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A Novel Risk Scoring System Reliably Predicts Readmission Following Pancreatectomy

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Abstract

Background—Postoperative readmissions have been proposed by Medicare as a quality metric and may impact provider reimbursement. Since readmission following pancreatectomy is common, we sought to identify factors associated with readmission in order to establish a predictive risk scoring system (RSS).

Study Design—A retrospective analysis of 2,360 pancreatectomies performed at nine, high-volume pancreatic centers between 2005 and 2011 was performed. Forty-five factors strongly associated with readmission were identified. To derive and validate a RSS, the population was randomly divided into two cohorts in a 4:1 fashion. A multivariable logistic regression model was constructed and scores were assigned based on the relative odds ratio of each independent predictor. A composite Readmission After Pancreatectomy (RAP) score was generated and then stratified to create risk groups.

Results—Overall, 464 (19.7%) patients were readmitted within 90-days. Eight pre- and postoperative factors, including prior myocardial infarction (OR 2.03), ASA Class 3 (OR 1.34), dementia (OR 6.22), hemorrhage (OR 1.81), delayed gastric emptying (OR 1.78), surgical site infection (OR 3.31), sepsis (OR 3.10) and short length of stay (OR 1.51), were independently predictive of readmission. The 32-point RAP score generated from the derivation cohort was highly predictive of readmission in the validation cohort (AUC 0.72). The low (0-3), intermediate (4-7) and high risk (>7) groups correlated to 11.7%, 17.5% and 45.4% observed readmission rates, respectively (p<0.001).

Conclusions—The RAP score is a novel and clinically useful RSS for readmission following pancreatectomy. Identification of patients with increased risk of readmission using the RAP score will allow efficient resource allocation aimed to attenuate readmission rates. It also has potential to serve as a new metric for comparative research and quality assessment.

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Keywords

Readmission; Pancreas surgery; Pancreatectomy; Risk score; Outcomes

Introduction

Healthcare expenditures currently represent nearly one-fifth of the gross domestic product of the United States and this proportion has increased steadily over the decades. In an attempt to control expansion of health-care costs the Centers for Medicare and Medicaid Services (CMS) has instituted measures to curb healthcare spending by eliminating waste. In this regard, the CMS has estimated that preventable readmissions account for nearly \$12 billion every year.¹ In 2012, the CMS, under the auspices of the Affordable Care Act's Hospital Readmissions Reduction Program, required reduced payment to hospitals with a high frequency of preventable readmissions.² By 2017, readmission rates after orthopedic and cardiac surgery will be employed as a quality metric that guides reimbursement to providers, with underperforming centers receiving up to a 3% payment reduction.³ Moving forward, readmission will likely function as a quality benchmark for other complex operations including pancreatectomy. It should be noted that despite the enactment of readmission as a quality indicator following complex operations the validity of this metric remains debatable.⁴

Recent interest on the subject of readmission following complex surgical procedures has resulted in the establishment of baseline rates of readmission and correlation with outcomes. Patients undergoing thoracic, vascular or hepatobiliary surgery experience a readmission rate of 11.1%, 11.9% and 15.8% respectively.⁵ Additionally, complex gastrectomies, pneumonectomies and mitral valve replacements exhibit even higher readmission frequencies of 16.6%, 18.1% and 22.2%.⁶ Moreover, readmission after major surgical procedures is associated with increased morbidity and mortality.^{5,7-13}

Over the past several decades, the mortality following pancreatic surgery has decreased, largely attributable to technical improvements and a regionalization of care.¹⁴⁻¹⁶ However, postoperative morbidity remains high leading to a readmissions rate ranging from approximately 20% to as high as 60%.^{5,14-18} Although much is currently known about readmission following pancreatectomy no method to identify the risk of readmission in an individual patient exists. The development of such a risk scoring system (RSS) would allow for the identification of high-risk patients and facilitate focused preventive measures either prior to discharge or in the early post-discharge period. Accordingly, the objective of this study was to identify factors predictive of readmission and to develop a RSS called the Readmission After Pancreatectomy (RAP) score. We demonstrate that the RAP score is a clinically relevant risk scoring system that accurately assigns risk of readmission to an individual patient following a major pancreatic resection.

Methods

Study population

The study cohort was derived from the Postoperative Morbidity Index (PMI) Study Group dataset.¹⁹ Briefly, this cohort was assembled from nine high-volume pancreatic centers (49 total surgeons) participating in the American College of Surgeons-National Surgical Quality Improvement Program (ACS-NSQIP). Participating institutions kept retrospective databases that assessed severity-based complications and 90-day readmission status following pancreatectomy.¹⁹ Merging of these datasets resulted in the formation of the de-identified Pancreatectomy Readmission Assessment Group Study. Each academic center's institutional review board approved this study.

Operation, Postoperative Variables Definitions and Readmission

Patients who had a major pancreatic resection (pancreaticoduodenectomy, distal pancreatectomy or central pancreatectomy) from 2005-2011 were identified and data were abstracted from the ACS-NSQIP database at each participating institution. All patients included in the study cohort were taken to the operating theatre for resection of a cyst or tumor of the pancreas. Those pancreatectomies performed for trauma or chronic pancreatitis were excluded. Patient selection for resection, operative technique and postoperative management were not protocolized but, rather, at the discretion of the attending surgeon at each institution. The definitions of pancreas-specific postoperative outcomes were determined prior to data extraction and graded according to the Modified Accordion Classification System.²⁰⁻²² General postoperative complications examined were pneumonia, sepsis, acute renal failure, surgical site infection (SSI), reinsertion of the endotracheal tube, deep venous thrombosis (DVT) and urinary tract infection (UTI) as defined by the ACS-NSQIP.²³ Readmission was designated into 30-day and 90-day readmission from the date of the index operation. Those patients whom were readmitted more than once during the 90-day period were counted only once for the derivation of the model.

Score Generation and Data Analysis

To generate the readmission score, the study population was randomly divided in a 4:1 fashion to derivation (n=1,888) and validation cohorts (n=472), respectively. The similarity of these cohorts was confirmed by comparing the baseline characteristics, operative variables and postoperative outcomes. Forty-five clinical variables with plausibility of predicting readmission were identified and analyzed using exploratory univariate logistic regression modeling. Twenty-nine variables that were significantly associated with readmission ($p < 0.20$) at the univariate level were then incorporated in a forward/backward fashion by referencing the Akaike information criterion, likelihood ratio test, the area under the receiver-operating curve, and the Hosmer-Lemeshow goodness-of-fit test to create the final multivariable logistic regression model. The variables gender and "other fistulas" (consisting of postoperative chylous, enteric and bilious fistulas) were forced into the model ($p < 0.20$) because of presumed biologic plausibility in readmission. The final predictive model consisted of 16 variables that increased the explanatory power of the model and eight of these variables were significant independent predictors of readmission ($p < 0.05$). Scores were assigned based on the relative odd's ratios of each independent predictor to generate a

32-point composite Readmission After Pancreatectomy (RAP) score. ROC curve analysis was employed to determine the predictive nature of the RAP score in the validation cohort. The RAP score was then stratified into three groups to classify patients as low, intermediate or high risk for readmission based on their individual composite score. Linear regression analysis was then performed on the observed readmission to establish the expected risk of readmission for patients within each 'group'.

Postoperative Complication Severity

PMI was used to quantify the impact of complications as previously described.^{20,24} PMI is a quantitative measure of the global burden placed on an individual following a postoperative complication. It is based on the previously established Modified Accordion Classification System with the added benefit of a weighted severity score attached to each particular complication.²⁴

Parametric and non-parametric variables were analyzed with Student's t-test and Mann-Whitney test, respectively, while incidences were compared with the chi-squared test. Analysis was performed with STATA 12.0 (StataCorp, College Station, Texas).

Results

Baseline Patient Characteristics, Operative Variables and Post-Pancreatectomy Outcomes in Readmitted vs. Non-readmitted Cohorts

A total of 2,360 patients were included in this study. All cause, 30-day and 90-day readmission rates were 15.0% (n=355) and 19.7% (n=464) respectively. There were 68 (14.7%) patients in the cohort that were readmitted multiple times. A comparison between patient specific characteristics, operative variables and post-pancreatectomy outcomes was made between those who were and were not readmitted at 90 days (Table 1 and Table 2). Age, gender and body mass index (BMI) did not differ between the readmitted and non-readmitted cohorts. Not surprisingly, however, there was a greater incidence of several high-risk preoperative patient characteristics, such as the presence of connective tissue disease (7.8% vs. 4.8%; $p=0.01$), chronic obstructive pulmonary disease (COPD) (7.8% vs. 4.8%; $p=0.03$), congestive heart failure (0.9% vs. 0.2%; $p=0.03$), steroid use (4.1% vs. 2.1%; $p=0.01$), Charlson Comorbidity Index (CCI) scores > 2 (35.8% vs. 28.5%, $p = 0.002$) and higher ASA class ($p<0.001$), in readmitted patients. There was no significant difference between any of the intraoperative variables between the readmission cohorts.

Postoperative complications including sepsis (17.0% vs. 3.4%, $p < 0.001$), pancreatic fistula (34.9% vs. 18.1%, $p < 0.001$), postoperative hemorrhage (15.7% vs. 8.9%, $p < 0.001$), delayed gastric emptying (DGE; 20.5% vs. 14.1%, $p = 0.001$), SSI (34.9% vs. 11.5%, $p < 0.001$), DVT (3.9% vs. 1.5%, $p = 0.001$) and UTI (6.9% vs. 3.8%, $p=0.004$) occurred more frequently in the readmitted cohort (Table 2). Hospital mortality (Accordion Grade 6) was 2.3% (n=55) across the entire cohort and was similar among the readmitted and non-readmitted cohorts (2.8% vs. 2.2%, $p=0.453$).

Risk Score Construction

After randomization, baseline patient characteristics, operative variables and postoperative outcomes were similar between the derivation and validation cohorts (Table 3). The final predictive model consisted of 16 variables that increased the explanatory power of the model: age > 60, hypertension, gender, COPD, preoperative myocardial infarction (MI), CTD, steroid use, jaundice, length of stay >10, sepsis, pancreatic fistula, postoperative hemorrhage, DGE, SSI, dementia and ASA Class 3 (Table 4). The area under the receiver operating characteristic curve (AUC) of the model was 0.70. Ultimately, eight variables that were significant independent predictors of readmission ($p < 0.05$) were utilized to generate the predictive risk model. These included prior myocardial infarction (OR 2.03), ASA Class 3 (OR 1.34), dementia (OR 6.22), postoperative hemorrhage (OR 1.81), delayed gastric emptying (OR 1.78), surgical site infection (OR 3.31), sepsis (OR 3.10) and length of stay < 10 days (OR 1.51). The OR of each covariate in the risk model was used to assign points to each variable by normalizing to ASA Class, which held the lowest OR and rounding to the nearest 0.5. To make the score an integer for ease of use this value was multiplied by 2. Accordingly, a 32-point composite Readmission After Pancreatectomy (RAP) score was derived (Table 5).

Risk Scoring System Stratification and Validation

The observed rate of readmission for each score within the derivation cohort was used to formulate a best-fit model to calculate the predicted readmission within the entire population. Patients were stratified based on predicted readmission into three disjoint groups: low (0-3), intermediate (4-7) and high risk (>7) based on the clinically relevant cutoffs of 15%, > 15% to 35% or > 35% (Table 6). The actual observed readmission frequency based on these strata was 11.7%, 17.5% and 45.4%, respectively, across the entire cohort ($p < 0.001$). The likelihood of readmission for the high-risk group was significantly increased in the validation cohort with an OR of 4.52 (95% CI=3.42-5.95; $p < 0.001$).

In order to validate the RAP score, patients in the validation cohort were stratified into the aforementioned risk groups. These risk categories did not vary in frequency between the derivation and validation cohorts ($p = 0.21$). The predicted readmission based on the RAP score correlated strongly ($r=0.92$) to that observed in the validation cohort (Figure 1). As with the derivation cohort, an increase in the composite RAP score correlated with a significant increase in the risk of readmission to the hospital (OR 5.14; 95% CI=3.06-8.65; $p < 0.001$ in the high risk group) in the validation cohort. The clinical utility of the risk stratification groups was substantiated by juxtaposing the observed readmission frequency in each risk group to that predicted by the linear regression equation: 11.7% compared to <15% in the low risk group, 17.5% compared to 15-35% in the intermediate risk group and 45.4% compared to >35% in the high risk group (Table 6). Moreover, both derivation and validation cohorts exhibited equivalent RAP score distributions and similar model strength with an AUC of 0.69 and 0.72, respectively.

Postoperative Complications and the Postoperative Morbidity Index

Overall, 61.7% ($n=1,457$) of patients experienced postoperative morbidity and 50.4% ($n=1,189$) had a clinically significant complication based on the Modified Accordion Score

(Grade 2). All postoperative complications across the cohort are listed in Table 2. Those in the low, intermediate and high-risk RAP score groups exhibited postoperative complication frequencies of 46.7%, 61.2% and 98.0% respectively. The most frequent surgical complication was pancreatic fistula, which occurred in 21.4% of patients followed by SSI (n= 379; 16.1%), DGE (n=363; 15.4%) and hemorrhage (n=242; 10.3%). One hundred and four patients (4.4%) developed a UTI, which was the most common non-surgical complication followed by pneumonia (n=85; 3.6%).

Complication severity experienced by patients was correlated to the risk of readmission using the PMI, which quantifies the burden of postoperative morbidities. The mean PMI as stratified by risk category for the RAP score was 0.140 ± 0.195 , 0.194 ± 0.223 and 0.389 ± 0.209 ($p < 0.001$) for those in the low, intermediate and high-risk groups. The mean PMI in the readmitted patient cohort equated to 0.371 ± 0.192 which was similar ($p > 0.05$) to that observed among the high risk patients as stratified in the RAP score and it indicates that on average patients who were readmitted necessitated an invasive intervention for their complications. The majority of patients (n=424; 53.3%) with a low risk RAP score had no complications corresponding to an Accordion Grade of 0 as compared to 38.9% (n=472) and 2% (n=7) in the intermediate and high risk groups ($p < 0.001$). Patients in the high-risk group experienced a 91.1% (n=319) rate of clinically significant complications (Accordion Grade 2, PMI = 0.26) as compared to 48.5% (n=589) and 35.4% (n=281) in the intermediate and low risk groups respectively ($p < 0.001$). A return to the operating theatre on index admission or single organ system failure occurred in 18.3% (n=64), 5.3% (n=64) and 5.8% (n=46) in the high, intermediate and low risk groups ($p < 0.001$). In hospital mortality (Accordion Grade 6) was reported as 4% (n=14), 2.72% (n=33) and 1.01% (n=8) in the high, intermediate and low risk groups ($p < 0.001$).

Discussion

Readmission following pancreatectomy has been extensively studied with numerous reports in the literature documenting the rate and causes of readmission. However there is no published method that can be used to predict the risk of readmission following pancreatectomy in individual patient. A mechanism to do could be an important tool in reducing unnecessary readmission since it will allow the focusing of limited resources on those who are at highest risk. In this study we created a RSS that reliably predicts the risk of readmission following pancreatectomy through the RAP score. The RAP score developed in our study demonstrates the ability to strongly predict the risk of readmission in our validation set. It is important that the RAP was developed using high quality and granular data from a large population of patients who underwent pancreatectomy at 9 high-volume programs. This feature makes it likely that the RAP score will be generalizable to other high-volume pancreatectomy programs throughout the United States. As CMS has targeted readmission as a quality measure and significant driver of health care cost efforts at reducing readmission are important.^{17,20}

The overall frequency of readmission in this cohort was 19.7%, which is similar to the range of 15% to 38% reported in previous studies.^{15,16,18,25-28} Some of these studies focused on long-term readmission, which may not be directly attributable to the impact of the operation

itself and are more likely related to the primary disease process.^{9,21,22,24} However studies evaluating short-term readmission at high volume centers reported similar recidivism frequencies of 15%-19%, accounting for readmissions specific to surgery rather than cancer progression and other etiologies.^{15,16} In our report, we have analyzed the records of 2,360 post-pancreatectomy patients from nine, high volume pancreatic centers around the country. This is the largest study to evaluate short-term, 90-day readmission after pancreatectomy, which captures those rehospitalizations most directly attributable to the impact of the operation. Readmission as tracked in the ACS-NSQIP dataset only captures readmissions within 30 days of their operation. This may lead to underestimation of readmission in those patients that had long hospital stays and are readmitted 30 to 90 days from their operation. The 90-day readmission frequency of 19.7% is on par with other studies and due to the heterogeneity of the data set, this may be used as a clinical benchmark of quality in pancreatic surgery.^{15,16} By extending the study period to 90 days, the study captured an additional 109 new readmissions. Sixty-eight patients were readmitted more than once and 47% (n=32) had corresponding RAP scores greater than 7 as compared to 34% among those patients that were readmitted once indicating that the higher your RAP score, the more likely you are to be readmitted multiple times.

Predictive factors for readmission included, prior MI, ASA Class 3, dementia, postoperative hemorrhage, DGE, SSI, sepsis and LOS < 10 days. Of note, important clinical factors not associated with readmission included: age, BMI, race, type of pancreatectomy (Whipple vs. distal), vascular reconstruction, surgeon experience and pancreatic fistula. Our study and all previous studies have identified predictors of readmission, however no scoring system exists to forecast the risk of readmission following pancreatectomy. Accordingly, we generated and validated the RAP score consisting of 8 patient related variables to predict the risk of readmission after pancreatectomy (Table 5).

Not surprisingly, preoperative comorbidities significantly impacted the risk of readmission following pancreatectomy. Dementia had the highest impact (OR 6.22, CI 1.78-21.81) on readmission in this study. It has been previously demonstrated that perioperative mortality is increased in patients with dementia, however its relationship to readmission in general surgery patients was unknown.²⁹ The exact reason for the increased risk of readmission in patients with dementia is unknown in our study. In addition, it is unknown how many of patients with dementia were discharged to a nursing home or rehabilitation center. Further study to assess the role of dementia in readmission is important and may shed light onto how this can be prevented.

ASA Class functions as a global surrogate of physiologic impairment based on preexisting comorbidities and is a predictor of death following surgical intervention.³⁰ While previous studies have reported the association between medical comorbidities and readmission this association following pancreatectomy remained unclear.^{5,15,16,28,31,32} Lucas et al.⁵ showed ASA Class to be predictive of readmission in a broad range of surgical patients, however reports on readmission following pancreatectomy have inconsistently linked comorbid conditions with readmission.^{15,28} For instance, Ahmad et al. utilized the Charlson Comorbidity Index (CCI), which also estimates the risk imposed by medical comorbidities on postoperative mortality, to examine its association with readmission among 1,300

patients.^{15,33} With this robust dataset, there was no significant difference in CCI scores between the readmitted and non-readmitted cohorts. Our data indicate that CCI scores did significantly differ between the groups with a mean CCI score of 1.9 in the non-readmitted cohort as compared to a score of 2.2 in the readmitted patients ($p = 0.002$). There was a significant association between CCI score and readmission on univariate analysis (OR, 1.52; CI, 1.20-1.94; $p = 0.001$). However, this risk index was ultimately excluded from the RAP score model since its calculation requires knowledge of 22 comorbid conditions, which is cumbersome when generating a clinically meaningful scoring system.

It was interesting that no intraoperative variables were predictive of readmission and the risk of readmission was mainly tied to postoperative complications and secondly to patient related factors. As expected, postoperative complications, including DGE, postoperative hemorrhage, SSI and sepsis, levied a heavy weight on the risk of readmission and comprised 50% of the variables in the RAP score. When evaluating complications, increasing Accordion grade and PMI were intimately involved in driving the need for readmission. Patients stratified into the high-risk RAP score displayed an increased frequency of Accordion grade 2 complications (91.1% vs. 35.4%, $p < 0.001$) as compared to the low-risk RAP scores. The burden of the complications as measured by PMI was similar between the high risk RAP score cohort and the readmitted group (0.39 vs. 0.37, $p > 0.05$). These results demonstrate that those among the high risk RAP score stratum were subject to invasive interventions secondary to their postoperative complications. This association highlights the importance of not only quantifying complications in the surgical literature but also categorizing their clinical impact on patients. Measuring PMI can help determine the burden imparted by postoperative morbidity and be used as a quality metric in surgery.^{19-21,24}

As previously reported, postoperative hemorrhage was predictive of readmission and occurred in 15.7% of readmitted patients.^{15,16} Sepsis and SSI were the most influential complications in the RAP score, each contributing 5 points and present in the readmitted cohort at a frequency of 17.0% and 34.9% respectively. Infectious complications have long been associated with readmission in many patient cohorts and their incidence range from 11% to 43.1%.^{15,16,18,34-36} While failed source control and ineffective antimicrobial therapy may drive preventable readmissions, the majority of these infectious complications are subtle at the time of discharge and, therefore, go unrecognized.³⁴

While pancreatic fistula was observed more frequently in the readmission cohort (34.9% vs. 18.1%, $p < 0.001$), its presence was not independently predictive of readmission. The same was true for biliary, enteric or chylous fistulas (Table 2). This is contrary to previous evidence from both single and multi-institutional studies which defined pancreatic leaks as significant predictors of readmission.^{15,16} This may be explained by the predominance of biochemical and low-grade fistulas (53.1% had Accordion grades of 2). Moreover, these patients were all resected at high volume pancreatic centers where, presumably, well-placed operative drains result in prompt recognition leading to improved outcomes and reduced patient morbidity once a fistula occurs. Recent evidence from a randomized trial exists for operative, intraperitoneal drainage in ameliorating the morbidity and mortality following

fistula development although further study into operative drainage and its impact on readmission, is needed to define this relationship.³⁷

The length of stay (LOS) following pancreatectomy has decreased over the past 3 decades. Some groups have postulated that early discharge from the hospital could precipitate rehospitalizations due to the lack of patient optimization.^{16,17} Our data corroborates these concerns as LOS of less than 10 days was predictive of short-term readmission. However, it must be noted that our findings are not consistent with the preponderance of the literature on LOS and readmission following pancreatectomy. We do not suggest that patients who are otherwise ready for discharge are kept beyond 10 days.

The clinical utility of a risk score is predicated on its ease of computation. Accordingly, only readily available clinical variables were utilized in the final RAP model. Furthermore, the relative odds ratios were rounded to the nearest whole number to assist in aggregating the composite score. Moreover, the RAP score provides a broad assessment of risk further improving its applicability in clinical practice. Readmission risk with the RAP score ranged from a predicted risk of 1.3% among those with a score of 0 to a predicted risk of 88.1% among those with the highest score of 18. Finally, based on clinical utility, the patient's RAP score was stratified into three distinct risk groups (low, intermediate and high), which affords the clinician a readily applicable risk assessment that can be used to guide patient management.

Additionally, the RAP score can also be used to judge quality of care by administrative agencies like CMS based on risk-stratified outcomes such as readmission. Due to the diverse set of factors driving readmission, hospitals should not be broadly penalized for readmissions without risk adjustment tools such as the RAP score to set the benchmarks for quality. Furthermore, it should be noted that although the risk of readmission can be modeled, there are many unquantifiable factors that drive readmission and even the most sophisticated risk models will not accurately predict every patient readmission. For example, patients at the highest end of the RAP score spectrum may not be readmitted due to in-hospital mortality (4% in the high risk group) or LOS greater than 90 days. While those in the low risk group may return to the hospital with what was an occult infection even having undergone an uneventful postoperative course. Even with these outliers, the RAP score can function to predict the risk of readmission following pancreatectomy more accurately than any method currently available.

Limitations

There are several limitations to this present study. First, as our follow-up period was limited to 90-days, the relationship between readmission and survival was not assessed in this current study. Second, the etiology for each readmission was not captured in this dataset (less than 20% of the patients had information coded on this variable), which precludes our ability to analyze the RAP scores association with certain categories of readmission and the frequency of “preventable readmissions”. Also of note was that readmission rate in this study was based on those patients readmitted to the index hospital. Because patients travel to tertiary centers to undergo pancreatic resection, this leads to an underestimation of

readmission at non-index hospitals. For example, our group recently analyzed the readmission of Maryland residents resected at Johns Hopkins. This study demonstrated that 21.6% of readmissions occurred at regional hospitals and, when accounted for, the observed frequency of readmission increased from 16.9% to 21.5%.³⁸ Therefore, it is uncertain if all readmissions are captured in this study.

Conclusion

This study derived and validated the RAP score, a novel and clinically useful risk prediction model for readmission following pancreatectomy. Identification of high-risk patients may allow for clinical optimization prior to discharge, thus mitigating health care costs through focused preventive measures. It also has potential to serve as a new metric for comparative research and quality assessment by administrative entities.

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Figure 1.
Linear regression model of observed versus predicted readmission according to the Readmission After Pancreatectomy (RAP) score.

Table 1
Demographics and Baseline Characteristics Amongst Readmitted and Non-readmitted Cohorts

Variable	All patients (n=2,360)	Readmitted (n=464; 19.7%)	Non-readmitted (n=1,896; 80.3%)	p-value*
Age	62.5 ± 13.5	61.7 ± 13.5	62.7 ± 13.5	0.18
Female	51.7% (1,220)	49.9% (231)	52.2% (989)	0.38
Race				0.05
Caucasian	81.1% (1,914)	77.2% (358)	82.1% (1,556)	
African American	8.9% (211)	11.0% (51)	8.4% (160)	
Other	9.96% (235)	11.9% (55)	9.5% (180)	
Diabetes mellitus				0.44
Type I	9.4% (222)	10.6% (49)	9.1% (173)	
Type II	12.3% (291)	11.0% (51)	12.7% (240)	
Connective tissue disease	5.3% (126)	7.8% (36)	4.8% (90)	0.01*
COPD	4.0% (95)	5.8% (27)	3.6% (68)	0.03*
CHF	0.3% (8)	0.9% (4)	0.2% (4)	0.03*
Coronary artery disease	10.5% (248)	12.9% (60)	9.9% (188)	0.06
Prior history of MI	4.2% (98)	6.9% (32)	3.5% (66)	0.001
History of dementia	0.5% (12)	1.3% (6)	0.3% (6)	<0.001*
BMI	27.2 ± 6.2	27.7 ± 6.2	27.1 ± 6.2	0.08
Weight Loss	13.3% (313)	13.4% (62)	13.2% (251)	0.94
Steroid Use	2.5% (59)	4.1% (19)	2.1% (40)	0.01*
Dialysis	0.2% (5)	0.4% (2)	0.2% (3)	0.25
Jaundice	34.8% (729)	32.0% (136)	35.5% (593)	0.17
Creatinine	0.9 ± 0.5	0.9 ± 0.4	0.9 ± 0.6	0.06
INR	1.1 ± 0.3	1.1 ± 0.1	1.1 ± 0.3	0.9
Bilirubin	1.9 ± 3.6	1.7 ± 3.1	1.9 ± 3.7	0.23
Tumor Size > 3cm	40.2% (887)	38.9% (167)	40.5% (720)	0.66
Smoker	19.0% (447)	22.0% (102)	18.2% (345)	0.06
ASA Class				<0.001*
Class 1	0.8% (19)	0.9% (4)	0.8% (15)	
Class 2	33.1% (782)	26.5% (123)	34.8% (659)	
Class 3	63.4% (1,496)	67.2% (312)	62.5% (1,184)	
Class 4	2.7% (63)	5.4% (25)	2.0% (38)	
CCI Score > 2	29.9% (706)	35.8% (166)	28.5% (540)	0.002*
Albumin	3.9 ± 0.6	3.9 ± 0.6	3.9 ± 0.6	0.1
Neoadjuvant chemotherapy	6.6% (156)	6.7% (31)	6.6% (125)	0.94
Operation Type				0.93
Whipple	68.1% (1,608)	68.3% (317)	68.1% (1,291)	
Other pancreatectomy	31.9% (752)	31.7% (147)	31.9% (605)	
Surgeon Experience				0.57

Variable	All patients (n=2,360)	Readmitted (n=464; 19.7%)	Non-readmitted (n=1,896; 80.3%)	p-value*
< 5 years	18.6% (440)	20.0% (93)	18.3% (347)	
5 to 15 years	38.9% (919)	39.4% (183)	38.8% (736)	
>15 years	42.4% (1,001)	40.5% (188)	42.9% (813)	
LOS (days)	10.8 ± 8.4	11.4 ± 8.4	10.6 ± 8.4	0.08
Multivisceral Resection	9.5% (224)	11.6% (54)	9.0% (170)	0.07
Minimally Invasive	6.9% (162)	6.0% (28)	7.1% (134)	0.43
Vascular Resection	11.4% (268)	12.5% (58)	11.1% (210)	0.39
Pathology				0.4
Benign	36.5% (855)	36.9% (170)	36.4% (685)	
Malignant	61.2% (1,433)	59.9% (276)	61.5% (1,157)	
Operative Transfusion	21.9% (488)	22.3% (99)	21.8% (389)	0.83
EBL	660 ± 950	730 ± 1350	640 ± 830	0.06
ADL				0.76
Dependent	2.6% (61)	2.4% (11)	2.6% (50)	
Independent	97.4% (2,297)	97.6% (451)	97.4% (1,846)	

Categorical data presented as percentage (number). Continuous data presented as mean ± standard deviation.

* p-value indicates statistical significance ($p < 0.05$) comparing derivation versus validation cohorts based on chi-square for categorical data and student's t-test for continuous data.

COPD indicates chronic obstructive pulmonary disease; CHF, congestive heart failure; BMI, body mass index; MI, myocardial infarction; INR, International Normalized Ratio; ASA, American Society of Anesthesiology; CCI, Charlson Comorbidity Index; LOS, length of stay; EBL, estimated blood loss; ADL, Activities of Daily Living;

Table 2
Postoperative Outcomes Amongst Readmitted and Non-readmitted Cohorts

Variable	All patients (n=2,360)	Readmitted (n=464, 19.7%)	Non-readmitted (n=1,896, 80.3%)	p-value*
Sepsis	6.1% (143)	17.0% (79)	3.4% (64)	<0.001*
Acute renal failure	1.2% (28)	1.7% (8)	1.1% (20)	0.23
Pancreatic fistula	21.4% (505)	34.9% (162)	18.1% (343)	<0.001*
Other fistulas				0.14
Biliary fistula	2.5% (60)	3.7% (17)	2.3% (43)	
Enteric fistula	0.3% (7)	0.7% (3)	0.2% (4)	
Chylous fistula	2.2% (52)	2.4% (11)	2.2% (41)	
Pneumonia	3.6% (85)	5.0% (23)	3.3% (62)	0.08
Postoperative hemorrhage	10.3% (242)	15.7% (73)	8.9% (169)	<0.001*
Delayed gastric emptying	15.4% (363)	20.5% (95)	14.1% (268)	0.001*
Surgical site infection	16.1% (379)	34.9% (162)	11.5% (217)	<0.001*
Reinsertion of endotracheal tube	2.9% (69)	4.3% (20)	2.6% (49)	0.22
Deep venous thrombosis	2.0% (47)	3.9% (18)	1.5% (29)	0.001*
Urinary tract infection	4.4% (104)	6.9% (32)	3.8% (72)	0.004*

* p-value indicates statistical significance (p<0.05)

Table 3
Demographics and Baseline Characteristics in Derivation and Validation Cohorts

Variable	Derivation Cohort (n=1,888; 80%)	Validation Cohort (n=472; 20%)	p-value*
Age	62.4 ± 13.5	62.7 ± 13.5	0.71
Female	52.0% (982)	50.4% (238)	0.53
Race			0.69
Caucasian	81.3% (1,535)	80.3% (379)	
African American	8.7% (164)	10.0% (47)	
Other	10.0% (189)	9.8% (46)	
Diabetes Mellitus			0.56
Type I	9.6% (181)	8.7% (41)	
Type II	12.6% (238)	11.2% (53)	
Connective Tissue Disease	5.5% (104)	4.7% (22)	0.46
COPD	4.0% (76)	4.0% (19)	1
CHF	0.4% (7)	0.2% (1)	0.6
CAD	10.1% (191)	12.1% (57)	0.21
Prior history of MI	4.0% (75)	4.9% (23)	0.38
History of dementia	0.2% (1)	0.6% (11)	0.31
BMI	27.2 ± 6.3	27.3 ± 6.1	0.73
Weight Loss	13.4% (252)	12.9% (61)	0.81
Steroid Use	2.7% (50)	1.9% (9)	0.36
Dialysis	0.3% (5)	0% (0)	0.26
Jaundice	35.3% (589)	33.1% (140)	0.41
Creatinine	0.9 ± 0.5	0.9 ± 0.2	0.16
INR	1.1 ± 0.3	1.0 ± 0.1	0.2
Bilirubin	1.9 ± 3.6	1.7 ± 3.2	0.24
Tumor Size > 3cm	40.5% (718)	38.9% (169)	0.66
Smoker	19.0% (359)	18.6% (88)	0.85
ASA			0.95
Class 1	0.9% (16)	0.6% (3)	
Class 2	33.3% (628)	32.6% (154)	
Class 3	63.2% (1,193)	64.2% (303)	
Class 4	2.7% (51)	2.5% (12)	
Albumin	3.9 ± 0.6	4.0 ± 0.6	0.14
Neoadjuvant	7.0% (132)	5.1% (24)	0.13
Operation Type			0.24
Whipple	68.7% (1,297)	65.9% (311)	
Other pancreatectomy	31.3% (591)	34.1% (161)	
Surgeon Experience			0.88
< 5 years	18.5% (349)	19.3% (91)	
5 to 15 years	38.9% (734)	39.2% (185)	
>15 years	42.6% (805)	41.5% (196)	

Variable	Derivation Cohort (n=1,888; 80%)	Validation Cohort (n=472; 20%)	p-value*
LOS (days)	10.8 ± 8.2	10.6 ± 9.0	0.59
Multivisceral Resection	9.5% (180)	9.3% (44)	0.89
Minimally Invasive	6.8% (129)	7.0% (33)	0.9
Vascular Resection	11.1% (209)	12.5% (59)	0.38
Pathology			0.91
Benign	36.5% (685)	36.6% (170)	
Malignant	61.1% (1,148)	61.4% (285)	
Operative Transfusion	21.9% (388)	21.7% (100)	0.92
EBL	670 ± 1,000	630 ± 760	0.5
ADL			0.36
Dependent	2.4% (46)	3.2% (15)	
Independent	97.6% (1,841)	96.8% (456)	
Postoperative sepsis	5.9% (111)	6.8% (32)	0.46
Postoperative renal failure	1.2% (23)	1.1% (5)	0.78
Postoperative pancreatic fistula	20.7% (391)	24.2% (114)	0.1
Other anastomotic leaks			0.36
Postoperative chylous fistula	2.3% (43)	1.9% (9)	
Postoperative enteric fistula	0.3% (5)	0.4% (2)	
Postoperative biliary fistula	2.3% (43)	3.6% (17)	
Postoperative pneumonia	3.6% (68)	3.6% (17)	1
Postoperative hemorrhage	10.2% (192)	10.6% (50)	0.79
Delayed gastric emptying	15.5% (293)	14.8% (70)	0.71
Surgical site infection	15.4% (291)	18.6% (88)	0.09
Reintubation	2.9% (55)	3.0% (14)	0.24
Deep venous thrombosis	1.9% (36)	2.3% (11)	0.56
Urinary tract infection	4.7% (88)	3.4% (16)	0.23

Categorical data presented as percentage (number). Continuous data presented as mean ± standard deviation.

* p-value comparing derivation versus validation cohorts based on chi-square for categorical data and student's t-test for continuous data.

COPD indicates chronic obstructive pulmonary disease; CHF, congestive heart failure; BMI, body mass index; MI, myocardial infarction; INR, International Normalized Ratio; ASA, American Society of Anesthesiology; CCI, Charlson Comorbidity Index; LOS, length of stay; EBL, estimated blood loss; ADL, Activities of Daily Living;

Table 4
Univariate and Multivariable Logistic Regression Models Used to Generate the Readmission After Pancreatectomy (RAP) Score

Covariates	Univariate Analysis OR	95% CI	p-value [†]	Multivariable Analysis OR	95% CI	p-value*	Points Assigned
Age > 60 yrs	0.85	0.68-1.07	0.18	0.78	0.59-1.03	0.08	0
Hypertension	1.36	1.08-1.72	0.008	1.19	0.90-1.57	0.23	0
Gender	0.86	0.69-1.08	0.2 [‡]	1.02	0.78-1.32	0.89	0
Race							
Caucasian	Reference	-	-	...	...	...	...
African American	1.49	1.03-2.18	0.04	...	...	...	...
Other	1.40	0.98-2.01	0.07	...	...	...	...
Coronary artery disease	1.37	0.96-1.94	0.08	...	...	...	...
COPD	1.62	0.97-2.72	0.07	1.37	0.75-2.49	0.3	0
CHF	5.59	1.25-25.11	0.03	...	...	...	...
Prior history of MI	2.30	1.41-3.75	0.001	2.03	1.15-3.57	0.01*	3
Prior history of dementia	5.06	1.53-16.7	0.008	6.22	1.78-21.81	0.004*	9
Connective tissue disease	1.75	1.12-2.71	0.01	1.26	0.73-2.18	0.4	0
BMI (stratified)							
BMI<18.5	Reference	-	-	...	...	...	...
BMI> 18.5 & BMI≤25	1.89	0.79-4.51	0.15	...	...	...	...
BMI>25 & BMI≤30	1.76	0.74-4.21	0.2	...	...	...	...
BMI>30	2.34	0.97-5.61	0.06	...	...	...	...
Preoperative steroid use	2.20	1.21-3.99	0.01	1.17	0.55-2.49	0.69	0
Jaundice	0.83	0.64-1.07	0.15	0.78	0.59-1.04	0.09	0
Smoker	1.25	0.94-1.65	0.13	...	...	...	...
ASA Class 3	1.48	1.15-1.90	0.002	1.34	1.03-1.75	0.03*	2
Albumin (<3.5)	1.28	0.96-1.70	0.09	...	...	...	...
Visceral resection	1.44	1.00-2.06	0.05	...	...	...	...
Postoperative variables							
Sepsis	5.66	3.82-8.38	<0.001	3.10	1.94-4.95	<0.001*	5
Acute renal failure	1.84	0.75-4.49	0.18	...	...	...	...

Covariates	Univariate Analysis OR	95% CI	p-value [†]	Multivariable Analysis OR	95% CI	p-value*	Points Assigned
Pancreatic fistula	2.07	1.60-2.67	<0.001	1.28	0.95-1.73	0.11	0
Other fistulas							
Biliary fistula	1.28	0.62-2.61	0.51 [†]	...	...	...	...
Enteric fistula	2.81	0.47-16.86	0.26 [†]	...	...	...	...
Chylous fistula	1.11	0.53-2.34	0.78 [†]	...	...	...	...
Pneumonia	1.78	1.04-3.03	0.035	...	...	...	...
Postoperative hemorrhage	1.95	1.40-2.71	<0.001	1.81	1.21-2.73	0.004*	3
Delayed gastric emptying	1.51	1.13-2.02	0.006	1.78	1.22-2.60	0.003*	3
Surgical site infection	3.93	3.00-5.14	<0.001	3.31	2.37-4.63	<0.001*	5
Reinsertion of endotracheal tube	1.65	0.96-2.86	0.07	...	...	...	...
Deep venous thrombosis	3.05	1.56-5.99	0.001	...	...	...	...
Urinary tract infection	1.70	1.05-2.74	0.03	...	...	...	...
Length of stay < 10 days	0.75	0.59-0.96	0.02	1.51	1.10-2.09	0.01*	2
Total points possible	-	-	-	-	-	-	32

... Variables removed because they diminished the explanatory power of the multivariable model

[†] Indicates a clinical relevant variables that were forced into multivariable model with a p-value 0.20

* p-value indicates statistically significance (p<0.05)

OR indicates odds ratio; CI, confidence interval; COPD, chronic obstructive pulmonary disease; BMI, body mass index; MI, myocardial infarction; ASA, American Society of Anesthesiology

Table 5
Predictive Factors from Multivariable Analysis Used to Generate the Readmission After
Pancreatectomy (RAP) Score

Covariates	OR	Multivariable Analysis (95% CI)	p-value	Points Assigned
ASA Class 3	1.34	(1.03-1.75)	0.03	2
Prior history of MI	2.03	(1.15-3.57)	0.01	3
Prior history of dementia	6.22	(1.78-21.81)	0.004	9
Sepsis	3.10	(1.94-4.95)	<0.001	5
Postoperative hemorrhage	1.81	(1.21-2.73)	0.004	3
Delayed gastric emptying	1.78	(1.22-2.60)	0.003	3
Surgical site infection	3.31	(2.37-4.63)	<0.001	5
Length of stay < 10 days	1.51	(1.10-2.09)	0.01	2
Total points possible	-	-	-	32

OR indicates odds ratio; CI, confidence interval; ASA, American Society of Anesthesiology; MI, myocardial infarction.

Table 6
Readmission After Pancreatectomy (RAP) Score Stratification

Risk Category	Score	Predicted Rate of Readmission	Observed Readmission in Total Population	p-value
Low	0-3	1-15%	11.7% (93)	< 0.001
Intermediate	4-7	15-35%	17.5% (212)	
High	>7	>35%	45.4% (159)	

The low, intermediate and high-risk groups had 795, 1,215 and 350 patients respectively