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# Impact of modifiable comorbidities on 30-day wound morbidity after open incisional hernia repair

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ABSTRACT

*Background:* We aimed to assess the impact of modifiable comorbidities—obesity, diabetes, and smoking—and their aggregate effect on wound complications after incisional hernia repair.
*Methods:* Data on all open, elective, incisional hernia repair with permanent synthetic mesh in clean wounds were collected from the Americas Hernia Society Quality Collaborative and reviewed. Three groups were defined: those with 0, 1, or 2+ modifiable comorbidities, with associations described for each specific comorbid condition. Primary outcomes included surgical site occurrences, surgical site infections, and surgical site occurrences requiring procedural intervention.
*Results:* A total of 3,908 subjects met the inclusion criteria. Mean hernia width was 9.6 ± 6.5 cm, mean body mass index was 32.1 ± 6.6 kg/m$^2$, 21% of patients had diabetes, and 9% were smokers. Of those, 31% had no modifiable comorbidities, 49% had 1 modifiable comorbidity, and 20% had 2+ modifiable comorbidities. Compared with having no modifiable comorbidities, having 1 modifiable comorbidity, or 2+ modifiable comorbidities significantly increased the odds of a surgical site occurrence (odds ratios 1.33 and 1.61, respectively). However, only patients with 2+ modifiable comorbidities had significantly increased odds of surgical site occurrences requiring procedural intervention compared with no modifiable comorbidities and 1 modifiable comorbidity (odds ratios 2.02 and 1.65, respectively). Patients with all 3 comorbidities had a two-fold increase in odds for all wound morbidity, followed similarly by obese patients with diabetes.
*Conclusion:* The presence of any number of comorbidities (1 modifiable comorbidity or 2+ modifiable comorbidities) increases the odds for wound events. However, having multiple comorbidities was associated with more procedural interventions for wound management. This was most evident in patients with all 3 comorbidities, and, in obese diabetics, underscoring the importance of preoperative counseling on expected recovery in such patients.



## Introduction

A central outcome measure in a vast number of hernia repair studies is wound morbidity, with multiple risk factors identified. Patient-centered risk factors known to increase wound morbidity in hernia surgery are smoking, obesity, chronic obstructive pulmonary disease (COPD), and diabetes.[1,2] Such high-risk patients are considered “comorbid” (grade 2) according to the modified Ventral Hernia Working Group (VHWG) classification, with an expected surgical site occurrence (SSO) rate of 27% compared with 14% in grade 1 patients without comorbidities.[3] In addition, these patient-centered variables have been used to develop tools to stratify the risk of postoperative wound morbidity.[4]

The relationship between each modifiable comorbidity ([MCM] obesity, smoking, and diabetes) and wound morbidity after hernia repair has been of particular interest because of potential for preoperative optimization.[5] Recently, Cox et al[6] studied the financial burden of hernia repair in these patients and found that those with MCMs, with or without complications, had significantly increased total hospital charges compared with the single comorbidity or no comorbidity groups. This study reiterated the importance of

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investigating and discussing the methods of preoperative optimization for this challenging patient population.

Although the association between each MCM and wound morbidity has been investigated,[7–12] the compounding impact of MCMs has not been thoroughly described. In this study, we aim to delineate the effect of each MCM on postoperative wound events and their aggregate effect in patients with multiple MCMs. In addition, we aimed to identify which permutation of comorbid conditions account for the strongest association. We hypothesize that patients with all three comorbidities will have the highest odds for developing wound events.

## Methods

### *Data collection and study design*

After obtaining exemption from the institutional review board (Cleveland Clinic Foundation, Cleveland, OH), all open elective incisional hernia repairs were identified within the Americas Hernia Society Quality Collaborative (AHSQC) registry. The AHSQC is a nationwide hernia-specific registry designed to improve hernia care using real-time continuous quality-improvement principles. At the time of this study, AHSQC had data available from 258 surgeons practicing in a variety of clinical settings including academic, community, and affiliated hospitals. The registry component of the AHSQC contains predetermined standardized definitions for data collection in the preoperative, intraoperative, and postoperative phases of hernia care. Details regarding the AHSQC and registry structure, governance, and data assurance process have been reported elsewhere.[13]

All open, elective, incisional hernia repairs recorded in the AHSQC between 2013 and 2017 were queried. We only included hernia repairs with permanent synthetic mesh. Patients with parastomal hernias, primary hernias, and an existing stoma were excluded from the analysis, as were all contaminated and dirty wound classes. Figure 1 depicts the inclusion and exclusion criteria for identifying the study population.

Analysis of the prospectively collected data was conducted with all relevant variables analyzed. These included demographics, preoperative evaluation, intraoperative details, and postoperative wound outcomes.

### *MCMs*

MCMs were defined as any comorbidity that has the potential to be optimized before a hernia repair and is currently identified by the modified VHWG grading scale as a risk factor for increased rates of wound events.[3] The 3 comorbidities that were considered for this study are as follows: obesity, diabetes, and smoking. Obesity was defined as body mass index (BMI) $\geq$ 30 kg/m$^2$ in accordance with the World Health Organization (WHO) classification.[14] Diabetes is defined by the AHSQC as patients who are being treated for diabetes mellitus or those patients who have HbA1c $\geq$ 6.5%, fasting plasma glucose $\geq$ 126 mg/dl, or random glucose $\geq$ 200 mg\dl. Current smokers are defined by the AHSQC as those who have smoked within 30 days of surgery.

The main study population was divided into three comparison arms as follows:

- The No MCM group included patients who were nonsmokers, nondiabetics, and having a BMI < 30 kg/m$^2$.
- The 1 MCM group included patients that have only one comorbidity—smokers, diabetics, or obesity.
- The 2+ MCM group of patients had two or more MCMs—obese diabetics, obese smokers, diabetic smokers, or patients with all three comorbidities.

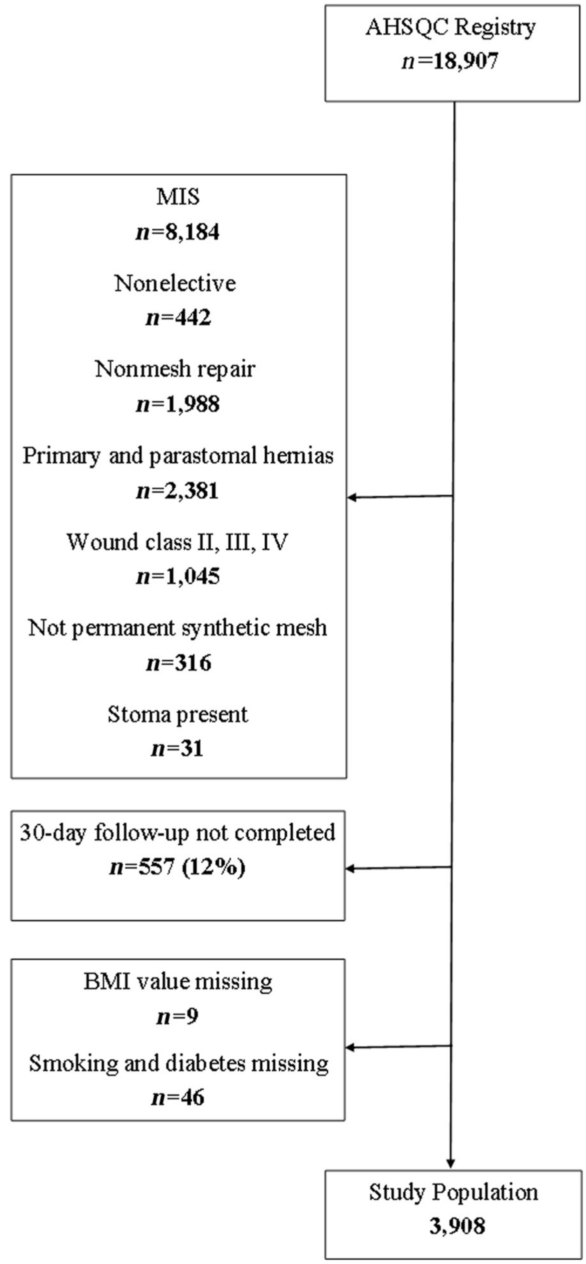


**Fig 1.** Inclusion and exclusion criteria.

### *Outcomes of interest*

Our main outcomes of interest were 30-day wound events, which include surgical site infection (SSI), SSO, and SSO requiring procedural intervention (SSOPI).[15] SSI was defined according to the Centers for Disease Control and Prevention classifications as superficial, deep, or organ space.[16] SSO included any SSI in addition to wound cellulitis, nonhealing incisional wound, fascial disruption, skin or soft tissue ischemia or necrosis, wound serous drainage, chronic sinus drainage, localized stab wound infection, seroma, hematoma, exposed synthetic mesh, or enterocutaneous fistula. Procedural interventions to be considered SSOPI included SSOs that required wound opening, wound debridement, suture excision, percutaneous drainage, partial mesh removal, or complete mesh removal. The follow-up period was 30 days.

**Table I**
Demographic, hernia, and operative characteristics for main groups*

| | *N* | No MCM $N = 1{,}220$ | 1 MCM $N = 1{,}925$ | 2+ MCM $N = 763$ | Combined $N = 3{,}908$ | Test statistic |
|---|---|---|---|---|---|---|
| Age (median [Q1-Q3]) | 3,908 | 62 [51–70] | 57 [47–66] | 58 [50–66] | 59 [49–67] | $P < .001$† |
| Gender | 3,908 | | | | | $P = .015$‡ |
| Female | | 51% (621) | 53% (1,022) | 58% (439) | 53% (2,082) | |
| Male | | 49% (599) | 47% (903) | 42% (324) | 47% (1,826) | |
| BMI (mean ± SD) | 3,908 | 26.2 ± 2.7 | 34.1 ± 5.9 | 36.6 ± 5.9 | 32.1 ± 6.6 | $P < .001$§ |
| ASA class | 3,907 | | | | | $P < .001$‡ |
| 1 | | 6% (79) | 3% (50) | 1% (7) | 3% (136) | |
| 2 | | 48% (581) | 40% (770) | 24% (185) | 39% (1,536) | |
| 3 | | 43% (523) | 55% (1,058) | 71% (538) | 54% (2,119) | |
| 4 | | 3% (37) | 2% (46) | 4% (33) | 3% (116) | |
| Immunosuppressants | 3,908 | 7% (85) | 6% (115) | 4% (33) | 6% (233) | $P = .054$‡ |
| COPD | 3,908 | 5% (64) | 6% (125) | 13% (99) | 7% (288) | $P < .001$‡ |
| Hernia width (mean ± SD) | 3,908 | 8.2 ± 5.5 | 10.0 ± 6.5 | 10.7 ± 7.3 | 9.6 ± 6.5 | $P < .001$§ |
| Hernia area (mean ± SD) | 3,908 | 102.7 ±116.7 | 146.6 ± 160.4 | 167.3 ± 204.6 | 137 ± 160.3 | $P < .001$§ |
| Mesh area (mean ± SD) | 3,897 | 532.2 ± 503.4 | 699.7 ± 648.8 | 765.4 ± 703.6 | 660.2 ± 625.2 | $P < .001$§ |
| Recurrent hernia | 3,908 | 32% (387) | 45% (864) | 48% (365) | 41% (1616) | $P < .001$‡ |
| Number of earlier hernia repairs | 1,614 | | | | | $P = .002$‡ |
| 1 | | 58% (222) | 50% (428) | 43% (158) | 50% (808) | |
| 2 | | 25% (95) | 27% (232) | 27% (97) | 26% (424) | |
| 3 | | 7% (28) | 11% (96) | 13% (49) | 11% (173) | |
| 4 | | 6% (24) | 5% (44) | 9% (32) | 6% (100) | |
| 5 | | 4% (17) | 7% (64) | 8% (28) | 7% (109) | |
| History of abdominal wall SSI | 3,908 | 15% (184) | 19% (360) | 20% (156) | 18% (700) | $P = .005$‡ |
| History of prosthetic mesh infection | 662 | 18% (30) | 30% (101) | 34% (51) | 27% (182) | $P = .002$‡ |
| Infected mesh removed | 182 | 93% (28) | 91% (92) | 98% (50) | 93% (170) | $P = .26$‡ |
| Mesh position | 3,908 | | | | | $P = .048$‡ |
| Inlay | | 4% (43) | 4% (70) | 3% (26) | 4% (139) | |
| Onlay | | 12% (146) | 10% (185) | 8% (60) | 10% (391) | |
| Sublay | | 85% (1,031) | 87% (1,670) | 89% (677) | 86% (3,378) | |
| Open intraperitoneal sublay | 3,908 | 11% (132) | 10% (192) | 10% (79) | 10% (403) | $P = .75$‡ |
| Myofascial release | 3,908 | 61% (741) | 68% (1,317) | 68% (520) | 66% (2,578) | $P = .001$‡ |
| Myofascial release approach | 1,956 | | | | | $P = .068$‡ |
| Rives-Stoppa | | 46% (255) | 39% (391) | 41% (160) | 41% (806) | |
| Transversus abdominis release | | 50% (276) | 57% (576) | 55% (214) | 54% (1,066) | |
| Anterior component separation | | 4% (21) | 5% (47) | 4% (16) | 4% (84) | |
| Subcutaneous flaps raised | 3,908 | 31% (376) | 30% (584) | 32% (243) | 31% (1,203) | $P = .75$‡ |
| Drains used | 3,908 | 69% (841) | 77% (1,479) | 76% (578) | 74% (2,898) | $P = .001$‡ |
| OR time > 2 h | 3,908 | 58% (705) | 70% (1,346) | 75% (574) | 67% (2,625) | $P < .001$‡ |

* *N* is the number of nonmissing values. Numbers after proportions are frequencies.
† Kruskal-Wallis test.
‡ Pearson test.
§ Analysis of variance test.

*Statistical analysis*

Data were reported as numbers and percentages for categorical variables and means, standard deviation, medians, and interquartile ranges (IQRs) for continuous variables where appropriate. A total of 9 (0.2%) patients had missing BMI values and were excluded from the study. A total of 46 (1.2%) patients had missing diabetes and smoking values, which excluded them from the analysis. Univariate analysis compared all 3 major groups using the Pearson $\chi^2$ test for categorical variables, the Fisher exact test for zero counts, and the Kruskal-Wallis test or analysis of variance for continuous variables. Pertinent variables and statistically significant differences shown on univariate analysis were chosen to build 3 multivariable logistic regression models evaluating each of the 3 classes of wound events (SSI, SSO, and SSOPI). Each comorbid group (1 MCM and 2+ MCM) was compared with the no MCM group. The 2+ MCM group was also compared with the 1 MCM group. The two comorbid groups (1 MCM and 2+ MCM) were then subdivided into all possible scenarios as follows: (1) 1 MCM: smokers, patients with diabetes, and patients with obesity; and (2) 2+MCM group: obese smokers, smokers with diabetes, obese patients with diabetes, and obese smokers with diabetes. To evaluate the separate influence of the aforementioned scenarios, a post hoc multivariable logistic regression was then built for all wound events (SSO, SSI, SSOPI), comparing each comorbid possibility with the no MCM group. Statistical analysis was conducted using R: The R Project for Statistical Computing 3.4.3.

## Results

*Demographics, comorbidities, and intraoperative details*

A total of 3,908 patients met inclusion criteria. Of those, 31% (1,220) had no MCM, 49% (1,925) had only 1 MCM, and 20% (763) had 2+ MCM. Univariate comparisons on patient demographics, clinical and hernia characteristics, and operative details are presented in Table I. The mean BMI for the entire population was 32.1 ± 6.6 kg/$m^2$, with the 2+ MCM having a higher BMI than the other 2 groups (36.6 ± 5.9 kg/m2 in 2+ MCM, compared with 26.2 ± 2.7 kg/$m^2$ in no MCM and 34.1 ± 5.9 kg/$m^2$ in 1 MCM; $P < .001$). Mean hernia width was 9.6 ± 6.5 cm for the entire cohort, with a significant difference between the 3 groups (8.2 ± 5.5 cm in no MCM, 10 ± 6.5 cm in 1 MCM, 10.7 ± 7.3 in 2+ MCM; $P < .001$). Patients with 2+ MCM were more prone to having chronic obstructive pulmonary disease (13% vs 5% in no MCM and 6% in 1 MCM, $P < .001$). In addition, in patients with a history of SSI, both the 2+ MCM and 1 MCM groups were more likely to have had a mesh infection (34% and 30%, respectively versus 18% in no MCM, $P = .002$). The overall

**Table II**
Distribution of comorbidities between the two comorbid groups

| | 1 MCM N = 1,925 | 2+ MCM N = 763 |
|---|---|---|
| Obesity | 82% (1,587) | 97% (740) |
| Diabetes | 10% (196) | 80% (612) |
| Smoking | 7% (142) | 29% (222) |
| BMI (mean ± SD) | 34.1 ± 5.9 | 36.6 ± 5.9 |

characteristics show a trend of increasing complexity with increasing comorbidities. Table II outlines the distribution of comorbidities between the 2 comorbid groups (1 MCM and 2+ MCM).

In this cohort, myofascial release was performed in 66% of cases, 41% using a release of the posterior rectus sheath, and 54% using a transversus abdominis release. Mesh was placed in the sublay position in 86% of cases, with 10% of cases being an intraperitoneal sublay.

### *Postoperative outcomes*

#### *SSOs*

We observed a significant difference in the incidence of all wound morbidity between the 3 major groups, with 18% incidence of complications in the 2 +MCM group, 14% in the 1 MCM group, and 10% in the no MCM group ($P < .001$). Most reported noninfectious SSOs were seromas (32%), followed by wound cellulitis (16%) and wound serous drainage (12%).

On multivariable logistic regression, the presence of any comorbidity, whether solely (1 MCM) or combined (2+ MCM), was associated with a significant increased odds of developing an SSO (odds ratio [OR] 1.3, OR 1.6, respectively). However, there was no significant difference in odds between having 2+ MCMs and having only 1 MCM (OR 1.2, $P = .1$). Table III presents a summary of analyses for the development of SSO.

On post hoc multivariable logistic regression, each of the 2 major comorbid groups were subdivided to include all possible comorbid combinations. Each individual possibility was then compared individually with the no MCM group. In the 1 MCM group, obesity was the only comorbidity significantly associated with increased odds for SSO (OR 1.3). In the 2+ MCM group, an obese diabetic and obese diabetic smoker were significantly associated with increased odds for SSO (OR 1.6, and OR 1.8, respectively). Figure 2 illustrates all post hoc logistic regression relationships.

#### *SSIs*

Table IV provides a summary of analyses for the developement of an SSI. On univariate analysis, a significant difference in SSI incidence between the 3 major groups was found, with a 6% rate in the 2+ MCM group, a 4% rate in the 1 MCM group, and a 2% rate in the no MCM group ($P < .001$). No significant differences in the type of reported SSIs were found. Most infections were classified as superficial (77%), and deep infections were reported in 24% of cases, and organ space infections in 1%. We observed only 6 infected synthetic meshes reported in the entire cohort—3 in the 1MCM group and 3 in the 2+ MCM group. Other infectious SSOs are reported in Table III.

**Table III**
Surgical site occurrence (SSO) analysis

Univariate analysis

| | No MCM (n = 1,220) | 1 MCM (n = 1,925) | 2+ MCM (n = 763) | Combined (n = 3,908) | P value |
|---|---|---|---|---|---|
| SSO | 10% (124) | 14% (277) | 18% (137) | 14% (538) | **< .001**[*] |
| Seroma | 35% (44) | 31% (86) | 31% (43) | 32% (173) | .72[*] |
| Wound cellulitis | 17% (21) | 18% (50) | 9% (13) | 16% (84) | .1[*] |
| Wound serous drainage | 10% (13) | 13% (37) | 12% (17) | 12% (67) | .67[*] |
| Nonhealing incisional wound | 3% (4) | 8% (23) | 12% (17) | 8% (44) | **.014**[*] |
| Hematoma | 10% (13) | 8% (21) | 2% (3) | 7% (37) | **.033**[*] |
| Fascial disruption | 0% (0) | 0% (1) | 1% (1) | 0% (2) | .73[†] |
| Exposed synthetic mesh | 1% (1) | 1% (4) | 2% (3) | 1% (8) | .6[*] |
| Skin of soft tissue ischemia | 4% (5) | 2% (6) | 6% (8) | 4% (19) | .12[*] |
| Skin of soft tissue necrosis | 2% (3) | 5% (14) | 7% (9) | 5% (26) | .23[*] |
| Localized stab wound infection | 1% (1) | 0% (1) | 0% (0) | 0% (2) | .48[†] |
| Stitch abscess | 1% (1) | 0% (0) | 0% (0) | 0% (1) | .24[†] |
| Enterocutaneous fistula | 0% (0) | 0% (0) | 1% (1) | 0% (1) | .48[†] |
| Infected synthetic mesh | 0% (0) | 1% (3) | 2% (3) | 1% (6) | .21[†] |
| Contaminated synthetic mesh | 1% (1) | 0% (0) | 1% (1) | 0% (2) | .23[†] |
| Infected hematoma | 0% (0) | 0% (1) | 1% (1) | 0% (2) | .73[†] |
| Infected seroma | 3% (4) | 2% (6) | 5% (7) | 3% (17) | .22[*] |
| Wound purulent discharge | 2% (3) | 3% (8) | 1% (2) | 2% (13) | .71[*] |

Multivariable logistic regression[‡]

| Variable | Odds ratio | CI 95% | P value |
|---|---|---|---|
| 1 MCM:No MCM | 1.328 | 1.052–1.677 | **.0172** |
| 2+ MCM:No MCM | 1.610 | 1.220–2.125 | **.0008** |
| 2+ MCM:1 MCM | 1.213 | 0.962–1.529 | .1027 |
| Hernia width Q3:Q1 (13:5) | 1.226 | 1.072–1.402 | .0029 |
| Immunosuppressants | 1.744 | 1.236–2.461 | .0015 |
| History of abdominal wall SSI | 1.498 | 1.160–1.934 | .0020 |
| Myofascial release | 0.671 | 0.515–0.875 | .0032 |
| OR time > 2 h | 1.443 | 1.079–1.930 | .0133 |
| Subcutaneous flaps raised | 1.378 | 1.110–1.710 | .0036 |

[*] Pearson test.
[†] Fisher exact test.
[‡] Age, gender, ASA class, COPD, history of recurrence, the use of drains, earlier prosthetic mesh infection, and mesh location were included in the model but did not reach statistical significance.

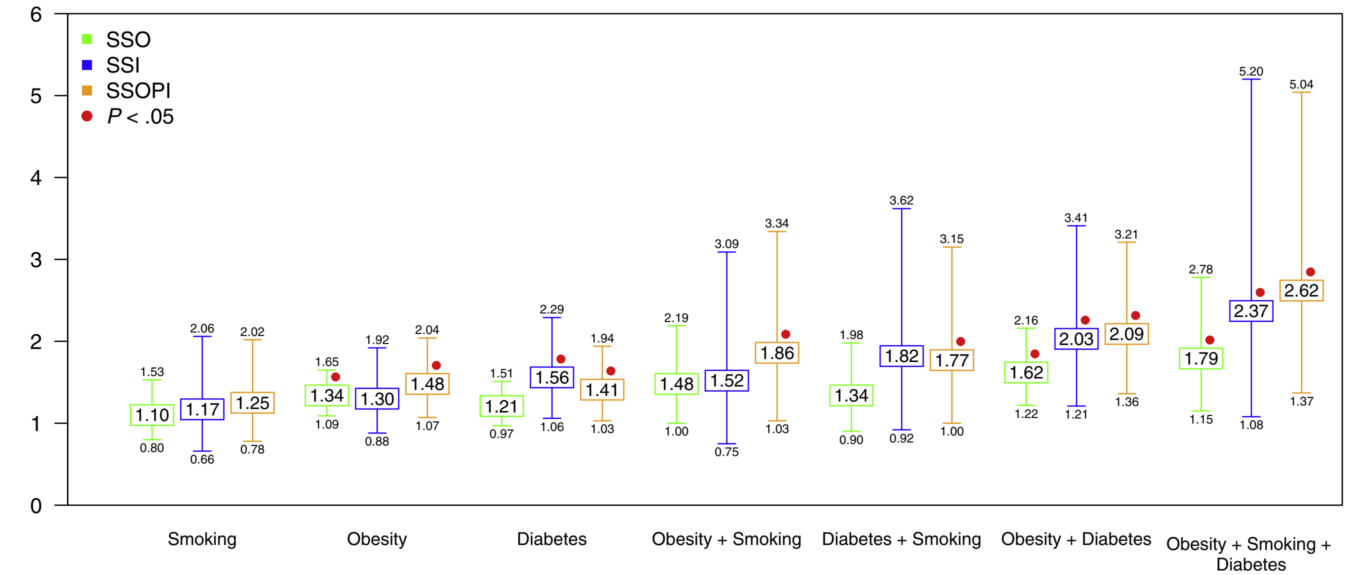


**Fig 2.** Post-hoc multivariable logistic regression as compared with no MCM.* *After adjusting age, gender, ASA class, immunosuppressants, chronic obstructive pulmonary disease, hernia width, recurrent, history of abdominal wall SSI, myofascial release, drains used, OR time > 2 h, before prosthetic mesh infection, mesh location, subcutaneous aps raised.

**Table IV**
Surgical site infections (SSI) analysis

Univariate analysis

| | No MCM ($n$ = 1,220) | 1 MCM ($n$ = 1,925) | 2+ MCM ($n$ = 763) | Combined ($n$ = 3,908) | $P$ value |
|---|---|---|---|---|---|
| SSI | 2% (27) | 4% (73) | 6% (42) | 4% (142) | **< .001*** |
| Superficial | 74% (20) | 81% (58) | 71% (30) | 77% (108) | .51* |
| Deep | 26% (7) | 18% (13) | 33% (14) | 24% (34) | .18* |
| Organ | 0% (0) | 3% (2) | 0% (0) | 1% (2) | .69† |

Multivariable logistic regression‡

| Variable | Odds ratio | CI 95% | $P$ value |
|---|---|---|---|
| 1 MCM:No MCM | 1.421 | 0.897–2.249 | .1342 |
| 2+ MCM:No MCM | 1.968 | 1.172–3.304 | **.0105** |
| 2+ MCM:1 MCM | 1.385 | 0.927–2.069 | .1118 |
| Age Q3:Q1 (49:67) | 0.719 | 0.556–0.931 | .0123 |
| History of abdominal wall SSI | 2.012 | 1.317–3.076 | .0012 |

* Pearson test.
† Fisher exact test.
‡ Hernia width, gender, ASA class, immunosuppressants, COPD, history of recurrence, myofascial release, drains used, OR time, earlier prosthetic mesh infection, mesh position, and subcutaneous flaps raised were included in the model but did not reach statistical significance.

On multivariable logistic regression, only those who have 2+ MCM were found to be significantly associated with increased odds of developing an SSI compared with those who have no MCM (1.96, $P$ = .01). No other significant associations were found between the other MCM groups.

A post hoc multivariable logistic regression was built for SSIs as we have described. For the 1 MCM group, diabetes was associated with the highest odds for developing an SSI (OR 1.6) and was the only significant finding. For the 2+ MCM group, being an obese diabetic or having all 3 comorbidities was significantly associated with increased odds for developing an SSI (OR 2.0, OR 2.4, respectively). Obese smokers or diabetic smokers were associated with increased but nonsignificant odds for developing SSI. Figure 2 illustrates all post hoc logistic regression relationships.

*SSOPIs*

On univariate analysis, a significant difference in SSOPI incidence between the 3 major groups was found, with a 9% SSOPI rate in the 2+ MCM group, a 5% rate in the 1 MCM group, and a 4% rate in the no MCM group ($P$ < .001). A total of 3 partial mesh excisions and 6 complete mesh excisions were performed, with the majority occurring in the 1 MCM group (3 partial and 4 complete mesh removals). Most SSOPIs reported for the entire cohort were wound opening (62%) and percutaneous drainage (27%). Wound debridement was performed significantly more frequently in the 2+ MCM group (32% vs 17% in 1 MCM and 13% in no MCM; $P$ < .001). The most common SSOs that required wound debridement in the 2+ MCM group were: 27% superficial SSIs, 32% deep SSIs, and 27% skin or soft tissue necrosis.

On multivariable logistic regression, there was increased odds for SSOPI in the 2+ MCM group compared with both the 1 MCM group and the no MCM group (OR 1.65, OR 2.02, respectively). Having only 1 MCM did not significantly increase the odds of SSOPI in comparison to having no MCM. Table V details the analyses on the development of SSOPI.

A post hoc logistic regression was built similarly to SSO and SSI. Compared with having no MCM, all combinations of comorbidities in the 2+ MCM group were found to be significant (diabetic smokers: OR 1.8, obese smokers: OR 1.9, obese diabetics: 2.1, obese diabetic smokers: 2.6; $P$ < .05 for all). In addition, in the 1 MCM

**Table V**
SSO or SSI requiring procedural intervention (SSOPI) analysis

| Univariate analysis | | | | | |
|---|---|---|---|---|---|
| | No MCM ($n$ = 1,220) | 1 MCM ($n$ = 1,925) | 2+ MCM ($n$ = 763) | Combined ($n$ = 3,908) | $P$ value |
| SSOPI | 4% (46) | 5% (104) | 9% (69) | 6% (219) | **< .001***  |
| Wound opening | 57% (26) | 66% (69) | 58% (40) | 62% (135) | .31* |
| Wound debridement | 13% (6) | 17% (18) | 32% (22) | 21% (46) | **< .001*** |
| Suture excision | 2% (1) | 1% (1) | 0% (0) | 1% (2) | .47† |
| Percutaneous drainage | 35% (16) | 26% (27) | 25% (17) | 27% (60) | .56* |
| Partial mesh removal | 0% (0) | 3% (3) | 0% (0) | 1% (3) | .43† |
| Complete mesh removal | 0% (0) | 4% (4) | 3% (2) | 3% (6) | .56† |

| Multivariable logistic regression‡ | | | |
|---|---|---|---|
| Variable | Odds ratio | CI 95% | $P$ value |
| 1 MCM:No MCM | 1.228 | 0.852–1.770 | .2717 |
| 2+ MCM:No MCM | 2.024 | 1.346–3.043 | **.0007** |
| 2+ MCM:1 MCM | 1.648 | 1.188–2.286 | **.0028** |
| Hernia width Q3:Q1 (13:5) | 1.322 | 1.101–1.586 | .0027 |
| History of abdominal wall SSI | 1.556 | 1.082–2.236 | .0170 |
| Subcutaneous flaps raised | 1.558 | 1.140–2.129 | .0054 |

* Pearson test.
† Fisher exact test.
‡ Age, gender, ASA class, immunosuppressants, COPD, history of recurrence, myofascial release, use of drains, OR time, earlier prosthetic mesh infection, and mesh position were included in the model but did not reach statistical significance.

group, obesity and diabetes were found to be significantly associated with SSOPI (OR 1.5, OR 1.4, respectively). Figure 2 illustrates all post hoc analyses for all wound events.

## Discussion

Our analysis found that patients with any number of MCMs are at increased odds for developing a wound event, with multiple comorbidities resulting in higher odds. Moreover, having more than one modifiable comorbidity was associated with increased odds for requiring a procedural intervention for wound management. Specifically, patients with all three comorbidities were found to have a two-fold increase in odds for all wound morbidity. Obese patients with diabetes had the second greatest association for all wound morbidity. Diabetes alone resulted in increased odds of SSIs and SSOPI, and obesity had increased odds for both SSOs and SSOPIs. Smoking alone was not found to be significantly associated with any wound morbidity. However, smoking had an increased association with SSOPIs when it coincided with obesity or diabetes.

Our group has previously conducted a single institution study on the use of synthetic mesh in the comorbid group of the VHWG grading system and evaluated the effect of compounded comorbidities. We found that all patient comorbidities equally contributed to increased SSOs, without a sole comorbidity emerging as significant on multivariable logistic regression. We then assessed the effect of compounding comorbidities and found a significant increase of SSOs as patients became more comorbid ($P$ = .02).[17] However, we were unable to identify whether any specific combination of comorbidities accounted for the highest odds, and the relatively small patient population may have predisposed to type II error in detecting which comorbidity resulted in significantly higher odds for wound events. In our current study, we present an analysis of 3,908 subjects, specifically identifying which permutation of comorbidities would result in additive effect on wound morbidities.

The relationship between obesity and complications after ventral hernia repair has been assessed in several studies. When trying to find a BMI threshold for all postoperative complications, both Owei et al[8] and Pernar et al[7] queried the National Surgical Quality Improvement (NSQIP) database and stratified their subjects into the WHO classification for BMI classes. Owei et al[8] found that the odds for all postoperative complications were significant at BMI > 30 (OR 1.22). However, Pernar et al[7] found the threshold to be BMI > 40 for the same complications. The difference could be attributed to the latter's reference comparison being a BMI < 25, thereby including underweight patients (according to WHO classification). This patient population was found to have higher odds for all complications in the Owei et al[8] study. In our study, obesity alone resulted in significant increased odds for SSO and SSOPI (OR 1.34, OR 1.48, respectively). However, although a BMI $\geq$ 30 was associated with increased odds for SSI, it did not reach statistical significance (OR 1.3, $P$ = 0.18).

Diabetes independently resulted in a significant increase in SSI and SSOPI (OR 1.56, OR 1.41, respectively). This correlates to the results of other studies. Huntington et al[10] found a significant association between diabetes and wound complication within the NSQIP database (OR 1.37). Upon further dividing diabetes into insulin dependent and noninsulin dependent, they found significantly increased odds of wound complications in insulin-dependent subjects (OR 1.42). Similarly, Qin et al[9] also studied the NSQIP database and found that insulin dependence resulted in increased odds of wound events in comparison with the nondiabetic group. This association was not found for the insulin-independent group. These two studies suggest that a distinction in postoperative outcomes exists between insulin-dependent and noninsulin-dependent diabetic patients. The AHSQC does not collect data with such distinctions and therefore, we are unable to comment on these findings.

Smoking in our analysis was not significantly associated with any wound event, except when combined with obesity or diabetes. This finding is consistent with earlier analysis conducted using the same database.[18]

The currently available literature on the presence of multiple comorbidities and their effect on outcomes is limited. Zavlin et al[19] assessed the outcomes of ventral hernia repair in patients with metabolic syndrome (diabetes, obesity, hypertension, and dyslipidemia), and found that these patients experienced significantly increased rates of medical and surgical complications, including wound infections. However, when performing adjustment analysis, each comorbidity was assessed separately. In contrast, our study assesses combined comorbidities as a singular variable, studying each possible combination of comorbidities as a distinct condition, with the results as described.

Altogether, these modifiable comorbidities play an important role in the recovery of hernia patients, and preoperative optimization is a highly important aspect of hernia repair surgery.[5] For obesity, most surgeons would agree that patients with a BMI 30 to 50 kg/m$^2$ need to receive preoperative intervention, with both medical and surgical management as options.[20] However, there is no current consensus on the "right" amount of weight to lose.[5] A recent analysis from our group found that wound complications progressively increase proportionally to BMI, with no clear ideal BMI cutoff point identified.[21] For diabetes, data specific to hernia repair is sparse, and therefore guidelines on preoperative optimization in hernia patients is often derived from studies assessing the associations of HbA1C with postoperative SSIs.[5,20] Currently, most surgeons agree that performing elective hernia repair on patients with HbA1C $\geq$ 8% is considered prohibitive, and any patient with HbA1C $\geq$ 6.5% should receive a preoperative intervention that is specific to their needs.[5,20] Finally, for smoking, avoiding elective surgery on current smokers and requiring 4 weeks of abstinence before the surgery is considered adequate for preoperative optimization.[5,20]

Our study presents some limitations that deserve mention. Smoking is not quantified in the AHSQC by packs per year, and therefore we are unable to draw exact details regarding this patient population. In addition, in our comparison arm, there were patients who did not smoke during the 30-day interval before surgery but could have been smoking before. Consequently, we are only studying the effect of smoking cessation in the 30-day preoperative interval without factoring in a history of smoking. These limitations could have contributed to our results showing no significant association. A similar limitation is present in our diabetic population. Although the AHSQC has started collecting HbA1c within the database, we did not have enough subjects to analyze this variable. Therefore, we are unable to identify which specific diabetic patient population drove the associated increased odds in wound events in our study.

In addition to these limitations, our study may be affected by those which are intrinsic to a retrospective analysis. Furthermore, in an effort to design a homogenous study population, we narrowed our inclusion criteria to include only open incisional hernia repairs using permanent synthetic mesh in clean fields. Although this created a more comprehensive analysis, it limits the generalizability of our findings. Moreover, we present a large database study, with some limitation related to data collection and measurement error.

Last, although significant associations were found for all wound morbidity, most of the SSIs were classified as superficial. The cohort had less than a 1% rate of mesh infection, and most noninfectious SSOs were benign wound events like seromas and wound serous drainage. Mesh removal was rarely required. Wound opening and percutaneous drainage resolved most wound events. The burden of these specific wound complications on patient recovery and postoperative quality of life is not well understood. Another limitation regarding our primary outcome of interest is using an interval of 30 days to detect these wound occurrences, with longer-term data unavailable. Finally, although we picked the 3 studied comorbidities because of the potential for modification before surgery, our study has not specifically analyzed the effect of weight loss, controlling diabetes, or smoking cessation. Instead, we highlight the relationship between each possible comorbid condition and the occurrence of wound events to provide a broader framework for engaging patients in shared decision-making during their preoperative course, as well as to guide future research on the effect of optimization for each of these MCMs.

In conclusion, MCMs cumulatively increase the risk of wound morbidity after open incisional hernia repair. In addition, the greater the number of MCMs, the more likely that wound morbidity will require a procedural intervention for management. This was most evident in patients with all three comorbidities and obese patients with diabetes. Such patients should receive exhaustive counseling on the effect their health status has on their postoperative recovery and the potential benefit of preoperative optimization.

## Conflict of interest

Dr. Michael J. Rosen receives salary support for his position in the leadership of the Americas Hernia Society Quality Collaborative (AHSQC), which is the data source for the present submission. Other unrelated conflicts of interest outside of the submitted work include grants from Intuitive Surgical Inc., grants from Pacira Pharmaceuticals Inc., board member support and stock options from Ariste Medical.

Dr. Ajita S. Prabhu reports grants from Intuitive Surgical Inc., personal fees from Intuitive Surgical Inc., and personal fees from Medtronic, outside the submitted work.

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Drs. Steven Rosenblatt, Hemasat Alkhatib, Clayton Petro, Li-Ching Huang, and Ms Sharon Phillips report no conflicts of interest.

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