

A Risk Model and Cost Analysis of Incisional Hernia After Elective Abdominal Surgery Based on 12,373 Cases

The Case for Targeted Prophylactic Intervention

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Objectives: Incisional hernia (IH) remains a common, highly morbid, and costly complication. Modest progress has been realized in surgical technique and mesh technology; however, few advances have been achieved toward understanding risk and prevention. In light of the increasing emphasis on prevention in today's health care environment and the billions in costs for surgically treated IH, greater focus on predictive risk models is needed.

Methods: All patients undergoing gastrointestinal or gynecologic procedures from January 1, 2005 to June 1, 2013, within the University of Pennsylvania Health System were identified. Comorbidities and operative characteristics were assessed. The primary outcome was surgically treated IH after index procedures. Patients with prior hernia, less than 1-year follow-up, or emergency surgical procedures were excluded. Cox hazard regression modeling with bootstrapped validation, risk factor stratification, and assessment of model performance were conducted.

Results: A total of 12,373 patients with a 3.5% incidence of surgically treated IH (follow-up 32.2 ± 26.6 months) were identified. The cost of surgical treatment of IH and management of associated complications exceeded \$17.5 million. Notable independent risk factors for IH were ostomy reversal (HR = 2.76), recent chemotherapy (HR = 2.04), bariatric surgery (HR = 1.78), smoking history (HR = 1.74), liver disease (HR = 1.60), and obesity (HR = 1.96). High-risk patients (20.6%) developed IH compared with 0.5% of low-risk patients (C-statistic = 0.78).

Conclusions: This study demonstrates an internally validated preoperative risk model of surgically treated IH after 12,000 elective, intra-abdominal procedures to provide more individualized risk counseling and to better inform evidence-based algorithms for the role of prophylactic mesh.

Keywords: incisional hernia, outcome, prophylactic, risk model

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Incisional hernia (IH) of the anterior abdominal wall remains a common, challenging, and costly surgical complication permeating virtually all surgical disciplines. Historically, innovation in hernia care has largely been represented by reactive strategies to treat IH, including advances in surgical mesh technology and pioneering operative techniques. Despite the scope of IH and modest results of reactive treatment strategies, approaches to this complex, multifactorial process have not evolved with the general zeitgeist of preventative medical care. Proactive strategies to prevent hernia are generally void from the surgical literature. Developing such an approach requires the ability to reliably and accurately identify high-risk patients, so that evidence-based risk reduction strategies can be implemented.

Hernia significantly impairs quality of life¹ and is associated with a substantial cost burden for society, which collectively speak to the significant need for effective preventative strategies. Furthermore, failure of initial herniorrhaphy inevitably increases the operative complexity of subsequent attempts at repair, perpetuating the inability to restore domain and abdominal wall integrity.² The incentive to explore proactive strategies cannot be overemphasized as hernia repair outcomes remain suboptimal despite the aforementioned advances. As the health care landscape evolves and reimbursement structures change, identification of high-risk patients and preventative surgical techniques to mitigate risk will undoubtedly become more central to surgical care. Implementing a preventative approach to management will reduce operative morbidity and the exorbitant cost of complications following abdominal surgery. Furthermore, the addition of reliable and simple risk models can augment preoperative counseling and enhance the surgical decision-making process.

As with many other common morbidities (eg, diabetes, hypertension), primary prevention affords a promising and, perhaps, more cost-effective strategy.^{3–7} Therefore, the aims of this current study are to perform an institutional review of patients within a large, academic health system undergoing open, intra-abdominal surgery in an elective setting to quantify the incidence of surgically treated IH, develop a clinically actionable risk stratification scheme, and to characterize health care cost and resource utilization.

METHODS

Study Design

After obtaining institutional board review approval (protocol #820208), a retrospective review was conducted on all patients ages 18 years and older undergoing non-emergent, open intra-abdominal, or gynecologic operation requiring abdominal wall fascial incision within the University of Pennsylvania Health System from January 2005 to June 2013. Eligible patients were identified by querying the electronic medical record for *International*

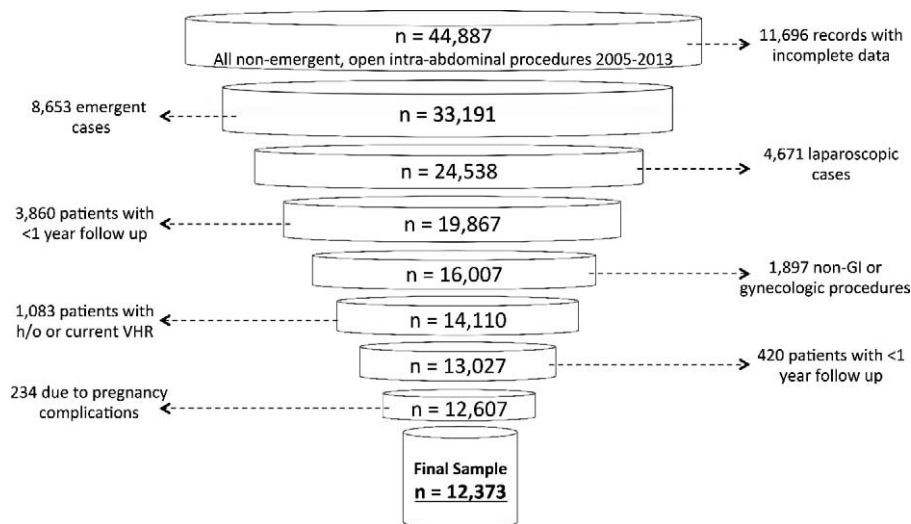


FIGURE 1. Flowchart of patient selection and exclusion criteria.

Classification of Diseases, Ninth Revision, Clinical Modification (ICD-9-CM) and year-specific *Current Procedural Terminology (CPT)* codes. Patients were classified accordingly as having a gastric, bowel, hepatobiliary, spleen, or gynecologic intervention via open surgical approach.

Relevant exclusion criteria included laparoscopic surgical approach without an open component, documented IH diagnosis before index procedure, concurrent ventral hernia repair with index procedure, gynecologic procedure due to complication of pregnancy, operation not involving the gastrointestinal tract or gynecologic organs, death within 1 year of procedure, clinical follow-up of less than 1 year, and surgery performed in the outpatient setting or emergently (Fig. 1).

Data Collection

Data pertaining to demographic information, medical history, and admitting diagnosis were obtained by querying the electronic medical record. Comorbidities were defined according to the Elixhauser index (Agency for Healthcare Research and Quality classifications),⁸ and body mass index (kg/m^2) was coded according to the World Health Organization classification (see Supplemental Digital Content 1, available at <http://links.lww.com/SLA/A827>).⁹ Cardiovascular disease was defined by the presence of coronary artery disease, peripheral vascular disease, or congestive heart failure. Pulmonary disease included history of chronic obstructive pulmonary disease, acute or chronic respiratory failure, or ventilator dependence. Renal disease was defined by acute or chronic renal failure requiring dialysis, and liver disease included a documented history of cirrhosis, ascites, or varices.^{10,11}

Patients were categorized by operative characteristics, according to the primary index operation as gastric, hepatobiliary, spleen, bowel, or gynecologic surgery (see Supplemental Digital Content 2, available at <http://links.lww.com/SLA/A828>). Gastric surgery was further subclassified as partial gastrectomy, total gastrectomy, or bariatric surgery. Bowel surgery was subdivided into small bowel and large bowel procedures, with large bowel procedures further classified into total colectomy, partial colectomy, and proctectomy. These subclassifications were not considered mutually exclusive; as such, patients undergoing multiple procedures across groups were treated similarly as those undergoing procedures in 1 group only. History of abdominal surgery was noted, as was active acute gastrointestinal inflammatory process and disseminated systemic infection. Prior

surgical complications were recorded as well, including history of superficial wound infection, wound dehiscence, abscess, seroma, hematoma, postoperative wound bleeding, enterocutaneous fistula, and small bowel obstruction (see Supplemental Digital Content 3, available at <http://links.lww.com/SLA/A829>).

The primary outcome of interest was surgical reoperation for postoperative IH defined by both *International Classification of Diseases, Ninth Revision (ICD-9)* diagnosis and procedure codes for hernia. This endpoint was chosen because it was the most reliable indicator for the presence of a true IH, defined as an abdominal wall fascial defect occurring at a prior laparotomy incision site. Patients with a prior diagnosis of IH or those who underwent IH repair before or concurrently with the index procedure were excluded from analysis. Secondary outcomes included time to IH repair, incidence of reoperation, and additional postoperative surgical complications, defined as superficial wound cellulitis, deep-space infection, wound dehiscence, seroma, hematoma, acute wound bleeding, enterocutaneous fistula, sepsis, and small bowel obstruction.

Financial Cost Data

Financial data were provided by the Department of Finance at the University of Pennsylvania Health System for each index admission and subsequent readmissions related to either the index procedure or complications within the study period. Cost data consisted of direct variable costs (operating room, labs, radiology, pharmacy, blood product, surgical implants, and perioperative services) and total costs incurred by the hospital for the duration of each admission. Costs for readmissions related to the index procedure and subsequent surgical complications such as hernia were also tabulated for the duration of patient follow-up. Professional fees were not included in financial reports, and all cost data were adjusted to 2014 US dollars using the medical components of the consumer price index to account for inflation.¹²

Data Analysis and Model Generation

Standard descriptive summary statistics were provided for baseline demographics, operative characteristics, and surgical outcomes. Continuous variables were reported as means with standard deviations and categorical variables as proportions. Bivariate analyses of independent variables and postoperative hernia repair incidence were performed. Pearson χ^2 test or Fisher exact test, as

well as Cox proportional hazards univariate tests were used to analyze categorical variables; unpaired Student *t* tests were employed for continuous variables. Variables with a *P* value of less than 0.1 in univariate analysis were used as independent variables in an initial Cox proportional hazards regression analysis. Variables yielding *P* value of less than 0.1 in the initial regression model were included in a bootstrap analysis to determine the set of variables that should remain in our final risk model.^{13,14}

In the bootstrap procedure, 1000 random samples of the cohort were generated with replacement. Each sample was then subject to stepwise multivariate logistic regression, covariates entered the model if *P* value less than 0.1, and remained in the model if *P* value less than 0.05. Frequencies of occurrence of each independent variable in the final model were noted; if predictors occurred in 50% or more of the bootstrap models, they were retained in a final multivariate Cox regression.¹⁵ The discriminatory capacity of the model was assessed by calculating the bias-corrected Harrell's C-statistic and model goodness-of-fit by comparing the Nelson-Aalen cumulative hazard function to the Cox-Snell Residuals.¹⁶ A simplified clinical risk assessment tool was derived by assigning point values to the rounded hazard ratio coefficients.^{17,18} A composite risk was defined as the summation of these point values for each individual patient. Risk stratification groups were then created on the basis of the composite hernia risk scores for each patient. Cross-validation of the regression model and composite risk score models

were performed by comparison of model discriminatory capacity via likelihood-ratio test and calibration against the ideal.¹⁹ Data management and analysis were performed using STATA IC 13.0 (StataCorp, College Station, TX).

RESULTS

Patient and Operative Characteristics

A total of 12,373 patients meeting inclusion criteria were identified. The average age was 55.9 years, and approximately 42% of patients were obese (Table 1). The most prevalent comorbidities included hypertension (54%), hyperlipidemia (36%), and history of smoking or active smoker (33%). Cardiovascular disease was present in 20% of patients, liver disease and renal disease in 12% of patients each, and pulmonary disease in 19%. Univariate analysis of patient factors associated with IH is provided in Table 1.

The index procedure was classified as follows: gastric surgery—10%, large bowel—31%, small bowel—5%, hysterectomy—35%, pancreatectomy—10%, splenectomy—5%, and hepatectomy—4% (Table 2). About 16% of patients had a history of abdominal surgery and nearly 10% a prior surgical complication. At the time of index surgery, 5.5% of patients had an active gastrointestinal inflammatory process, 3% presented with disseminated systemic infection, and about 11% underwent concurrent ostomy

TABLE 1. Summary of Patient Characteristics and Association With Development of Postoperative Incisional Hernia

Factor	Subgroup	N	Factor Prevalence	% Hernia, No Factor	% Hernia, With Factor	<i>P</i>
Sex	Male	4133	33.4%	2.9%	3.7%	0.023
Race/ethnicity	White	8154	65.9%	2.1%	3.7%	<0.001
	Black	2759	22.3%	3.3%	2.5%	0.030
	Asian	124	1.0%	3.2%	0.0%	0.051
	Native American	12	0.1%	3.1%	18.2%	0.004
	Hispanic	272	2.2%	3.1%	3.8%	0.533
Age	<45 yr	2598	21.0%	3.2%	3.1%	0.765
	45–65 yr	5704	46.1%	2.7%	3.7%	0.003
	65–80 yr	3266	26.4%	3.2%	3.0%	0.493
Hypertension		6632	53.6%	2.4%	3.8%	<0.001
Obese		5209	42.1%	2.4%	4.2%	<0.001
WHO BMI classification	Underweight (<18.5 kg/m ²)	384	3.1%	3.1%	2.4%	0.446
	Normal (18.5–29.9 kg/m ²)	6879	55.6%	4.0%	2.4%	<0.001
	Class I (30.0–34.9 kg/m ²)	2178	17.6%	2.9%	4.2%	0.002
	Class II (35.0–39.9 kg/m ²)	1052	8.5%	2.9%	5.2%	<0.001
	Class III (>40.0 kg/m ²)	1893	15.3%	3.1%	3.4%	0.455
Smoker		4071	32.9%	2.5%	4.4%	<0.001
Anemia		4702	38.0%	2.6%	4.0%	<0.001
Hyperlipidemia		4442	35.9%	2.7%	4.0%	<0.001
Benign gynecologic mass		3502	28.3%	3.9%	1.2%	<0.001
Cardiovascular disease		2475	20.0%	3.1%	3.3%	0.552
Pulmonary disease		2351	19.0%	3.0%	3.8%	0.041
GI malignancy		1943	15.7%	3.2%	3.0%	0.746
	Nonlarge bowel	1015	8.2%	3.3%	1.6%	0.004
	Large bowel	1336	10.8%	3.0%	4.5%	0.002
Renal disease		1534	12.4%	3.1%	3.7%	0.201
Liver disease		1522	12.3%	2.8%	5.9%	<0.001
Diabetes		1027	8.3%	3.1%	3.8%	0.197
Intestinal obstruction		953	7.7%	3.0%	4.6%	0.011
Malnutrition		940	7.6%	3.0%	5.0%	0.001
History of chemotherapy		718	5.8%	2.9%	7.1%	<0.001
History of radiation		544	4.4%	3.1%	4.4%	0.095
Alcohol abuse		148	1.2%	3.1%	6.7%	0.012
Irritable bowel syndrome		124	1.0%	3.1%	8.3%	0.001

WHO BMI indicates World Health Organization body mass index.

TABLE 2. Summary of Surgical Characteristics and Association With Development of Postoperative Incisional Hernia

Factor	Subgroup	N	Factor Prevalence	% Hernia, No Factor	% Hernia, With Factor	P
History GI surgery		1918	15.5%	2.8%	5.3%	<0.001
Systemic infection		346	2.8%	3.1%	4.8%	0.074
Acute GI inflammation		681	5.5%	2.8%	8.7%	<0.001
Gastric surgery		1188	9.6%	3.1%	4.1%	0.058
	Partial gastrectomy	606	4.9%	3.1%	3.2%	0.922
	Total gastrectomy	136	1.1%	3.2%	1.5%	0.274
	Bariatric surgery	371	3.0%	3.0%	7.9%	<0.001
Hepatectomy		483	3.9%	3.2%	2.1%	0.190
Pancreatectomy		1151	9.3%	3.2%	2.5%	0.202
Splenectomy		544	4.4%	3.2%	3.0%	0.852
Large bowel surgery		2722	22.0%	2.4%	5.9%	<0.001
	Proctectomy	594	4.8%	3.0%	6.2%	<0.001
	Total colectomy	309	2.5%	3.1%	3.3%	0.898
	Partial colectomy, with proctectomy	111	0.9%	3.1%	11.5%	<0.001
	Partial colectomy, no proctectomy	1745	14.1%	2.6%	6.4%	<0.001
Small bowel resection		594	4.8%	3.0%	5.4%	0.002
Hysterectomy		4516	36.5%	3.9%	1.8%	<0.001
Fistulectomy		124	1.0%	3.1%	10.4%	<0.001
Ostomy creation		1064	8.6%	2.9%	5.9%	<0.001
Ostomy reversal		210	1.7%	3.0%	13.8%	<0.001
History of wound complication		1114	9.0%	2.8%	6.4%	<0.001
	Superficial infection	285	2.3%	3.0%	7.6%	<0.001
	Wound dehiscence	49	0.4%	3.1%	6.4%	0.204
	Seroma	25	0.2%	3.1%	11.5%	0.014
	Hematoma	87	0.7%	3.2%	1.3%	0.336
	Bleeding	186	1.5%	3.2%	2.8%	0.802
	Fistula	198	1.6%	3.1%	7.4%	0.001
	Small bowel obstruction	817	6.6%	3.0%	4.6%	0.013

GI indicates gastrointestinal.

TABLE 3. Final Cox Proportional Hazards Regression and Factor Weights for Development of Postoperative Incisional Hernia

Risk Factor	Hazard Ratio (95% CI)	P	Risk Score
Hispanic or Native American	2.94 (1.76–4.90)	<0.001	3
Concurrent ostomy/fistula takedown	2.76 (2.00–3.79)	<0.001	3
Recent chemotherapy	2.04 (1.53–2.71)	<0.001	2
Obesity	1.96 (1.57–2.46)	<0.001	2
Bariatric procedure	1.78 (1.19–2.66)	0.004	2
History of alcohol abuse	1.74 (0.92–3.29)	0.084	2
White	1.74 (1.35–2.25)	<0.001	2
History of smoking	1.74 (1.43–2.11)	<0.001	2
Proctectomy	1.66 (1.16–2.38)	0.005	2
History of liver disease	1.60 (1.25–2.03)	<0.001	2
Acute inflammatory process	1.48 (1.10–1.98)	0.009	1
Partial colectomy	1.45 (1.14–1.83)	0.002	1
Small bowel resection	1.43 (1.07–1.92)	0.014	1
History surgical wound complication	1.43 (1.10–1.86)	0.007	1
Concurrent ostomy creation	1.37 (1.05–1.79)	0.018	1
Malnutrition	1.33 (0.99–1.80)	0.056	1
Age >45 yr	1.26 (1.00–1.61)	0.050	1
Cardiovascular disease	0.76 (0.59–0.98)	0.039	0
Subtotal hysterectomy	0.58 (0.28–1.19)	0.141	N/A*
Normal weight	0.53 (0.39–0.71)	<0.001	-1
Asian	0.49 (0.23–1.03)	0.061	-1
Benign gynecologic mass	0.43 (0.29–0.64)	<0.001	-1

*Factor not weighted due to insignificant *P*. Harrell's *C* = 0.78.
CI indicates confidence interval; N/A, not applicable.

creation or takedown. Univariate analysis of operative factors associated with IH is provided in Table 2.

Factors Associated With Surgically Treated IH

With an average follow-up of 32.2 ± 26.6 months, postoperative IH repair was performed in a total of 436 patients (3.5%) (Table 3). After bootstrapped logistic regression, a number of patient and procedural factors were identified as independent predictors of postoperative hernia. The strongest patient factors associated with hernia included liver disease (HR = 1.60, $P < 0.001$), history of chemotherapy (HR = 2.04, $P < 0.001$), body mass index greater than 30 kg/m² (HR = 1.96, $P < 0.001$), and smoking history (HR = 1.74, $P < 0.001$). Predictive operative characteristics were concurrent ostomy or fistula takedown (HR = 2.76, $P < 0.001$), open bariatric procedure (HR = 1.78, $P = 0.004$), proctectomy (HR = 1.66, $P = 0.005$), and acute GI inflammatory process (HR = 1.48, $P = 0.009$). Protective factors included Asian race (HR = 0.49, $P = 0.061$), normal weight (HR = 0.53, $P < 0.001$), and benign gynecologic mass (HR = 0.43, $P < 0.001$).

Risk Stratifying Postoperative IH Repair

A composite risk score was calculated for patients, allowing stratification into low (risk score: 0–1), moderate (risk score: 2–6), high (risk score: 7–10), and extreme (risk score: 11 or higher) risk groups for surgically treated IH (Figs. 2 and 3). The incidence of postoperative hernia ranged from 0.5% in the low risk group to 20.6% in the extreme risk group, demonstrating a 41-fold variation in risk across groups.

The discriminatory capacity of both the risk factor model and the composite risk score model was excellent (*C*-statistic = 0.78 and

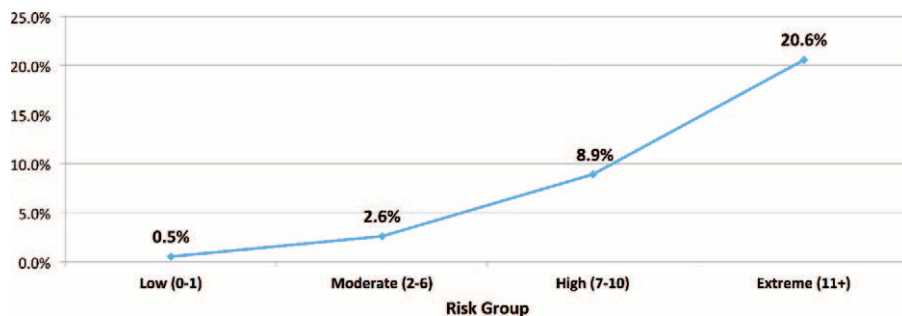


FIGURE 2. Stratification of incisional hernia risk across risk groups and summary of secondary outcomes.

0.77, respectively). Calibration plots were created to visually assess goodness-of-fit, and the likelihood-ratio test ($\chi^2 = 26.9$, $P = 0.18$), suggesting adequate model goodness-of-fit.

Secondary Outcomes and Costs

In addition to modeling risk for postoperative hernia repair, the risk model was found to correlate with secondary outcomes. Specifically, all-cause reoperation rate ranged from 26.4% in the low risk group to nearly 79% in the extreme risk group, and the initial hospital length of stay for low and extreme risk groups was 4.4 days and 15.3 days, respectively (Table 4). Patients who underwent hernia repair had a significantly higher incidence of secondary surgical complications than those patients without hernia (31% vs 22%, $P < 0.001$) (Table 4). Small bowel obstruction was the most prevalent complication overall (12%), followed by superficial wound cellulitis (4.3%), sepsis (2.7%), and postoperative bleeding (2.7%). Finally, the time to first readmission for a surgical complication correlated with risk groups as well, with higher risk groups demonstrating shorter time to readmission overall.

The average total cost of the index admission was $\$27,065 \pm \$51,805$, whereas total readmission costs averaged $\$34,489 \pm \$60,901$. There was no difference in index costs for patients experiencing hernia versus those without hernias ($\$26,968$ vs $\$29,809$, $P = 0.974$), average readmission costs were significantly higher for patients with hernia ($\$32,807$ vs $\$57,267$, $P < 0.001$) as was the overall combined cost of care ($\$41,053$ vs $\$81,183$, $P < 0.001$). Furthermore, patients experiencing hernia and subsequent recurrence requiring additional surgery averaged $\$98,424$ in combined costs of care ($P < 0.001$). The risk stratification model also significantly predicted increasing costs for high and extreme risk groups ($P < 0.001$), as demonstrated in Table 4.

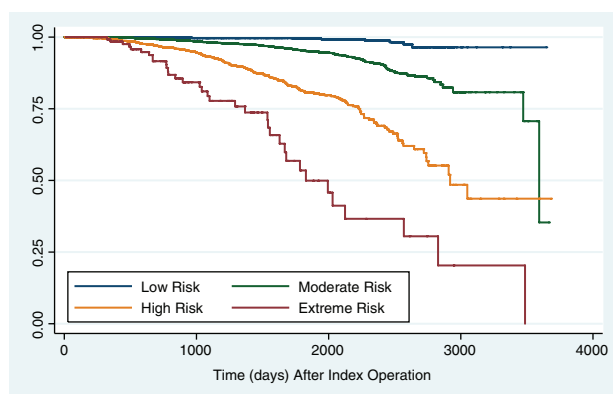


FIGURE 3. Hernia-free survival curves stratified by risk group.

DISCUSSION

Surgical risk stratification represents a promising opportunity to identify high-risk patients, enhance preoperative counseling, optimize patient selection, and incorporate evidence-based strategies to mitigate adverse outcomes and contain costs. Although IH is a commonly encountered surgical complication, modest progress has been achieved in preoperative identification of patients at risk for hernia after open abdominal surgery. In this study, we analyze data from 12,373 patients treated within 1 large, academic medical system over a 7-year period for nonemergent intra-abdominal surgery and create a risk model and stratification system for predicting the incidence of surgically treated IH. The IH risk model presented herein provides an actionable preoperative tool derived from patient and operative factors with good discrimination and the added benefit of delineation of morbidity and health care resource utilization. Although the rate of surgically treated IH was relatively low at 3.5%, the costs of subsequent hernia repairs, admissions, and secondary/tertiary reoperations were staggering, exceeding \$17.5 million overall. These findings emphasize the importance of early, preoperative risk stratification in elective intra-abdominal procedures to create opportunities for risk reduction strategies so as to reduce morbidity and health care costs.

To date, there has been a paucity of data in the literature describing risk factors for IH after laparotomy. Much of our understanding of the disease process pertains to the subsequent management of hernia and risk factors for hernia recurrence after repair.²⁰ Increased understanding of hernia repair has been the primary, and arguably sole, focus in advancing the treatment of this disease process.

A cursory review of the past 30 years of literature demonstrates several discrete evolutions in the operative treatment of hernia. First, primary herniorrhaphy without mesh has been deemed unequivocally inferior to hernia repair with mesh reinforcement. The appropriately oft-cited study by Luijendijk et al²¹ demonstrated a hernia recurrence rate of 24% and 43% with and without mesh, respectively. In another landmark study, Ramirez et al²² championed the concept of unloading fascial tension with the components separation technique. Recent literature focuses on an ongoing discussion regarding the development and utilization of various biomaterials, namely, different varieties of acellular dermal matrix. The initial promise of these biomaterials has since been tempered as their ultimate utility, cost-effectiveness, and efficacy are increasingly scrutinized.^{23–26} Currently, progress has remained stagnant, and by a conservative estimate, the rate of hernia recurrence after repair remains between 10% and 20% overall, approximately 1 in 3 at 10 years,²⁷ and as high as 80% in bridged biologic repairs.²³ Altogether, given the prevalence of hernia and associated morbidity, profound decrease in quality of life, and cost burden, there is considerable room for improvement. From a broader perspective, the efforts in advancing hernia care have been directed almost entirely toward reactive strategies. Like many stalemates in the progress of medicine, a need for improvement coupled with stagnant

TABLE 4. Summary of Surgical Outcomes and Costs for Patients With and Without Hernia*

Outcome	Subgroup	Overall	No Hernia (N = 11,937)	With Hernia (N = 436)	P
Surgical complication	Overall	21.8%	21.5%	31.0%	0.000
	Superficial infection	4.3%	4.1%	9.3%	0.000
	Wound dehiscence	0.7%	0.7%	1.3%	0.173
	Seroma	0.3%	0.3%	1.3%	0.001
	Hematoma	1.1%	1.2%	0.5%	0.254
	Bleeding	2.7%	2.7%	2.4%	0.696
	Fistula	1.7%	1.6%	4.0%	0.001
	Sepsis	2.7%	2.7%	1.9%	0.313
	Small bowel obstruction	11.6%	11.5%	16.7%	0.002
	Index case LOS days		7.5 (16.4)	7.4 (16.6)	8.8 (8.4)
Readmission	Incidence overall	42.9%	41.4%	89.2%	<0.001
	Emergent	69.8%	56.7%	71.0%	<0.001
	Months to first readmission	8.9 (14.9)	9.0 (15.2)	7.8 (10.3)	0.087
	Reoperation	14.6%	12.4%	82.5%	<0.001
	Readmit added LOS days	4.1 (12.4)	3.8 (12.0)	13.0 (18.8)	<0.001
	Number of readmissions	1.43 (2.99)	1.34 (2.9)	4.34 (4.82)	<0.001
Costs	Index admission	\$27,065 (51,805)	\$26,968 (52,307)	\$29,809 (34,647)	0.974
	Total cost of readmissions	\$34,489 (60,901)	\$32,807 (59,016)	\$57,267 (78,929)	<0.001
	Combined cost of care	\$42,422 (73,635)	\$41,053 (72,457)	\$81,183 (93,600)	<0.001
	Cost for 2+ hernia repairs†	—	\$41,053 (72,457)	\$98,424 (119,765)	<0.001
Months follow-up		32.2 (26.6)	31.6 (26.5)	47.1 (24.3)	<0.001

*Summary data reported as proportions for binary outcomes and as means (standard deviation) for continuous outcomes.

†Outcome represents patients with ≥ 2 readmissions for herniorrhaphy after hernia development.

LOS indicates length of stay in days.

progress necessitates a paradigm shift with broader changes in practice currents for hernia care.

One may argue that transitioning from a model of reactive repair to proactive prevention represents the needed paradigm shift. Medicine at large has placed increasing emphasis on preventative care, and the benefits of this approach may extend to abdominal hernia care. In fact, this disease may be particularly well-suited for such an approach, as 1 hernia repair has been shown to beget another.² As a result, a number of surgeons have suggested selective prophylactic mesh placement at the time of an index intra-abdominal procedure. The call for change has been followed by a series of studies demonstrating the benefits of prophylactic mesh augmentation (PMA) through reduced rates of IH and an acceptable complication profile,^{28–33} particularly in colorectal surgery patients.^{34,35} Prophylactic mesh augmentation provides needed biomechanical integrity after laparotomy, which returns the tensile strength of the abdominal wall to the preincised state in animal models.³⁶

Although an intuitive concept based on established principles, the aforementioned studies provide a high level of evidence that demonstrates that prophylactic mesh lowers the rate of IH after elective, open intra-abdominal surgery. These data in isolation, however, are of limited utility because it is an untenable proposition to place mesh, particularly biologic mesh, prophylactically after every laparotomy given its costs. The added surgical time, increased added surgery time, technical challenges, concern for variation, cost, and foreign body burden have precluded and serve as barriers the routine utilization of prophylactic mesh because the risk-benefit may not be realized. The cost-utility of prophylactic mesh, and specifically synthetic mesh, has recently been assessed by Fischer et al,³⁷ in which the primary fascial suture repair was compared with PMA in high-risk abdominal surgery patients. The results of the aforementioned study demonstrated an absolute reduction of hernia formation of 15% with prophylactic mesh and that PMA was less costly when the cost of treating all complications was considered; furthermore, prophylactic mesh continued to be the dominant strategy across a wide range of willingness-to-pay thresholds and robust Monte-Carlo sensitivity analyses. Specifically, in the base case scenario, PMA was

cost-effective up to a mesh price of \$3,700, assuming a willingness-to-pay of \$50,000 per quality-adjusted life-year and a risk reduction of 15%, but the price of mesh could be as high \$10,000 for higher willingness-to-pay and risk reductions. Overall, these findings strongly suggest that PMA has the potential for significant health care saving, particularly when used in high-risk patients. This study and other emerging evidence supporting the efficacy of PMA techniques provide convincing data that mesh reinforcement can augment the biomechanical integrity of fascial closure and reduce IH risk with acceptable risks of complications and at an overall significant benefit to society. The question undoubtedly then remains: Who can benefit most from prophylactic mesh?

That question provided the framework for the current study. The literature is void of validated risk models for IH after laparotomy to inform selective, targeted use of prophylactic mesh in high-risk individuals. By informing patient selection, such a risk model represents the missing link between the goal of reducing the incidence of hernia after midline laparotomy and the demonstrated efficacy of prophylactic mesh. In addition, the risk model presented in this analysis coupled, when coupled with existing and emerging comparative effectiveness data demonstrating the benefits of PMA, will provide a foundation for the development of diagnostic and procedural billing codes for reimbursement for risk stratification and subsequent mesh augmentation. Additionally, the feasibility of this general risk model provides a future foundation for the creation of specialty- and procedure-specific IH risk models using larger databases.

The IH risk model presented herein provides an actionable preoperative tool derived from patient and operative factors. The benefit of this risk model can be appreciated by comparing 2 preoperative patient scenarios (see Supplemental Digital Content 4, available at <http://links.lww.com/SLA/A830>). A patient undergoing a low risk procedure with no patient-level risk factors has a very low risk of IH of 0.5%, whereas a comorbid patient undergoing a higher-risk abdominal surgery will have a considerable higher risk of 20.6%, representing more than a 40-fold variation. The model also demonstrates good predictive capacity and discrimination for IH, in addition to morbidity outcomes and health care resource utilization.

This risk model holds promise as a useful tool to provide improved, procedure-specific, preoperative risk counseling for patients undergoing common intra-abdominal surgical procedures. An important consideration when interpreting this analysis and the findings of our study is that meticulous suture technique is critical to mitigate hernia risk. There is minimal added time and cost associated with evidence-based optimal fascial closure in which a single layer, slow-absorbing, continuous suture with a suture-to-fascial defect length of at least 4–1 using a small stitch (<10 mm) technique.^{38–40}

This study is not without limitations. The study population consisted of patients treated within a single health system, which may limit the generalizability of the analysis. We do use a large, strictly defined cohort to improve the potential utility of this risk model. In addition, the incorporation of a bootstrap technique augments the statistical reliability of the risk model. We integrated cost data in the analysis to better understand the financial impact of hernia on cost, but these cost data are similarly limited in their generalizability and may not be representative of other health systems. Furthermore, the primary endpoint of IH was the incidence of surgically treated cases that does not accurately capture the true overall incidence of hernia, and undoubtedly our selection criteria underestimate the true incidence of IH. The authors recognize this important limitation, but the retrospective nature of the study along with the lack of standardized criteria informing diagnosis of hernia would have led to unreliable results if diagnostic codes were used. IH location was not reviewed on an individual patient basis, and it is likely that a portion was subcostal or paramedian and not midline. Although incision type is a predictive factor of hernia formation⁴¹ and a study limitation that must be considered, we attempt to mitigate confounding by indirectly modeling incision location via procedure type.

Although the risk model was intentionally generated solely using preoperatively identifiable characteristics to provide risk assessment for patients before any surgical intervention, this design does not take into account certain operative characteristics and postoperative events. Regarding intraoperative details, degree of wound contamination and length of fascial incision are typically known before surgery and their inclusion would enhance the risk model. Postoperative surgical site infections are a well-established driver of IH,⁴² but incorporating postoperative events into the risk model requires knowledge of who will develop a surgical site infection, which may not be known. Finally, patients lost to follow up due to departure from our health system likely contribute to the incidence of hernia that was not captured in this analysis; thus, we likely underestimate the true incidence of IH. In an effort to mitigate this inherent design issue, we limited our analysis only to patients who had at least 1 year of follow-up.

CONCLUSIONS

This study presents an internally validated risk model of surgically treated IH after 12,000 elective, intra-abdominal procedures. The strongest predictors of IH included concurrent ostomy takedown, bariatric or proctectomy surgery, and presence of an active GI inflammatory process. The cumulative costs incurred for the management of hernia and related complications exceeded \$17.5 million overall. This risk model may serve as the basis for more individualized risk counseling and better inform evidence-based algorithms for the role of prophylactic mesh in preventing IH. Prophylactic mesh may represent a novel strategy to more optimally address risk reduction in high-risk laparotomy patients.

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