ORIGINAL ARTICLE

CT fluoroscopy-guided pancreas transplant biopsies: a retrospective evaluation of predictors of complications and success rates

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SUMMARY

To identify predictors of biopsy success and complications in CT-guided pancreas transplant (PTX) core biopsy. We retrospectively identified all CT fluoroscopy-guided PTX biopsies performed at our institution (2000–2017) and included 187 biopsies in 99 patients. Potential predictors related to patient characteristics (age, gender, body mass index (BMI), PTX age, PTX volume) and procedure characteristics (biopsy depth, needle size, access path, number of samples, interventionalist's experience) were correlated with biopsy success (sufficient tissue for histologic diagnosis) and the occurrence of complications. Biopsy success (72.2%) was more likely to be obtained in men [+25.3% (10.9, 39.7)] and when the intervention was performed by an experienced interventionalist [+27.2% (8.1, 46.2)]. Complications (5.9%) occurred more frequently in patients with higher PTX age [OR: 1.014 (1.002, 1.026)] and when many (3–4) tissue samples were obtained [+8.7% (−2.3, 19.7)]. Multivariable regression analysis confirmed male gender [OR: 3.741 (1.736, 8.059)] and high experience [OR: 2.923 (1.255, 6.808)] (biopsy success) as well as older PTX age [OR: 1.019 (1.002, 1.035)] and obtaining many samples [OR: 4.880 (1.240, 19.203)] (complications) as independent predictors. Our results suggest that CT-guided PTX biopsy should be performed by an experienced interventionalist to achieve higher success rates, and not more than two tissue samples should be obtained to reduce complications. Caution is in order in patients with older transplants because of higher complication rates.

Transplant International 2021; 34: 855–864

Key words
biopsy, computed tomography, pancreas transplant, predictors

Received: 14 November 2020; Revision requested: 9 December 2020; Accepted: 17 February 2021; Published online: 13 March 2021

Introduction

The first successful pancreas transplantation was performed in 1966 [1]. Until 2014, more than 48 000 pancreas transplantations were performed worldwide, and numbers are on the rise [2]. Most patients who need a pancreas transplant are insulin-dependent diabetics (type I) with complete loss of endocrine pancreatic function [3,4]. Pancreas transplant (PTX) biopsy is a well-established procedure and is the gold standard in the differential diagnosis of transplant failure, for example, rejection, inflammation, or medication-associated

doi:10.1111/tri.13849

toxicity [5–9]. Rejection is the most common cause of pancreatic graft loss [10]. Compared with other solid organ transplants, the rejection rate in PTX is higher [11,12]. Early detection of pancreatic transplant rejection is important to initiate immediate treatment. On the other hand, aggressive immunosuppressive therapy with its associated acute and chronic toxicities must be avoided if rejection is not present [13]. This is why it is of utmost importance to accurately diagnose pancreas graft rejection [14]. Biopsy procedures for obtaining PTX tissue differ in terms of the imaging modality used for guidance and monitoring [15]. Risks for biopsy-related complications include the intra- or retroperitoneal position of the graft, its poor palpability, the close relationship to other abdominal organs, the complicated vascular connection, and the variability of possible graft positions. To minimize these risks, real-time imaging [e.g., sonography or computed tomography (CT) fluoroscopy] is indicated to visualize the organ and its environment during tissue sampling [16,17]. Sonography is frequently used in clinical practice because of its cost-effectiveness, wide availability, and absence of radiation exposure. However, sonographic conditions are often impaired, and visualization of the puncture pathway can be limited because of overlying gas-filled enteric structures or in obese patients [7,18]. CT and CT fluoroscopy enable precise imaging of the graft, its environment, and the inserted puncture needle and in addition provide real-time 3D information about the puncture pathway without the limitations of sonography. Besides the higher costs and limited availability, radiation exposure is the main disadvantage of CT imaging compared with sonography [19]. An alternative to core biopsies is fine needle aspiration, which is less invasive because it is performed with smaller-diameter puncture needles; however, fine needle aspiration yields evaluable material in only 70% of cases [20]. If percutaneous biopsy is not feasible, surgical approaches (laparoscopic or open) to access the graft can be considered [21,22]. Image-guided puncture of PTX has proven to be a safe procedure [6–8,20,23]. Nevertheless, the literature reports peri-interventional complications of various degrees of severity [5–8]. Mild complications include mild peri-interventional pain, small hematomas, self-limiting hematuria in transplants with bladder drainage, and mild pancreatitis, which can only be detected by laboratory test. These nonsevere complications require observation only [6–8]. Possible severe complications of PTX biopsies are the occurrence of arteriovenous or pancreatic fistulae, severe postinterventional pain with vasovagal reactions, major bleeding requiring transfusion or surgical/endovascular intervention, and organ failure [6,7,23]. Severe complications can lead to loss of PTX function and may ultimately lead to permanent damage and even death. The aim of this study was to identify potential factors that influence the occurrence of complications and the success of CT fluoroscopy-guided PTX biopsy.

Materials and methods

Patients and clinical data

Our institutional review board approved this retrospective study. The study protocol conforms to the ethical guidelines of the 2002 Declaration of Helsinki. Our institutional database was searched for patients that underwent CT-guided PTX biopsy at our center between 2000 and 2017. Our institutional algorithm for PTX biopsy is as follows: We recommend PTX biopsy in the case of an increase in blood glucose or HbA1c and/or confirmed doubling of the "baseline" lipase in the plasma (i.e., even if the lipase value is still normal). In the presence of this constellation, vascular or morphological causes of pancreas dysfunction will be excluded by contrast-enhanced computed tomography. If there is no explanation in imaging for graft dysfunction, then the indication for PTX biopsy is given. As CT-guided PTX biopsy is the preferred imaging-guidance approach in our institute, only this approach was chosen and evaluated.

All included patients were transplanted with the following institutional implantation technique: The exocrine secretion was managed by duodenojejunostomy. For vascular reconstruction, donor superior mesenteric artery and splenic artery were extended with a Y-graft (iliac artery) and anastomosed to the right common iliac artery. Portomesenteric veins were anastomosed to the inferior vena cava. Grafts were placed intraperitoneally with a right, head-up position. Extracted data of each patient included procedural CT images and the interventional radiologist's report, patient characteristics (age, gender, body mass index (BMI), transplant age), intervention characteristics (biopsy depth, needle size, tissue sample size, and interventionalist's experience), documentation of postinterventional clinical course until discharge and pathology reports on tissue specimens. PTX volume was measured in pre-interventional planning scans. 3D segmentation was performed using Visage 7 (Visage Imaging, San Diego, CA, USA). Volumetry of the whole PTX was performed manually using the 3D polygonal region of interest (ROI) tool. Measurements were obtained blindly from patient

characteristics. Exclusion criteria were insufficient outcome data (e.g., incomplete digitally retrievable information on the histological evaluation and postinterventional course) and patient's age <18 years. Experience of the interventionalist was classified binarily into low and high experience. High experience was defined as >2 years of experience in percutaneous interventions with a minimum of 100 abdominal biopsies. Tissue sample size was defined as number of samples taken and corresponds to the number of biopsy attempts. Biopsy success was defined as a histological tissue sample that allowed evaluation of rejection according to the Banff schema for grading pancreas allograft rejection [24]. Complications were graded into nonsevere and severe if further investigations were needed according to Gupta *et al.* [25].

CT-guided PTX biopsy

Written informed consent to the procedure was obtained from all patients. Biopsy procedures were only performed in patients with a platelet count >50 000/m^3, and adequate coagulation defined as activated partial thromboplastin time (aPTT) <50s and prothrombin time (PT) >50%. No outpatient procedures were performed. All biopsies were carried out on the same CT scanner (Somatom Definition AS, Siemens, Erlangen, Germany) using the coaxial biopsy technique [QuickCore® Biopsy Needle (Cook Medical; Bloomington, IN, USA)]. CT-guided PTX biopsies were performed by interventional radiologists with different levels of experience. In all patients, noncontrast-enhanced CT scans (120 kVp, automatic tube current modulation; supine position) of the lower abdomen (full coverage of PTX) were performed to plan the puncture tract (Fig. 1). If no access could be established in the planning CT scan, the CT scan was repeated in a different patient position. If the second scan also failed to identify an access because of overlying filled enteric structures, the biopsy was postponed to another day with prior laxative intake. After thorough disinfection of the skin and draping, local anesthesia was applied (approx. 20 ml of 1% lidocaine). Biopsy was performed under CT fluoroscopic guidance (standard setting: 100 kVp) in coaxial biopsy technique with different needle sizes (17G/18G and 19G/20G coaxial/biopsy needles; Fig. 2). In some cases, mild hydrodissection (saline flush) was used to displace adjacent bowel. The number of tissue samples obtained was decided by the radiologist. The tissue was preserved in 10 ml of 4% formaldehyde and directly sent to the department of pathology for histological processing.

Statistical analysis

Statistical analysis was performed using SPSS STATISTICS (IBM, Version 25.0; Armonk, NY, USA) and Stata (StataCorp, Version 16.1; College Station, TX, USA). The Kolmogorov–Smirnov test showed nonnormal

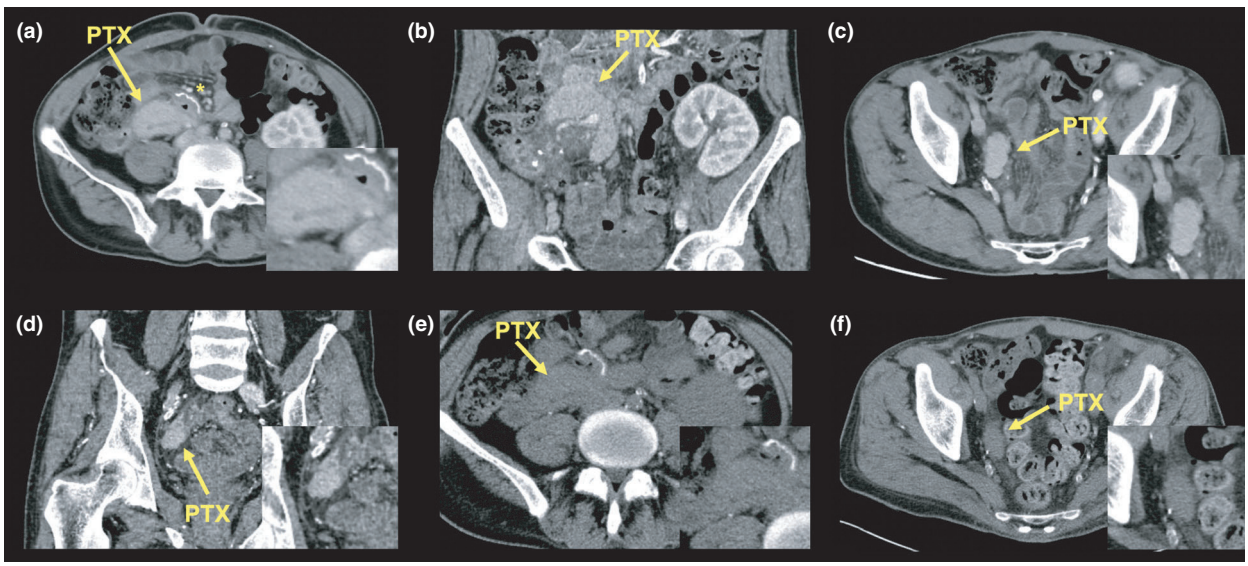

Figure 1 Example images obtained in a 51-year-old patient with failure of exocrine PTX function. (a–d) Contrast-enhanced CT scan acquired 5 days prior to the CT-guided core biopsy; a (axial) & b (coronal): Enterically drained pancreatic head of the transplant with adjacent small bowel loops and PTX vessels (asterisk); note the kidney transplant in the left iliac fossa. c (axial) & d (coronal): Pancreatic tail with location deep in the right small pelvis. (e, f) Unenhanced planning CT scan acquired immediately before the CT-guided PTX core biopsy starts. In this case, a parailiac access path was chosen to biopsy the pancreatic tail (procedure is displayed in Fig. 2).

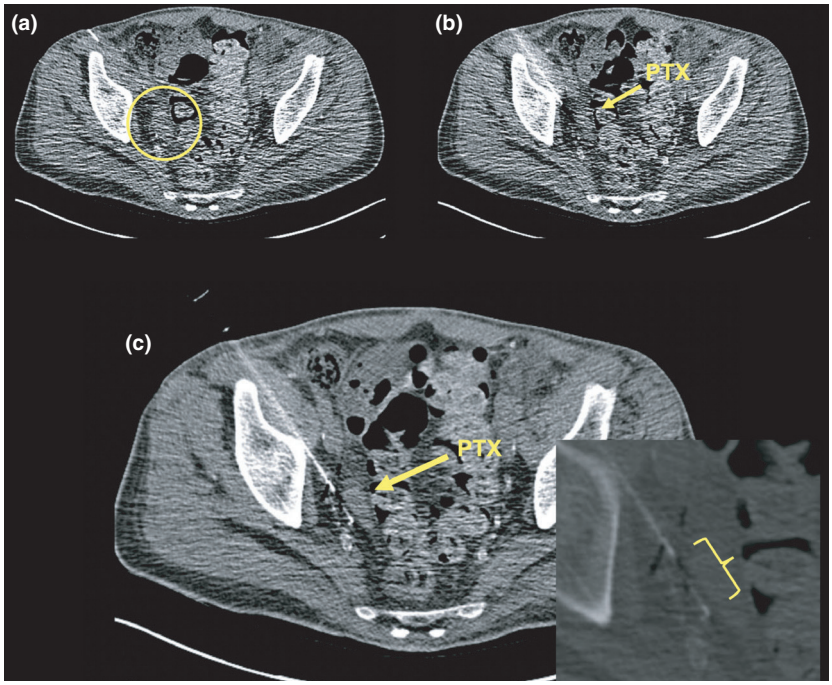

Figure 2 CT-guided PTX core biopsy with CT fluoroscopy via a right parailiac access path. Images a and b show the in-plane access to the pancreatic tail with a 19G coaxial needle (100 kVp, soft tissue window). The coaxial needle was placed right next to the pancreatic tail. Image C shows how the biopsy needle passes the pancreatic tail tangentially to avoid injury to central duct structures. To ensure that pancreatic tissue was hit, tube voltage was increased to 120 kVp. The small section shows the extended biopsy needle (bone window). The transplant was successfully biopsied without complications: Histologic work-up showed a chronic inflammatory reaction but no evidence of acute cellular rejection.

distribution of the data, so that nonparametric testing was performed. Median values and corresponding interquartile ranges were reported accordingly. For analyzing qualitative data, the chi-square test was used (effect size: difference in proportions) [26,27]. Correlation analysis was performed using Spearman's rank correlation. Univariable logistic regression analysis was performed for each continuous variable and multivariable Firth's logistic regression with analysis of Odds Ratio (OR) estimates were computed [28,29]. 95% confidence intervals (CI) were computed for each effect size. For all analysis, P values <0.05 were considered to indicate statistically significant differences.

Results

Patients and clinical data

A total of 227 CT-guided PTX biopsies were carried out at our institution between 2000 and 2017. Forty biopsies had to be excluded from our retrospective analysis because of incomplete retrospectively digitally retrievable outcome data, leaving a total of 187 CT-guided PTX biopsies in 99 patients (34 female/65 male) for analysis. Patient and procedure characteristics are summarized in Table 1. Analysis of the clinical data showed that PTX age correlated significantly with PTX volume (correlation coefficient: −0.520, $P < 0.001$), patient age (correlation coefficient: 0.235, $P = 0.001$), and BMI (correlation coefficient: 0.148, $P = 0.043$). For further analysis, two subgroups based on number of tissue samples taken (one or two versus three or more) were formed.

Predictors of biopsy success

The results of correlation analysis for biopsy success with patient and procedure characteristics are summarized in Table 2. Biopsies were successful (sufficient evaluable tissue) in 135 instances (72.2%). Biopsy success correlated significantly with the patient's gender and was more often achieved in male patients [+25.3% (10.9, 39.7)]. In addition, there was a significant correlation with the interventionalist's level of experience [−27.2% (−46.2, −8.1)]. Regarding the interventionalist's experience, more experienced interventionalists achieved a 77% biopsy success rate compared to only 50% for less experienced interventionalists. There was a statistical trend, that success rate was higher in patients

Transplant International 2021; 34: 855–864

Table 1. Patient and procedure characteristics.

Characteristic	Factor	Number [%]/ median [IQR]	Range
Patients		*N* = 99	
Gender	Male	65 [65.7%]	
	Female	34 [34.4%]	
CT-guided biopsies		*N* = 187	
Gender	Male	127 [67.9%]	
	Female	60 [32.1%]	
Age (years)		48 [12]	26–68
BMI (kg/m^2)		23.6 [4.7]	17.9–38.2
PTX age (months)		52 [98]	0–199
PTX volume (cm^3)		78.9 [40.3]	25.6–268.7
Biopsy depth (cm)		9.4 [4.4]	4.0–18.2
Needle size (G)	20G	144 [76.6%]	
	18G	44 [23.4%]	
Access	Anterior	153 [81.4%]	
	Posterior	35 [18.6]	
Number of samples	1	86 [46.0%]	
	2	62 [33.2%]	
	3	34 [18.2%]	
	4	5 [2.7%]	
Experience	Low	30 [16.0%]	
	High	157 [84.0%]	

with higher BMI [OR: 1.094 (0.992, 1.207)]. Multivariable logistic regression analysis showed significant results for gender with higher likelihood of biopsy success in male patients [OR: 3.741 (1.736, 8.059)] and for the interventionalist's experience in favor for experienced interventionalists [OR: 2.923 (1.255, 6.808)] (Table 3).

Predictors of complications

Correlation analysis results for the occurrence of complications in relation with patient and intervention characteristics are summarized in Table 4. Peri-interventional complications occurred in 11 patients (5.9%). There were 4 severe (2.1%) complications. They were accounted for by pancreatic fistula, pancreatitis, and significant bleeding (hematoma) that required prolonged ICU treatment and/or operative treatment. Nonsevere (minor) complications ($n = 7$) were peripancreatic hematoma ($n = 6$) and prolonged abdominal pain ($n = 1$) (Fig. 3). The occurrence of complications (nonsevere and severe) correlated significantly with the following patient characteristics: BMI [OR: 1.182 (1.030, 1.356)] and PTX age [OR: 1.014 (1.002, 1.026)]. Regarding intervention characteristics, complications correlated with the number of tissue samples taken [−8.7% (−19.7, 2.3)]. The occurrence of complications was significantly higher if more tissue samples were taken. Complications occurred in 12.8% of the patients

Table 2. Patient- and procedure-related characteristics analyzed as potential predictors of biopsy success.

Biopsy success		No	Yes		
Characteristic	Factor	Number [%]/ median [IQR]	Number [%]/ median [IQR]	Effect size [95% CI]	Significance
Total		52 [27.8%]	135 [72.2%]		
Patient characteristics					
Gender	**Male**	**25 [19.7%]**	**102 [80.3%]**	**+25.3% [10.9, 39.7]**	**<0.001**
	Female	**27 [45.0%]**	**33 [55.0%]**		
Age (years)		46 [13]	48 [13]	1.033 [0.992, 1.075]	0.119
BMI (kg/m^2)		22.5 [4.4]	23.9 [4.5]	1.094 [0.992, 1.207]	0.071
PTX age (months)		48 [95]	61 [98]	1.003 [0.997, 1.009]	0.327
PTX volume (cm^3)		76.2 [41.4]	81.0 [40.9]	1.005 [0.994, 1.015]	0.360
Procedure characteristics					
Biopsy depth (cm)		9.4 [5.1]	9.4 [4.6]	1.035 [0.929, 1.153]	0.530
Needle size (G)	20G	39 [27.3%]	104 [72.7%]	+2.2% [−13.1, 17.5]	0.769
	18G	13 [29.5%]	31 [70.5%]		
Access	Anterior	39 [25.5%]	114 [74.5%]	+12.7% [−5.0, 30.4]	0.134
	Posterior	13 [38.2%]	21 [61.8%]		
Number of samples	Few (1–2)	41 [27.7%]	107 [72.3%]	+0.5% [−15.3, 16.3]	0.950
	Many (3–4)	11 [28.2%]	28 [71.8%]		
Experience	**Low**	**15 [50.0%]**	**15 [50.0%]**	**−27.2% [−46.2, −8.1]**	**0.003**
	High	**37 [28.8%]**	**120 [77.2%]**		

Effects sizes are shown as differences in proportions (categorical variables) or as odds ratios (continuous variables). $P < 0.05$ was considered significant (bolded).

Table 3. Multivariable Firth's logistic regression analysis of predictors of biopsy success (evaluable tissue).

					95% CI for OR	
Biopsy success	Odds ratio	Standard error	*z*	*P*	Lower	Upper
Gender (male)	**3.741**	**1.465**	**3.37**	**0.001**	**1.736**	**8.059**
Age (years)	1.017	0.023	0.74	0.458	0.973	1.063
BMI (kg/m^2)	1.017	0.066	1.03	0.302	0.944	1.205
PTX age (months)	1.005	0.004	1.30	0.193	0.997	1.013
PTX volume (cm^3)	1.012	0.006	1.89	0.058	1.000	1.024
Biopsy depth (cm)	0.941	0.079	−0.73	0.468	0.799	1.109
Needle size (20G)	1.121	0.455	0.28	0.778	0.506	2.484
Access path (posterior)	0.647	0.337	−0.84	0.403	0.233	1.795
Number of samples (many)	0.784	0.324	−0.59	0.556	0.349	1.762
Experience (high)	**2.923**	**1.261**	**2.49**	**0.013**	**1.255**	**6.808**
Penalized log likelihood = −69.870						

$P < 0.05$ was considered significant (bolded).

with three or more tissue samples and in 4.1% of those with one or two samples. Higher BMI was associated with a increased risk of complications [OR: 1.182 (1.030, 1.356)]. There was also an increased risk for patients with older transplants [OR: 1.014 (1.002, 1.026)] and a statistical trend between greater biopsy depth and increased occurrence of complications [OR: 1.194 (0.982, 1.453)]. Multivariable Firth's logistic regression analysis showed significant results for PTX age with a higher likelihood of complications in older transplants [OR: 1.019 (1.002, 1.035)] and for the number of tissue samples with a higher chance for complications if many (>2) were obtained [OR: 4.880 (1.240, 19.203)]. BMI as a predictor of complications showed no significant results [OR: 1.113 (0.936, 1.324)] in the multivariable analysis (Table 5). Subgroup analysis of patients with severe (n = 4/11) versus nonsevere (n = 7/11) complications revealed no significant differences regarding BMI, PTX age, biopsy depth, and number of samples (P = 0.412–0.788).

In the subgroup of patients with severe complications, three patients developed pancreatitis with pancreatic fistula. One of these patients with fistula was diagnosed with grade III rejection in the biopsy's histological evaluation, no histological evidence of rejection was found in the other two patients. Because of the complicative biopsy procedures, these patients developed peripancreatic collections caused by the pancreatic fistula. These collections were initially drained in two patients, the other patient had surgery. One patient recovered under drainage, and the other drained patient was subsequently surgically treated in the absence of clinical improvement. The fourth patient with severe complications developed an intraparenchymal hematoma of the PTX and subsequent pancreatitis. This patient had to be treated in the intensive care unit for 5 days and recovered under conservative therapy.

Discussion

Pancreatic transplantation is still rare compared with transplants of other solid organs [30]. Scientific data on CT-guided PTX biopsy are still sparse and published studies are limited by smaller patient populations. The aim of our study was to systematically identify patient- or procedure-related characteristics that affect the success and complication rates of CT-guided PTX core biopsies. In our rather large cohort of 187 biopsies, we identified male gender and an experienced interventional radiologist as positive predictors of biopsy success defined as acquisition of sufficient evaluable pancreatic tissue for histology. Older transplant age and sampling many specimens (>2) were found to be associated with the occurrence of more peri-interventional complications.

Generally, exocrine drainage of PTX can be anastomosed to the small bowel (enteric drainage) or the urinary bladder (vesical drainage). Nowadays, enteric drainage is preferred to vesical drainage [16,31,32]. For enterically drained PTX, accessibility may vary because of different surgical implantation techniques [33]. Originally, enteric drainage was described with a Roux-en-Y loop [34]. Currently, the majority of PTX are performed without Roux-en-Y technique in favor of a direct side-to-side anastomosis as performed at our institution [35]. Alternative implantation techniques include duodenal drainage (via duodenoduodenostomy)

with retroperitoneal placement of the allograft. In this scenario, the surgical technique facilitates endoscopic graft biopsy for the diagnosis of rejection [36–38]. Another implantation variant with good endoscopic access for biopsy is gastric drainage, in which the donor duodenum is anastomosed to the greater curvature of the stomach [39]. The accessibility of the graft for tissue sampling also differs between vesical drainage and enteric drainage. Whereas a bladder-drained PTX can also be biopsied endoscopically via a transvesical approach, percutaneous access to an enterically drained PTX can be more challenging because of adjacent small bowel loops. Most published studies investigated population including solely or predominantly patients with bladder-drained PTX or did not mention the PTX site. Studies investigating larger numbers of biopsies were only performed with ultrasound guidance [6,8,18]. Reported severe complication rates ranged from 2.6% to 3.1% and up to 11% when minor complications were included [5,6,18,25]. Our study presents the largest cohort of CT-guided biopsies of solely enterically drained pancreas grafts implanted with the most widely used surgical implantation technique today. The incidence of complications in our study is consistent with previously published data. We found an overall complication rate of 5.9% with severe complications occurring in 2.1% of cases. Our results showed that patients with an elevated BMI or an "older" PTX had a higher risk of peri-interventional complications. Of note, the risk of complications increased when more tissue samples were obtained whereas the success rate in terms of obtaining evaluable tissue did not. As percutaneous biopsy of pancreas grafts is generally a safe procedure, there are little data on severe complications. The comparable studies with large number of cases report mainly bleeding events and less frequently pancreatitis-related complications [6,18]. Our study underlines the importance of those previously published complications. The low incidence of bleedings in our cohort can be partially explained by the use of coaxial needles, for which it has already been shown that fewer bleedings occur [40]. However, pancreatitis-related complications, while still rare, were more frequent in our evaluation. The one case with significant bleeding also led to subsequent pancreatitis, which required further treatment. In our cohort, every hemorrhage was self-limiting, and no patient required bleeding-related angiography or surgery. In the long-term course, two of our four patients with severe complications showed a functional deterioration of the graft up to the loss of function. Whether the loss of function is because of the complications or the diagnosed rejection/natural course of functional

Table 4. Patient- and procedure-related characteristics analyzed as potential predictors of complications.

Complications		No	Yes		
Characteristic	Factor	Number [%]/ median [IQR]	Number [%]/median [IQR]	Effect size [95% CI]	Significance
Total		176 [94.1%]	11 [5.9%]		
Patient characteristics					
Gender	Male	117 [92.1%]	10 [7.9%]	+6.2% [0.5, 11.9]	0.092
	Female	59 [98.3%]	1 [1.7%]		
Age (years)		47 [11]	53 [11]	1.046 [0.968, 1.130]	0.259
BMI (kg/m^2)		**23.4 [4.5]**	**25.3 [2.8]**	**1.182 [1.030, 1.356]**	**0.018**
PTX age (months)		**51 [98]**	**111 [146]**	**1.014 [1.002, 1.026]**	**0.022**
PTX volume (cm^3)		79.9 [40.9]	76.3 [39.5]	0.992 [0.971, 1.014]	0.471
Procedure characteristics					
Biopsy depth (cm)		9.3 [4.3]	12.0 [4.1]	1.194 [0.982, 1.453]	0.075
Needle size (G)	20G	136 [95.1%]	7 [4.9%]	−4.2% [−13.4, 5.0]	0.301
	18G	40 [90.9%]	4 [9.1%]		
Access	Anterior	144 [94.1%]	9 [5.9%]	+0.0% [−8.7, 8.7]	1.000
	Posterior	32 [94.1%]	2 [5.9%]		
Number of samples	**Few (1–2)**	**142 [95.9%]**	**6 [4.1%]**	**−8.7% [−19.7, 2.3]**	**0.038**
	Many (3–4)	**34 [87.2%]**	**5 [12.8%]**		
Experience	Low	27 [90.0%]	3 [10.0%]	+4.9% [−6.3, 16.2]	0.296
	High	149 [94.9%]	8 [5.1%]		

Effects sizes are shown as differences in proportions (categorical variables) or as odds ratios (continuous variables). $P < 0.05$ was considered significant (bolded).

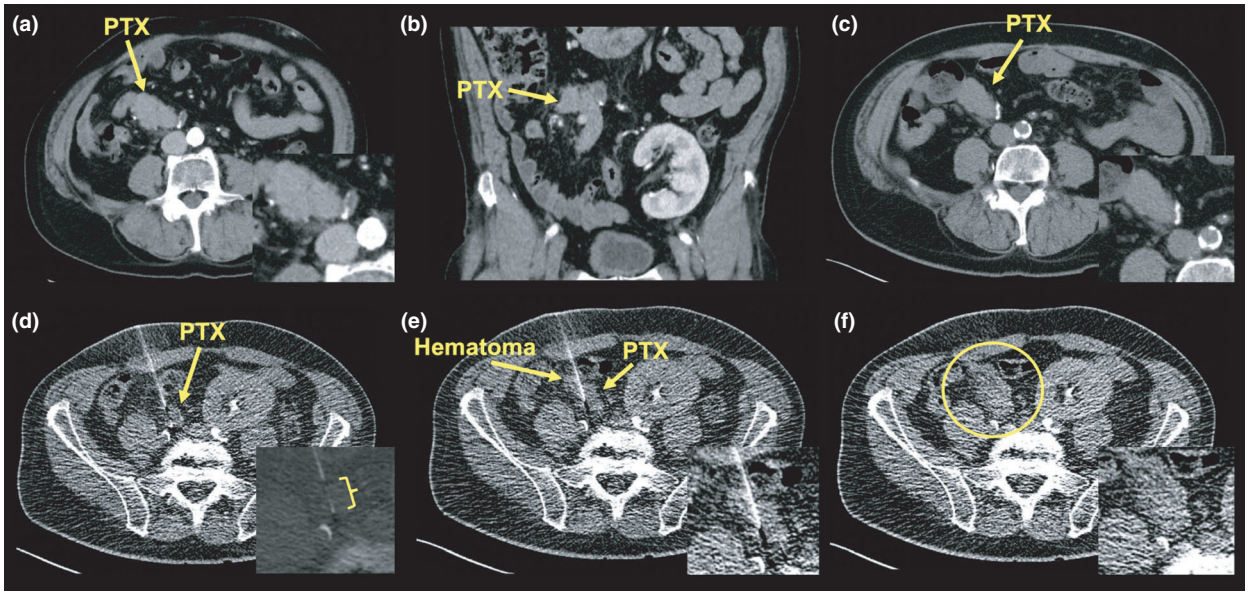

Figure 3 Example images of a CT-guided PTX core biopsy in a 67-year-old patient with nonsevere (minor) complications. (a, b) Contrast-enhanced CT images obtained 8 days prior to the CT-guided core biopsy. The enterically drained PTX is located in the right mid-abdomen and no explanation for graft failure (e.g., vascular) was found in diagnostic imaging. (c) Unenhanced planning CT with access to the pancreatic body in the right mid-abdomen. (d–f) CT fluoroscopy showing a self-limiting peripancreatic hematoma along the access route. The biopsy was still successful. The hematoma required no further medical investigations and can, therefore, be classified as a nonsevere (minor) complication.

Table 5. Multivariable Firth's logistic regression analysis of predictors of the occurrence of peri-interventional complications.

					95% CI for OR	
Complications	Odds ratio	Standard error	*z*	*P*	Lower	Upper
Gender (male)	2.565	2.671	0.90	0.366	0.333	19.750
Age (years)	0.970	0.049	−0.60	0.548	0.880	1.070
BMI (kg/m^2)	1.113	0.099	1.21	0.226	0.936	1.324
PTX age (months)	**1.019**	**0.008**	**2.21**	**0.027**	**1.002**	**1.035**
PTX volume (cm^3)	1.005	0.012	0.38	0.707	0.981	1.029
Biopsy depth (cm)	1.115	0.190	0.64	0.521	0.799	1.556
Needle size (20G)	0.426	0.317	−1.15	0.252	0.099	1.835
Access path (posterior)	0.482	0.459	−0.77	0.443	0.074	3.115
Number of samples (many)	**4.880**	**3.411**	**2.27**	**0.023**	**1.240**	**19.203**
Experience (high)	0.242	0.202	−1.69	0.090	0.047	1.249
Penalized log likelihood = −11.467						

$P < 0.05$ was considered significant (bolded).

deterioration ultimately remains unclear. Earlier studies report success rates of PTX biopsies varying between 84% and 96% [5,6,18,19]. For CT-guided biopsies, the reported success rate is on the order of 90% [5,19]. Overall, published success rates are higher than in our study (72.2%). As already discussed for complication rates, the difference could again be explained by an easier access to the transplant in patients with bladder-drained PTX. Besides the fact that all patients in our study had enteric anastomoses, there were also many cases with poor sonographic transplant visibility, which limits comparability of our results with sonography-guided biopsies. This

Transplant International 2021; 34: 855–864

assumption is underlined by the study of Lee *et al.* [8], who, while achieving an overall success rate of 83% and mostly using ultrasound guidance, performed additional CT to localize the PTX if it was not detectable by sonography, resulting in a 73% success rate in these cases. Regarding predictors of biopsy success, Lee *et al.* [8] correlated biopsy needle sizes with successful outcome in 42 biopsies. In this subset, evaluable samples were obtained with both 18G and 20G needles, underscoring our results that there seems to be no difference between using 20G or 18G needles. Our results show that CT-guided biopsy success tends to be lower in patients with a low BMI. This phenomenon could be partly explained by the limited space for needle adjustment when no peripancreatic fat is present. At the same time, the risk of adjacent small bowel injury is higher and the scope for action of the interventional radiologist is limited. In our cohort, there were more complications in patients with higher BMI, but BMI was not confirmed as an independent predictor of complications in our multivariable logistic regression model. Another result reported here is that the sample size or the number of passes through the pancreatic parenchyma does not affect the success rate, while it affects the risk of complications. The higher success rate we found for experienced interventional radiologists was to be expected.

Our study has some limitations mainly because of its retrospective design. Because of the retrospective nature, we probably missed some minor complications because they were not documented. Furthermore, there was no standardization in terms of needle size and number of samples to be taken, which could have led to a bias in these results. These factors were at the discretion of the interventional radiologist and adapted to the circumstances (e.g., difficult access path). There could be a selection bias in patients included to CT-guided biopsy sampling regarding the used imaging modality for visualization. However, since CT-guided PTX puncture is the first-choice modality in our institute, the bias should be negligible.

In conclusion, CT-guided PTX core biopsy is a safe and effective procedure for sampling tissue from an enterically drained PTX. The intervention should be performed by an experienced interventional radiologist. The risk of complications can be reduced by taking no more than two samples without compromising the chances of successful biopsy. Because of a higher complication rate, special caution is required when PTX biopsy is performed in older transplants.

Authorship

UF: designed research, collected and analyzed the data, and wrote the paper. RT: collected data and analyzed the data, and wrote the paper. P-DB: collected and analyzed the data. TAA: collected and analyzed the data. AK, DG, ELH, RÖ, JP, and BG: performed research/study, contributed important data/samples. TD: contributed important data/samples, designed research, and wrote the paper.

Funding

This study was not supported by any funding.

Conflict of interest

The authors report grants and personal fees from Siemens, outside the submitted work.

Ethical approval

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. Our institutional review board approved this retrospective study (registration number: EA1/311/16).

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