be subject to change in future studies.

The use of secretin in patients with acute pancreatitis is controversial. On one hand, the package insert of the manufacturer states that secretin is contraindicated in patients with acute pancreatitis. On the other hand, in case of severe rejection, the gland is already severely damaged, and the additional secretin stimulus seems does not appear to add any more damage. The pathophysiologic features of transplant rejection with graft pancreatitis are different from those of acute pancreatitis. After discussing this issue in our study group that consisted of transplant surgeons, nephrologists, and radiologists, as well as with experienced personnel from other centers, we decided that the use of secretin did not pose a substantial risk to our patients.

Although our study provided results that showed that a combination of perfusion measurements and quantification of exocrine function of the grafts is effective and adds supplementary value to the evaluation of graft function, our study had limitations. First, the patient population was small. This study, however, was planned as a pilot evaluation to demonstrate the feasibility of MR imaging se-

cretion measurements in combination with perfusion imaging results in the same examination. A further obstacle was the limited use of biopsy in the group with normal function. Therefore, we could have missed some minor, but clinically and therapeutically irrelevant, changes in allografts in those patients. An additional limitation was the composition of the study population. Since we could only include normal outcomes and patients with advanced stages of graft dysfunction, no conclusion about the ability to detect early stages of dysfunction could be made.

In summary, MR perfusion measurements proposed by Krebs et al (10) are useful in the differentiation of normal functioning pancreatic allografts from diseased grafts. We have found, however, that by adding the quantification of stimulated exocrine secretion not only is overlap between groups decreased but certainty of the diagnosis may be increased. Therefore, functional MR imaging with secretin-augmented MR pancreatography in combination with dynamic contrast-enhanced MR perfusion measurements appears to be a noninvasive, fast, and reliable diagnostic tool in the evaluation of graft function after pancre-

atic transplantation. To validate these findings, future studies must be conducted with larger patient populations.

#### References

1. Becker BN, Odorico JS, Becker YT, et al. Simultaneous pancreas-kidney and pancreas transplantation. *J Am Soc Nephrol* 2001; 12:2517-2527.
2. Stratta RJ, Taylor RJ, Bynon JS, et al. Patterns of rejection after combined pancreas-kidney transplantation. *Transplant Proc* 1994; 26:524-525.
3. Wong JJ, Krebs TL, Klassen DK, et al. Sonographic evaluation of acute pancreatic transplant rejection: morphology—Doppler analysis versus guided percutaneous biopsy. *AJR Am J Roentgenol* 1996; 166:803-807.
4. Nelson NL, Largen PS, Stratta RJ, et al. Pancreas allograft rejection: correlation of transduodenal core biopsy with Doppler resistive index. *Radiology* 1996; 200:91-94.
5. Nikolaidis P, Amin RS, Hwang CM, et al. Role of sonography in pancreatic transplantation. *RadioGraphics* 2003; 23:939-949.
6. Papadimitriou JC, Drachenberg CB, Wiland A, et al. Histologic grading of acute allograft rejection in pancreas needle biopsy: correlation to serum enzymes, glycemia, and response to immunosuppressive treatment. *Transplantation* 1998; 66:1741-1745.
7. Sugitani A, Egidi MF, Gritsch HA, Corry RJ. Serum lipase as a marker for pancreatic allograft rejection. *Clin Transplant* 1998; 12:224-227.
8. Klassen DK, Hoen-Saric EW, Weir MR, et al. Isolated pancreas rejection in combined kidney pancreas transplantation. *Transplantation* 1996; 61:974-977.
9. Lee BC, McGahan JP, Perez RV, Boone JM. The role of percutaneous biopsy in detection of pancreatic transplant rejection. *Clin Transplant* 2000; 14:493-498.
10. Krebs TL, Daly B, Wong-You-Cheong JJ, Carroll K, Bartlett ST. Acute pancreatic transplant rejection: evaluation with dy-

- dynamic contrast-enhanced MR imaging compared with histopathologic analysis. *Radiology* 1999; 210:437-442.
11. Heverhagen JT, Battmann A, Kirsch M, et al. Magnetic resonance hydrometry: non-invasive quantification of the exocrine pancreatic function. *Rofo Fortschr Geb Rontgenstr Neuen Bildgeb Verfahr* 2002; 174:291-296.
  12. Punwani S, Gillams AR, Lees WR. Non-invasive quantification of pancreatic exocrine function using secretin-stimulated MRCP. *Eur Radiol* 2003; 13:273-276.
  13. Heverhagen JT, Muller D, Battmann A, et al. MR hydrometry to assess exocrine function of the pancreas: initial results of noninvasive quantification of secretion. *Radiology* 2001; 218: 1-67.
  14. Gruessner RW, Kendall DM, Drangstveit MB, Gruessner AC, Sutherland DE. Simultaneous pancreas-kidney transplantation from live donors. *Ann Surg* 1997; 226: 471-480.
  15. Lo A, Stratta RJ, Hathaway DK, et al. Long-term outcomes in simultaneous kidney-pancreas transplant recipients with portal-enteric versus systemic-bladder drainage. *Am J Kidney Dis* 2001; 38:132-143.
  16. Cattral MS, Bigam DL, Hemming AW, et al. Portal venous and enteric exocrine drainage versus systemic venous and bladder exocrine drainage of pancreas grafts: clinical outcome of 40 consecutive transplant recipients. *Ann Surg* 2000; 232: 688-695.
  17. Patel B, Wolverson MK, Mahanta B. Pancreatic transplant rejection: assessment with duplex US. *Radiology* 1989; 173: 131-135.
  18. Kelcz F, Sollinger HW, Pirsch JD. MRI of the pancreas transplant: lack of correlation between imaging and clinical status. *Magn Reson Med* 1991; 21:30-38.
  19. Fernandez MP, Bernardino ME, Neylan JF, Olson RA. Diagnosis of pancreatic transplant dysfunction: value of gadopentetate dimeglumine-enhanced MR imaging. *AJR Am J Roentgenol* 1991; 156: 1171-1176.
  20. Yuh WT, Wiese JA, Abu-Yousef MM, et al. Pancreatic transplant imaging. *Radiology* 1988; 167:679-683.
  21. Vahey TN, Glazer GM, Francis IR, et al. MR diagnosis of pancreatic transplant rejection. *AJR Am J Roentgenol* 1988; 150: 557-560.
  22. Matos C, Metens T, Deviere J, et al. Pancreatic duct: morphologic and functional evaluation with dynamic MR pancreatography after secretin stimulation. *Radiology* 1997; 203:435-441.