Impact of bowel preparation on elective colectomies for diverticulitis: analysis of the NSQIP database

Haoran Zhuo¹†, Zheng Liu²†, Benjamin J. Resio³, Jialiang Liu², Xishan Wang², Kevin Y. Pei⁴ and Yawei Zhang⁵*

Abstract

Background: Recent data based on large databases show that bowel preparation (BP) is associated with improved outcomes in patients undergoing elective colorectal surgery. However, it remains unclear whether BP in elective colectomies would lead to similar results in patients with diverticulitis. The purpose of this study was to investigate whether bowel preparation affected the surgical site infections (SSI) and anastomotic leakage (AL) in patients with diverticulitis undergoing elective colectomies.

Study design: We identified 16,380 diverticulitis patients who underwent elective colectomies from the American College of Surgeons National Surgical Quality Improvement Program (ACS-NSQIP) colectomy targeted database (2012–2017). Multivariate logistic regression models were employed to investigate the impact of different bowel preparation strategies on postoperative complications, including SSI and AL.

Results: In the identified population, a total of 2524 patients (15.4%) received no preparation (NP), 4715 (28.8%) mechanical bowel preparation (MBP) alone, 739 (4.5%) antibiotic bowel preparation (ABP) alone, and 8402 (51.3%) MBP + ABP. Compared to NP, patients who received any type of bowel preparations showed a significantly decreased risk of SSI and AL after adjustment for potential confounders (SSI: MBP [OR = 0.82, 95%CI: 0.70–0.96], ABP [0.69, 95%CI: 0.52–0.92]; AL: MBP [OR = 0.66, 95%CI: 0.51–0.86], ABP [0.56, 95%CI: 0.34–0.93]), where the combination type of MBP + ABP had the strongest effect (SSI: OR = 0.58, 95%CI:0.50–0.67; AL: OR = 0.46, 95%CI:0.36–0.59). The significantly decreased risk of 30-day mortality was observed in the bowel preparation of MBP + ABP only (OR = 0.32, 95%CI: 0.13–0.79). After the further stratification by surgery procedures, patients who received MBP + ABP showed consistently lower risk for both SSI and AL when undergoing open and laparoscopic surgeries (Open: SSI [OR = 0.51, 95%CI: 0.37–0.69], AL [OR = 0.47, 95%CI: 0.25–0.91]; Laparoscopic: SSI [OR = 0.58, 95%CI: 0.47–0.72], AL [OR = 0.49, 95%CI: 0.35–0.68]).

Conclusions: MBP + ABP for diverticulitis patients undergoing elective open or laparoscopic colectomies was associated with decreased risk of SSI, AL, and 30-day mortality. Benefits of MBP + ABP for diverticulitis patients underwent robotic surgeries warrant further investigation.

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Background
The role of bowel preparations prior to elective colectomies continues to be debated. Previous studies have suggested that oral antibiotic bowel preparation (ABP) and the combination of oral antibiotic and mechanical bowel preparation (ABP + MBP) before colectomy may decrease the risk of postoperative complications such as anastomotic leakage (AL), surgical site and deep space infections, and 30-day mortality [1–3]; while the effects of MBP alone remain controversial [4–9]. However, these previous studies were largely generated from colectomy patients for whom the indication for surgery was not distinguished, or from patients with colorectal cancer only. Information concerning the role of bowel preparation before elective colectomies for other bowel diseases, like diverticulitis, is lacking.

Diverticulitis is an increasingly common disease, accounting for nearly 300,000 hospital admissions and $1.8 billion of direct medical costs per year in the U.S. in the last decade [10]. Although nonsurgical treatment is largely considered for diverticulitis management, patients with certain diverticulitis conditions still require colectomy [10, 11]. Specifically, surgical treatment is considered among patients with recurrent chronic diverticulitis, and is effectively performed with low mortality rate for acute diverticulitis patients [10–13]. However, the postoperative morbidity and mortality rates of colectomy are higher among patients with diverticulitis compared to colorectal cancer [14, 15]. Bowel preparation is one measure to mitigate the postoperative complications of colectomy among colorectal cancer or all cases underwent surgery [16–18]. To date, there is very little published data investigating the role of BP prior to elective colectomy specifically among patients with diverticulitis. To sum up, it remains unclear whether BP with elective colectomies would have benefits among diverticulitis cases. The purpose of this study was to investigate the impact of bowel preparation on surgical site infection (SSI) and AL in patients with diverticulitis undergoing elective colectomy.

Methods
Study population
We conducted a retrospective cohort study using the general American College of Surgeons National Surgical Quality Improvement Program (ACS NSQIP) and colectomy targeted ACS NSQIP database from 2012 to 2017. The full details of data collection for NSQIP can be found elsewhere [19]. In brief, the NSQIP database is nationally validated, risk-adjusted, and outcomes-based programs to measure and improve the quality of surgical care, including prospective information on presurgical risk factors and 30-day postoperative mortality/morbidity outcomes from random sampling of multiple participating institutions. 16,723 individuals were eligible in our study with chronic diverticulitis, known types of bowel preparation and major outcomes (SSI, AL), and underwent elective colorectal resections. According to NSQIP, the use of MBP and ABP were separately recorded according to “yes,” “no,” or “unknown,” and MBP did not include enemas or suppositories and ABP did not include parenteral antibiotics [2]. Elective colorectal resections were identified by primary Current Procedural Terminology (CPT) codes (44140, 44145, 44160, 44204, 44205, and 44207). We excluded 343 Patients from analysis with urgent or emergency cases, preoperative ventilator dependent, renal failure, systemic sepsis, or classified by an American Society of Anesthesiologists (ASA) physical status of five (V), which was in order to remove potential non-elective surgeries.

Covariates
Primary exposure was the type of bowel preparation that derived from the combination of MBP and ABP, with implementation of both types as ABP + MBP and individual use of ABP and MBP separately. Other covariates included preoperative characteristic of age, race/ethnicity, sex, body mass index (BMI), ASA classification, smoking status, non-independent functional status, diabetes, hypertension, history of congestive heart failure (CHF), chronic obstructive pulmonary disease (COPD), weight loss (> 10% loss of body weight in the last 6 months), bleeding disorder (including clotting deficiencies and long-term anticoagulation therapy that was not stopped before surgery) and steroid use, and intraoperative characteristics of resection type (left, right), wound classification (clean, clean contaminated, contaminated, dirty/infected) [20], approach type (open, laparoscopic, robotic), and operative time > 3 h.

Outcome assessment
Primary outcomes were overall SSI rates (superficial, deep, and organ space), as defined by the U.S. CDC [21]; and AL was defined as any leak of endoluminal contents through an anastomosis. Secondary outcomes were 30-day mortality, wound dehiscence, infectious complications (wound infection, pneumonia, urinary tract infection, sepsis), pulmonary complications (pneumonia,
pulmonary embolism, reintubation), cardiac complications (myocardial infarction and cardiac arrest), ileus, length of hospital stay (LOS) ≥ 4 days, and reoperations/readmissions.

Statistical analysis
Included patients were divided into four groups based on the type of BP: no preparation (NP); ABP; MBP; MBP + ABP. We used Pearson's Chi-squared test and ANOVA test to investigate patients' demographics, preoperative comorbidities and intraoperative characteristics among the four groups of BP type. Multivariable logistic regression was used to examine the association between preoperative BP and both major and secondary outcomes in diverticulitis patients. The one-to-one greedy propensity score matching on the selected demographic characteristics (age, race/ethnicity) and preoperative risk factors (ASA classification, CHF, weight loss > 10%, preoperative steroid use) between each BP type (MBP alone, ABP alone, MBP + ABP) and NP was also used to examine the association between BP type and major outcomes. The role of BP was further investigated for major outcomes only (SSI, AL) among a stratified population that underwent open, laparoscopic, and robotic surgeries as well as patients underwent left- and right-sided colectomy. All significance tests were implemented in SAS 9.4 with a significance level of two-tailed Type I error (α) of 0.05.

Results
Of the identified 16,380 diverticulitis patients who underwent elective colectomies, 2524 (15.4%) received NP, 4715 (28.8%) MBP alone, 739 (4.5%) ABP alone, and 8402 (51.3%) MBP + ABP. Patients who received NP were more likely to be non-whites (P < 0.0001), ASA III-IV (P = 0.011), to have experienced congestive heart failure (P = 0.046) and to have had preoperative steroids (P = 0.006) compared to those who received MBP alone, ABP alone, or MBP + ABP. Patients who received ABP alone were more likely to be younger than 55 years (P = 0.002) and to have lost weight (P = 0.004) than others (Table 1).

Among intraoperative characteristics, patients who received no bowel preparation before surgery were more likely to undergo open procedures and right resection, and least likely to have robotic approach. Patients with ABP alone were more likely to have undergone left resections, experienced wound contamination and had an operation time > 3 h (Table 2).

The overall incidence rates of SSI and AL were 8.55% and 2.74%, respectively. Patients who received MBP + ABP had significantly lower rates of SSI and AL than the other BP types (Table 3). Similarly, the incidence rates for secondary outcomes including 30-day mortality, wound dehiscence, infectious complications, and reoperation were lower among patients received MBP + ABP compared to other bowel preparation types.

Primary outcomes
After adjustment for baseline demographics and pre- and intra-operative characteristics, patients who received any type of BP had significantly lower risk of SSI and AL compared to those without BP (SSI: MBP [OR = 0.82, 95% CI: 0.70–0.96], ABP OR = 0.69, 95% CI: 0.52–0.92]; AL: MBP [OR = 0.66, 95% CI: 0.51–0.86], ABP OR = 0.56, 95% CI: 0.34–0.93]), where the combination type of MBP + ABP had the strongest effect (SSI: OR = 0.58, 95% CI: 0.50–0.67; AL: OR = 0.46, 95% CI: 0.36–0.59) (Table 4). In a smaller sample of comparable populations that were matched on selected demographic characteristics and preoperative risk factors using propensity score, we observed similar associations between bowel preparations and better outcomes and SSI and AL except that the association between ABP and SSI was not significant.

After the further stratification of the general population by surgery procedure, patients who received MBP + ABP showed consistently lower risk for both SSI and AL among open and laparoscopic surgeries (SSI: open [OR = 0.51, 95% CI: 0.37–0.69], laparoscopic [OR = 0.58, 95% CI: 0.47–0.72]; AL: open [OR = 0.47, 95% CI: 0.25–0.91], laparoscopic [OR = 0.49, 95% CI: 0.35–0.68]). The significantly decreased rate of SSI was also observed among patients with ABP alone who underwent open procedures (OR = 0.49, 95% CI: 0.23–0.98). MBP alone was associated with a decreased rate of AL among laparoscopic procedures (OR = 0.69, 95% CI: 0.49–0.97). Little evidence of decreased risk of SSI and AK was observed among patients received bowel preparations before robotic colectomy (Table 5).

For different resection locations, the strongest effect of reduced risk of SSI and AL was observed using the combination type of MBP + ABP among patient with left resections (SSI: OR = 0.60, 95% CI: 0.51–0.70; AL: OR = 0.47, 95% CI: 0.37–0.60). The significantly decreased risk of SSI and AL was also observed among patients with ABP alone underwent left resections (SSI: OR = 0.68, 95% CI: 0.51–0.92; AL: OR = 0.58, 95% CI: 0.35–0.95). MBP alone remained significantly associated with a decreased rate of AL among patients with left resections (OR = 0.68, 95% CI: 0.52–0.87). Limited evidence was found among right resection due to small sample size (Table 5).
Secondary outcomes

Patients who received MBP + ABP had significantly decreased risk of secondary outcomes, including 30-day mortality (OR = 0.32, 95%CI: 0.13–0.79), wound dehiscence (OR = 0.42, 95%CI: 0.25–0.70), pulmonary complications (OR = 0.59, 95%CI: 0.38–0.93), ileus (OR = 0.73, 95%CI: 0.62–0.85), LOS ≥ 4 days (OR = 0.78, 95%CI: 0.71–0.85), reoperation (OR = 0.62, 95%CI: 0.50–0.78), and readmission (OR = 0.77, 95%CI: 0.66–0.91) compared to those without BP. Similarly, patients with ABP alone also had decreased risk of ileus (OR = 0.67, 95%CI: 0.48–0.94), LOS ≥ 4 days (OR = 0.80, 95%CI: 0.67–0.95), and

Table 1  Demographic and preoperative characteristics of diverticulitis patients who underwent elective colectomy by type of bowel preparation

| Type of bowel preparation | NP (N=2524) (%) | MBP alone (N=4715) (%) | ABP alone (N=739) (%) | MBP + ABP (N=8402) (%) |
|---------------------------|-----------------|------------------------|-----------------------|------------------------|
| **Age (years)**           |                 |                        |                       |                        |
| <55                       | 981 (38.87)     | 1760 (37.33)           | 298 (40.32)           | 3176 (38.70)          |
| 55–64                     | 755 (29.91)     | 1412 (29.95)           | 214 (28.96)           | 2645 (31.48)          |
| 65–74                     | 546 (21.63)     | 1096 (23.24)           | 172 (23.27)           | 1907 (22.70)          |
| ≥75                       | 242 (9.59)      | 447 (9.48)             | 55 (7.44)             | 674 (8.02)            |
| **Race/ethnicity**        |                 |                        |                       |                        |
| White                     | 1909 (75.63)    | 3851 (81.68)           | 594 (80.38)           | 7021 (83.56)          |
| (row %)                   | 14.27           | 28.79                  | 44.4                  | 52.49                 |
| Black                     | 181 (7.17)      | 266 (5.64)             | 42 (5.68)             | 472 (5.62)            |
| (row %)                   | 18.83           | 27.68                  | 4.37                  | 49.12                 |
| Hispanic                  | 183 (7.25)      | 222 (4.71)             | 56 (7.58)             | 485 (5.77)            |
| (row %)                   | 19.34           | 23.47                  | 5.92                  | 51.27                 |
| Others/Unknown            | 251 (9.94)      | 376 (7.97)             | 47 (6.36)             | 424 (5.05)            |
| (row %)                   | 22.86           | 34.24                  | 4.28                  | 38.62                 |
| **Sex**                   |                 |                        |                       |                        |
| Male                      | 1091 (43.23)    | 2063 (43.75)           | 322 (43.57)           | 3743 (44.55)          |
| Female                    | 1433 (56.77)    | 2652 (56.25)           | 417 (56.43)           | 4659 (55.45)          |
| **BMI (kg/m²)**           |                 |                        |                       |                        |
| <25                       | 583 (23.57)     | 1036 (22.29)           | 160 (21.83)           | 1823 (21.91)          |
| 25–29                     | 862 (34.84)     | 1696 (36.49)           | 244 (33.29)           | 2958 (35.55)          |
| 30–34                     | 590 (23.85)     | 1111 (23.90)           | 188 (25.65)           | 2095 (25.18)          |
| ≥35                       | 439 (17.74)     | 805 (17.32)            | 141 (19.24)           | 1444 (17.36)          |
| **ASA classification**    |                 |                        |                       |                        |
| 1–2                       | 1500 (59.43)    | 3000 (63.63)           | 465 (62.92)           | 5324 (63.37)          |
| 3–4                       | 1022 (40.49)    | 1709 (36.25)           | 273 (36.94)           | 3073 (36.57)          |
| Missing                   | 2 (0.08)        | 6 (0.13)               | 1 (0.14)              | 5 (0.06)              |
| **Current smoker**        |                 |                        |                       |                        |
| 2000 (79.58)              | 21.00           | 969 (20.55)            | 137 (18.54)           | 1602 (19.07)          |
| Non-independent functional health status | | | | |
| 28 (1.11)                 | 1.11            | 76 (1.61)              | 8 (1.08)              | 125 (1.49)            |
| **Diabetes**              |                 |                        |                       |                        |
| 2000 (79.58)              | 10.06           | 457 (9.69)             | 77 (10.42)            | 830 (9.88)            |
| 1022 (40.49)              | 4.68            | 169 (3.58)             | 21 (2.84)             | 274 (3.26)            |
| 61 (2.42)                 | 2.42            | 101 (2.14)             | 32 (4.33)             | 199 (2.37)            |
| **COPD**                  |                 |                        |                       |                        |
| 2000 (79.58)              | 0.48            | 18 (0.38)              | 1 (0.14)              | 16 (0.19)             |
| 12 (0.48)                 | 3.68            | 169 (3.58)             | 21 (2.84)             | 274 (3.26)            |
| **Weight loss >10%**      |                 |                        |                       |                        |
| 2000 (79.58)              | 2.42            | 101 (2.14)             | 32 (4.33)             | 199 (2.37)            |
| **Bleeding disorder**     |                 |                        |                       |                        |
| 2000 (79.58)              | 1.86            | 80 (1.70)              | 11 (1.49)             | 140 (1.67)            |
| **Preoperative steroid**  |                 |                        |                       |                        |
| 2000 (79.58)              | 4.68            | 151 (3.20)             | 20 (2.71)             | 326 (3.88)            |

Bold values are significant results with two-side P-values <0.05
readmission (OR = 0.55, 95% CI: 0.38–0.78) compared to NP. On the contrary, preoperative MBP was associated with increased risk of LOS ≥ 4 days (OR = 1.13, 95% CI: 1.02–1.25) compared to NP.

### Discussion

In this study, we found that patients who received any type of BP (MBP, ABP, MBP + ABP) had a significantly reduced risk of SSI and AL compared to NP, with the strongest association with the utility of combined mechanical and antibiotic preparation. This benefit of combination type of MBP + ABP was similar among open and laparoscopic surgeries, as well as left-side resections. In addition, combination type of MBP + ABP was significantly associated with decreased risk of secondary outcomes (30-day mortality, wound dehiscence, pulmonary complications, ileus, bleeding requiring transfusion, LOS ≥ 4 days, reoperation, and readmission) compared to NP.
Table 4  Multivariable logistic regression and propensity score (PS) matching\(^b\) to investigate the effect of different bowel preparation types on primary and secondary outcomes

| Overall | NP (REF) | ABP | MBP + ABP |
|---------|---------|-----|-----------|
|         | N       | N   | OR\(^*\)  | 95% CI\(^*\) | P-value\(^*\) | N       | OR\(^*\)  | 95% CI\(^*\) | P-value\(^*\) | N       | OR\(^*\)  | 95% CI\(^*\) | P-value\(^*\) |
| SSI     | 1400    | 298 | 458 | 0.82 (0.70, 0.96) | 0.015 | 62     | 0.69 (0.52, 0.92) | 0.012 | 582     | 0.58 (0.50, 0.67) | <0.0001 |
| (PS matching model \(^b\)) Matched sample | 298/248 | 0.81 (0.68, 0.97) | 0.024 | 65/62     | 0.95 (0.66, 1.37) | 0.781 | 298/177 | 0.56 (0.46, 0.64) | <0.0001 |
| Anastomotic leak\(^a\) | 441 | 139 | 0.66 (0.51, 0.86) | 0.002 | 19     | 0.56 (0.34, 0.93) | 0.024 | 172     | 0.46 (0.36, 0.59) | <0.0001 |
| (PS matching model \(^b\)) Matched sample | 111/78 | 0.66 (0.49, 0.89) | 0.006 | 33/19     | 0.57 (0.32, 1.00) | 0.050 | 111/62 | 0.52 (0.38, 0.72) | <0.0001 |
| 30-day mortality | 101 | 25 | 38 | 0.80 (0.48, 1.33) | 0.391 | 4     | 0.54 (0.19, 1.56) | 0.253 | 34     | 0.42 (0.25, 0.70) | 0.001 |
| Wound dehiscence | 316 | 60 | 87 | 0.79 (0.57, 1.11) | 0.179 | 25     | 1.50 (0.93, 2.42) | 0.101 | 144     | 0.77 (0.57, 1.05) | 0.140 |
| Infectious complication | 131 | 30 | 40 | 0.70 (0.43, 1.13) | 0.145 | 4     | 0.47 (0.16, 1.34) | 0.158 | 57     | 0.59 (0.38, 0.89) | 0.022 |
| Pulmonary complication | 56 | 12 | 14 | 0.60 (0.27, 1.30) | 0.194 | 1     | 0.29 (0.04, 2.23) | 0.233 | 29     | 0.75 (0.38, 1.49) | 0.417 |
| Cardiac complication | 1200 | 231 | 378 | 0.89 (0.75, 1.06) | 0.194 | 45     | 0.67 (0.48, 0.94) | 0.019 | 546     | 0.73 (0.62, 0.85) | <0.001 |
| Ileus | 9794 | 1599 | 3067 | 1.13 (1.02, 1.25) | 0.021 | 421     | 0.80 (0.67, 0.95) | 0.010 | 4707     | 0.78 (0.71, 0.85) | <0.0001 |
| LOS ≥ 4 days | 2000 | 119 | 200 | 0.91 (0.72, 1.15) | 0.419 | 25     | 0.72 (0.46, 1.12) | 0.146 | 246     | 0.62 (0.50, 0.78) | <0.0001 |
| Reoperation | 1216 | 227 | 376 | 0.90 (0.76, 1.08) | 0.255 | 37     | 0.55 (0.38, 0.78) | 0.001 | 576     | 0.77 (0.66, 0.91) | 0.002 |

Bold values are significant results with two-side P-values < 0.05

\(^a\) Include patients underwent anastomosis

\(^b\) One-to-one greedy propensity score matching on age, race/ethnicity, ASA classification, history of congestive heart failure (CHF), weight loss (> 10% loss of body weight in the last 6 months), preoperative steroid use (Note: the sample size might be smaller due to the inability to find comparable observations on all matched variables)

*Adjusted for demographic characteristics (age, race/ethnicity, sex, body mass index (BMI), smoking status), preoperative comorbidities (ASA classification, non-independent functional status, diabetes, hypertension, history of congestive heart failure (CHF), chronic obstructive pulmonary disease (COPD), weight loss (> 10% loss of body weight in the last 6 months), bleeding disorder, steroid use), and intosooperative conditions (resection type, wound classification, approach type, operative time > 3 h)

LOS: length of total hospital stays (day)
to NP. Evidence strongly supported that the combination type of MBP + ABP before colectomy is associated with reduced postoperative complications among diverticulitis patients.

The impact of bowel preparation regimens in patients undergo elective colectomy for diverticulitis is unknown. Although a Dutch study indicated that MBP alone prior to elective colorectal surgery for diverticulitis failed to decrease the AL rate and other septic complications compared to no bowel preparation [22], our study suggested that MBP alone was associated with decreased rate of SSI and AL in the general population. However, neither ABP alone or MBP + ABP were mentioned in the Dutch study and the results were limited by a relatively small sample size and the consideration of open procedures and left-sided colorectal surgery only. In the present study, we included a larger sample size which allowed for stratified analysis based on surgical approach (open, laparoscopic, robotic) and extent of anatomic resection (left, right). In our stratified analyses, we confirmed that MBP alone failed to decrease the risk of SSI and AL in open procedures but observed a significantly decreased risk of AL in laparoscopic procedures and left-sided resections for diverticulitis. In theory, MBP is believed to significantly reduce the bacterial burden, thereby protecting patients from postoperative anastomotic and infectious complications [23]. Laparoscopic procedures were also recommended as more reliable and efficacious forms of modality than open procedures due to shorter operative time and reduced blood loss for chronic diverticular disease [24]. Although the beneficial effects of MBP alone among colorectal cancer cases is controversial [4–9], this study demonstrated that MBP alone was associated with the decreased complication of AL when compared to no preparation.

The benefits of combination type MBP + ABP are superior to any preparation strategy that has been widely reported [1, 2, 25, 26]. Such combination preparation is physiologically sound: ABP reduces the bacterial concentration of the colonic mucosa while MBP improves antibiotic efficacy by reducing fecal bulk [27]. Our study also suggested that MBP + ABP was consistently associated with decreased rates of against postoperative complications and mortality among diverticulitis cases. The effect size of the association from MBP + ABP was strongest among all bowel preparations for the general population.
and a stratified population that underwent open and laparoscopic procedures. Little evidence in our study showed that bowel preparations before robotic colectomy was associated with decreased rates of any complications or mortality. It is possible that the small sample size of robotic procedures prevented us from finding significant results. Another possibility for the nonsignificant results might be the counteraction between the advantages of robotic colectomy on short-term outcomes and the negative impact of no bowel preparation [28]. Additional studies regarding the effects of any type of bowel preparation on robotic colectomies are needed.

Diverticulitis in Western countries is commonly left-sided while the right-sided is rare. The similar skewed distribution with dominant left-sided resections (left: 98.1%, right: 1.9%) was also observed in our study population. The benefits of bowel preparation, especially MBP + ABP, prior to elective colectomy among diverticulitis was observed in left-sided resections, while the limited sample size of right-sided resections precluded us from observing any significant outcomes among patient with right colectomy.

Protective effects of ABP alone on colorectal cancer have been identified for postoperative infectious complications, length of hospital stay, and readmission [29, 30]. For diverticulitis, our study found that ABP alone provided similar protective effects on SSI, AL, LOS ≥ 4 days, and readmission. In stratified analyses, ABP alone was not found to be associated with a reduced risk of infectious complications in laparoscopic procedures, but ABP alone was observed to significantly associated with decreased complication of SSI in open colectomies. However, our study was limited by a small number of ABP alone patients and more studies with larger sample sizes are needed to further confirm our findings.

There were several limitations to our study. First, the ACS-NSQIP database does not include historical information such as other previous treatment for diverticulitis, the number of episodes, as well as the prior administration of systemic antibiotics or parenteral antibiotics for each patient, which may be related to the outcomes of surgery. Nowadays, parenteral antibiotics is serving as routinely received preparation before colectomy [31]. As no evidence in NSQIP suggested a systematic difference of parenteral antibiotics receiving among patients received MBP, ABP or MBP + ABP, disregarding the potential implementation of parenteral antibiotics would induce relatively conservative effect size of BP in our study as the risk of AK and SSI would otherwise be higher if no parenteral antibiotics were received. Second, patients who underwent bowel preparation, particularly mechanical, were healthier suggesting that patient who received no bowel prep were potentially selected due to inability to tolerate the regimen. However, preoperative patient characteristics were adjusted in the multivariable regression analysis to minimize the potentiality of selection bias. Third, different practice patterns of surgeons might be another confounder, which is possible that the same surgeons who did not proceed bowel preparation for elective cases were essentially those with worse outcomes. However, the findings that bowel preparation had decreased risk of complication rates and mortality were preserved across different surgical procedures. It is likely that our results in the US cohort might not be generalizable to other populations or countries. Studies from distinct regions have observed different results of bowel preparations in the clinical practice and currently there are no “gold standard” practical guidelines with respect to it [32–34]. Further studies using different study population are therefore warranted to verify our results. Finally, we cannot exclude the possibility of residual confounding effect from other variables that were untracked by the database having influenced our results.

Despite these limitations, we have found that bowel preparation for chronic diverticulitis patients undergoing elective colectomies was associated with the decreased risk of postoperative complications and mortality. Our results were based on an observational cohort and the observed associations might not be causal effect. The observed associations should therefore be interpreted with caution and verified by further studies before considered into the clinical practice.

Conclusion
Implementation of bowel preparation prior to an elective colectomy was successful in reducing SSI and AL among diverticulitis patients. The combination of ABP and MBP had the strongest effect reducing the risk of SSI, AL, and 30-day mortality in patients underwent open and laparoscopic procedures, suggesting that MBP + ABP might be a preferred bowel preparation type in cases of elective colorectal surgery for diverticulitis. Future randomized prospective trials are warranted to investigate the impact of bowel preparation, especially among robotic colectomies, and to provide more definitive answers.

Acknowledgements
No acknowledgments.

Author contributions
HZ and ZL contributed to the study concept and design, acquisition, analysis, and interpretation of the data, and drafting of the manuscript. BJR, JL, XW, KYP and YZ contributed to the study concept and design, analysis, and interpretation of the data, and critical revision of the manuscript for important intellectual content. All authors read and approved the final manuscript.
Funding
No funding was received.

Availability of data and materials
The data used is from the ACS-NSQIP and clinical records created by care providers is freely available to all institutional members who comply with the ACS-NSQIP data use agreement. The list and definitions of variables collected in the database can be found at the ACS-NSQIP website (https://www.facs.org/quality-programs/acs-nsqip).

Declarations

Ethics approval and consent to participate
All methods were carried out in accordance with relevant guidelines and regulations. We have collected the clinical data of the patients from the database, and the data used in our study were anonymized before its use. There were not any administrative permissions required to access the raw data used in our study.

Consent for publication
Not applicable.

Competing interests
All author declared that they have no competing interests.

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Received: 1 June 2022   Accepted: 24 August 2022
Published online: 12 September 2022

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