

Mortality and Morbidity After Hartmann's Procedure Versus Primary Anastomosis Without a Diverting Stoma for Colorectal Perforation: A Nationwide Observational Study

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Abstract

Background The benefit of primary anastomosis (PA) without a diverting stoma over Hartmann's procedure (HP) for colorectal perforation remains controversial. We compared postoperative mortality and morbidity between HP and PA without a diverting stoma for colorectal perforation of various etiologies.

Methods Using the Japanese Diagnosis Procedure Combination database, we extracted data on patients who underwent emergency open laparotomy for colorectal perforation of various etiologies from July 1, 2010 to March 31, 2014. We compared 30-day mortality, postoperative complication rates, and postoperative critical care interventions between HP and PA groups using propensity score matching, inverse probability of treatment weighting, and instrumental variable analyses to adjust for measured and unmeasured confounding factors.

Results We identified 8500 eligible patients (5455 HP and 3045 PA). In the propensity score-matched model, a significant difference between the HP and PA groups was detected in 30-day mortality (7.7% vs. 9.6%; risk difference, 1.9%; 95% confidence interval [CI], 0.5–3.4). The inverse probability of treatment weighting showed similar results (8.8% vs. 10.7%; risk difference, 1.9%; 95% CI, 1.0–2.8). In the instrumental variable analysis, the point estimate suggested similar direction to that of the propensity score analyses (risk difference, 4.4%; 95% CI, –3.3 to 12.1). The PA group had significantly higher rates of secondary surgery for complications (4.6% vs. 8.4%; risk difference, 3.8%; 95% CI, 2.5–4.1) and slightly longer duration of postoperative critical care interventions.

Conclusions This study revealed a significant difference in 30-day mortality between HP and PA without a diverting stoma.

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Introduction

Colorectal perforation with severe peritonitis is a life-threatening status that has various etiologies. Lower bowel perforation followed by severe peritonitis requires emergency surgery, including (1) resection of the diseased colonic segment with an end colostomy (Hartmann procedure, HP), and (2) primary anastomosis (PA) with or without a diverting ileostomy or colostomy [1–5].

In studies of patients with diverticulitis, comparisons of outcomes after HP and PA have shown mixed results. Observational studies suggested that PA was not associated with greater morbidity or mortality [6–8], whereas a few randomized studies indicated that PA was significantly associated with lower morbidity than HP [9, 10]. However,

data are lacking on other underlying diseases (such as bowel perforation by intra-abdominal malignancy, inflammatory bowel disease, ischemic disease, ileus, or iatrogenesis) in terms of selecting HP or PA.

In most previous studies comparing HP with PA, patients receiving PA included (1) those who underwent PA with a diverting stoma, or (2) those who underwent PA either with or without a diverting stoma [11]. There have been a few studies that directly compared postoperative outcomes between HP and PA without a diverting stoma, but these were limited because of small sample sizes [12–14]. The aims of the present study were to compare mortality, morbidity, and critical care procedures between HP and PA without a diverting stoma in patients with colorectal perforation caused by various underlying diseases, using a large-scale national inpatient database in Japan.

Materials and methods

Ethics

This study was approved by the institutional review board of the University of Tokyo, which waived the requirement for informed patient consent because of the anonymous nature of the data. The study complied with the Helsinki Declaration, version 2013.

Diagnosis Procedure Combination database

The Diagnosis Procedure Combination database is a national administrative claims and discharge abstract database in Japan. Details have been described in elsewhere [15, 16]. Briefly, all 82 academic hospitals are obliged to participate in the database, while participation by community hospitals is voluntary. In 2014, approximately 1100 hospitals participated in the database, and the number of patients included was approximately 7 million, representing approximately 50% of all inpatient admissions to acute care hospitals in Japan. The database includes the following data: diagnoses at admission and complications occurring after admission, classified according to the 10th revision of the International Classification of Diseases (ICD-10) and written in Japanese; types of surgery; daily dosages and records of drugs and devices; and discharge status. To optimize the accuracy of the recorded diagnoses, the responsible physicians are obliged to record the diagnoses with reference to the medical charts. Disease categories and their ICD-10 codes used in this study are listed in Supplemental Table 1.

Study design

This was a retrospective cohort study.

Patient selection

Patients with colorectal perforation who underwent emergency open laparotomy from July 1, 2010 to March 31, 2014 were identified in the database. The inclusion criteria for the current analysis were: (1) age of 15 years or older, (2) emergency admission, (3) confirmed diagnosis of free perforation of the colon or rectum on admission, and (4) open abdominal laparotomy performed on day 1. We excluded patients who had malignant neoplasms of lymphoid, hematopoietic and related tissue (ICD-10 codes, C81–C96) because they may be likely to receive immunochemotherapy. We excluded ulcerative colitis patients (K51) with lower intestinal perforation because they may receive total proctocolectomy. We also excluded abdominal trauma patients (S30–S39) because they may be likely to have other life-threatening injury. Patients who received an ileostomy were also excluded.

In Japan, PA for lower bowel perforation is generally made without a diverting stoma. We therefore categorized the eligible patients into an HP group and PA group without a diverting stoma.

Outcomes

The primary outcome of interest was 30-day mortality. Subgroup analyses were performed to compare mortalities between the HP and PA groups according to different underlying etiologies including diverticulitis, intra-abdominal malignancy, inflammatory bowel disease (Crohn's disease, Behçet's disease, and radiation enterocolitis), bowel ischemia, ileus, or iatrogenic and foreign body injury.

Secondary outcomes included postoperative complications and requirement for postoperative critical care interventions. Postoperative complications included surgical complications, stoma complications, and medical complications.

Postoperative critical care interventions included vasopressor use, mechanical ventilation, continuous renal replacement therapy, polymyxin B hemoperfusion, central venous catheterization, and tube feeding.

Statistical analyses

Propensity score analyses

One-to-one propensity score matching was performed between the HP and PA groups. This can minimize

Table 1 Baseline patient characteristics in the unmatched and propensity score-matched groups

	Unmatched groups			Matched groups		
	Primary anastomosis (<i>n</i> = 3045) <i>n</i> (%)	Hartmann's procedure (<i>n</i> = 5455) <i>n</i> (%)	SD, %	Primary anastomosis (<i>n</i> = 2800) <i>n</i> (%)	Hartmann's procedure (<i>n</i> = 2800) <i>n</i> (%)	SD, %
Age, years						
15–59	745 (24.5)	779 (14.3)	26.0	503 (18.0)	567 (20.3)	−5.8
60–69	542 (17.8)	1130 (20.7)	−7.4	542 (19.4)	519 (18.5)	2.3
70–79	836 (27.5)	1646 (30.2)	−6.0	835 (29.8)	804 (28.7)	2.4
≥80	922 (30.3)	1900 (34.8)	−9.6	920 (32.9)	910 (32.5)	0.9
Sex male	1680 (55.2)	2538 (46.5)	17.5	1460 (52.1)	1463 (52.3)	−0.4
Body mass index category (kg/m ²)						
<18.5	546 (17.9)	1000 (18.3)	−1.0	528 (18.9)	495 (17.7)	3.1
18.5–24.9	1696 (55.7)	2992 (54.8)	1.8	1526 (54.5)	1544 (55.1)	−1.2
25–29.9	382 (12.5)	694 (12.7)	−0.6	339 (12.1)	355 (12.7)	−1.8
≥30	85 (2.8)	159 (2.9)	−0.6	84 (3.0)	88 (3.1)	−0.6
Missing	336 (11.0)	610 (11.2)	−0.6	323 (11.5)	318 (11.4)	0.3
Comorbidity index						
0	1802 (59.2)	2982 (54.7)	9.1	1566 (55.9)	1617 (57.8)	−3.8
1	236 (7.8)	517 (9.5)	−6.1	234 (8.4)	221 (7.9)	1.8
2	769 (25.3)	1410 (25.8)	−1.1	763 (27.3)	729 (26.0)	2.9
≥3	238 (7.8)	546 (10.0)	−7.7	237 (8.5)	233 (8.3)	0.7
Etiology						
Diverticular disease	1087 (35.7)	1522 (27.9)	16.8	862 (30.8)	894 (31.9)	−2.4
Colon carcinoma	629 (20.7)	1108 (20.3)	1.0	624 (22.3)	610 (21.8)	1.2
Inflammatory bowel disease	23 (0.8)	27 (0.5)	3.7	22 (0.8)	15 (0.5)	3.7
Iatrogenic or foreign objects	13 (0.4)	20 (0.4)	0.0	13 (0.5)	14 (0.5)	0.0
Ischemic disease	64 (2.1)	110 (2.0)	0.7	64 (2.3)	54 (1.9)	2.8
Ileus	92 (3.0)	174 (3.2)	−1.2	91 (3.3)	79 (2.8)	2.9
Data not provided	1137 (37.3)	2494 (45.7)	−17.1	1124 (40.1)	1134 (40.5)	−0.8
Japan coma scale						
Grade0 (alert)	2566 (84.3)	4420 (81.0)	8.7	2323 (83.0)	2345 (83.8)	−2.2
Grade1 (delirium)	280 (9.2)	635 (11.6)	−7.9	278 (9.9)	278 (9.9)	0.0
Grade2 (somnia)	88 (2.9)	174 (3.2)	−1.7	88 (3.1)	80 (2.9)	1.2
Grade3 (coma)	111 (3.6)	226 (4.1)	−2.6	111 (4.0)	97 (3.5)	2.6
Disseminated intravascular coagulation	390 (12.8)	1009 (18.5)	−15.7	390 (13.9)	397 (14.2)	−0.9
Peritonitis	2188 (71.9)	4160 (76.3)	−10.1	2056 (73.4)	2071 (74.0)	−1.4
Mechanical ventilation (day 1)	344 (11.3)	602 (11.0)	1.0	341 (12.2)	302 (10.8)	4.4
Vasopressor (day 1)	1228 (40.3)	2709 (49.7)	−19.0	1218 (43.5)	1175 (42.0)	3.0
Blood transfusion (day 1)	650 (21.3)	1347 (24.7)	−8.1	648 (23.1)	608 (21.7)	3.4
Albumin (day 1)	940 (30.9)	2208 (40.5)	−20.1	938 (33.5)	920 (32.9)	1.3
Glucocorticoid (day 1)	483 (15.9)	1001 (18.4)	−6.6	466 (16.6)	455 (16.3)	0.8
Hospital type (academic)	423 (13.9)	940 (17.2)	−9.1	422 (15.1)	407 (14.5)	1.7
Saline for intra-abdominal irrigation (ml)						
<5000	1032 (33.9)	1445 (26.5)	16.2	883 (31.5)	503 (31.3)	0.4
≥5000, <10,000	664 (21.8)	1013 (18.6)	8.0	588 (21.0)	542 (20.9)	0.2
≥10,000, <15,000	553 (18.2)	1268 (23.2)	−12.4	550 (19.6)	835 (20.5)	−2.2
≥15,000	521 (17.1)	1234 (22.6)	−13.8	521 (18.6)	920 (18.6)	0.0
Missing	275 (9.0)	495 (9.1)	−0.3	258 (9.2)	1460 (8.7)	1.8

Total may not become 100% owing to rounding off

SD standardized difference

confounding in an observational study [17–19]. To estimate the propensity score, a logistic regression model was used with the baseline independent variables (details are described in Supplemental Text). Etiology, body mass index, and saline for intra-abdominal irrigation were categorized, and missing data were included as a missing category. The C-statistic for evaluating the goodness of fit was calculated. Using a nearest-neighbor matching method, each patient in the PA group was matched with one patient in the HP group without replacement, with the closest estimated propensity within a caliper (0.2 standard deviations of the propensity score). The balance in the baseline variables between the propensity-matched HP and PA groups was examined using standardized differences, where $>10\%$ was regarded as imbalanced [20, 21]. We also used a propensity score method for inverse probability of treatment weighting (IPTW) using the same population as that in the propensity score matching analysis. Each patient was weighted by the inverse probability of being in the observed group [22, 23]. In the propensity score analyses, the risk differences and 95% confidence intervals (CI) in 30-day mortality were calculated. Same calculation was performed for subgroups. Postoperative complication rates were compared between HP and PA groups using the risk differences and their 95% CIs. We also compared the proportions and the duration receiving postoperative critical care procedures between the HP and PA groups, using the Chi-square test and Wilcoxon rank-sum test.

Instrumental variable analysis

Propensity score analysis cannot remove hidden biases caused by unmeasured confounders. We therefore conducted an instrumental variable (IV) analysis to control for unmeasured confounders as a confirmatory analysis of the propensity score analyses. The IV method seeks to find a randomized test embedded in an observational study and use this embedded randomized test to estimate the treatment effect [24, 25].

We used “last surgical procedure at the hospital” as an instrumental variable. This means the most recently performed surgical procedure for colorectal perforation at the same hospital was used for the instrumental variable. In this approach, if the last surgical procedure performed at the same hospital was HP, the hospital was regarded as an HP preference for each patient. Otherwise, the hospital was regarded as a PA preference [26, 27]. The last surgical procedure rule was used as an IV for the treatment selection because it was considered independent of patient characteristics and not directly related to the outcome [26]. In the IV analysis, we excluded hospitals that had fewer than 10 surgical patients [28]. We tested the strength of the IV using partial F-statistics, which greater than 10 suggests

that the instrument is not weak [29]. To further assess the validity of our instrument, we examined the covariate balance [30]. We used a two-stage least-squares regression with the same covariates as in the propensity score estimation for IV analysis to estimate the risk difference and its 95% CI for 30-day mortality.

Categorical variables are presented as numbers and percentages. Continuous variables are presented as median and interquartile range. All tests of significance were two-tailed, and $P < 0.05$ was considered significant. All statistical analyses were conducted using IBM SPSS version 22 (IBM Corp., Armonk, NY, USA) and STATA/MP 14.0 (Stata Corp., College Station, TX, USA).

Results

A total of 8500 eligible patients with colorectal perforation were treated during the study period. There were 5455 HP patients and 3045 PA without diverting stoma patients, from which 2800 propensity score-matched pairs were generated (Fig. 1). The C-statistic was 0.62 in the model for calculating propensity scores.

Table 1 shows the baseline characteristics of the unmatched and propensity score-matched groups. In the unmatched groups, significantly higher proportions of HP patients were older or female, had disseminated intravascular coagulation, received a vasopressor or albumin on day 1, or had physiological saline for intra-abdominal irrigation during surgery. Patients were significantly more likely to receive PA if they were younger or male, or had diverticular perforation. The distributions of the variables in the propensity score-matched groups were well balanced.

There were no significant differences in 30-day mortality between the HP and PA groups in the unmatched patients (9.4% vs. 8.8%; risk difference, -0.5% ; 95% CI, -1.8 to 0.7); however, significant differences were observed in the propensity score-matched patients (7.7% vs. 9.6%; risk difference, 1.9% ; 95% CI, 0.5 – 3.4). In the propensity score IPTW analysis, significant differences were observed (8.8% vs. 10.7%; risk difference, 1.9% ; 95% CI, 1.0 – 2.8) (Fig. 2).

In the IV analysis, we identified 5563 eligible patients (HP 3575; PA 1988). The F-statistic was calculated to be 202 ($P < 0.001$). As noted in the Supplemental Table 2, patient backgrounds were well balanced between the groups with HP preference and PA preference in the IV analysis. There were no significant differences in 30-day mortality (risk difference, 4.4% ; 95% CI, -3.3 to 12.1) (Fig. 2).

Table 2 shows postoperative complications in the propensity score-matched groups. There was no significant difference in overall postoperative complication rates

Fig. 1 Study flow diagram detailing the stratification and selection of patients with colorectal perforation in the 2010–2014 Diagnosis Procedure Combination database

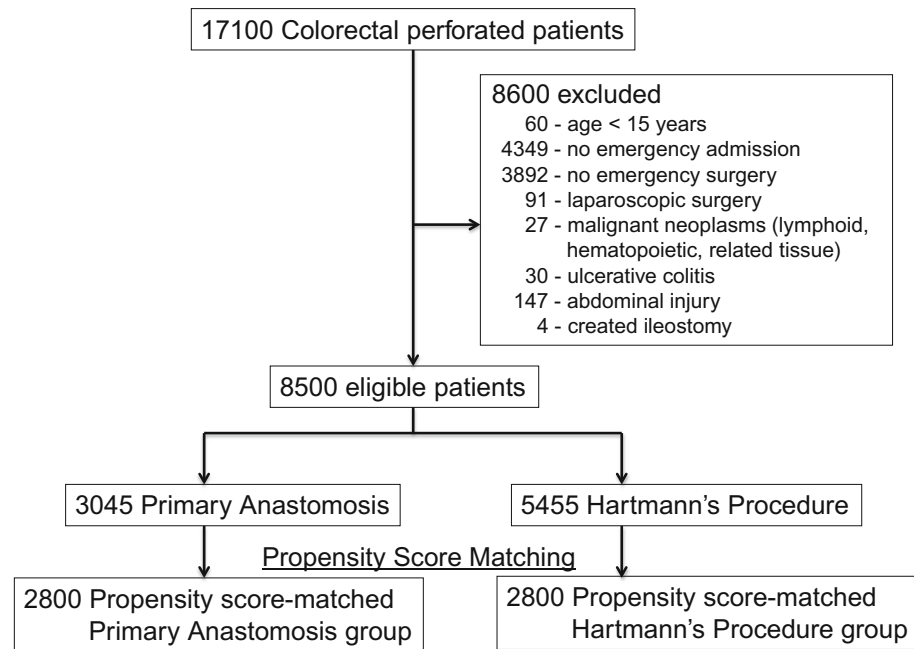
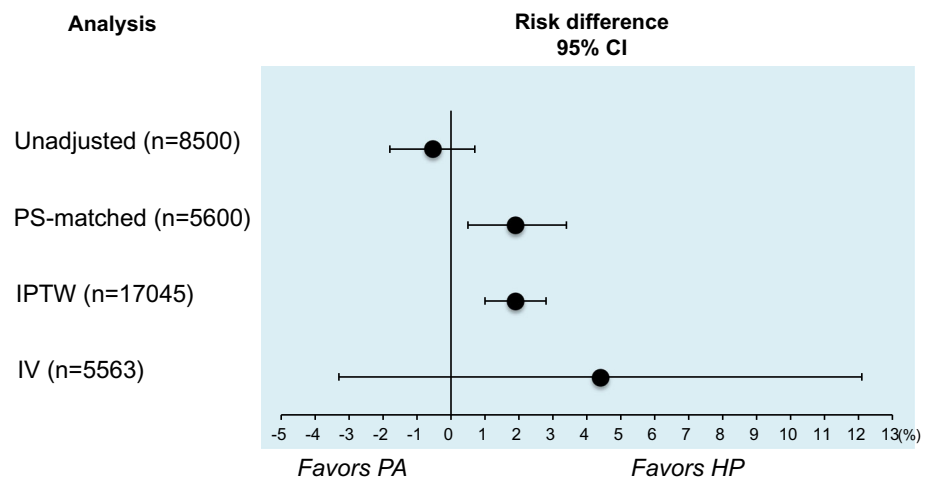


Fig. 2 Risk difference in 30-day mortality between PA and HP. *PS* propensity score, *IPTW* inverse probability of treatment weighting, *IV* instrumental variable, *PA* primary anastomosis, *HP* Hartmann's procedure, *CI* confidence interval



between the HP and PA groups. The PA group had a significantly higher proportion requiring secondary surgery for complications under general anesthesia. Anastomotic leaks occurred in 2.4% of the PA group, and stoma recreation or stoma plasty was conducted in 1.4% of the HP group. Medical complications were not significantly different between the HP and PA groups.

Table 3 shows postoperative critical care interventions in the propensity score-matched groups. The number of days of critical care intervention and vasopressor and mechanical ventilation use was lower in the HP group than in the PA group. The interval from admission to starting tube feeding or oral feeding was significantly shorter in the HP group.

Table 4 shows the subgroup analyses of 30-day mortality between the HP and PA groups in the propensity score-matched groups. The PA group had significantly higher 30-day mortality in the subgroups of higher age (≥ 80) category, female sex, vasopressor use, and glucocorticoid administration.

The number of patients who underwent stoma creation for secondary surgery (complications) was 117, and the overall stoma reversal rate was 23.1% (27/117) in the propensity score-matched PA patients who were readmitted to the same hospitals. The overall stoma reversal rate was 30.6% (856/2800) in the propensity score-matched HP patients who were readmitted to the same hospitals.

Table 2 Postoperative complications in propensity score-matched groups

	Matched groups		Risk difference, %	95% confidence interval
	Primary anastomosis (<i>n</i> = 2800) <i>n</i> (%)	Hartmann's procedure (<i>n</i> = 2800) <i>n</i> (%)		
Overall postoperative complications	699 (25.0)	641 (22.9)	2.1	(−0.2 to 4.3)
Surgical complications				
Overall surgical interventions under general anesthesia	235 (8.4)	129 (4.6)	3.8	(2.5 to 5.1)
Anastomotic leak	67 (2.4)	–	–	–
Bleeding	10 (0.4)	22 (0.8)	−0.4	(−0.9 to −0.0)
Intra-abdominal abscess (requiring surgery)	31 (1.1)	34 (1.2)	−0.1	(−0.7 to 0.5)
Intra-abdominal abscess (requiring percutaneous drainage)	60 (2.1)	51 (1.8)	0.3	(−0.4 to 1.1)
Postoperative ileus (requiring surgery)	27 (1.0)	11 (0.4)	0.6	(0.1 to 1.0)
Postoperative ileus (requiring long-tube drainage)	72 (2.6)	54 (1.9)	0.6	(−0.1 to 1.4)
Abdominal wall dehiscence	72 (2.6)	89 (3.2)	−0.6	(−1.5 to 0.3)
Wound infection	97 (3.5)	109 (3.9)	−0.4	(−1.4 to 0.6)
Medical complications	247 (8.8)	241 (8.6)	0.2	(−1.3 to 1.7)
Acute myocardial infarction	10 (0.4)	4 (0.1)	0.2	(−0.1 to 0.5)
Pulmonary embolization or deep venous thrombosis	10 (0.4)	15 (0.5)	−0.2	(−0.6 to 0.2)
Stroke or intracranial hemorrhage	22 (0.8)	31 (1.1)	−0.3	(−0.9 to 0.2)
Urinary tract infection	12 (0.4)	8 (0.3)	0.1	(−0.2 to 0.5)
Acute renal failure	100 (3.6)	95 (3.4)	0.2	(−0.8 to 1.1)
Pneumonia or ventilator-associated pneumonia	51 (1.8)	54 (1.9)	−0.1	(−0.8 to 0.6)
Acute respiratory distress syndrome or lung edema	60 (2.1)	53 (1.9)	0.3	(−0.5 to 1.0)
Stoma complications (Total)	–	69 (2.5)	–	–
Stoma recreation or stoma plasty (under general anesthesia)	–	40 (1.4)	–	–
Stoma plasty (under local anesthesia)	–	9 (0.3)	–	–
Stoma stenosis	–	1 (0.04)	–	–
Parastomal hernia	–	7 (0.3)	–	–
Mucocutaneous separation with skin erosion	–	8 (0.3)	–	–
Stoma prolapse	–	6 (0.2)	–	–

Discussion

This study revealed a significant difference in 30-day mortality between the HP and PA without a diverting stoma groups in the propensity score analyses; however, the difference was insignificant in the IV analysis owing to lack of power. The PA group was significantly more likely to receive secondary surgery for complications and had a slightly longer duration of postoperative critical care interventions.

Because of the rarity of colorectal perforation, large randomized controlled trials comparing HP and PA without a diverting stoma may be practically difficult to implement. Indeed, previous randomized controlled trials were limited as a result of their small sample sizes [9, 10]. Observational studies can be a feasible alternative, but previous observational studies had biases related to measured and unmeasured confounders [14, 31–35].

The current observational study performed robust analyses to adjust for measured and unmeasured confounders. Our propensity score and IV analyses successfully balanced the covariates between the HP and PA groups. Our results showed that the F-statistic was greater than 10, which indicated the IV was not weak. Although the IV analysis showed a wide 95% confidence interval in 30-day mortality, the point estimate suggested similar direction to that of the propensity score analyses and confirmed the consistency of the results. The reason for the wide confidence interval may be that variance of estimates in two-stage least-squares regression analyses is generally much larger than that in linear regression analyses at a given sample size because IV methods involve two estimation stages [36]. Two-stage least-squares regression analyses generally require larger sample sizes to provide an estimate closer on average to the true effect than linear regression analyses [37].

Table 3 Postoperative critical care interventions in the propensity score-matched groups

	Matched groups		<i>P</i> value
	Primary anastomosis (<i>n</i> = 2800)	Hartmann's procedure (<i>n</i> = 2800)	
Vasopressor, <i>n</i> (%)	1453 (51.9)	1422 (50.8)	.41
Mechanical ventilation, <i>n</i> (%)	1219 (43.5)	1223 (43.7)	.91
CRRT, <i>n</i> (%)	315 (11.3)	316 (11.3)	.97
PMX, <i>n</i> (%)	614 (21.9)	632 (22.6)	.56
Central venous catheterization, <i>n</i> (%)	1501 (53.6)	1513 (54.0)	.75
Tube feeding, <i>n</i> (%)	422 (15.1)	398 (14.2)	.36
Oral feeding, <i>n</i> (%)	2583 (92.3)	2624 (93.7)	.032
Duration of critical care interventions, days, median (IQR)			
Vasopressor	3 (1–7)	3 (1–6)	.018
Mechanical ventilation	4 (2–11)	3 (2–8)	<.001
CRRT	3 (2–7)	3 (2–5)	.33
PMX	2 (1–2)	2 (1–2)	.48
Central venous catheterization	11 (6–22)	10 (6–18)	.002
Interval from admission to starting tube feeding	8 (5–15)	6 (4–12)	<.001
Interval from admission to starting oral feeding	6 (5–8)	6 (4–8)	<.001

CRRT continuous renal replacement therapy, IQR interquartile range, PMX polymyxin B hemoperfusion

Table 4 Subgroup analyses of 30-day mortality in propensity score-matched groups

	Matched groups				Risk difference, %	95% confidence interval
	Primary anastomosis		Hartmann's procedure			
	%	No. of deaths/ total no.	%	No. of deaths/ total no.		
Age, years						
15–59	1.6	8/503	1.2	7/567	0.4	(–1.2 to 2.0)
60–69	4.1	22/542	4.2	22/519	–0.2	(–2.7 to 2.3)
70–79	8.4	70/835	7.5	60/804	0.9	(–1.7 to 3.6)
≥80	18.4	169/920	13.9	126/910	4.5	(1.2 to 7.9)
Sex						
Male	8.4	122/1460	7.0	102/1463	1.4	(–0.6 to 3.3)
Female	11.0	147/1340	8.5	113/1337	2.5	(0.3 to 4.8)
Etiology						
Diverticular disease	4.2	36/862	4.5	40/894	–0.3	(–2.2 to 1.6)
Colon carcinoma	9.8	61/624	7.4	45/610	2.4	(–0.7 to 5.6)
Inflammatory bowel disease	0.0	0/22	0.0	0/15	0	(–20.4 to 14.9)
Iatrogenic or foreign objects	0.0	0/13	7.1	1/14	–7.1	(–31.5 to 16.4)
Ischemic disease	29.7	19/64	20.4	11/54	9.3	(–6.6 to 24.1)
Ileus	11.0	10/91	11.4	9/79	–0.4	(–10.5 to 9.2)
Data not provided	12.7	143/1124	9.6	109/1134	3.1	(0.5 to 5.7)
Peritonitis	9.9	203/2056	7.8	162/2071	2.1	(0.3 to 3.8)
Mechanical ventilation (day 1)	22.0	75/341	19.2	58/302	2.8	(–3.5 to 9.0)
Vasopressor (day 1)	18.6	227/1218	14.6	171/1175	4.1	(1.1 to 7.1)
Blood transfusion (day 1)	19.0	123/648	15.3	93/608	3.7	(–0.5 to 7.8)
Glucocorticoid (day 1)	18.7	87/466	13.4	61/455	5.3	(0.5 to 10.0)

Subgroup analyses for etiologies showed no significant difference in 30-day mortality between the HP and PA groups. This suggests that HP and PA without a diverting stoma may be equivalent for any etiology in terms of early mortality. The 30-day mortality rate in patients with vasopressor use, glucocorticoid use, and age of ≥ 80 years was significantly higher in the PA than HP group. Physicians should thus be recommended to select HP surgery for patients with shock, immunosuppressive conditions, or older age, whereas physicians can select PA surgery for patients without severe conditions.

Previous studies showed no significant difference in complication rates between HP and PA for primary surgery [8, 9]. Our study also showed no significant difference in overall complication rates between HP and PA, but also showed that the PA group had higher proportions receiving secondary surgery for complications. Notably, anastomotic leakage was found in 2.4% of the PA group. This may be biologically plausible because anastomosis of inflamed and edematous colon due to perforation is generally difficult. The results thus suggest that PA without a diverting stoma is not necessarily advantageous in terms of requiring secondary surgery for complications in an emergency setting.

The proportions receiving postoperative critical care interventions were not significantly different between the HP and PA groups. Durations of critical care interventions were slightly longer in the PA group, possibly because the PA group was more likely to have postoperative fecal or intestinal fluid leak than the HP group. However, these slight differences, although statistically significant, may not be clinically important.

The stoma reversal rates in this study (30.6% in the HP group and 23.1% in the PA group) were lower than those in previous studies (40–60%) [38, 39]. One reason for the relatively low stoma reversal rate in our study may be that our patients were relatively old; $>60\%$ of patients were older than 70 years, and $>30\%$ of patients were older than 80 years. Therefore, the physicians may have hesitated to perform stoma reversal surgery in consideration of the patients' life expectancy. For patients who underwent stoma creation after PA surgery, stoma closure would be the third operation. Thus, most patients may have hesitated to also undergo a stoma reversal surgery.

The strengths of our study were: (1) inclusion of the largest number of patients compared with previous studies; (2) investigation of various etiologies; (3) comparison of surgical procedures of HP versus PA without a diverting stoma; (4) investigation of postoperative critical care interventions; and (5) use of advanced analytic methods for observational studies, such as propensity score and IV analyses. The current study thus provided more valid outcomes after stricter analysis compared with previous studies. However, the study has several limitations. First,

although a propensity score method was used to adjust for differences in baseline characteristics and disease severity, bias could still be present in the form of confounders, such as the surgeons who performed the surgery and presence of intra-abdominal debris, which can be expressed as the Mannheim peritonitis index or Hinchey classification stage [40, 41]. Surgeons' attributes, such as surgical knowledge, clinical training, experience, and inherent skills, can influence outcomes [9]. We tried to adjust for these unmeasured confounders using IV analysis, which can theoretically adjust for such unmeasured confounders. Second, the database did not contain clinical data about laboratory findings and vital signs. Instead, we used mechanical ventilation or vasopressor use and blood transfusion or albumin administration as markers of respiratory failure, shock, and abnormal laboratory findings [42]. Third, to handle missing data, we categorized the etiology, body mass index, and saline for intra-abdominal irrigation data and included a category for missing values. After propensity score matching, the proportions of patients with missing data were well balanced between the HP and PA groups. Fourth, we could not distinguish between right or left hemicolectomy because of a lack of the relevant data in the database. However, a previous study showed no significant difference between the therapies for right-sided and left-sided diverticulitis [43], and the site of perforation of colorectal diverticulitis, malignancy, or other diseases was not associated with worse short-term outcomes [43–45]. Finally, we could not evaluate long-term outcomes in the current study because we could not follow up patients after discharge from hospital apart from patients who were readmitted to the same hospitals. Thus, we could not detect stoma reversal surgery which was done at another hospital.

Conclusions

This retrospective observational nationwide study revealed a significant difference in 30-day mortality between HP and PA without a diverting stoma in adult patients with various underlying etiologies. Physicians should be recommended to select HP surgery for patients with shock, immunosuppressive conditions, or advanced age. Further large-scale investigations or randomized controlled trials are required to adjust for unmeasured confounders.

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Compliance with ethical standards

Conflict of interest All other authors have no conflicts of interest.

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