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Original Article

Risk of conversion to open surgery during robotic and laparoscopic pancreatoduodenectomy and effect on outcomes: international propensity score-matched comparison study

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Abstract

Background: Minimally invasive pancreatoduodenectomy (MIPD) is increasingly being performed because of perceived patient benefits. Whether conversion of MIPD to open pancreatoduodenectomy worsens outcome, and which risk factors are associated with conversion, is unclear.

Methods: This was a *post hoc* analysis of a European multicentre retrospective cohort study of patients undergoing MIPD (2012–2017) in ten medium-volume (10–19 MIPDs annually) and four high-volume (at least 20 MIPDs annually) centres. Propensity score matching (1 : 1) was used to compare outcomes of converted and non-converted MIPD procedures. Multivariable logistic regression analysis was performed to identify risk factors for conversion, with results presented as odds ratios (ORs) with 95 per cent confidence intervals (c.i).

Results: Overall, 65 of 709 MIPDs were converted (9.2 per cent) and the overall 30-day mortality rate was 3.8 per cent. Risk factors for conversion were tumour size larger than 40 mm (OR 2.7, 95 per cent c.i.1.0 to 6.8; $P = 0.041$), pancreatobiliary tumours (OR 2.2, 1.0 to 4.8; $P = 0.039$), age at least 75 years (OR 2.0, 1.0 to 4.1; $P = 0.043$), and laparoscopic pancreatoduodenectomy (OR 5.2, 2.5 to 10.7; $P < 0.001$). Medium-volume centres had a higher risk of conversion than high-volume centres (15.2 *versus* 4.1 per cent, $P < 0.001$; OR 4.1, 2.3 to 7.4, $P < 0.001$). After propensity score matching (56 converted MIPDs and 56 completed MIPDs) including risk factors, rates of complications with a Clavien–Dindo grade of III or higher (32 *versus* 34 per cent; $P = 0.841$) and 30-day mortality (12 *versus* 6 per cent; $P = 0.274$) did not differ between converted and non-converted MIPDs.

Conclusion: Risk factors for conversion during MIPD include age, large tumour size, tumour location, laparoscopic approach, and surgery in medium-volume centres. Although conversion during MIPD itself was not associated with worse outcomes, the outcome in these patients was poor in general which should be taken into account during patient selection for MIPD.

Introduction

Minimally invasive pancreatoduodenectomy (MIPD) is gaining popularity in well selected patients in high-volume centres[1,2]. Although the feasibility of laparoscopic pancreatoduodenectomy (LPD) was demonstrated in two recent single-centre RCTs[3,4], the safety of the laparoscopic approach is still questioned[5]. These

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concerns were confirmed by the early termination of the only multicentre randomized trial, the LEOPARD-2 trial[6], owing to unexpected worse outcomes in patients treated with LPD without clear benefits of the laparoscopic approach. The complexity of MIPD is further underlined by high conversion rates of up to 40 per cent[1,7]. Despite a previous nationwide training programme in LPD[8], the conversion rate during the LEOPARD-2 trial[6] was 20 per cent.

Conversion might worsen surgical outcomes and hence nullify the potential benefits of the minimally invasive approach, as has been described for minimally invasive colorectal and liver surgery[9,10]. Data on the impact of conversion on patient outcomes after MIPD are limited to single-centre studies[11,12] or national databases without information about the reason for conversion[13]. The high conversion rate during MIPD illustrates the need for identification of risk factors and assessment of the impact of conversion on outcomes of MIPD. Additionally, volume may be relevant to conversion and overall outcomes of MIPD. The recent Miami guidelines[2] advised a minimum of 20 MIPDs procedures per centre per year.

The present study aimed to evaluate the impact of conversion on surgical outcomes, and to identify preoperative risk factors for conversion during MIPD in medium- and high-volume MIPD pancreatic centres.

Methods

This was a *post hoc* analysis of a European multicentre retrospective cohort study[14] of patients undergoing MIPD in medium- and high-volume centres. Medium-volume centres were defined as those performing 10–19 MIPDs annually, and high-volume centres as those undertaking at least 20 MIPDs each year. This study was carried out according to the STROBE guidelines[15]. Need for ethical approval was waived by the institutional review board at Amsterdam UMC, location Academic Medical Centre, owing to the retrospective character of the study. In addition to the data obtained for the previous study of MIPD[14], contributing surgeons were asked to provide information regarding the reason for conversion.

Patients who underwent MIPD between 1 January 2012 and 30 June 2017 in 14 centres from six countries were included. Patients were excluded if they underwent hybrid or open pancreatoduodenectomy, total pancreatectomy, or were operated in centres with an annual volume of less than 10 MIPDs. Patients were grouped into MIPD with conversion *versus* MIPD without conversion to open surgery.

Definitions

Conversion was defined as any resection started with a laparoscopic or robotic approach, but requiring either laparotomy or hand assistance for reasons other than trocar placement or specimen extraction. Preoperative variables included baseline characteristics, such as age, sex, BMI, ASA fitness grade, surgical history, and information from CT/MRI on organ or vascular involvement. Duct diameter was defined as the width in millimetres of the pancreatic duct at the neck of the pancreas on preoperative imaging. Resection margins were categorized as R0 (distance between margin and tumour 1 mm or more), R1 (distance from margin to tumour less than 1 mm), and R2 (macroscopically positive margin) according to the Royal College of Pathologists' definition[16]. Tumour location was grouped into pancreatobiliary tumours located in the pancreatic head, such as pancreatic tumours and distal bile duct tumours, and those located outside of the pancreatic head, such as ampullary and duodenal tumours. The National Comprehensive Cancer Network version 2.2017 definitions[17] were used to distinguish upfront resectable from borderline resectable tumours. Postoperative morbidity was classified according to the Clavien–Dindo classification of surgical complications[18]. Complications graded as Clavien–Dindo grade III or higher were considered to represent severe morbidity. The International Study Group of Pancreatic Surgery definitions of postoperative pancreatic fistula[19], postpancreatectomy haemorrhage (PPH)[20] and delayed gastric emptying[21] were used. For these outcomes, only grade B/C complications were considered.

Additional analyses

A first additional analysis was undertaken to investigate potential differences between short-term outcomes of conversion during LPD and robotic pancreatoduodenectomy (RPD). A second analysis was performed to assess whether the reason for conversion influenced the surgical short-term outcome. The conversion group was divided into elective conversion (because of vascular involvement by tumour, oncological concerns, adhesions or technical difficulties) and emergency conversion (bleeding)[9]. In a third analysis, the impact of centre experience on conversion rate was analysed by comparing the conversion rate in medium-volume centres (10–19 MIPDs annually) with rates in high-volume centres (20 or more MIPDs each year).

Statistical analysis

Normally and non-normally distributed variables were presented as median (i.q.r.) and analysed using the Student's t test and Mann-Whitney U test, respectively. Categorical variables are reported as counts with proportions, and were evaluated using the χ^2 or Fisher's exact test, as appropriate.

To assess whether baseline or tumour characteristics influenced the outcome of MIPD conversion, propensity score matching was undertaken, with subsequent comparative analysis of patients who underwent MIPD conversion *versus* those in whom MIPD was completed. A logistic regression model was used to calculate the propensity score for each patient to undergo MIPD conversion. Propensity scores were based on the baseline variables age, BMI, ASA physical status grade, malignancy, and the need for vascular resection. Patients were matched in a 1 : 1 ratio with a caliper width of 0.1 standard deviations. To identify potential risk factors associated with conversion, including age (at least 75 years), sex, BMI (30 kg/m^2 or more), ASA physical status grade, past medical and surgical history, neoadjuvant treatment, tumour location and size, malignancy, pancreatic texture (soft or hard/fibrotic), pancreatic duct dilatation, vascular or additional organ involvement and surgical approach (LPD or RPD), univariable and multivariable analyses were performed using binary logistic regression with backwards stepwise elimination; the results are reported as odds ratios (ORs) with 95 per cent confidence intervals. Variables associated with conversion with $P < 0.200$ in univariable analysis and factors reported by surgeons as the intraoperative reason for conversion were considered for multivariable analysis.

The level of statistical significance was set at two-sided $P < 0.050$. Statistical analysis was done using SPSS® Statistics for Windows® version 24.0 (IBM, Armonk, New York, USA).

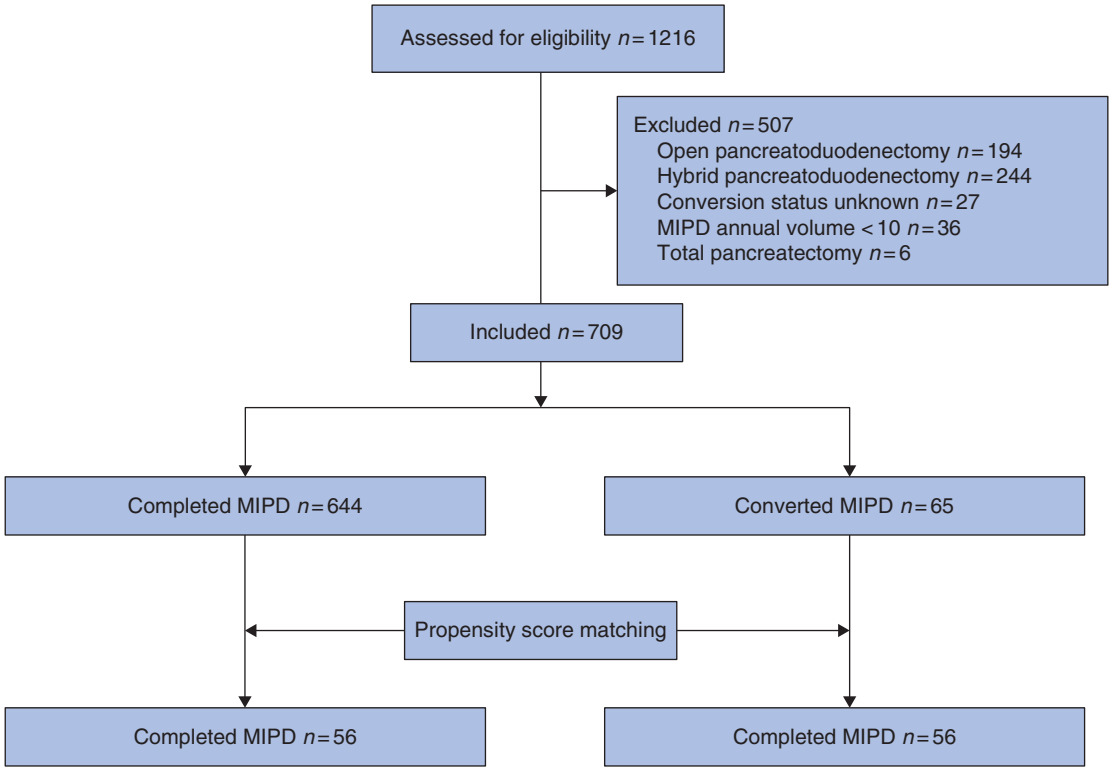

Fig. 1 Study flow chart
MIPD, minimally invasive pancreatoduodenectomy.

Results

Overall, 1216 patients undergoing pancreatoduodenectomy were included in the original cohort. After excluding 507 patients (*Fig. 1*), 709 MIPDs from 10 medium- and four high-volume centres in six countries were included in subsequent analyses. Median percentage of MIPD to total annual volume of pancreatoduodenectomy was 33 (range 7–72) per cent. The conversion rate was 9.2 per cent (65 procedures) (*Table 1*). The most commonly reported reasons for conversion are shown in *Table 2*. Twelve conversions (20 per cent) were considered as emergencies.

Risk factors for conversion

Results for potential risk factors included in the univariable analyses are shown in *Table 3*. Subsequent multivariable analysis showed that LPD (OR 5.2, 95 per cent c.i. 2.5 to 10.7; $P < 0.001$), age at least 75 years (OR 2.0, 1.0 to 4.1; $P = 0.043$), pancreatobiliary tumours (OR 2.2, 1.0 to 4.8; $P = 0.039$) and tumour size larger than 40 mm (OR 2.7, 1.0 to 6.8; $P = 0.041$) were associated with a higher risk of conversion.

Cohort baseline and unadjusted outcomes

Patients who required conversion from MIPD were older (68 *versus* 66 years; $P = 0.004$), more often men (68 *versus* 49.1 per cent; $P = 0.006$), and with an ASA fitness grade of III–IV (32 *versus* 20.5 per cent; $P = 0.029$) than those who had a completely minimally invasive procedure (*Table 1*). Converted procedures included larger tumours (median 26 (i.q.r. 19–40) *versus* 25 (17–31) mm; $P = 0.033$), more commonly pancreatobiliary tumours (85 *versus* 73.0 per cent; $P = 0.042$), and more often required an extended resection owing to vascular (33 *versus* 4.8 per cent; $P < 0.001$) or additional organ (9 *versus* 1.3 per cent; $P < 0.001$) tumour involvement (*Table 4*). The conversion rate was twice as high during LPD than RPD (52 of 459 (11.3 per cent) *versus* 13 of 250 (5.2 per cent); $P = 0.007$) (*Table 4*).

Although the severe morbidity rate was comparable for procedures that were converted and completed MIPDs (32 *versus* 27.7 per cent; $P = 0.431$), converted procedures were associated with a higher 30-day (10 *versus* 3.1 per cent; $P = 0.019$) and 90-day (12.7 *versus* 4.9 per cent; $P = 0.026$) mortality rate. The overall 30-day mortality rate was 3.8 per cent.

In multivariable logistic regression with adjustment for potential confounding preoperative and intraoperative variables, no significant associations were found between conversion and short-term surgical outcomes (overall morbidity, complications of Clavien–Dindo grade at least III, 30-day mortality) (*Table S1*).

Propensity score-matched analysis

Of all procedures, 56 (86 per cent) converted MIPDs were matched with 56 completed MIPD procedures (*Tables 1 and 4*). Nine patients were not matched, because no propensity score could be calculated (4) or because of extreme baseline characteristics (5). The outcomes of non-matched converted procedures are summarized in *Table S2*. After propensity score matching, MIPD conversion was associated with greater blood loss (median 500 (i.q.r. 230–800) *versus* 275 (100–500) ml; $P = 0.005$) and intraoperative blood transfusion (33 *versus* 13 per cent; $P = 0.015$) than non-converted MIPD. There were no statistically significant differences between groups with regard to severe morbidity (32 *versus*

Table 1 Baseline characteristics in the total and propensity-matched cohorts

	Total cohort			Propensity-matched cohort		
	Converted MIPD (*n* = 65)	Completed MIPD (*n* = 644)	*P*‡	Converted MIPD (*n* = 56)	Completed MIPD (*n* = 56)	*P*‡
Age (years)*	68 (63–76)	66 (57–73)	0.004§	69 (62–76)	72 (67–77)	0.214§
≥ 75 years	21 (32)	122 (19.1)	0.012	19 (34)	23 (41)	0.435
Unknown	0	6		0	0	
Sex ratio (F : M)	21 : 44	328 : 316	0.006	20 : 36	28 : 28	0.127
BMI (kg/m^2)*	24 (22–28)	24 (21–26)	0.180§	24 (22–28)	24 (21–28)	0.324§
BMI > 30	9 (15)	59 (9.8)	0.248	9 (16)	9 (16)	1.000
Unknown	3	44		0	0	
ASA grade III–IV	21 (32)	123 (20.5)	0.029	19 (34)	14 (25)	0.300
Unknown	0	45		0	0	
Co-morbidities	45 (71)	384 (64.8)	0.290	41 (73)	43 (77)	0.663
Unknown	2	51		0	0	
Previous abdominal surgery	21 (50)	189 (47.1)	0.723	20 (56)	18 (44)	0.307
Unknown	23	243		20	15	
Tumour location on preoperative imaging			0.042			0.112
Pancreatobiliary	55 (85)	437 (73.0)		47 (84)	40 (71)	
Ampullary/duodenal	10 (15)	162 (27.0)		9 (16)	16 (29)	
Unknown	11	45		0	0	
Pancreatic duct dilatation > 5 mm	20 (37)	192 (34.8)	0.747	18 (38)	8 (27)	0.293
Unknown	0	93		9	26	
Vascular involvement on preoperative imaging	4 (8)	33 (7.6)	0.857	4 (10)	3 (8)	0.692
Upfront resectable†	3 (75)	31 (94)		4 (100)	3 (100)	
Borderline resectable†	1 (25)	2 (6)		0 (0)	0 (0)	
Unknown	17	210		16	16	
Additional organ involvement on preoperative imaging	2 (4)	11 (2.5)	0.506	2 (5)	0 (0.0)	0.147
Unknown	17	209		16	15	
Neoadjuvant therapy	2 (4)	7 (1.2)	0.161	1 (2)	1 (2)	0.854
Unknown	8	65		3	15	
Tumour size on preoperative imaging (mm)*	25 (17–31)	25 (19–32)	0.899§	25 (19–33)	25 (19–33)	0.994§
Unknown	22	248		20	24	
Final histopathology						
Malignant	55 (85)	461 (80.9)	0.464	47 (84)	47 (89)	0.472
Unknown	0	74		0	3	
PDAC	45 (69)	352 (57.8)	0.100	37 (66)	44 (79)	0.423
IPMN	7 (11)	44 (7.2)		7 (13)	3 (5)	
Neuroendocrine tumour	3 (5)	42 (6.9)		3 (5)	3 (5)	
Other	10 (15)	171 (28.1)		9 (16)	6 (11)	
Unknown	0	35		0	0	
Final tumour size (mm)*	26 (19–40)	25 (17–31)	0.033§	26 (19–40)	20 (15–30)	0.018§
> 4 cm	9 (16)	37 (8.5)	0.062	7 (14)	2 (5)	0.164
Unknown	10	211		7	12	

Values in parentheses are percentages unless indicated otherwise; values are median (i.q.r.). †For patients with vascular tumour involvement on preoperative imaging, resectability was categorized according to the National Cancer Comprehensive Network version 2.2017[17]. MIPD, minimally invasive pancreatoduodenectomy; PDAC pancreatic ductal adenocarcinoma, IPMN intraductal papillary mucinous neoplasm. ‡χ^2 or Fisher's exact test, except §Mann–Whitney *U* test.

Table 2 Surgeon-reported reason for conversion

	No. of patients (*n* = 65)
Elective conversion	
Vascular involvement by tumour	18 (30)
Adhesions	8 (13)
Technical difficulties	6 (10)
Oncological concerns	5 (8)
Pancreatitis	5 (8)
Obesity	4 (7)
Small pancreatic duct	2 (3)
Emergency conversion	
Bleeding	12 (20)
Unknown	5

Values in parentheses are percentages.

34 per cent; $P = 0.841$), grade B/C PPH (18 *versus* 15 per cent; $P = 0.666$) and 30-day mortality (12 *versus* 6 per cent; $P = 0.274$).

Additional analyses in total cohort

Thirteen of the 65 conversions (20 per cent) were required during RPD (*Table 5*). Conversions during RPD were associated with increased operating time (median 480 (i.q.r. 477–582) *versus* 370 (327–483) min; $P = 0.004$) and increased incidence of grade B/C PPH (5 of 13 (39 per cent) *versus* 5 of 52 (10 per cent); $P = 0.022$) compared with conversions required during LPD. The 30-day mortality rate was higher after RPD than LPD conversion but the difference was not significant (3 of 13 (23 per cent) *versus* 3 of 52 (6 per cent); $P = 0.109$).

Overall, 12 conversions (18 per cent) were considered an emergency (owing to bleeding) (*Table 2* and *Table S3*). Emergency

Table 3 Univariable and multivariable logistic analysis of preoperative risk factors for conversion

	Univariable analysis		Multivariable analysis	
	Odds ratio	P	Odd ratio	P
Age ≥ 75 years	2.0 (1.2, 3.5)	0.013	2.0 (1.0, 4.1)	0.043
Female sex	0.5 (0.3, 0.8)	0.007	0.6 (0.3, 1.1)	0.094
ASA grade III–IV	1.8 (1.1, 3.2)	0.031	Removed in step 5	
BMI ≥ 30 kg/m^2	1.6 (0.7, 3.3)	0.251	Removed in step 2	
Any co-morbidity	1.4 (0.8, 2.4)	0.291		
Past surgical history	1.4 (0.78, 2.3)	0.259		
Neoadjuvant therapy	3.0 (0.6, 14.7)	0.181	Removed in step 3	
Vascular involvement on CT	1.1 (0.4, 3.3)	0.857		
Additional organ involvement	1.7 (0.4, 7.8)	0.510		
Surgical approach				
Robotic	1.00 (reference)		1.00 (reference)	
Laparoscopic	0.4 (0.2, 0.8)	0.008	5.2 (2.5, 10.7)	<0.001
Tumour location				
Ampullary – duodenal	1.00 (reference)		1.00 (reference)	
Pancreatobiliary	2.0 (1.0, 4.1)	0.045	2.2 (1.0, 4.8)	0.039
Pancreas texture				
Soft	1.00 (reference)			
Firm/fibrotic	1.4 (0.8, 2.3)	0.237		
Pancreatic duct dilatation > 5 mm	0.9 (0.5, 1.6)	0.747		
Tumour type				
Benign	1.00 (reference)		1.00 (reference)	
Malignant	1.3 (0.6, 2.6)	0.465	2.6 (0.9, 8.0)	0.090
Tumour size > 40 mm	2.1 (1.0, 4.5)	0.067	2.7 (1.0, 6.8)	0.041

Values in parentheses are 95 per cent confidence intervals.

Table 4 Surgical outcome in the total and propensity-matched cohorts

	Total cohort			Propensity-matched cohort		
	Converted MIPD (n = 65)	Completed MIPD (n = 644)	P‡	Converted MIPD (n = 56)	Completed MIPD (n = 56)	P‡
Surgical approach			0.007			0.067
Laparoscopic	52 (80)	407 (63.2)		44 (79)	51 (91)	
Robotic	13 (20)	237 (36.8)		12 (21)	5 (9)	
Duration of operation (min)*	420 (330–492)	415 (339–510)	0.784§	438 (330–495)	402 (355–477)	0.809§
Estimated blood loss (ml)*	500 (250–1000)	200 (100–400)	< 0.001	500 (230–800)	275 (100–500)	0.005
Intraoperative blood transfusion	21 (33)	77 (12.8)	< 0.001	18 (33)	6 (13)	0.015
Pancreas texture			0.148			0.336
Soft	33 (52)	352 (61.8)		29 (52)	32 (60)	
Firm/fibrotic	30 (48)	218 (38.2)		27 (48)	21 (40)	
Multivisceral resection	6 (9)	8 (1.3)	< 0.001	4 (7)	4 (7)	1.000
Vascular resection†	21 (33)	29 (4.8)	< 0.001	15 (27)	13 (23)	0.663
R0 resection	49 (80)	494 (87.0)	0.151	42 (83)	45 (83)	0.930
Overall morbidity	38 (58)	359 (58.5)	0.999	34 (61)	33 (59)	0.847
Clavien–Dindo grade of complications			0.028			0.431
I–II	17 (26)	189 (30.8)		16 (29)	14 (25)	
IIIa/b	8 (12)	112 (18.2)		7 (13)	11 (20)	
IVa/b	5 (8)	34 (5.5)		3 (5)	5 (9)	
V	8 (12)	24 (3.9)		8 (14)	3 (5)	
Clavien–Dindo grade ≥ III complications	21 (32)	170 (27.7)	0.431	18 (32)	19 (34)	0.841
Postoperative pancreatic fistula grade B and C	15 (23)	135 (22)	0.862	13 (23)	13 (23)	1.000
Delayed gastric emptying, grade B and C	8 (12)	88 (14.5)	0.635	7 (19)	10 (13)	0.383
Postpancreatectomy haemorrhage, grade B and C	10 (15)	60 (9.9)	0.168	10 (18)	8 (15)	0.666
Reoperation	10 (18)	62 (11.5)	0.169	10 (20)	8 (22)	0.803
Medium or intensive care	8 (14)	37 (6.6)	0.045	7 (14)	5 (11)	0.702
Duration of hospital stay (days)*	16 (10–24)	15 (10–24)	0.614§	16 (11–25)	13 (8–21)	0.111§
Readmission	8 (14)	45 (7.5)	0.101	7 (14)	7 (15)	0.835
30-day mortality	6 (10)	18 (3.1)	0.019	6 (12)	3 (6)	0.274
90-day mortality	7 (13)	26 (4.9)	0.026	7 (15)	4 (9)	0.395

Values in parentheses are percentages unless indicated otherwise; *values are median (i.q.r.). Data were incomplete for some variables; Data were missing for some patients. †Vascular resection included in total cohort: 48 portal vein or superior mesenteric vein and four arterial resections. MIPD, minimally invasive pancreatoduodenectomy. ‡χ^2 or Fisher's exact test, except §Mann–Whitney *U* test.

Table 5 Surgical outcomes after converted laparoscopic *versus* robotic distal pancreatectomy

	Laparoscopic ($n = 52$)	Robotic ($n = 13$)	$P^{\dagger}$
Duration of operation (min)*	370 (327–483)	480 (477–582)	0.004‡
Estimated blood loss (ml)*	500 (300–1000)	250 (75–750)	0.059‡
Intraoperative blood transfusion	18 (35)	3 (23)	0.402
Clavien–Dindo grade ≥ III complications	15 (28)	6 (46)	0.233
Postoperative pancreatic fistula, grade B and C	13 (25)	2 (15)	0.462
Delayed gastric emptying, grade B and C	7 (13)	1 (8)	0.571
Postpancreatectomy haemorrhage, grade B and C	5 (10)	5 (39)	0.022
Reoperation	7 (16)	3 (23)	0.682
30-day mortality	3 (6)	3 (23)	0.109

Values in parentheses are percentages unless indicated otherwise; *values are median (i.q.r.). Data were missing for some patients. †χ^2 or Fisher's exact test, except ‡Mann–Whitney *U* test.

conversions were associated with increased intraoperative blood loss (median 1000 (i.q.r. 525–1401) *versus* 425 (207–750) ml; $P = 0.005$) and a higher blood transfusion rate (8 of 12 (67 per cent) *versus* 10 of 48 (21 per cent); $P = 0.004$) than elective conversions. Rates of severe morbidity (4 of 12 (33 per cent) *versus* 14 of 48 (29 per cent); $P = 0.740$) and 30-day mortality (1 of 12 (8 per cent) *versus* 3 of 43 (7 per cent); $P = 1.000$) were comparable after emergency and elective conversions.

The third additional analysis demonstrated that medium-volume centres (annual volume 10–19 MIPDs) had a higher conversion rate than those performing 20 or more MIPDs: 49 of 323 (15.2 per cent) *versus* 16 of 386 (4.1 per cent) ($P < 0.001$) (OR 4.1, 95 per cent c.i. 2.3 to 7.4; $P < 0.001$). The 30-day mortality rate was similar in medium- and high-volume centres (4.9 *versus* 2.7 per cent; $P = 0.155$)

Discussion

This multicentre international study identified several risk factors for conversion during MIPD including older age (75 years or more), pancreatobiliary tumours, tumours larger than 40 mm, and laparoscopic surgery. The conversion rate was 9.2 per cent among 709 MIPD procedures, but lower in high-volume centres (performing at least 20 MIPDs per year) than medium-volume centres. In a matched analysis, there was no significant difference in severe morbidity and 30-day mortality between converted and non-converted MIPDs. Yet, the 30-day mortality rate was relatively high in both groups, meaning that these risk factors might predict poor outcome in general. This should be taken into account during patient selection for MIPD.

The conversion rate of 9.2 per cent is in line with rates of between 3.1 and 16.9 per cent in other studies[4,11,22,23]. In contrast, nationwide studies[13,24] analysing data from the National Surgical Quality Improvement Program (NSQIP) reported higher conversion rates of up to 24.6 per cent, but did not contain data on annual MIPD volume per centre. The fact that the NSQIP database comprises data from 120 centres with different experience in the minimally invasive approach might explain the higher conversion rate. It should also be noted that the NSQIP definition of conversion also includes procedures for which conversion to open surgery was preplanned[25]. These hybrid pancreatoduodenectomies were excluded from the present analysis.

In the present study, converted MIPD was associated with an increased 30-day mortality rate of 10.0 per cent, whereas the rate for completed MIPD was 3.1 per cent. The latter is in line with mortality rates for open pancreatoduodenectomy[3,14]. The majority of conversions were due to unexpected increased complexity of the procedure because of vascular involvement by tumour or oncological concerns, potentially influencing the surgical outcome negatively. After propensity score matching, morbidity and mortality rates were comparable following converted and completed MIPDs. In contrast, studies analysing the nationwide NSQIP database reported increased (severe) morbidity following MIPD conversion when propensity score-matched to either completed MIPD[13,25] or open pancreatoduodenectomy[24]. It is currently unclear whether inclusion of data from low-volume centres in the NSQIP studies affected the surgical outcomes. However, centres with very low annual volumes of both MIPD (fewer than 7 procedures) and pancreatoduodenectomy in general (fewer than 24 procedures) were associated with a higher conversion rate in a National Cancer Database study[26] including 3754 MIPD procedures. In the present study, medium-volume MIPD centres performing 10–19 MIPDs annually had a higher conversion rate than those undertaking 20 or more MIPDs annually. Notably, the recent Miami international evidence-based guidelines[2] on minimally invasive pancreatic resection advised a minimum centre volume of 20 MIPDs per year.

The high mortality rates in both the converted MIPD and matched completed MIPD groups highlight the importance of correct identification of patients suitable for the minimally invasive approach. The present study found that older age (75 years or more), pancreatobiliary tumours, tumour size greater than 40 mm, and LPD were associated with an increased conversion rate. Older patients have increased co-morbidities that may affect the postoperative course. The association between large tumour size and conversion confirms the concerns expressed in a worldwide survey of minimally invasive pancreatic resection among 435 surgeons[27]. One-third of responding surgeons considered large tumours a contraindication to MIPD, mainly owing to increased technical difficulties.

Interestingly, procedures for ampullary and duodenal tumours were less likely to be converted than those for pancreatobiliary tumours. One explanation might be that ampullary tumours often present at an earlier stage owing to early obstruction of the bile ducts, with consequent obstructive jaundice[28]. Another explanation might be the anatomical location of these tumours, further away from major vasculature[29,30].

In the present study, laparoscopy (64.8 per cent) was the most common approach to MIPD. Conversely, the 250 RPD procedures were performed in only four centres, with a conversion rate of 5.2

per cent, compared with 11.3 per cent during LPD. The reduced risk of conversion during RDP has already been suggested in several other studies[24,31]. Nonetheless, rates of grade B/C PPH and 30-day mortality were both increased after RPD conversion compared with LPD conversion in the present analysis. Although the latter did not reach statistical significance and the sample size for this subgroup analysis was very small, this is clearly a topic of concern[12,26]. The National Cancer Database study[26] reported a fourfold increased 90-day mortality for converted *versus* completed RPD, whereas conversion of LPD was not associated with an increased risk of death. Another study[12] of 30 RPDs documented a mortality rate of 33 per cent among converted RPDs. Torphy and colleagues[26] suggested that conversion may take longer in RPD with consequently greater intraoperative blood loss. In the present study, there was no difference in intraoperative blood loss between converted LPDs and RPDs, and bleeding was the main reason for conversion in only one robotic procedure. Vascular involvement was the most common reason for conversion in this study; the lack of haptic feedback may potentially lead to adventitial injury during dissection of arteries and veins, and consequently PPH, as suggested by the Pittsburgh group[32,33]. It seems imperative for robotic pancreatic surgery teams to have clear criteria for when to convert, and to train specifically in conversion of robotic procedures as a part of their training programme.

This study has several limitations. First, the retrospective design comes with inherent selection and reporting bias. During the initial data collection, however, conversion was not a specific primary endpoint and therefore did not receive specific additional focus. Yet, the conversion rate in this study was comparable to rates reported in other studies, including data from high-volume centres. Second, the total number of events was small in the matched analysis and type II (false-negative) errors might have occurred. Statistical non-significance is an indication of uncertainty and the findings might still be clinically relevant[34], such as the high mortality rate. Therefore, the authors emphasize that the impact of conversion should be studied further in prospective studies such as the ongoing pan-European E-MIPS registry analysis of minimally invasive pancreatic surgery (http://www.e-mips.com). Third, only data from medium- and high-volume centres were included. These results cannot therefore be extrapolated to low-volume centres. Finally, although conversion occurred less often during RPD than LPD, no definitive conclusion can be drawn on this point as the surgical outcomes of converted RPD appeared to be worse. Whether this was a reflection of case selection (only the most difficult procedures were converted in RPD, whereas LPD procedures were converted more easily), associated with the learning curve (RPD programmes began later during the implementation of MIPD) or a true effect (conversion of RPD is more dangerous) should be studied further.

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Supplementary material

Supplementary material is available at *BJS* online.

References

1. Boggi U, Amorese G, Vistoli F, Caniglia F, De Lio N, Perrone V *et al.* Laparoscopic pancreaticoduodenectomy: a systematic literature review. *Surg Endosc* 2015;**29**:9–23
2. Asbun HJ, Moekotte AL, Vissers F, Kunzler F, Cipriani F, Alseidi A *et al.* The Miami international evidence-based guidelines on minimally invasive pancreas resection. *Ann Surg* 2020;**271**:1–14
3. Poves I, Burdío F, Morató O, Iglesias M, Radosevic A, Ilzarbe L *et al.* Comparison of perioperative outcomes between laparoscopic and open approach for pancreatoduodenectomy. *Ann Surg* 2018;**268**:731–739
4. Palanivelu C, Senthilnathan P, Sabnis SC, Babu NS, Srivatsan Gurumurthy S, Anand Vijai N *et al.* Randomized clinical trial of laparoscopic *versus* open pancreatoduodenectomy for periampullary tumours. *Br J Surg* 2017;**104**:1443–1450
5. Dokmak S, Ftériche FS, Aussilhou B, Bensafta Y, Lévy P, Ruszniewski P *et al.* Laparoscopic pancreaticoduodenectomy should not be routine for resection of periampullary tumors. *J Am Coll Surg* 2015;**220**:831–838
6. van Hilst J, De Rooij T, Bosscha K, Brinkman DJ, Van Dieren S, Dijkgraaf MG *et al.* Laparoscopic *versus* open pancreatoduodenectomy for pancreatic or periampullary tumours (LEOPARD-2): a multicentre, patient-blinded, randomised controlled phase 2/3 trial. *Lancet Gastroenterol Hepatol* 2019;**4**:199–207
7. Adam MA, Choudhury K, Dinan MA, Reed SD, Scheri RP, Blazer DG *et al.* Minimally invasive *versus* open pancreaticoduodenectomy for cancer: practice patterns and short-term outcomes among 7061 patients. *Ann Surg* 2015;**262**:372–377
8. de Rooij T, van Hilst J, Topal B, Bosscha K, Brinkman DJ, Gerhards MF *et al.* Outcomes of a multicenter training program in laparoscopic pancreatoduodenectomy (LAELAPS-2). *Ann Surg* 2019;**269**:344–350
9. Halls MC, Cipriani F, Berardi G, Barkhatov L, Lainas P, Alzoubi M *et al.* Conversion for unfavorable intraoperative events results in significantly worst outcomes during laparoscopic liver resection: lessons learned from a multicenter review of 2861 cases. *Ann Surg* 2018;**268**:1051–1057
10. de Neree tot Babberich MPM, van Groningen JT, Dekker E, Wiggers T, Wouters MWJM, Bemelman WA *et al.* Laparoscopic conversion in colorectal cancer surgery: is there any improvement over time at a population level? *Surg Endosc* 2018;**32**:3234–3246
11. Asbun HJ, Stauffer JA. Laparoscopic *vs* open pancreaticoduodenectomy: overall outcomes and severity of complications using the Accordion severity grading system. *J Am Coll Surg* 2012;**215**:810–819
12. Chalikonda S, Aguilar-Saavedra JR, Walsh RM. Laparoscopic robotic-assisted pancreaticoduodenectomy: a case-matched comparison with open resection. *Surg Endosc* 2012;**26**:2397–2402
13. Beane JD, Pitt HA, Dolejs SC, Hogg ME, Zeh HJ, Zureikat AH. Assessing the impact of conversion on outcomes of minimally invasive distal pancreatectomy and pancreatoduodenectomy. *HPB* 2018;**20**:356–363
14. Klompmaker S, van Hilst J, Wellner UF, Busch OR, Coratti A, D'Hondt M *et al.* Outcomes after minimally-invasive *versus* open pancreatoduodenectomy. *Ann Surg* 2020;**271**:356–363
15. Von Elm E, Altman DG, Egger M, Pocock SJ, Gøtzsche PC, Vandenbroucke JP. The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement: guidelines for reporting observational studies. *Lancet* 2007;**370**:1453–1457

16. Campbell F, Cairns A, Duthie F, Feakins R. *Dataset for the Histopathological Reporting of Carcinomas of the Pancreas, Ampulla of Vater and Common Bile Duct from the Royal College of Pathologists*. https://www.rcpath.org/uploads/assets/34910231-c106-4629-a2de9e9ae6f87ac1/g091-pancreasdataset-mar17.pdf (accessed 3 October 2018)
17. Tempero MA, Malafa MP, Al-Hawary M, Asbun H, Bain A, Behrman SW *et al.* Pancreatic adenocarcinoma, version 2.2017, NCCN Clinical Practice Guidelines In Oncology. *J Natl Compr Cancer Netw* 2017;**15**:1028–1061
18. Clavien PA, Barkun J, De Oliveira ML, Vauthey JN, Dindo D, Schulick RD *et al.* The Clavien–Dindo classification of surgical complications: five-year experience. *Ann Surg* 2009;**250**:187–196
19. Bassi C, Dervenis C, Butturini G, Fingerhut A, Yeo C, Izbicki J *et al.* Postoperative pancreatic fistula: an international study group (ISGPF) definition. *Surgery* 2005;**138**:8–13
20. Wente MN, Veit JA, Bassi C, Dervenis C, Fingerhut A, Gouma DJ *et al.* Postpancreatectomy hemorrhage (PPH)—an international study group of pancreatic surgery (ISGPS) definition. *Surgery* 2007;**142**:20–25
21. Wente MN, Bassi C, Dervenis C, Fingerhut A, Gouma DJ, Izbicki JR *et al.* Delayed gastric emptying (DGE) after pancreatic surgery: a suggested definition by the International Study Group of Pancreatic Surgery (ISGPS). *Surgery* 2007;**142**:761–768
22. Dokmak S, Ftériche FS, Aussilhou B, Lévy P, Ruszniewski P, Cros J *et al.* The largest European single-center experience: 300 laparoscopic pancreatic resections. *J Am Coll Surg* 2017;**225**:226.e2–234.e2
23. Zureikat AH, Postlewait LM, Liu Y, Gillespie TW, Weber SM, Abbott DE *et al.* A multi-institutional comparison of perioperative outcomes of robotic and open pancreaticoduodenectomy. *Ann Surg* 2016;**264**:640–649
24. Stiles ZE, Dickson P V., Deneve JL, Glazer ES, Dong L, Wan JY *et al.* The impact of unplanned conversion to an open procedure during minimally invasive pancreatectomy. *J Surg Res* 2018;**227**:168–177
25. Hester CA, Nassour I, Christie A, Augustine MM, Mansour JC, Polanco PM *et al.* Predictors and outcomes of converted minimally invasive pancreaticoduodenectomy: a propensity score matched analysis. *Surg Endosc* 2019;**34**:544–550
26. Torphy RJ, Friedman C, Halpern A, Chapman BC, Ahrendt SS, McCarter MM *et al.* Comparing short-term and oncologic outcomes of minimally invasive *versus* open pancreaticoduodenectomy across low and high volume centers. *Ann Surg* 2019;**270**:1147–1155
27. van Hilst J, de Rooij T, Abu Hilal M, Asbun HJ, Barkun J, Boggi U *et al.* Worldwide survey on opinions and use of minimally invasive pancreatic resection. *HPB* 2017;**19**:190–204
28. Moekotte AL, Lof S, Van Roessel S, Fontana M, Dreyer S, Shablak A et al. Histopathologic predictors of survival and recurrence in resected ampullary adenocarcinoma. *Ann Surg* 2020;272:1086–1093
29. Shyr BU, Chen SC, Shyr YM, Wang SE. Surgical, survival, and oncological outcomes after vascular resection in robotic and open pancreaticoduodenectomy. *Surg Endosc* 2020;**34**:377–383
30. Chapman BC, Gleisner A, Ibrahim-Zada I, Overbey DM, Paniccia A, Meguid C *et al.* Laparoscopic pancreaticoduodenectomy: changing the management of ampullary neoplasms. *Surg Endosc* 2018;**32**:915–922
31. Kamarajah SK, Sutandi N, Robinson SR, French JJ, White SA. Robotic *versus* conventional laparoscopic distal pancreatic resection: a systematic review and meta-analysis. *HPB* 2019;**21**:1107–1118
32. Magge D, Zenati M, Lutfi W, Hamad A, Zureikat AH, Zeh HJ *et al.* Robotic pancreatoduodenectomy at an experienced institution is not associated with an increased risk of post-pancreatic hemorrhage. *HPB* 2018;**20**:448–455
33. Zeh HJ, Zureikat AH, Secrest A, Dauoudi M, Bartlett D, Moser AJ. Outcomes after robot-assisted pancreaticoduodenectomy for periampullary lesions. *Ann Surg Oncol* 2012;**19**:864–870
34. Wasserstein RL, Lazar NA. The ASA's statement on p-values: context, process, and purpose. *Am Stat* 2016;**70**:129–133