

Hospital surgical volume, perioperative transfusion, and 30-day mortality after pancreatic surgery: a nationwide population-based retrospective cohort study in South Korea

Sunghee Hong¹, Seyoon Kim², Yun Kyung Jung², Seonju Kim³, Junghyun Yoon⁴, Dongho Choi², Boyoung Park^{4,5}

¹*Institute for Health and Society, Hanyang University, Seoul, Korea*

²*Department of Surgery, Hanyang University College of Medicine, Seoul, Korea*

³*Department of Public Health Sciences, Hanyang University College of Medicine, Seoul, Korea*

⁴*Department of Preventive Medicine, Hanyang University College of Medicine, Seoul, Korea*

⁵*Hanyang Institute of Bioscience and Biotechnology, Hanyang University, Seoul, Korea*

Purpose: We evaluated national trends in 30-day mortality following pancreatic surgery and the factors associated with 30-day mortality in South Korea, with special attention to hospital surgical volume and perioperative transfusion as perioperative risk markers.

Methods: We performed a retrospective, population-based study using Korean National Health Insurance Service data. Adults who underwent pancreatic surgery during 2012–2020 were included ($n = 40,937$). The annual 30-day mortality rates were described overall and stratified by year, age, sex, and pancreatic surgical procedure. We analyzed the associations between hospital surgical volume, perioperative transfusion, and 30-day mortality.

Results: The annual number of pancreatic surgeries increased from 4,055 in 2012 to 5,278 in 2020, whereas 30-day mortality remained stable (1.2%–1.9%, P -trend = 0.401). Mortality was lowest in high-volume hospitals (1.0%) and highest in the lowest-volume hospitals (5.9%). Perioperative transfusion and greater transfusion volume were strongly associated with increased 30-day mortality; both were more frequent and of greater quantities in lower-volume hospitals. Across the transfusion strata, a higher hospital surgical volume was consistently associated with lower mortality. In multivariable analyses, lower hospital volume and greater transfusion volume were independently associated with increased 30-day mortality, demonstrating a clear volume–outcome gradient and dose–response relationship with the transfusion amount.

Conclusion: Despite the increasing surgical volume nationwide, the 30-day mortality after pancreatic surgery in South Korea remained unchanged. Lower hospital volume and perioperative transfusion independently predicted increased 30-day mortality. Given lower transfusion rates in high-volume hospitals, these findings support centralizing pancreatic surgery in specialized centers and highlight the importance of optimized perioperative management.

[Ann Surg Treat Res 2026;111(3):148–156]

Key Words: Blood transfusion, High-volume hospitals, Mortality, Pancreatectomy

Received January 14, 2026, Revised March 5, 2026,
Accepted March 20, 2026

Corresponding Author: Boyoung Park

Department of Preventive Medicine, Hanyang University College of Medicine, 222 Wangsimri-ro, Seongdong-gu, Seoul 04763, Korea

Tel: +82-2-2220-0682, Fax: +82-2-2220-0699

E-mail: hayejine@hanyang.ac.kr

ORCID: <https://orcid.org/0000-0003-1902-3184>

Copyright 2026, the Korean Surgical Society

© Annals of Surgical Treatment and Research is an Open Access Journal. All articles are distributed under the terms of the Creative Commons Attribution Non-Commercial License (<http://creativecommons.org/licenses/by-nc/4.0/>) which permits unrestricted non-commercial use, distribution, and reproduction in any medium, provided the original work is properly cited.

INTRODUCTION

Pancreatic surgery is a complex procedure associated with significant risks, including high rates of postoperative complications such as pancreatic fistula, delayed gastric emptying, and postoperative hemorrhage [1]. Additionally, the anatomical location of the pancreas, which is surrounded by critical blood vessels and organs, further complicates the procedure and increases the likelihood of intraoperative challenges and perioperative morbidity [2]. Despite the advancements in surgical techniques, pancreatic surgery still presents significant challenges that require meticulous planning and execution [3]. Among the factors associated with the outcomes of pancreatic surgery, hospital surgical volume is an important structural factor, other than patient characteristics or underlying medical status. Numerous studies have established an inverse relationship between hospital surgical volume and mortality, indicating that hospitals performing a higher volume of surgeries tend to achieve better patient outcomes, including lower mortality rates [4-8]. Over the past few years, several countries have implemented centralization of pancreatic surgeries, and studies have shown that such policies have contributed to a reduction in mortality associated with pancreatic surgery [9,10].

Among the various outcomes after surgery, the 30-day postoperative mortality rate is a critical measure of surgical success and safety [11], and understanding trends in this metric, along with how hospital surgical volumes affect outcomes, is crucial for guiding improvements in surgical care. Furthermore, patients requiring additional transfusions during pancreatic surgery generally experience poorer outcomes [12-16]. However, limited research has comprehensively examined the relationship among hospital surgical volume, transfusion practices, and 30-day postoperative mortality in South Korea's national healthcare system.

Therefore, we aimed to examine trends in 30-day postoperative mortality among patients who underwent pancreatic surgery between 2012 and 2020. Additionally, the 30-day postoperative mortality according to hospital pancreatic surgical volume and transfusion practices was assessed to provide insights for improving medical policies and clinical practice.

METHODS

Ethics statement

This study was approved by the Institutional Review Board of Hanyang University College of Medicine (No. 202207-001 and 202211-009). The Korean National Health Insurance Service (NHIS) granted permission to use the Korean National Health Insurance Service-National Health Information Database (NHIS-

NHID) data after anonymizing individual identities.

Data source and study population

This population-based retrospective study used data from the NHIS-NHID. The NHIS, a mandatory health insurance system that covers all Korean residents, provides detailed information on demographics, healthcare service utilization, and prescribed medications. Patients who underwent pancreatic surgery between 2012 and 2020 were identified. The surgical procedures were identified using the administrative reimbursement codes in the NHIS. The codes used for pancreatic surgery are as follows:

- Partial resection of the pancreas: limited resections targeting specific pancreatic areas, including local excision (Q7550), segmentectomy (Q7563, Q7564), wedge resection (Q7566), and duodenum-preserving pancreatic head resection (Q7562)
- Distal pancreatectomy: resection of the pancreatic body and tail, either with splenectomy (Q7655) or spleen preservation (Q7567)
- Pancreaticoduodenectomy: removal of the pancreatic head and surrounding structures, with subtypes including pylorus-preserving pancreaticoduodenectomy (Q7572) and the traditional Whipple procedure (Q7571)
- Total pancreatectomy: complete removal of the pancreas (Q7561)
- Other procedures: pancreatic enterostomy (Q7591, Q7292); surgery for pancreatic stones (Q7531, Q7532); treatments for abscesses, pseudocysts, or cysts (Q7511, Q7522, Q7541, Q7542, Q7543); and operations for pancreatic trauma (Q7520)

Cause of 30-day mortality

The NHIS-NHID dataset can be integrated with other data using a 13-digit unique resident registration number. In this study, a link was established with the Statistics Korea mortality database to retrieve cause-of-death information for individuals who underwent pancreatic surgery between 2012 and 2020. The Statistics Korea death certificate data provide the cause of death, classified according to the International Classification of Diseases, 10th Revision (ICD-10), along with the date of death recorded for each matched case. We assessed all-cause and cause-specific mortalities within 30 days of surgery. The causes of death were categorized into the following groups: pancreatic cancer, liver and bile duct cancer, injury, external causes, and other unspecified causes. This classification system was designed to enable comprehensive analysis of mortality patterns among patients who underwent pancreatic surgery.

Definition of pancreatic surgery volume and its classification

Medical institutions were categorized as tertiary or general hospitals. Additionally, institutions that performed pancreatic

surgeries were grouped based on the annual volume of pancreatic surgeries. The 1st, 2nd, 3rd, 4th, and 5th groups represented institutions with >30 (highest volume), 21–30, 11–20, 5–10, and <5 pancreatic surgeries per year, respectively, as classified in a previous meta-analysis [17]. The number of surgeries performed was calculated separately for each type of surgery. Among the tertiary hospitals, no institution performed <10 pancreatic surgeries per year; therefore, the 4th and 5th volume groups were combined. Of the 40,937 surgeries initially identified, 4 were excluded from the hospital-level analysis because of missing medical institutional information. Consequently, 40,933 patients were included in the volume-based analyses.

Definition of transfusion

Transfusion was identified by the prescription of ≥ 1 unit of allogenic whole blood or RBC from 1 week before surgery to within 30 days after surgery in the NHIS-NHID. The amount of transfusion among those who received transfusion was divided into 1–3, 4–7, and ≥ 8 units.

Statistical analysis

Descriptive statistics were used to describe 30-day mortality according to sex, age group, and pancreatic surgical procedures. Temporal trends in 30-day mortality between 2012 and 2020 were evaluated using the Cochran-Armitage trend test. Differences in mortality rates, transfusion rates, and transfusion volumes across hospital pancreatic surgery volume quintiles (1st–5th), stratified by institutional type (tertiary vs. general hospitals), were analyzed, and volume–outcome trends were assessed using the Cochran-Armitage trend test. In addition, 30-day mortality rates are presented according to the combination of transfusion status, transfusion volume, and pancreatic surgery volume. To estimate independent associations with 30-day mortality, multivariable logistic regression models were used to calculate the adjusted odds ratios (aORs); covariates included hospital volume group, hospital type, transfusion amount, age, sex, and type of surgery. All the analyses were performed using SAS ver. 9.4 (SAS Institute Inc.).

RESULTS

This study included 40,937 patients who underwent pancreatic surgery between 2012 and 2020. During this period, as shown in Table 1, the number of surgeries increased from 4,055 in 2012 to 5,278 in 2020. Despite this increase in the number of pancreatic surgeries performed annually, the 30-day postoperative mortality rate remained stable, fluctuating between 1.2% and 1.9%, with no significant trend over time (P -trend = 0.401).

Throughout the study period, a larger proportion of male

patients consistently underwent pancreatic surgery. Age was another factor influencing 30-day mortality, as mortality rates were lowest among patients <50 years (0.4%–1.4%) and progressively increased with age, peaking among those aged ≥ 75 years, with rates ranging from 1.8% to 3.6%. The type of surgical procedure was associated with notable differences in mortality rates. Although less frequently performed, total pancreatectomy showed the greatest variation in mortality, with rates ranging from 5.1% in 2012 to 1.5% in 2020 and a peak of 8.2% in 2018. Pancreaticoduodenectomy, the most common procedure, had a more stable mortality rate, ranging from 0.8% to 1.4%. A decreasing or increasing trend in the mortality rate during the study period according to sex, age group, or surgical procedure was not observed.

The underlying causes of death recorded within 30 days of pancreatic surgery between 2012 and 2020 are shown in Fig. 1. Although year-to-year fluctuations were observed across categories, the trend analysis based on ICD-10 codes indicated that only pancreatic cancer, as the recorded underlying cause of death, showed a statistically significant increasing trend over the study period (P -trend = 0.016). By contrast, liver and bile duct cancers, injury, external causes, and other categories showed no statistically significant temporal trends.

Table 2 highlights the 30-day postoperative mortality for all pancreatic surgeries and specific procedures, including pancreaticoduodenectomy, distal pancreatectomy, and partial resection of the pancreas according to hospital pancreatic surgery volume. Hospitals in the 1st volume group had the lowest overall mortality rate of 1.0%. The mortality rates for pancreaticoduodenectomy, distal pancreatectomy, and partial resection were 0.8%, 0.4%, and 0.4%, respectively in hospitals in the 1st volume group. As the hospital surgical volume decreased across groups, the mortality rates progressively increased, reaching 5.5% in the 4th group and 5.9% in the 5th group (P -trend < 0.001). For all types of pancreatic surgery, decreased surgical volume was associated with increased mortality (P -trend < 0.001), with mortality rates of 5.5% for pancreaticoduodenectomy, 4.0% for distal pancreatectomy, and 2.1% for partial resection in the 5th group.

Table 3 compares the transfusion rates and amounts in the overall, tertiary, and general hospitals across surgical volume groups. As the surgical volume decreased, transfusion rates increased significantly (P -trend < 0.001), with 35.5% of patients who underwent surgery in the highest-volume hospitals and 69.1% of patients in the lowest-volume hospitals requiring blood transfusions. Among tertiary hospitals, those in the highest-volume category had the lowest transfusion rates, with 34.7% receiving transfusions and up to 58.2% in the lowest-volume categories. Among the transfused patients in tertiary hospitals in the highest-volume category, 13.6% required ≥ 8 units; otherwise, 28.3% of the patients who received surgeries in

Table 1. Trends in number of pancreatic surgeries and 30-day mortality according to sex, age group, and pancreatic surgery procedures in patients who underwent pancreatic surgery during 2012–2020

Variable	2012	2013	2014	2015	2016	2017	2018	2019	2020	P-trend
All pancreas surgery patients	4,055	4,210	4,188	4,289	4,404	4,664	4,813	5,036	5,278	
Mortality (%)	1.8	1.2	1.5	1.7	1.3	1.4	1.9	1.3	1.2	0.401
Sex										
Male	2,301	2,392	2,361	2,412	2,483	2,674	2,749	2,782	2,993	
Mortality (%)	2.6	1.5	1.9	2.2	1.6	1.7	2.3	1.3	1.5	0.242
Female	1,754	1,818	1,827	1,877	1,921	1,990	2,064	2,254	2,285	
Mortality (%)	0.7	0.9	1.0	1.0	0.9	1.0	1.3	1.2	0.7	0.380
Age group										
<50 yr	722	668	655	607	606	613	566	528	550	
Mortality (%)	1.0	0.6	0.9	0.8	1.2	1.0	1.4	0.8	0.4	0.777
50–59 yr	1,008	1,013	937	960	982	965	945	924	842	
Mortality (%)	1.2	1.0	0.9	1.4	0.4	1.0	1.0	1.0	0.8	0.468
60–69 yr	1,183	1,270	1,301	1,382	1,386	1,483	1,537	1,644	1,825	
Mortality (%)	1.4	1.1	1.2	1.2	1.0	1.2	1.6	0.9	1.0	0.423
70–74 yr	644	717	677	725	703	721	785	854	894	
Mortality (%)	3.0	1.1	2.2	2.2	1.8	1.9	1.5	0.7	1.7	0.106
≥75	498	542	618	615	727	882	980	1,086	1,167	
Mortality (%)	3.6	3.0	3.1	3.3	2.8	2.0	3.8	2.9	1.8	0.171
Pancreatic surgery procedure										
Total pancreatectomy	99	103	85	113	98	96	98	120	135	
Mortality (%)	5.1	1.0	0.0	2.7	2.0	3.1	8.2	2.5	1.5	0.733
Pancreatoduodenectomy	2,232	2,418	2,490	2,495	2,549	2,723	2,922	2,974	3,077	
Mortality (%)	1.4	1.2	1.6	1.7	1.5	1.1	1.5	1.2	0.8	0.390
Distal pancreatectomy	1,204	1,264	1,220	1,268	1,360	1,476	1,459	1,592	1,698	
Mortality (%)	1.2	0.9	1.2	1.1	0.5	1.4	1.2	0.8	1.0	0.652
Partial resection of pancreas	343	292	248	251	275	218	215	220	232	
Mortality (%)	2.6	1.0	0.8	0.4	1.1	0.5	2.3	1.4	1.7	0.900
Others	109	84	91	115	78	105	71	75	105	
Mortality (%)	6.4	6.0	6.6	8.7	6.4	8.6	15.5	8.0	10.5	0.420

tertiary hospitals in the lowest-volume category were transfused 8 or more units of blood. A similar surgical volume-transfusion relationship was observed in general hospitals (P -trend < 0.001). However, the relationship between the surgical volume and transfusion amount was not statistically significant in general hospitals (P -trend = 0.849).

Table 4 shows the 30-day mortality rates across the

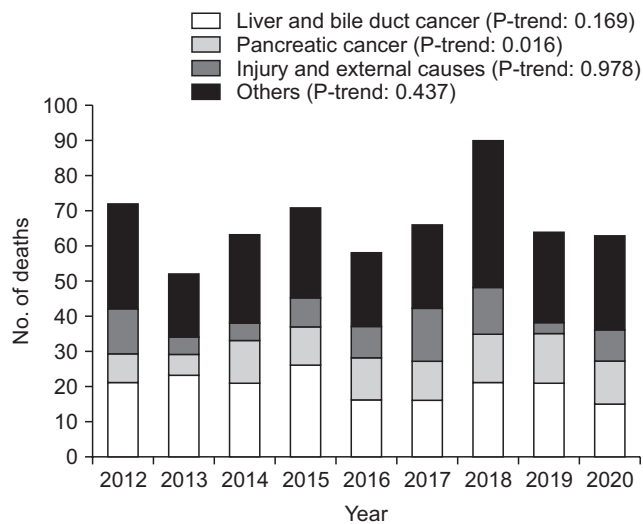


Fig. 1. Causes of death within 30 days after pancreatic surgery, 2012–2020. Black, dark grey, light grey, and grey bars represent liver and bile duct cancers, pancreatic cancer, injury, external causes, and others, respectively.

combinations of surgical volume groups and transfusions. In high-volume hospitals, the 30-day mortality rate was 1.0%; however, non-transfused patients had a mortality rate of 0.1%, whereas transfused patients had a mortality rate of 2.7%, reaching 13.0% for those receiving 8 or more units (P < 0.001). This trend persisted across all hospital groups, with higher mortality in the transfused patients and rising mortality with increasing transfusion volumes. In the lowest-volume hospitals, non-transfused patients had a mortality rate of 1.6% and transfused patients had a mortality rate of 7.9%, which increased to 17.6% among those receiving ≥ 8 units. Across the transfusion strata, lower 30-day mortality rates were observed in higher-volume hospitals.

Table 5 presents the multivariable aORs for 30-day mortality. A clear volume–outcome gradient was observed, with progressively higher mortality as hospital volume decreased. Compared with the highest-volume hospitals, the adjusted odds of mortality were 1.62-fold higher in the second-tier hospitals and increased to 3.27-fold in the lowest-volume centers; all volume groups showed statistically significant increases in mortality (P < 0.001). The transfusion amount showed the strongest association with mortality, exhibiting a robust dose–response relationship. While the risk increased at 1–3 units (aOR, 3.98), it rose markedly to 12.71 for 4–7 units and to 73.59 for patients receiving ≥ 8 units (all P < 0.001).

This institutional disparity was further reflected by hospital type, with general hospitals having 30% higher adjusted odds of mortality than tertiary hospitals (aOR, 1.30; 95% CI, 1.02–1.66;

Table 2. Thirty-day mortality rates according to hospital pancreatic surgery volume and pancreatic surgery procedures in patients who underwent pancreatic surgery during 2012–2020

Variable	Total	Pancreatic surgery volume					P-trend
		1st	2nd	3rd	4th	5th	
All ^{a)}							
No. of hospitals	232	45	14	23	20	130	
No. of surgeries	40,933	33,316	2,966	2,729	1,096	826	
Mortality (%)	1.4	1.0	2.4	2.9	5.5	5.9	<0.001
Pancreaticoduodenectomy ^{b)}							
No. of hospitals	166	24	13	29	22	78	
No. of surgeries	40,779	26,934	3,697	6,553	2,200	1,395	
Mortality (%)	1.5	0.8	1.9	2.4	3.4	5.5	<0.001
Distal pancreatectomy ^{b)}							
No. of hospitals	187	6	8	25	27	121	
No. of surgeries	40,851	18,458	4,589	8,092	6,106	3,606	
Mortality (%)	1.4	0.4	1.2	2.1	2.4	4.0	<0.001
Partial resection of pancreas ^{b)}							
No. of hospitals	136	1	2	2	7	124	
No. of surgeries	36,143	2,702	11,195	1,497	4,052	20,749	
Mortality (%)	1.6	0.4	0.3	1.7	1.4	2.1	<0.001

^{a)}Hospitals were categorized into 5 groups according to the annual procedure volume (1st, >30; 2nd, 21–30; 3rd, 11–20; 4th, 5–10; and 5th, <5 surgeries per year).

^{b)}Each specific surgical procedure is categorized by volume of each procedure.

Table 3. Transfusion rates and volume of transfusion according to pancreatic surgery volume and hospital type in patients who underwent pancreatic surgery during 2012–2020

Pancreatic surgery volume	No. of surgeries	Transfusion			Volume of transfusion (unit)			
		No	Yes	P-trend	1–3	4–7	≥8	P-trend
All ^{a)}				<0.001				0.013
1st	33,316	21,504 (64.5)	11,812 (35.5)		7,455 (63.1)	2,744 (23.2)	1,613 (13.7)	
2nd	2,966	1,524 (51.4)	1,442 (48.6)		802 (55.6)	376 (26.1)	264 (18.3)	
3rd	2,729	1,278 (46.8)	1,451 (53.2)		841 (58.0)	371 (25.6)	239 (16.5)	
4th	1,096	409 (37.3)	687 (62.7)		341 (49.6)	200 (29.1)	146 (21.3)	
5th	826	255 (30.9)	571 (69.1)		251 (44.0)	172 (30.1)	148 (25.9)	
Tertiary hospital ^{b)}				<0.001				<0.001
1st	30,103	19,658 (65.3)	10,445 (34.7)		6,636 (63.5)	2,393 (22.9)	1,416 (13.6)	
2nd	1,452	747 (51.4)	705 (48.6)		404 (57.3)	169 (24.0)	132 (18.7)	
3rd	449	165 (36.7)	284 (63.3)		125 (44.0)	82 (28.9)	77 (27.1)	
4th and 5th	91	38 (41.8)	53 (58.2)		23 (43.4)	15 (28.3)	15 (28.3)	
General hospital				<0.001				0.849
1st	3,213	1,846 (57.5)	1,367 (42.5)		819 (59.9)	351 (25.7)	197 (14.4)	
2nd	1,514	777 (51.3)	737 (48.7)		398 (54.0)	207 (28.1)	132 (17.9)	
3rd	2,280	1,113 (48.8)	1,167 (51.2)		716 (61.4)	289 (24.8)	162 (13.9)	
4th	1,005	371 (36.9)	634 (63.1)		318 (50.2)	185 (29.2)	131 (20.7)	
5th	826	255 (30.9)	571 (69.1)		251 (44.0)	172 (30.1)	148 (25.9)	

Values are presented as number or number (%).

^{a)}Hospitals were categorized into 5 groups according to the annual procedure volume (1st, >30; 2nd, 21–30; 3rd, 11–20; 4th, 5–10; and 5th, <5 surgeries per year).

^{b)}Because no tertiary hospital performed fewer than 10 surgeries annually during the study period, the 4th and 5th volume groups were combined.

Table 4. Thirty-day mortality according to transfusion status, transfusion volume, and hospital pancreatic surgery volume

Pancreatic surgery volume	Variable	No. of surgeries	Transfusion		Volume of transfusion (unit)		
			No	Yes	1–3	4–7	≥8
1st	No. of surgeries	33,316	21,504	11,812	7,455	2,744	1,613
	30-day mortality (%)	1.0	0.1	2.7	0.5	2.3	13.0
2nd	No. of surgeries	2,966	1,524	1,442	802	376	264
	30-day mortality (%)	2.4	0.3	4.6	0.9	3.2	17.8
3rd	No. of surgeries	2,729	1,278	1,451	841	371	239
	30-day mortality (%)	2.9	0.2	5.2	1.4	3.2	21.8
4th	No. of surgeries	1,096	409	687	341	200	146
	30-day mortality (%)	5.5	1.2	8.0	3.8	6.5	19.9
5th	No. of surgeries	826	255	571	251	172	148
	30-day mortality (%)	5.9	1.6	7.9	3.6	5.8	17.6
P-trend				<0.001		0.140	

Values are presented as number or percentage.

Hospitals were categorized into 5 groups according to the annual procedure volume (1st, >30; 2nd, 21–30; 3rd, 11–20; 4th, 5–10; and 5th, <5 surgeries per year).

$P = 0.035$). Patient demographics and surgical type significantly influenced outcomes. Each one-year increase in age was associated with a 4% increase in the adjusted odds of death (aOR, 1.04; $P < 0.001$), and male sex was independently associated with a higher risk compared with female sex (aOR, 1.43; $P = 0.002$). While most specific surgical procedures did not show statistically significant differences, the "Others" category was

associated with a markedly higher adjusted odds of mortality (aOR, 3.96; 95% CI, 2.92–5.38; $P < 0.001$).

DISCUSSION

Between 2012 and 2020, although the annual number of pancreatic surgeries increased during the study period, the 30-

Table 5. Multivariable-adjusted ORs for 30-day mortality according to hospital volume and transfusion amount after pancreatic surgery

Variable	Adjusted OR (95% CI)	P-value
Hospital volume group ^{a)}		
1st	Reference	
2nd	1.62 (1.28–2.05)	<0.001
3rd	2.39 (1.80–3.18)	<0.001
4th	3.00 (2.14–4.22)	<0.001
5th	3.27 (2.12–5.04)	<0.001
Hospital type		
Tertiary hospital	Reference	
General hospital	1.30 (1.02–1.66)	0.035
Transfusion amount (unit)		
No transfusion	Reference	
1–3	3.98 (2.74–5.78)	<0.001
4–7	12.71 (8.88–18.18)	<0.001
≥8	73.59 (53.19–101.81)	<0.001
Age (per year increase)	1.04 (1.03–1.05)	<0.001
Sex		
Female	Reference	
Male	1.43 (1.19–1.73)	0.002
Type of surgery		
Distal pancreatectomy	Reference	
Total pancreatectomy	1.17 (0.79–1.74)	0.429
Pancreaticoduodenectomy	1.03 (0.83–1.27)	0.815
Partial resection of pancreas	1.26 (0.82–1.92)	0.287
Others	3.96 (2.92–5.38)	<0.001

OR, odds ratio; CI, confidence interval.

^{a)}Hospitals were categorized into 5 groups according to the annual procedure volume (1st, >30; 2nd, 21–30; 3rd, 11–20; 4th, 5–10; and 5th, <5 surgeries per year).

day mortality rate remained relatively stable, ranging from 1.2% to 1.9%. The persistent non-negligible mortality rate underscores the need for additional strategies to further improve short-term outcomes after pancreatic surgery.

Hospitals with high pancreatic surgical volumes were associated with lower mortality rates and dose–response patterns. These findings align with those of international studies demonstrating superior outcomes in high-volume settings [8–10]. Similar volume–outcome relationships have been observed in other complex procedures, including esophageal, liver, and lung surgeries [6,18–21]. A high surgical volume is typically accompanied by greater clinical experience, well-coordinated multidisciplinary teams, and structured perioperative care pathways. Together, these factors may contribute to improved management of complex cases and reduced postoperative complications, further supporting the centralization of complex surgeries in high-volume centers [4,5,9,10,22].

This study also demonstrated a significant association between perioperative transfusion, greater transfusion volume, and increased 30-day mortality, independent of hospital

surgical volume, other patient characteristics, and the type of surgery. Even after adjusting for institutional case volume, blood transfusion and transfusion volume remained strongly associated with mortality. These findings are consistent with those of previous studies, indicating that patients who required perioperative transfusion during pancreatic surgery tended to experience worse short-term outcomes, including higher rates of postoperative complications and mortality [12–16]. However, given the retrospective study design and reliance on administrative claims data, perioperative transfusions should be interpreted with caution. Rather than representing a directly associated causal factor, transfusion likely reflects intraoperative complexity, substantial blood loss, and underlying disease severity [23,24], which could not be identified through claim-based data. Therefore, the observed associations should be understood within the broader context of surgical risk and case complexity.

Importantly, not only 30-day mortality but also transfusion rates and transfusion volumes were lower in higher-volume hospitals with a dose-response pattern. This pattern likely reflects accumulated surgical experience, technical proficiency, and institutional capacity to manage complex cases [6,25,26]. Surgeons with higher case volumes tend to achieve lower intraoperative blood loss, which reflects greater precision and efficiency [27]. High-volume hospitals may be better equipped to manage complex procedures and perioperative risks through established protocols, coordinated multidisciplinary teams, and access to specialized resources [6,28,29]. These factors may contribute to reduced intraoperative blood loss, and consequently, lower transfusion requirements [30]. Therefore, the differences in transfusion utilization observed across the hospital volume groups are more likely to reflect variations in experience and perioperative management.

Building on these findings, the centralization of pancreatic surgery in high-volume centers has been associated with not only improved patient outcomes but also with decreased transfusion rates. However, increased centralization may pose challenges to patient access, particularly in rural or underserved regions [31]. Establishing regional hub hospitals equipped and trained to perform complex pancreatic surgeries can help mitigate these challenges by reducing travel burdens while maintaining high standards of surgical care, thereby balancing the benefits of centralization with healthcare accessibility [6].

In South Korea, developing a network that links high-volume centers with regional hubs could facilitate knowledge sharing, ensure consistent care standards, and improve nationwide access. Centralization in high-volume hospitals has been associated with lower mortality and reduced transfusion needs [32], underscoring their capacity to manage surgical risks more effectively. Therefore, adopting centralization policies modeled after those implemented in other countries may enhance the

quality and safety of pancreatic surgical care in South Korea, and ultimately improve patient outcomes and public health.

The primary strength of this study is its use of comprehensive nationwide data from the NHIS-NHID, which covers all pancreatic surgeries performed in Korea and provides valuable insights that extend beyond individual hospital settings. However, this study has some limitations, including the reliance on administrative codes that may not capture all clinical details and potential confounders, such as comorbidities and surgical complications, which were not included in the dataset. The cause-of-death classification was based on the ICD codes from administrative data and may reflect the underlying disease rather than the immediate postoperative cause of death. Therefore, deaths attributed to pancreatic cancer should be interpreted cautiously because we could not distinguish cancer-related mortality from deaths due to postoperative complications. Additionally, the preoperative and postoperative laboratory data of patients that may affect the transfusion itself and mortality were unavailable in the national database, limiting the scope of our analysis. Although the hospital's pancreatic surgical volume was examined, other important institutional factors that could affect outcomes, such as the level of specialized care or resource availability, were not evaluated. Finally, variations in transfusion practices, including patient blood management strategies and transfusion thresholds across hospitals, which may have affected the findings, were not considered.

This study demonstrated a strong association between hospital pancreatic surgical volume, perioperative transfusion, and 30-day mortality, with lower 30-day mortality and transfusion rates observed in high-volume centers. Although perioperative transfusion was independently associated with mortality, it likely reflects surgical complexity and underlying disease severity. A higher surgical volume and better outcome relationship may reflect the capacity of the surgeon or

institution to manage complex cases. Overall, these findings support the centralization of pancreatic surgery in experienced high-volume centers to enhance short-term outcomes.

ACKNOWLEDGEMENTS

Fund/Grant Support

None.

Conflict of Interest

No potential conflict of interest relevant to this article was reported.

ORCID iD

Sunghye Hong: <https://orcid.org/0000-0001-8105-9861>

Seyoon Kim: <https://orcid.org/0009-0005-4037-8926>

Yun Kyung Jung: <https://orcid.org/0000-0002-5193-5418>

Seonju Kim: <https://orcid.org/0000-0002-9979-9910>

Junghyun Yoon: <https://orcid.org/0000-0003-0356-6037>

Dongho Choi: <https://orcid.org/0000-0002-1255-1964>

Boyoung Park: <https://orcid.org/0000-0003-1902-3184>

Author Contribution

Conceptualization: DC, BP, SH

Data curation: SH, Seyoon Kim, Seonju Kim

Formal analysis: SH, YKJ

Funding acquisition, Project administration, Resources, Supervision: DC, BP

Investigation: Seyoon Kim, JY, Seonju Kim

Methodology: SH, YKJ, BP

Software: SH, Seonju Kim

Validation: YKJ, JY

Visualization: SH, Seyoon Kim

Writing – Original Draft: SH, Seyoon Kim

Writing – Review & Editing: All authors

REFERENCES

1. Ho CK, Kleeff J, Friess H, Büchler MW. Complications of pancreatic surgery. *HPB (Oxford)* 2005;7:99-108.
2. Schneider M, Hackert T, Strobel O, Büchler MW. Technical advances in surgery for pancreatic cancer. *Br J Surg* 2021;108:777-85.
3. Torphy RJ, Fujiwara Y, Schulick RD. Pancreatic cancer treatment: better, but a long way to go. *Surg Today* 2020;50:1117-25.
4. Birkmeyer JD, Stukel TA, Siewers AE, Goodney PP, Wennberg DE, Lucas FL. Surgeon volume and operative mortality in the United States. *N Engl J Med* 2003;349:2117-27.
5. Gooiker GA, van Gijn W, Wouters MW, Post PN, van de Velde CJ, Tollenaar RA, et al. Systematic review and meta-analysis of the volume-outcome relationship in pancreatic surgery. *Br J Surg* 2011;98:485-94.
6. Birkmeyer JD, Siewers AE, Finlayson EV, Stukel TA, Lucas FL, Batista I, et al. Hospital volume and surgical mortality in the United States. *N Engl J Med* 2002;346:1128-37.
7. van der Geest LG, van Rijssen LB, Molenaar IQ, de Hingh IH, Groot Koerkamp B, Busch OR, et al. Volume-outcome relationships in

- pancreatoduodenectomy for cancer. *HPB (Oxford)* 2016;18:317-24.
8. Gooiker GA, Lemmens VE, Besselink MG, Busch OR, Bonsing BA, Molenaar IQ, et al. Impact of centralization of pancreatic cancer surgery on resection rates and survival. *Br J Surg* 2014;101:1000-5.
 9. de Wilde RF, Besselink MG, van der Tweel I, de Hingh IH, van Eijck CH, Dejong CH, et al. Impact of nationwide centralization of pancreaticoduodenectomy on hospital mortality. *Br J Surg* 2012;99:404-10.
 10. Ahola R, Sand J, Laukkanen J. Centralization of pancreatic surgery improves results: review. *Scand J Surg* 2020;109:4-10.
 11. Damhuis RA, Wijnhoven BP, Plaisier PW, Kirkels WJ, Kranse R, van Lanschot JJ. Comparison of 30-day, 90-day and in-hospital postoperative mortality for eight different cancer types. *Br J Surg* 2012;99:1149-54.
 12. Mavros MN, Xu L, Maqsood H, Gani F, Ejaz A, Spolverato G, et al. Perioperative blood transfusion and the prognosis of pancreatic cancer surgery: systematic review and meta-analysis. *Ann Surg Oncol* 2015;22:4382-91.
 13. Zhang L, Liao Q, Zhang T, Dai M, Zhao Y. Blood transfusion is an independent risk factor for postoperative serious infectious complications after pancreaticoduodenectomy. *World J Surg* 2016;40:2507-12.
 14. Sutton JM, Kooby DA, Wilson GC, Squires MH, Hanseman DJ, Maithel SK, et al. Perioperative blood transfusion is associated with decreased survival in patients undergoing pancreaticoduodenectomy for pancreatic adenocarcinoma: a multi-institutional study. *J Gastrointest Surg* 2014;18:1575-87.
 15. Javed AA, Ronnekleiv-Kelly SM, Hasanain A, Pflüger MJ, Habib JR, Wright MJ, et al. Blood transfusion is associated with worse outcomes following pancreatic resection for pancreatic adenocarcinoma. *Ann Pancreat Cancer* 2022;5:1.
 16. Ye L, Livingston EH, Myers B, Hines OJ. The effect of perioperative blood transfusion on long-term survival outcomes after surgery for pancreatic ductal adenocarcinoma: a systematic review. *Pancreas* 2021;50:648-56.
 17. Hata T, Motoi F, Ishida M, Naitoh T, Katayose Y, Egawa S, et al. Effect of hospital volume on surgical outcomes after pancreaticoduodenectomy: a systematic review and meta-analysis. *Ann Surg* 2016;263:664-72.
 18. Wouters MW, Wijnhoven BP, Karim-Kos HE, Blaauwgeers HG, Stassen LP, Steup WH, et al. High-volume versus low-volume for esophageal resections for cancer: the essential role of case-mix adjustments based on clinical data. *Ann Surg Oncol* 2008;15:80-7.
 19. Bach PB, Cramer LD, Schrag D, Downey RJ, Gelfand SE, Begg CB. The influence of hospital volume on survival after resection for lung cancer. *N Engl J Med* 2001;345:181-8.
 20. Barocas DA, Mitchell R, Chang SS, Cookson MS. Impact of surgeon and hospital volume on outcomes of radical prostatectomy. *Urol Oncol* 2010;28:243-50.
 21. Richardson AJ, Pang TC, Johnston E, Hollands MJ, Lam VW, Pleass HC. The volume effect in liver surgery: a systematic review and meta-analysis. *J Gastrointest Surg* 2013;17:1984-96.
 22. Schmidt CM, Turrini O, Parikh P, House MG, Zyromski NJ, Nakeeb A, et al. Effect of hospital volume, surgeon experience, and surgeon volume on patient outcomes after pancreaticoduodenectomy: a single-institution experience. *Arch Surg* 2010;145:634-40.
 23. Morris FJ, Fung YL, Craswell A, Chew MS. Outcomes following perioperative red blood cell transfusion in patients undergoing elective major abdominal surgery: a systematic review and meta-analysis. *Br J Anaesth* 2023;131:1002-13.
 24. Parikh S, Bentz T, Crowley S, Greenspan S, Costa A, Bergese S. Perioperative blood management. *J Clin Med* 2025;14:3847.
 25. Halm EA, Lee C, Chassin MR. Is volume related to outcome in health care?: a systematic review and methodologic critique of the literature. *Ann Intern Med* 2002;137:511-20.
 26. Chang SH. One hundred sixty pancreaticoduodenectomies for periampullary cancers in a growing-volume setting: a single-institution and a single-surgeon's experience. *Ann Surg Treat Res* 2019;97:130-5.
 27. Zil-E-Ali A, Aziz F, Goldfarb M, Radtka JF. The implications of surgeon case volume and hospital volume on outcomes of aortobifemoral bypasses in obese patients. *J Vasc Surg* 2023;77:1776-87.
 28. Ghaferi AA, Birkmeyer JD, Dimick JB. Hospital volume and failure to rescue with high-risk surgery. *Med Care* 2011;49:1076-81.
 29. Schmidt CM, Powell ES, Yiannoutsos CT, Howard TJ, Wiebke EA, Wiesenauer CA, et al. Pancreaticoduodenectomy: a 20-year experience in 516 patients. *Arch Surg* 2004;139:718-27.
 30. Kim H, Chung JK, Ahn YJ, Lee HW, Jung IM. The 13-year experience of performing pancreaticoduodenectomy in a mid-volume municipal hospital. *Ann Surg Treat Res* 2017;92:73-81.
 31. Stitzenberg KB, Sigurdson ER, Egleston BL, Starkey RB, Meropol NJ. Centralization of cancer surgery: implications for patient access to optimal care. *J Clin Oncol* 2009;27:4671-8.
 32. Finks JF, Osborne NH, Birkmeyer JD. Trends in hospital volume and operative mortality for high-risk surgery. *N Engl J Med* 2011;364:2128-37.