Development and Validation of a Risk Stratification Score for Ventral Incisional Hernia after Abdominal Surgery: Hernia Expectation Rates in Intra-Abdominal Surgery (The HERNIA Project)

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BACKGROUND: Ventral incisional hernias (VIH) develop in up to 20% of patients after abdominal surgery. No widely applicable preoperative risk-assessment tool exists. We aimed to develop and validate a risk-assessment tool to predict VIH after abdominal surgery.

STUDY DESIGN: A prospective study of all patients undergoing abdominal surgery was conducted at a single institution from 2008 to 2010. Variables were defined in accordance with the National Surgical Quality Improvement Project, and VIH was determined through clinical and radiographic evaluation. A multivariate Cox proportional hazard model was built from a development cohort (2008 to 2009) to identify predictors of VIH. The HERNIAscore was created by converting the hazards ratios (HR) to points. The predictive accuracy was assessed on the validation cohort (2010) using a receiver operator characteristic curve and calculating the area under the curve (AUC).

RESULTS: Of 625 patients followed for a median of 41 months (range 0.3 to 64 months), 93 (13.9%) developed a VIH. The training cohort (n = 428, VIH = 70, 16.4%) identified 4 independent predictors: laparotomy (HR 4.77, 95% CI 2.61 to 8.70) or hand-assisted laparoscopy (HAL, HR 4.00, 95% CI 2.08 to 7.70), COPD (HR 2.35; 95% CI 1.44 to 3.83), and BMI $\geq$ 25 kg/m^2 (HR1.74; 95% CI 1.04 to 2.91). Factors that were not predictive included age, sex, American Society of Anesthesioloigsts (ASA) score, albumin, immunosuppression, previous surgery, and suture material or technique. The predictive score had an AUC = 0.77 (95% CI 0.68 to 0.86) using the validation cohort (n = 197, VIH = 23, 11.6%). Using the HERNIAscore: HERNIAscore = 4*Laparotomy+3*HAL+1*COPD+1* BMI $\geq$ 25, 3 classes stratified the risk of VIH: class I (0 to 3 points),5.2%; class II (4 to 5 points),19.6%; and class III (6 points), 55.0%.

CONCLUSIONS: The HERNIAscore accurately identifies patients at increased risk for VIH. Although external validation is needed, this provides a starting point to counsel patients and guide clinical decisions. Increasing the use of laparoscopy, weight-loss programs, community smoking prevention programs, and incisional reinforcement may help reduce rates of VIH. (J Am Coll Surg 2015;220:405−413. © 2015 by the American College of Surgeons)

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Abbreviations and Acronyms
AUC = area under the curve
HAL = hand-assisted laparoscopy
HR = hazard ratio
SSI = surgical site infection
VIH = ventral incisional hernia

In developed countries, one-third of all individuals will undergo abdominal surgery in their lifetime.[1] Twenty percent of these patients will develop a ventral incisional hernia (VIH). Ventral incisional hernias cause significant morbidity for patients: they can increase in size, worsen an individual's ability to function, cause skin breakdown, or incarcerate and strangulate, requiring emergency surgery.[2,3] Although outcomes of emergency VIH repair are poor, elective repair can be complex and associated with high rates of complications including surgical site infections (SSI: 20% to 30%) and hernia recurrences (20% to 30%).[4,5] It is estimated that the United States spends $3.2 billion annually on the surgical management of ventral hernias. Each major complication after surgical management of a ventral hernia repair costs the health care system $30,000 to $210,000 to address.[6]

There is currently no widely accepted scoring system for predicting VIH formation after abdominal surgery. Several studies have evaluated VIH risk after specific procedures, such as transplantation or cardiac surgery, but the applicability to other procedures is unknown.[7-9] Two recent prospective studies of patients undergoing elective and urgent abdominal surgery have identified risk factors for VIH after open abdominal surgery.[10,11] Itatsu and colleagues[10] followed more than 4,000 consecutive patients, while Veljkovik and associates[11] used a cohort of 603 patients to develop and validate a hernia risk scoring system equation. Both models included postoperative complications such as SSIs, which may limit their use preoperatively to counsel patients or to change perioperative management to modify risk. In addition, the generalizability of their findings is unknown because both studies were performed outside of the United States. For example, in the Itatsu and colleagues' study,[10] the mean body mass index (BMI) was 21.9 kg/m^2, which is less than the average BMI in the United States of 28.5 kg/m^2.[10,12] In Veljkovik and coauthors'study,[11] there was significant variation in use of prophylactic antibiotics due to lack of standardized protocols. Last, the 2 studies varied in follow-up time; the Itatsu study had a significantly longer follow-up than the Veljkovik study (median 17 months vs mean 6.9 months).[10,11] The optimal duration of follow-up for diagnosing VIH is controversial, but recommended follow-up is for at least 3 years.[13] Furthermore, inclusion of patients with less than 6 months of follow-up may bias the results if differential loss to follow-up occurred (ie, patients were lost because they developed a VIH and sought care elsewhere or patients were lost because they had no complications or ongoing issues). On the other hand, patients who develop a VIH within 6 months of surgery may have different risk factors.

The primary aim of this project was to develop and validate a predictive score for VIH after abdominal surgery. The secondary aims were to compare whether a score that includes postoperative complications such as SSI more accurately predicts VIH than one that does not; to assess whether the risk factors for VIH differ depending on the length of follow-up; and to determine whether the risk factors for fascial dehiscence (and early VIH formation) are the same as those for the overall cohort.

METHODS

After institutional review board approval, a prospective cohort study was performed of all consecutive patients undergoing abdominal operations, including elective and urgent or emergent cases, performed at a single institution between January 2008 and December 2010. Patients who underwent ventral hernia repair as the primary procedure, any closure reinforced by mesh, or any case in which the fascia was not closed were excluded. Because of a lack of consensus regarding the diagnosis of VIH, the primary outcome of VIH was considered to have occurred based on either clinical examination or radiographic imaging.[14] Secondary outcomes included fascial dehiscence, SSI, length of stay, and reoperation, which was defined as any procedure violating the abdominal fascia or peritoneal cavity performed in the operating room suite.

Patient demographics, comorbidities, and intraoperative data were collected. All comorbidities and complications were defined in accordance with the National Surgical Quality Improvement Project (NSQIP). Variables not used by NSQIP were defined as follows. Patients with a temporary abdominal closure were listed as "open abdomen," and the index operation was when their fascia was closed. Operative approach included purely laparoscopic surgery (all incisions <15 mm in size), hand-assisted laparoscopy including any laparoscopic surgery with an incision extending beyond 15 mm in size for hand placement or organ extraction, and laparotomy. Fascial incision type was classified as midline incision along the linea alba, any transverse fascial incision, and

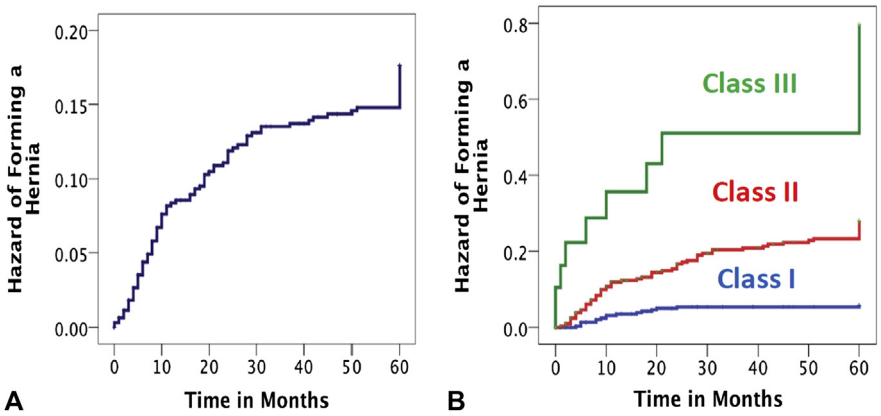


Figure 1. Kaplan-Meier curve of the hazard of ventral incisional hernia over time (A) of overall cohort and (B) of cohorts by HERNIAscore class. HERNIAscore = 4*Laparotomy + 3* hand-assisted laparoscopy + 1*COPD + 1*BMI $\geq$ 25 kg/m^2.

other, which included longitudinal paramedian incisions. Sutures were classified as fast-absorbable if the reported rate of complete absorption was less than 6 months (eg, polyglactin: Vicryl [Ethicon] or Polysorb [Covidien]), slow-absorbable if the reported rate of complete absorption was greater than 6 months (eg, polydioxanone: PDS [Ethicon] or Dexon [Covidien]), and permanent suture (eg, polypropylene: Prolene [Ethicon] or Surgilene [Coviden]). Closure technique was reported as running, interrupted, or other suturing techniques including mixed techniques.

Ventral incisional hernia was analyzed for the overall cohort using the Kaplan-Meier method. The overall cohort was then divided into development (2008 to 2009) and validation (2010) cohorts. The predictive model was based on the development cohort. Univariate analyses included unpaired *t*-test or Wilcoxon rank-sum test for continuous data and Fisher's exact test for categorical data. All preoperative and intraoperative variables were initially included for multivariable model development. A backward stepwise Cox regression, to adjust for follow-up duration and time to event, was performed to identify variables independently predictive of VIH. Hazard ratios (HRs) with 95% confidence intervals (95% CI) were generated. The proportionality of hazards was estimated graphically using log minus log survival curves. Variables with confidence intervals not crossing 1 and a p value <0.05 were considered statistically significant. Models were evaluated for interactions and colinearity.

Based on the final model, the HERNIAscore was developed by rounding the hazard ratios to the nearest integer minus 1.[15] The HERNIAscore was assessed on the validation cohort using a receiver operator characteristic curve (ROC). An area under the curve (AUC) $>$ 0.70 was considered a viable model. All patients in the development and validation cohorts were assigned a HERNIAscore, and actual rates of ventral incisional hernia were reported. Patients were classified into 3 groups based on similar rates of VIH formation. All statistical calculations were accomplished using SPSS (IBM Corp).

Sensitivity analyses were performed. A Cox regression model for VIH formation was created for the development cohort using preoperative, intraoperative, and postoperative variables (SSI); for all patients with 6 months or more of follow-up; for all patients with less than 6 months of follow-up; and for patients who developed a fascial dehiscence.

RESULTS

Overall cohort

The overall cohort included 625 patients with a median (range) follow-up of 41 months (0.3 to 64 months); 93 (13.9%) developed a VIH (Fig. 1A; Tables 1, 2, and 3). A CT scan was performed in 439 patients (70.2%); among these patients, 346 (78.8%) had no hernia by exam or CT, 59 (13.4%) had hernia by exam and CT, 14 (3.2%) had hernia by CT but not exam, and 20 (4.6%) had a hernia by exam but not CT ($p = 0.390$).

Development cohort

In the development cohort (n = 428), 70 (16.4%) patients were diagnosed with a VIH. Patients who developed VIH were more likely to be older, have an elevated American Society of Anesthesiologists (ASA) score, be diagnosed with COPD, undergo a longer operation, have an open laparotomy, have a midline incision, and have had permanent sutures used for fascial closure (Tables 1 and 2). No interactions were noted; in

Table 1. Demographics and Comorbidities

Variable	Overall cohort (n = 625)	Development cohort (n = 428)		
		Hernia (n = 70)	No hernia (n = 358)	p Value
Age, y, mean ± SD	60.8 ± 11.4	62.6 ± 9.11	60.3 ± 12.0	<0.001
Sex, male, n (%)	588 (94.1)	69 (98.6)	333 (93.0)	0.098
Ethnicity, white, n (%)	343 (54.9)	47 (67.1)	192 (53.6)	0.048
Functional status, n (%)				0.846
Independent	551 (88.2)	59 (84.3)	314 (87.7)	
Partially dependent	39 (6.2)	5 (7.1)	24 (6.7)	
Dependent	35 (5.6)	6 (8.6)	20 (56)	
ASA score, n (%)				0.040
1	12 (1.9)	0 (0)	11 (3.1)	
2	94 (15.0)	4 (5.7)	58 (16.2)	
3	395 (63.2)	47 (67.1)	221 (61.7)	
4	123 (19.7)	19 (27.1)	67 (18.7)	
5	1 (0.2)	0 (0)	1 (0.3)	
BMI, kg/m^2, mean ± SD	28.1 ± 5.7	28.7 ± 6.5	28.1 ± 5.6	0.418
Collagen vascular disorder, n (%)	30 (4.8)	4 (5.7)	20 (5.6)	1.000
Diabetes mellitus, n (%)	160 (25.6)	16 (22.9)	92 (25.7)	0.655
COPD, n (%)	83 (13.3)	19 (27.1)	35 (9.8)	<0.001
Hypertension, n (%)	430 (68.8)	51 (72.9)	246 (68.7)	0.571
Cardiovascular disease, n (%)	169 (27.0)	21 (30.0)	98 (27.4)	0.663
Liver disease, n (%)				
Any	86 (13.8)	7 (10.0)	53 (14.8)	0.350
Severe	25 (4.0)	2 (2.9)	14 (3.9)	1.000
Immunosuppression, n (%)	30 (4.8)	4 (5.7)	16 (4.5)	0.551
Active smoking, n (%)	215 (34.4)	19 (27.1)	121 (33.8)	0.330
Alcohol use disorder, n (%)	83 (13.3)	9 (12.8)	42 (11.7)	0.840
Hematocrit, %, mean ± SD	38.1 ± 6.0	36.6 ± 6.1	38.4 ± 5.9	0.022
Albumin, g/dL, mean ± SD	3.4 ± 0.7	3.2 ± 0.7	3.4 ± 0.7	0.120
Creatinine, mg/dL, mean ± SD	1.1 ± 0.7	1.1 ± 0.4	1.1 ± 0.8	0.487
Previous operation, median				
Yes, n (%)	295 (47.2)	36 (50.7)	160 (44.6)	0.359
Number (range)	0 (0–13)	1 (0–13)	0 (0–9)	0.266
History of SSI, n (%)	60 (9.6)	13 (18.3)	33 (9.2)	0.033
Open abdomen, n (%)	16 (2.6)	4 (5.7)	7 (2.0)	0.088

ASA, American Society of Anesthesiologist Score; SSI, surgical site infection.

particular, there was no interaction between COPD and immunosuppression. Patients who developed a VIH were more likely to have had an SSI at the time of the index abdominal surgery, have a longer length of hospital stay, and undergo another abdominal operation (Table 3).

Model development

The results of the Cox hazard model are reported in Table 4. The model was assessed for predictive accuracy on the validation cohort with an AUC of 0.77 (95% CI 0.68 to 0.86). The HERNIAscore and rates of VIH formation are reported in Table 5. The Kaplan-Meier curve demonstrates the rate of VIH formation over time for the 3 risk classes (Fig. 1B).

Sensitivity analyses

When postoperative variables were included in the Cox regression, SSI was strongly associated with VIH (Table 4). Compared with patients followed 6 months or more, patients followed for less than 6 months were older, more likely to be functionally dependent, have more comorbidities, previous abdominal operations and SSIs, undergo an emergency operation, have an open abdomen, have a contaminated surgical field, and develop an SSI. Evaluation of only patients who had at least of 6

Table 2. Operative Details

Variable	Overall cohort (n = 625)	Development cohort (n = 428)		
		Hernia (n = 70)	No hernia (n = 358)	p Value
Acute, n (%)	187 (29.9)	26 (37.1)	103 (28.8)	0.199
Operative service, n (%)				0.002
General	432 (69.1)	53 (75.7)	246 (68.7)	
Gynecology	10 (1.6)	0 (0)	8 (2.2)	
Plastic	1 (0.2)	1 (1.4)	0 (0)	
Thoracic	2 (0.3)	0 (0)	1 (0.3)	
Vascular	16 (2.6)	2 (2.9)	8 (2.2)	
Urology	164 (26.2)	4 (5.7)	95 (26.5)	
Operative duration, h, mean ± SD	3.6 ± 2.1	4.1 ± 2.5	3.5 ± 2.0	0.020
Transfusion				
Yes/no, n (%)	128 (20.5)	23 (32.9)	63 (17.6)	
Number, median (range)	0 (0−17)	0 (0−7)	0 (0−17)	
EBL, mL, median (range)	159 (5−7,000)	200 (10−3,000)	150 (5−7,000)	0.747
Operative approach, n (%)				<0.001
Open	220 (35.2)	37 (52.9)	112 (31.2)	
HAL	136 (21.8)	21 (30.0)	80 (22.3)	
Laparoscopic	269 (43.0)	12 (17.1)	166 (46.4)	
Fascial incision type, n (%)				<0.001
Midline	292 (46.7)	54 (77.1)	152 (42.5)	
Transverse	59 (9.4)	5 (7.1)	38 (10.6)	
Other	274 (43.8)	11 (15.7)	168 (46.9)	
Wound class, n (%)				0.373
1	75 (12.0)	9 (12.9)	39 (10.9)	
2	455 (72.8)	45 (64.3)	261 (72.9)	
3	50 (8.0)	7 (10.0)	32 (8.9)	
4	45 (7.2)	9 (12.9)	26 (7.3)	
Suture, n (%)				<0.001
Fast-absorbable	247 (39.5)	11 (15.7)	156 (43.6)	
Slow-absorbable	342 (54.7)	52 (74.3)	181 (50.6)	
Permanent	22 (3.5)	7 (10.0)	13 (3.6)	
Other	14 (2.2)	0 (0)	8 (2.2)	
Closure technique, n (%)				0.194
Running	385 (61.6)	46 (65.7)	212 (59.2)	
Interrupted	98 (15.7)	7 (10.0)	68 (19.0)	
Other	142 (22.7)	17 (24.3)	78 (21.8)	

EBL, estimated blood loss; HAL, hand-assisted laparoscopy.

months of follow-up (n = 583) did not change the model. In patients who had less than 6 months of follow-up (n = 42), only COPD was associated with VIH. Factors predictive of fascial dehiscence included incision type and closure of an open abdomen.

DISCUSSION

In this prospective study, a model to predict VIH after abdominal surgery was developed and validated. Three preoperative and intraoperative findings independently associated with VIH formation were identified: surgical approach (open laparotomy vs hand-assisted laparoscopy vs laparoscopy), COPD, and BMI $\geq$ 25 kg/m^2. In the lowest risk patients, the risk of developing a VIH was 5.5%; in the highest risk group more than half of all individuals developed a VIH. This risk score is straightforward to use, practical, and can be estimated preoperatively to determine a patient's risk of forming a VIH.

Although previous studies have evaluated risk factors for VIH after abdominal surgery, most would not be able to be used for preoperative counseling because of

Table 3. Outcomes and Follow-up Duration

Variable	Overall cohort (n = 625)	Development cohort (n = 428)		
		Hernia (n = 70)	No hernia (n = 358)	p Value
Ventral incisional hernia, n (%)	93 (13.9)	—	—	—
Fascial dehiscence, n (%)	19 (3.0)	13 (18.3)	—	—
Surgical site infection n (%)	51 (11.6)	15 (31.9)	19 (8.4)	<0.001
Length of stay, d, median (range)	6 (0–384)	9 (2–64)	5 (0–147)	<0.001
Reoperation abdominal, n (%)	120 (19.2)	36 (51.4)	43 (12.0)	<0.001
Follow-up duration, mo, median (range)	41 (0.25–64)	48 (1–58)	46 (0.25–64)	0.412

the inclusion of postoperative complications (such as SSI) or interventions (such as time to suture removal) in the predictive model.[7-12,16,17] In addition, many studies evaluated only a single operation type. The applicability of these studies to other procedure types or for use in preoperative planning is limited. The HERNIAscore was derived from abdominal operations performed in multiple subspecialties and can potentially be applied in the preoperative period to a wide variety of abdominal procedures. Furthermore, although surgical approach is an intraoperative factor, the final operative approach did not differ from the planned preoperative approach in 99% of cases.

Laparoscopy was associated with a decreased incidence of VIH compared with laparotomy or hand-port assisted surgery. On univariate analysis, fascial incision type (transverse 11.6%, midline 26.2%, and paramedian 6.1%) and suture type used (fast-absorbable 6.6%, slow-absorbable 22.3%, permanent 35.0%) were strongly associated with VIH formation. Midline incisions, compared with transverse or paramedian incisions, have been shown to increase the risk of VIH.[11,18] However, for open surgery, midline incisions have gained widespread adoption due to relative ease of use as well as flexibility in accessing all areas of the peritoneal cavity. In addition, paramedian and transverse incisions may be associated with defunctionalizing the abdomen by dividing the perforating nerves. Although fast-absorbable sutures have been shown to increase the risk of VIH in other studies, in this study, closure with this suture type had the lowest rate of VIH on univariate analysis.[19,20] This is likely related to selection bias, with laparoscopic port sites being closed with fast absorbable sutures while high-risk incisions may be closed with permanent sutures. The technique that had the greatest impact on outcomes was the use of smaller incisions, in particular, laparoscopic incisions <15 mm in size.[16,17] The impact of fascial incision type and suture type may have been mitigated through the increasing use of laparoscopy. One final factor of importance that was not included in this analysis is the use of small bites (0.5 × 0.5 cm) vs large bites (1.0 × 1.0 cm). Small bites have been shown to decrease SSI rates and VIH rates.[21,22] However, in both studies, the patient populations had mean BMI < 25 kg/m^2, and the benefit of small bites in an obese patient population remains to be evaluated.

Other studies have found age, sex, immunosuppression, diabetes, and wound class to be risk factors for VIH formation. Surprisingly, COPD was either not reported or not associated with VIH in these studies. The association in this study between COPD and VIH and fascial dehiscence may be related to a higher prevalence of COPD in veterans. Nonetheless, COPD is a biologically plausible

Table 4. Multivariable Cox Regression Analyses: Main Analysis of Development Cohort and Sensitivity Analysis

	Main analysis Development cohort (n = 428)		Sensitivity analyses							
			Including SSI (n = 428)		>6-mo follow-up (n = 583)		<6-mo follow-up (n = 42)		Fascial dehiscence (n = 625)	
Variable	HR	95% CI	HR	95% CI	HR	95%CI	HR	95% CI	HR	95% CI
COPD	2.35	1.44–3.83	2.53	1.55–4.13	2.8	1.54–5.09	3.72	1.27–10.87	—	—
Laparoscopic								—		
HAL	4.00	2.08–7.70	3.42	1.78–6.61	4.34	2.15–8.75	—	—	7.35	0.82–66.14
Laparotomy	4.77	2.61–8.70	3.69	2.00–6.83	5.48	2.89–10.39	—	—	12.83	1.64–100.50
BMI ≥ 25 kg/m^2	1.74	1.04–2.91	—	—	1.84	1.04–3.27	—	—	—	—
SSI	—	—	2.44	1.51–3.94	—	—	—	—	—	—
Open abdomen	—	—	—	—	—	—	—	—	4.01	1.22–13.13
AUC	0.77	0.68–0.86	0.80	0.71–0.90	—	—	—	—	—	—

AUC, area under the curve; HAL, hand-assisted laparoscopy; SSI, surgical site infection.

Table 5. Predictive Score for and Actual Rates of Ventral Incisional Hernia after Abdominal Surgery

	Risk of hernia formation based on HERNIAscore points*		
Cohort	**Class I (0–3 points)**	**Class II (4–5 points)**	**Class III (6 points)**
Development cohort (n = 428), n (%)	14 (6.8)	48 (23.2)	8 (50.0)
Validation cohort (n = 197), n (%)	2 (2.0)	18 (19.6)	3 (75.0)
Overall cohort (n = 625), n (%)	16 (5.2)	66 (22.1)	11 (55.0)

*HERNIAscore = 4*Laparotomy + 3* hand-assisted laparoscopy + 1*COPD + 1*BMI $\geq$ 25 kg/m^2. Points based on hazard ratios rounded to the nearest integer minus 1.

risk factor and is known to be associated with VIH and VIH recurrence.[23] There may be a role for COPD through 2 mechanisms: increasing intra-abdominal pressure through cough and weakening of the tissues through an underlying collagen disorder. Immunosuppression due to steroid treatment could be an additional contributing factor; however, in this study, there was no difference in steroid use between patients with and without a VIH, and there was no interaction between steroids and COPD.

Overweight, defined as a BMI $\geq$ 25 kg/m^2, has been correlated to VIH in this study as well as in numerous other studies. Body mass index has been correlated with the presence of a VIH as well as the risk of VIH incarceration.[24] Increased intra-abdominal pressure and changes of the abdominal wall configuration (from a vertical linear structure to a circular structure) may explain the strong association of BMI and VIH. Unlike other prospective studies predicting VIH after abdominal surgery, this study assessed a patient population with a higher mean BMI, seen in communities consuming a largely Westernized diet.

A number of other factors with potential biologic plausibility and evidence from other studies were found to be significant on univariate analysis but not on the final Cox regression multivariate analysis: American Society of Anesthesiologists score, diabetes mellitus, anemia, hypoalbuminemia, history of SSI, current open abdomen, and operative duration. Reasons for the lack of significance may include careful patient selection, optimization of patient comorbidities preoperatively, or VIH risk reduction with operative strategies such as use of laparoscopy. In addition, given the number of hernias in the development cohort, the large number of variables, and the relative rarity of certain comorbidities, factors identified in other studies to be associated with VIH (ie, preoperative chemotherapy or blood transfusions) may not have been statistically significant in this model.

In this study, a sensitivity analysis identified SSI to be associated with VIH (Table 4). Although the predictive accuracy of the model including SSI was no better than the HERNIAscore, the model is consistent with previous literature identifying SSI as a risk factor for VIH formation after abdominal surgery. These studies differ from this one in terms of lack of routine perioperative protocols to prevent SSIs such as antibiotic prophylaxis[11] or low incidence of risk factors such as being overweight.[10] In addition, SSI and VIH share common risk factors such as incision size and BMI. Further study is necessary to determine what the optimal strategies are for prevention of VIHs: optimization of preoperative comorbidities, prevention of SSIs, or both.

Preoperative risk reduction, patient selection, and intraoperative choices may help to decrease VIH rates. Weight loss programs, nutritional optimization, and decreasing the prevalence of smoking in communities may help decrease rates of VIH. Increasing use of laparoscopic surgery, particularly avoiding increasing incisions to more than 15 mm may have an impact on lowering VIH rates. In cases in which open surgery or larger incisions are warranted, reinforcement of the incision line with mesh remains an intriguing option. Studies assessing the role of incision reinforcement with stoma formation, the morbidly obese, and with laparoscopic cholecystectomy have been demonstrated to improve outcomes in randomized controlled trials.[25] However, concern remains for prosthetic infection, particularly in the face of contamination.[26] Additional study is needed on the effectiveness of prosthetic incisional reinforcement.

There are a number of limitations to this study. First, this model was based on a veteran population treated at a single tertiary-referral, academic teaching institution. Therefore, the higher incidence of COPD, the low rate of conversion from laparoscopic to open surgery, and the use of standardized perioperative SSI prevention protocols may reduce the generalizability of these results. Second, there may have been misclassification of the primary outcome and intraoperative factors such as wound classification[27,28] or under-diagnosis of comorbidities. There is no gold standard for the diagnosis of ventral hernias. Clinical examination is potentially subject to underdiagnosis, can vary widely between clinicians, and is affected by patient factors such as obesity.[14] Radiographic imaging has been shown to have significant inter-observer variability.[4] Even patient-reported results are inaccurate, with up to one-third of patients unaware that they have a VIH.[3] Consensus is needed to identify a clinically

relevant and standardized method of reporting the presence and absence of a ventral hernia. Third, follow-up duration was variable and some patients had limited follow-up. Although less than 10% of patients had less than 6 months of follow-up, differential loss to follow-up cannot be excluded. In addition, the Cox regression adjusted for follow-up and sensitivity analysis demonstrated no substantial difference in including or excluding those patients with less than 6 months of follow-up. Last, a number of factors that have been shown to be clinically important in postoperative VIH risk were not included, such as suture bite size.

CONCLUSIONS

Ventral incisional hernia after abdominal surgery is common and the HERNIAscore allows simple, accurate preoperative risk assessment. The HERNIAscore is based on surgical approach, COPD, and obesity:

$$\text{HERNIAscore} = 4 * \text{laparotomy} + 3 * \text{HAL} + 1 * \text{COPD} + 1 * \text{BMI} \geq 25\ \text{kg/m}^2.$$

Although further external validation is required, the HERNIAscore offers clinicians and patients a starting point for discussion of risks of surgery, risk-assessment, and potential interventions to decrease the risk for VIH formation. Prospective trials are needed to further validate this score and to assess whether changes in perioperative management can prevent hernias.

Author Contributions

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Discussion

DR TODD HENIFORD (Charlotte, NC): This paper described a risk stratification score to predict the development of eventual incisional hernias in surgical patients. The authors are well known for their germane and significant additions to the surgical literature, and I believe that this paper will continue that trend.

I accept as true that large databases with complete and unbiased data and appropriate statistical modeling can significantly help us to plan surgery, make choices in the operating room, identify outlier practices and outcomes, save money, educate our patients, and, in this case, possibly consider additional operative procedures during a good first operation to prevent the need for future surgery. In this case, we may be able to prevent a ventral hernia repair later.

The data they have presented are clinically strong and include hundreds of patients and variables. The data have been appropriately vetted, and the subsequent formula they have chosen for their hernia score is simple and easily applied in the clinical setting.

I have a number of questions for the authors. First, the study was performed at a Veterans Administration (VA) hospital, and the patient population is approximately 95% male. Previous studies in hernia repair that have been performed at the VA have been criticized for their lack of seasoned attending surgeon participation. Indeed, in one of the most famous papers, recurrence rates were directly linked to the level of the most senior resident in the procedure. I would like to know if there was a requirement for the attending surgeon to be present at closure. Did the level of the senior-most resident involved in the operation play a role in the actual ventral hernia formation rate? Did you examine this statistically?

Furthermore, this VA study included only 37 women out of more than 600 patients. Is it truly a model that is applicable to females? Should the females have been excluded from the study, and should this be called the "male hernia score"?

Many studies have shown that the risk of wound issues in abdominal hernias increases with body mass index. Did you see this in your data? If you did, why did you choose a BMI $\geq$ 25 kg/m^2? Why not stairstep it, increasing points for 30, 35, 40 kg/m^2, or greater than that?

In the model, you included a large number of laparoscopic procedures. Actually, 43% of the operations in this study were laparoscopic. Did they skew the data? How did you count these patients? You described incisions that are both horizontal and up and down and how they affected recurrence. Are the laparoscopic procedures included? Also, in the closure of the abdomen, you described a simple closure vs running closure and size of the bite of fascia. How did 43% of those patients affect that outcome?

It appeared that all factors were put into the predictive model. Would it have been more appropriate to develop a predictive model only using factors that were significant in univariate analysis? Did you use all factors in the model and then perform backwards elimination?

Last, of the 625 patients in the overall cohort, there were only 6 patients who had a score of 6. And of those 20 patients, 11 of them formed a ventral hernia. Are 20 patients enough for us to base any future surgery that we might perform? If someone has a score of 6 with 55% ventral hernia rate, should they have mesh placed at that initial operation or does this need further study?

DR BRYAN RICHMOND (Charleston, WV): The authors present a series of 625 abdominal surgery patients prospectively followed for development of ventral incisional hernia. Variables that have been previously described in the literature as risk factors for ventral hernia development were examined via univariate and multivariate analysis with a Cox proportional hazard model. A scoring system to predict the occurrence of ventral hernia was then developed by generating receiver operating characteristic curves, with the goal of identifying practices or patient risk factors that could be modified so that ventral hernia rates could be reduced below the 15% to 20% incidence that we commonly see.

Four preoperative factors emerged in their model and were included in the scoring system: laparotomy or hand assist approaches, COPD, and BMI $\geq$ 25 kg/m^2. The scoring system, the HERNIA score, provides a simple method for predicting the occurrence of ventral hernia in the at-risk patient. Once again, it represents a tremendous achievement on the part of the authors.

That said, I have 2 questions I would like to pose.

1. The gestalt of the paper seems to be, once again, to predict the risk of the occurrence of ventral hernia so steps can be taken to prevent ventral hernia in the highest risk patients. Laparotomy carries with it the highest risk, 4 points, and in your model alone would predict a ventral hernia rate of greater than 20%.

   With additional risk factors added, the risk increases to 50% at 6 points. It's logical to continue to press the envelope with minimally invasive approaches to limit the number of laparotomies in the interest of ventral hernia risk reduction,