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The Effectiveness of Anti-Adhesion Barriers on Prevention of Postoperative Adhesive Bowel Obstruction: Disease-Free Survival Analysis

Shota Ebinuma^{1,2} | Susumu Kunisawa¹  | Daisuke Takada^{1,3} | Kiyohide Fushimi⁴ | Akinobu Taketomi² | Yuichi Imanaka^{1,5} 

¹Department of Healthcare Economics and Quality Management, Graduate School of Medicine, Kyoto University, Kyoto, Japan | ²Department of Gastroenterological Surgery 1, Hokkaido University Graduate School of Medicine, Sapporo, Japan | ³Department of Food Science and Nutrition, Faculty of Human Life and Science, Doshisha Women's College of Liberal Arts, Kyotanabe, Japan | ⁴Department of Health Policy and Informatics, Institute of Science Tokyo Graduate School of Medical and Dental Sciences, Tokyo, Japan | ⁵Department of Health Security System, Center for Health Security, Graduate School of Medicine, Kyoto University, Kyoto, Japan

Correspondence: Yuichi Imanaka (imanaka-y@umin.net)

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Keywords: abdominal gastroenterological cancers | anti-adhesion barriers | disease-free survival analysis | postoperative adhesive bowel obstruction | propensity score matching

ABSTRACT

Background: Anti-adhesion barriers are effective in reducing adhesion formation, but their impact on preventing adhesive bowel obstruction remains unclear. This study aimed to evaluate the effectiveness of anti-adhesion barriers in preventing adhesive bowel obstruction using a nationwide medical database in Japan.

Method: Surgical cases for abdominal gastroenterological cancers were categorized into six categories based on procedure type (Open or Laparoscopic) and target organ (Stomach, Colorectum, and Hepatobiliary-pancreas). Patients were classified into an anti-adhesion barriers group (treatment) or a non-anti-adhesion barriers group (comparison). Propensity score matching was performed to balance baseline characteristics. Survival analysis with hospitalizations due to adhesive bowel obstruction as the outcome was conducted, and hazard ratios (HR) were calculated using univariate Cox regression analysis.

Results: A total of 163 194 cases were analyzed. In the Open Colorectum and Laparoscopic Colorectum categories, the cumulative incidence curve for the treatment group was lower than that of the comparison group (Log-rank test; Open Colorectum: $p < 0.01$, Laparoscopic Colorectum: $p = 0.01$). The HR was significantly lower in both categories (Open Colorectum: 0.87 [95% CI: 0.80–0.95], Laparoscopic Colorectum: 0.84 [95% CI: 0.73–0.96]). In other categories, no significant differences were found between the two groups. [Correction added on 2 February 2026, after first online publication: The p values of Open Colorectum and Laparoscopic Colorectum have been corrected.]

Conclusion: This study suggests that anti-adhesion barriers use could effectively reduce the risk of adhesive bowel obstruction in Open Colorectum and Laparoscopic Colorectum surgeries, but not in Open Stomach, Open Hepatobiliary-pancreas, or Laparoscopic Stomach surgeries. Further research is needed to confirm these findings and explore broader applications.

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1 | Introduction

Adhesive bowel obstruction is a serious complication in abdominal surgery and remains a major clinical concern. Postoperative adhesive bowel obstruction occurs in approximately 10% of patients following colon surgery, leading to substantial healthcare costs and morbidity [1]. This condition can sometimes necessitate invasive treatments, resulting in further risks to patients [2]. To prevent postoperative adhesions that cause adhesive bowel obstruction, anti-adhesive barriers are used in clinical practice [3, 4].

Numerous studies have been reported to investigate the effectiveness of anti-adhesion barriers in preventing adhesive bowel obstruction, but the results have been inconsistent. Although anti-adhesion barriers have demonstrated efficacy in reducing postoperative adhesion formation itself that could cause various adverse events (organ damage during subsequent surgeries, infertility, chronic pelvic pain, and adhesive bowel obstruction), their impact on preventing adhesive bowel obstruction remains inconsistent [5, 6]. Several randomized controlled trials and systematic reviews have assessed the effectiveness of anti-adhesion barriers in preventing adhesive bowel obstruction [7–11]. Even after the publication of systematic reviews, subsequent studies, including recent large-scale database analyses, have reported conflicting results [12–16]. Moreover, the timing of adhesive bowel obstruction occurrence varies widely, and the observation periods in previous studies have been inconsistent, making it difficult to determine the temporal trends of adhesive bowel obstruction development [17].

The aim of the study is to evaluate the effectiveness of anti-adhesion barriers in preventing adhesive bowel obstruction. Using a nationwide medical database, we collected gastroenterological cancer surgery cases and categorized them by operative procedure and organ. We classified the cases into two groups based on whether anti-adhesion barriers were used during surgery and conducted a survival analysis to assess the impact of anti-adhesion barriers use on the prevention of adhesive bowel obstruction.

2 | Methods

2.1 | Data Source

We utilized the Diagnosis Procedure Combination (DPC) database maintained by the research group funded by Japan's Ministry of Health, Labour and Welfare. Participating hospitals voluntarily provide data to this group annually. In 2016, approximately 1200 hospitals contributed to this database [18].

The DPC database comprises several files. Form 1 contains discharge summaries, including disease names (the primary disease, the trigger disease, the most and second-most medical-resource-intensive disease, and comorbidities coded based on the International Classification of Diseases 10th Revision (ICD-10)), patient demographics (age, sex, height, and weight), admission and discharge dates, and surgical details. Surgical details are recorded using a schedule code consisting of one alphabetic character followed by three to five Arabic numerals or Japanese characters.

Files E and F contain information on medical procedures and medications administered during hospitalization, including

dates and quantities. Each medical procedure and medication is coded using a claim code consisting of nine Arabic numerals. These codes enable case selection and identification of medical services provided.

2.2 | The Study Population

The target population for this study consisted of patients who underwent abdominal gastroenterological cancer surgery. To ensure data consistency, we restricted the analysis to institutions that provided data throughout the observation period uninterrupted.

Inclusion criteria were defined based on the study population. We included cases in which primary abdominal gastroenterological cancer surgeries (stomach, small bowel, colon, rectum, anus, liver, bile duct, and pancreas) were performed between April 2011 and March 2016. These cases were identified by the registration of the gastroenterological cancer ICD-10 code under the most medical-resource-intensive disease category, along with the corresponding gastroenterological cancer surgery codes (Tables S1 and S2).

Exclusion criteria comprised cases with missing data and those involving reoperation after the primary surgery. Reoperations were defined as surgeries performed to treat complications arising from the initial abdominal gastroenterological cancer surgery. Cases meeting these criteria were classified as reoperation cases and excluded from the analysis.

2.3 | Categorizing the Study Population

We categorized the study population into six categories based on the surgical procedure and the target organ. Previous studies have reported that the type of surgical approach—open versus laparoscopic—significantly influences the occurrence of adhesive bowel obstruction [19]. Additionally, prior clinical studies on similar topics have often focused on specific target organs. Considering these factors, we determined that analyzing the data separately by surgical procedure and organ would be appropriate.

The study population was categorized according to the type of surgery (Open or Laparoscopic) and the target organ:

- Stomach
- Colorectum (including small bowel, colon, rectum, and anus)
- Hepatobiliary-pancreas (including liver, bile duct, and pancreas)

2.4 | Treatment

We classified the study population in each category into two groups based on the use of sheet-type anti-adhesion barriers. Cases in which the claim code “730840000” (indicating sheet-type synthetic anti-adhesion barriers) was registered on the date

of surgery were assigned to the group using anti-adhesion barriers (treatment group). All other cases were assigned to the group not using anti-adhesion barriers (comparison group). During the observation period, two types of sheet-type anti-adhesion barriers were covered by the national health insurance in Japan. Although these products differ in their characteristics and mechanisms of adhesion prevention, they share the same clinical purpose—prevention of postoperative adhesion formation. Therefore, we treated them as a single category in this study.

2.5 | Statistical Analysis

We conducted a survival analysis with adhesive bowel obstruction as the primary outcome. Outcomes were defined by identifying hospitalizations in which an ICD-10 code corresponding to adhesive bowel obstruction was registered in the most medical-resource-intensive disease, the primary disease, or the trigger disease. The relevant ICD-10 codes included as follows:

- K56.5: bowel adhesion with obstruction
- K56.6: Other and unspecified bowel obstruction
- K56.7: undetailed ileus
- K91.3: postoperative bowel obstruction

Follow-up was confirmed through the presence of outpatient visit or hospitalization records, with a maximum observation period of 60 months postoperatively. Termination criteria included as follows:

- Interruption of outpatient visits or hospitalization records for more than 1 year
- Abdominal surgery unrelated to bowel obstruction
- Death

Data were combined and tracked using hospital and patient codes from the DPC database Form 1.

We performed propensity score (PS) matching and analyzed the matched cohort to balance covariates between the treatment and comparison groups [20]. PS were calculated using a logistic regression model, incorporating covariates possibly associated with treatment or outcomes, which were extracted from the database. The covariates included as follows:

- Patient demographics: age, sex, and body mass index (BMI)
- Comorbidities: hypertension, arrhythmia, chronic heart failure, ischemic heart disease, diabetes, chronic obstructive pulmonary disease (COPD), asthma, and cerebrovascular disease
- Medications: antithrombotic and steroid use
- Other factors: maintenance hemodialysis, cancer stage, high-volume center, and general anesthesia time

High-volume centers were defined based on previous studies, as no clear standard definition exists [21]. For this study, we defined a high-volume center as a facility that performs at least:

- 30 stomach surgeries per year
- 50 colorectal surgeries per year
- 30 hepatobiliary-pancreatic surgeries per year

We performed 1:1 nearest neighbor PS matching with a maximum caliper width of 0.1 of the standardized deviation of the logit of the PS. Covariate balance between the two groups was assessed using the absolute standardized difference (ASD) in both the pre-matched and matched cohorts [22].

After obtaining the matched cohort, we evaluated the effectiveness of the treatment using survival analysis. Cumulative incidence curves were constructed with hospitalization due to adhesive bowel obstruction as the outcome, and the log-rank test was performed to assess differences between the two groups. Proportional hazards between the groups were verified using a log-minus-log plot. An adjusted hazard ratio (HR) and its 95% confidence interval (95% CI) were calculated using univariate Cox regression analysis.

All analyses were conducted using R version 4.2.1 (R Foundation for Statistical Computing, Vienna, Austria) with packages “MatchIt”, “survival”, and “survminer”.

3 | Results

3.1 | Characteristics of the Study Cohort

We collected cases from 296 hospitals. During the study period, 178 073 cases met the inclusion criteria. After excluding 14 879 cases based on the exclusion criteria, 163 194 cases were included in the study population (Figure 1).

- Open Stomach: 31 499 cases (comparison group: 14 155; treatment group: 17 344).
- Open Colorectum: 40 016 cases (comparison group: 20 149; treatment group: 19 867).
- Open Hepatobiliary-pancreas: 22 421 cases (comparison group: 13 876; treatment group: 8545).
- Laparoscopic Stomach: 20 438 cases (comparison group: 17 399; treatment group: 3039).
- Laparoscopic Colorectum: 48 357 cases (comparison group: 35 328; treatment group: 13 029).
- Laparoscopic Hepatobiliary-pancreas: 463 cases (comparison group: 361; treatment group: 102).

Baseline demographic and clinical characteristics for the overall cohort and each category are presented in Table 1.

3.2 | Propensity Score Matching

After PS matching, we obtained matched pairs for each category:

- Open Stomach: 13 938 pairs.
- Open Colorectum: 18 603 pairs.
- Open Hepatobiliary-pancreas: 8534 pairs.

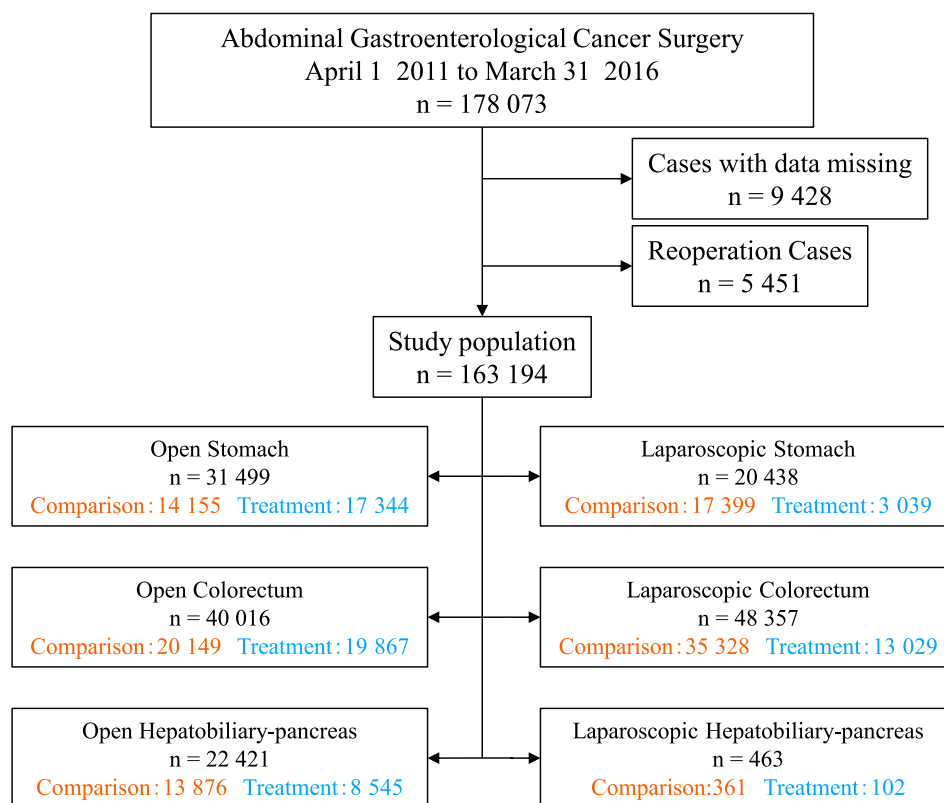


FIGURE 1 | Flowchart for the study population selection process.

- Laparoscopic Stomach: 3027 pairs.
- Laparoscopic Colorectum: 13027 pairs.
- Laparoscopic Hepatobiliary-pancreas: 97 pairs.

The baseline demographic, clinical characteristics of each category before matching are described on the left side and those after matching are on the right side of Tables S3–S8. Figure 2 shows the ASD distribution for each variable before and after PS matching for each category. The ASD after matching was less than 0.1 for almost all variables except for some variables in the Laparoscopic Hepatobiliary-pancreas category.

3.3 | Survival Analysis

Figure 3 shows the cumulative incidence curve of adhesive bowel obstruction for each category. In the Open Colorectum and Laparoscopic Colorectum categories, the treatment group exhibited fewer outcomes compared to the comparison group, with minimal overlap in the 95% CIs throughout the observation period (log-rank test; Open Colorectum: $p < 0.01$, Laparoscopic Colorectum: $p = 0.01$) [Correction added on 2 February 2026, after first online publication: The p values of log-rank test of Laparoscopic Colorectum has been corrected.]. In the Open Stomach, Open Hepatobiliary-pancreas, and Laparoscopic Stomach categories, the cumulative incidence curves of the two groups were close or overlapped for most of the observation period (log-rank test; Open Stomach: $p = 0.1$, Open Hepatobiliary-pancreas: $p = 0.5$, Laparoscopic Stomach: $p = 1.0$) [Correction added on 2 February 2026, after first online publication: The

p values of log-rank test; Open Stomach, Open Hepatobiliary pancreas and Laparoscopic stomach have been corrected.]. In the Laparoscopic Hepatobiliary-pancreas category, the matched cohort size was too small to generate a meaningful cumulative incidence curve.

Figure S1 shows the log-minus-log plots of each category. In the Open Colorectum and Laparoscopic Colorectum categories, the plots for the two groups were approximately parallel without intersecting, suggesting the proportional hazards assumption was not violated. Table 2 presents the number of outcomes in each category, the outcome rate per 100 person-years, and the adjusted HR obtained from the univariate Cox regression model. In the Open Colorectum and Laparoscopic Colorectum categories, the treatment group had fewer outcomes and a lower outcome rate compared to the comparison group. The adjusted HR was less than 1.0, with the 95% CI excluding 1.0 [Correction added on 2 February 2026, after first online publication: The HR values of Open Colorectum and Laparoscopic Colorectum have been corrected.].

- Open Colorectum: HR = 0.87 (95% CI: 0.80–0.95)
- Laparoscopic Colorectum: HR = 0.84 (95% CI: 0.73–0.96)

In the Open Stomach, Open Hepatobiliary-pancreas, and Laparoscopic Stomach categories, the outcome rates varied between groups, but the 95% CIs for the adjusted HR included 1.0 [Correction added on 2 February 2026, after first online publication: The HR values of Open Stomach, Open Hepatobiliary-pancreas and Laparoscopic Stomach have been corrected.].

TABLE 1 | Baseline demographics and clinical characteristics of all study population and each category.

	All <i>n</i> = 163 194	Open Stomach <i>n</i> = 31 499	Open Colorectum <i>n</i> = 40 016	Open Hepatobiliary- pancreas <i>n</i> = 22 421	Laparoscopic Stomach <i>n</i> = 20 438	Laparoscopic Colorectum <i>n</i> = 48 357	Laparoscopic Hepatobiliary- pancreas <i>n</i> = 463
Demographics							
Age (mean (SD))	69.6 (11)	70.6 (10.6)	71.1 (11.4)	69.5 (9.7)	67.6 (11.1)	68.7 (11.3)	69.2 (10)
Male (%)	99 779 (61.1)	22 008 (69.9)	22 360 (55.9)	14 338 (63.9)	13 508 (66.1)	27 223 (56.3)	342 (73.9)
Height (cm) (mean (SD))	159.3 (9.4)	159.9 (9.2)	158 (9.7)	159.7 (9.3)	160.7 (9.1)	159.2 (9.4)	160.9 (8.4)
Weight (kg) (mean (SD))	57.3 (11.7)	56.9 (11.4)	55.5 (11.9)	57.7 (11.1)	58.7 (11.2)	58.1 (11.7)	62.3 (24)
BMI (mean (SD))	22.5 (3.6)	22.2 (3.5)	22.1 (3.7)	22.5 (3.4)	22.6 (3.3)	22.8 (3.5)	24 (9.7)
Medical history							
Hypertension (%)	36 925 (22.6)	7077 (22.5)	9014 (22.5)	5945 (26.5)	4139 (20.3)	10 639 (22.0)	111 (24.0)
Arrhythmia (%)	6803 (4.2)	1401 (4.4)	1665 (4.2)	1024 (4.6)	729 (3.6)	1969 (4.1)	15 (3.2)
Heart failure (%)	4412 (2.7)	927 (2.9)	1276 (3.2)	571 (2.5)	374 (1.8)	1250 (2.6)	14 (3.0)
Ischemic heart disease (%)	10 509 (6.4)	2379 (7.6)	2582 (6.5)	1561 (7.0)	1190 (5.8)	2770 (5.7)	27 (5.8)
Diabetes (%)	27 269 (16.7)	4819 (15.3)	6410 (16.0)	6117 (27.3)	2686 (13.1)	7114 (14.7)	123 (26.6)
COPD (%)	1831 (1.1)	465 (1.5)	381 (1.0)	256 (1.1)	239 (1.2)	485 (1.0)	5 (1.1)
Asthma (%)	2372 (1.5)	458 (1.5)	612 (1.5)	298 (1.3)	286 (1.4)	709 (1.5)	9 (1.9)
Cerebrovascular disease (%)	6527 (4.0)	1427 (4.5)	1885 (4.7)	745 (3.3)	689 (3.4)	1769 (3.7)	12 (2.6)
Medications							
Antithrombotic (%)	12 382 (7.6)	2676 (8.5)	3184 (8.0)	2327 (10.4)	1175 (5.7)	2974 (6.2)	46 (9.9)
Steroid (%)	3635 (2.2)	616 (2.0)	1220 (3.0)	564 (2.5)	272 (1.3)	955 (2.0)	8 (1.7)
Hemodialysis (%)	1089 (0.7)	224 (0.7)	335 (0.8)	149 (0.7)	82 (0.4)	292 (0.6)	7 (1.5)
Cancer stage							
0 (%)	2702 (1.7)	29 (0.1)	589 (1.5)	291 (1.3)	34 (0.2)	1759 (3.6)	0 (0)
I (%)	52 743 (32.3)	11 146 (35.4)	5166 (12.9)	3566 (15.9)	16 707 (81.7)	16 006 (33.1)	152 (32.8)
II (%)	41 982 (25.7)	7315 (23.2)	12 861 (32.1)	6622 (29.5)	2130 (10.4)	12 819 (26.5)	235 (50.8)
III (%)	45 115 (27.6)	9146 (29.0)	14 061 (35.1)	6355 (28.3)	1282 (6.3)	14 208 (29.4)	63 (13.6)

(Continues)

TABLE 1 | (Continued)

	All	Open Stomach	Open Colorectum	Open Hepatobiliary-pancreas	Laparoscopic Stomach	Laparoscopic Colorectum	Laparoscopic Hepatobiliary-pancreas
	n = 163 194	n = 31 499	n = 40 016	n = 22 421	n = 20 438	n = 48 357	n = 463
IV (%)	20 652 (12.7)	3863 (12.3)	7339 (18.3)	5587 (24.9)	285 (1.4)	3565 (7.4)	13 (2.8)
Surgical information							
High-volume center (%)	91 653 (56.2)	24 369 (77.4)	31 455 (78.6)	13 372 (59.6)	17 953 (87.8)	42 288 (87.4)	336 (72.6)
Anesthesia time (min) (mean (SD))	301 (95.8)	310.8 (97.2)	272.6 (112.2)	495.3 (172.9)	384.7 (103.7)	332.6 (118.2)	390.2 (135.3)
Treatment							
Anti-adhesive barrier	61 926 (37.9)	17 344 (55.1)	19 867 (49.6)	8545 (38.1)	3039 (14.9)	13 029 (26.9)	102 (22.0)

- Open Stomach: HR = 0.92 (95% CI: 0.83–1.01)
- Open Hepatobiliary-pancreas: HR = 0.94 (95% CI: 0.76–1.15)
- Laparoscopic Stomach: HR = 0.99 (95% CI: 0.75–1.32)

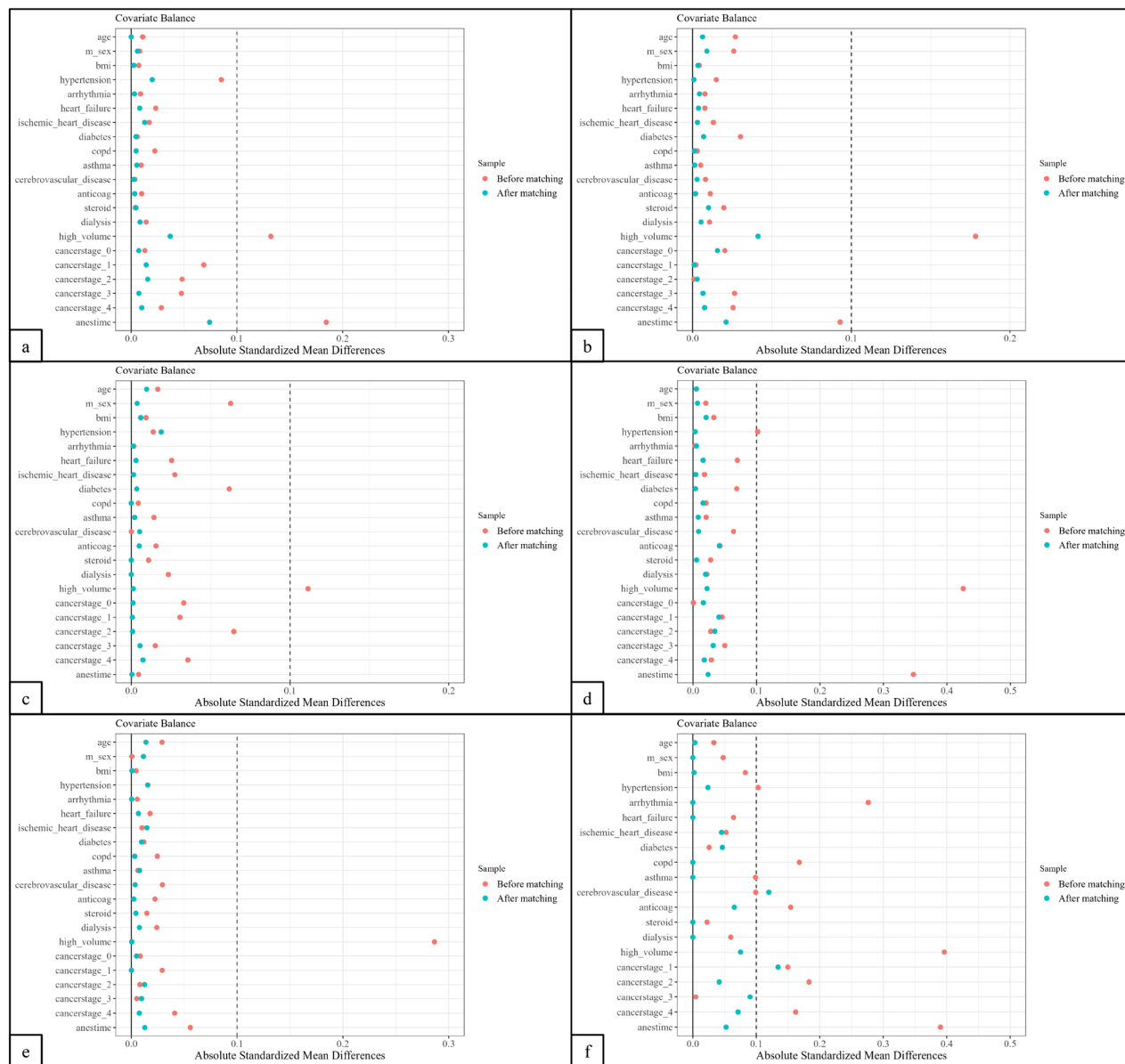
In the Laparoscopic Hepatobiliary-pancreas category, the number of matched pairs and outcomes was too small to estimate an HR.

4 | Discussion

Using the DPC database, we investigated the effectiveness of anti-adhesion barriers use in preventing adhesive bowel obstruction following abdominal gastroenterological cancer surgery. We categorized cases into six categories based on surgical approach and target organ, further classifying each category into treatment and comparison groups according to anti-adhesion barriers usage during surgery. PS matching was applied within each category to ensure covariate balance, and survival analysis was performed with hospitalization due to adhesive bowel obstruction as the primary outcome. Our findings showed that, during the observation period, the treatment group in the Open Colorectum and Laparoscopic Colorectum categories had a significantly lower incidence of adhesive bowel obstruction compared to the comparison group. In contrast, in all other categories, there were no significant differences in outcomes between the two groups. In the Open Colorectum and Laparoscopic Colorectum categories, the log-minus-log plots indicated that the proportional hazards assumption was met. The HR was <1.0, with the 95% CI excluding 1.0, indicating a lower risk of adhesive bowel obstruction in the treatment group.

Our results suggest that anti-adhesion barriers are effective in preventing adhesive bowel obstruction in patients at high risk of developing adhesive bowel obstruction. Intraperitoneal organs are protected by serous fluid circulating in the abdominal cavity and serous membranes covering organ surfaces [23]. During surgery, the drying of serous fluid and damage to the peritoneal membrane caused by surgical manipulation trigger wound healing processes, leading to adhesion formation on organ surfaces. In colorectal surgery, the intestinal tract is subjected to frequent and direct manipulation, increasing the risk of injury to the intestinal surface [24, 25]. Since the primary site of disease in adhesive bowel obstruction is the intestinal tract, adhesion formation in this region may theoretically increase the risk of disease. In contrast, during stomach and hepatobiliary-pancreas surgeries, direct manipulation of the intestinal tract is less frequent, except during the reconstruction phase [26–30]. This difference in surgical manipulation may explain why anti-adhesion barriers were associated with a reduced risk of adhesive bowel obstruction in the colorectal categories but showed no significant effect in the stomach and hepatobiliary-pancreas categories. Benign diseases were not included in the study population because the use of anti-adhesion barriers is not recommended in cases of active inflammation, such as infectious diseases. However, if used appropriately with consideration of the degree of inflammation, the findings of this study may also be applicable to surgical cases involving benign conditions.

This study provides valuable insights into the effectiveness of anti-adhesion barriers in preventing adhesive bowel obstruction. Previous studies have primarily focused on single organs



Meaning of Covariates

Covariates	Meaning
age	Age of the patient
m_sex	Whether the patient is male or not
bmi	Body mass index of the patient
hypertension	Medical history of hypertension
arrhythmia	Medical history of arrhythmia
heart_failure	Medical history of heart failure
ischemic_heart_disease	Medical history of ischemic heart disease
diabetes	Medical history of diabetes
copd	Medical history of chronic obstructive pulmonary disease
asthma	Medical history of asthma
cerebrovascular_disease	Medical history of cerebrovascular disease
anticoag	Whether the patient used antithrombotic drug
steroid	Whether the patient used steroid drug
dialysis	Whether the patient underwent dialysis
high_volume	High-volume center
cancerstage_0	Cancer stage 0
cancerstage_1	Cancer stage I
cancerstage_2	Cancer stage II
cancerstage_3	Cancer stage III
cancerstage_4	Cancer stage IV
anesthetic	General Anesthesia Time

FIGURE 2 | Graph of the distribution of ASD for each variable before and after PS matching in each category: (a) Open Stomach, (b) Open Colorectum, (c) Open Hepatobiliary-pancreas, (d) Laparoscopic Stomach, (e) Laparoscopic Colorectum, and (f) Laparoscopic Hepatobiliary-pancreas.

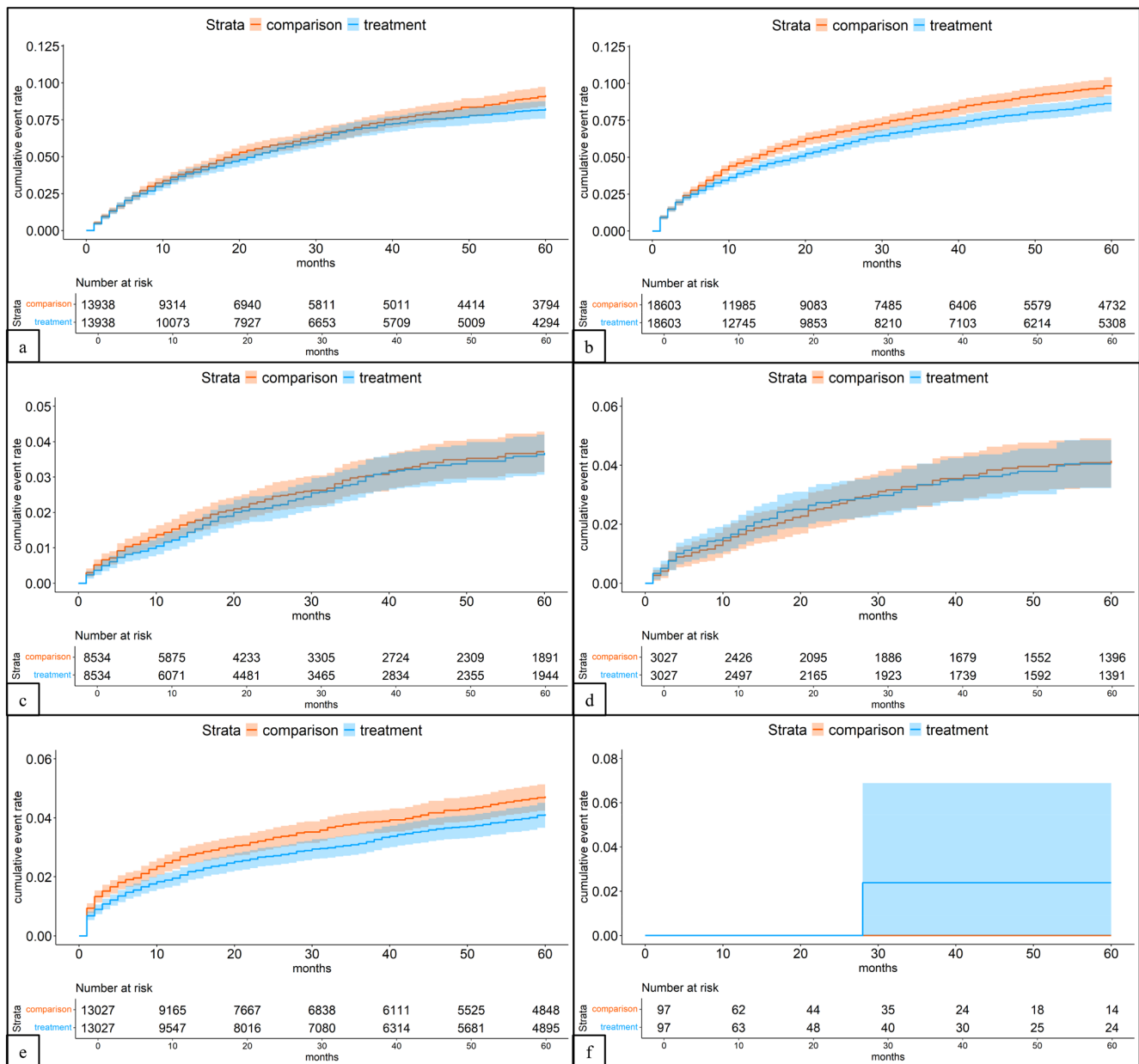


FIGURE 3 | Cumulative incidence curves for each category: (a) Open Stomach, (b) Open Colorectum, (c) Open Hepatobiliary-pancreas, (d) Laparoscopic Stomach, (e) Laparoscopic Colorectum, and (f) Laparoscopic Hepatobiliary-pancreas [Correction added on 2 February 2026, after first online publication: Figure 3 has been replaced].

or procedure [7–15]. More recently, database studies have been conducted, incorporating organ-specific analyses [16]. In this study, we applied survival time analysis to evaluate outcomes for each surgical procedure and organ using a large, real-world database, providing detailed information by visualizing the time trend in the incidence of adhesive bowel obstruction using a cumulative incidence curve. Our findings could be highly suggestive, considering the distinct characteristics of each procedure and organ, including the pathophysiology of adhesive bowel obstruction.

There are several limitations in this study. First, the outcome of this study may not always accurately reflect adhesive bowel obstruction, the primary issue of interest. In the absence of

prior studies utilizing the same database, the outcome was independently defined. However, when comparing the incidence of adhesive bowel obstruction in this study population (7483 out of 163 194 cases; 4.6%) with previously reported rates in the literature (approximately 2.4%–10%, varying by organ and procedure), no significant discrepancies were observed. Although the causes of bowel obstruction are varied and there is still a possibility of misclassification in the diagnosis of adhesive bowel obstruction, this could suggest that the definition used in this study is relatively appropriate [1, 31–34].

Second, some important factors related to adhesive bowel obstruction, such as a history of prior surgeries before the observation period and detailed intraoperative information (e.g.,

TABLE 2 | Outcome summary of each category [Correction added on 2 February 2025, after first online publication: Table 2 has been corrected.].

		Comparison			Treatment		
		Matching Pair	Outcome (%)	Outcome Rate (/100 person-year)	Outcome (%)	Outcome Rate (/100 person-year)	HR (95% CI)
Open	Stomach	13 938	766 (5.5)	2.33	764 (5.5)	2.10	0.92 (0.83–1.01)
	Colorectum	18 603	1 141 (6.1)	2.70	1 048 (5.6)	2.29	0.87 (0.80–0.95)
	Hepatobiliary Pancreas	8 534	187 (2.2)	0.96	181 (2.1)	0.91	0.94 (0.76–1.15)
Laparoscopy	Stomach	3 027	93 (3.1)	0.97	95 (3.1)	0.95	0.99 (0.75–1.32)
	Colorectum	13 027	442 (3.4)	1.22	381 (2.9)	1.02	0.84 (0.73–0.96)
	Hepatobiliary Pancreas	97	0 (0.0)	0	1 (1.0)	<0.01	—

specific procedures and blood loss volume), were not captured in the database. Although propensity score matching was used to adjust for covariates, residual confounding may still exist due to the unavailability of these variables.

Third, follow-up data based on outpatient visits and hospitalization records may not comprehensively represent actual follow-up status. Some patients might have sought care at multiple institutions, and surgeries or postoperative follow-ups might have been conducted at different facilities. As a result, tracking patients who were transferred to other institutions was not possible, a limitation inherent to the nature of the database. However, the follow-up in this study was reasonably comparable to previously reported data. In the CONCORD-3 Study, the 5-year relative survival rates (2010–2014) in Japan were reported as follows: 60.3% for the stomach, 67.8% for the colon, 64.8% for the rectum, 30.1% for the liver, and 8.3% for the pancreas [35]. In this study, the proportion of patients who were followed for at least 5 years postoperatively, regardless of outcome occurrence, was 46.6% for the stomach, 47.2% for the small intestine/colon, 51.0% for the rectum/anus, 41.1% for the liver, and 29.0% for the biliary tract/pancreas. Although the follow-up rates for each organ were lower than those in the CONCORD-3 study, this difference may be attributed to the distinction between relative survival rates reported in the CONCORD-3 study and the observed survival rates in this study. Given these considerations, the follow-up method in this study appears to be reasonable to some extent for survival analysis.

Fourth, this study was conducted using a database from Japan, and the frequency and background of anti-adhesion barrier use observed in this study are specific to Japan and may not be directly generalizable to other countries. However, since no racial differences have been reported in adhesion formation or the effects of anti-adhesion agents, the findings of this study are expected to be applicable to other populations as well. Although the pricing and supply systems of anti-adhesion barriers are likely to vary across countries, the results of this study may serve as a valuable reference for discussions regarding the appropriate indications and conditions for their use in different healthcare settings.

5 | Conclusions

This study suggested that anti-adhesion barriers could be effective in preventing adhesive bowel obstruction in patients undergoing Open Colorectum and Laparoscopic Colorectum surgery, but not in patients undergoing Open Stomach, Open Hepatobiliary-pancreas, or Laparoscopic Stomach surgeries. Due to the limited number of cases, we were unable to conduct a sufficient statistical analysis for laparoscopic hepatobiliary-pancreatic surgeries; therefore, conclusions regarding this group remain inconclusive. As adhesive bowel obstruction remains a critical complication in gastroenterological surgeries, this finding could highlight the potential role of anti-adhesion barriers in improving surgical outcomes. Given the ongoing interest in this field and the continued implementation of prospective studies, further research is warranted to address the limitations of this study—such as the inability to adjust for key clinical factors—and to confirm the effectiveness and broader applicability of anti-adhesion barriers in clinical practice.

Author Contributions

Shota Ebinuma: conceptualization, methodology, data curation, investigation, validation, formal analysis, writing – original draft, writing – review and editing, visualization. **Susumu Kunisawa:** methodology, writing – review and editing, supervision, software. **Daisuke Takada:** methodology, writing – review and editing. **Kiyohide Fushimi:** writing – review and editing, resources. **Akinobu Taketomi:** writing – review and editing. **Yuichi Imanaka:** project administration, writing – review and editing, funding acquisition.

Ethics Statement

This study was approved by the Ethics Committee of the Graduate School of Medicine, Kyoto University (Approval number: R0135).

Consent

Data for this study was anonymized, and individual informed consent was waived.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request. The database generated and analyzed during the study can be obtained from the corresponding author upon reasonable request.

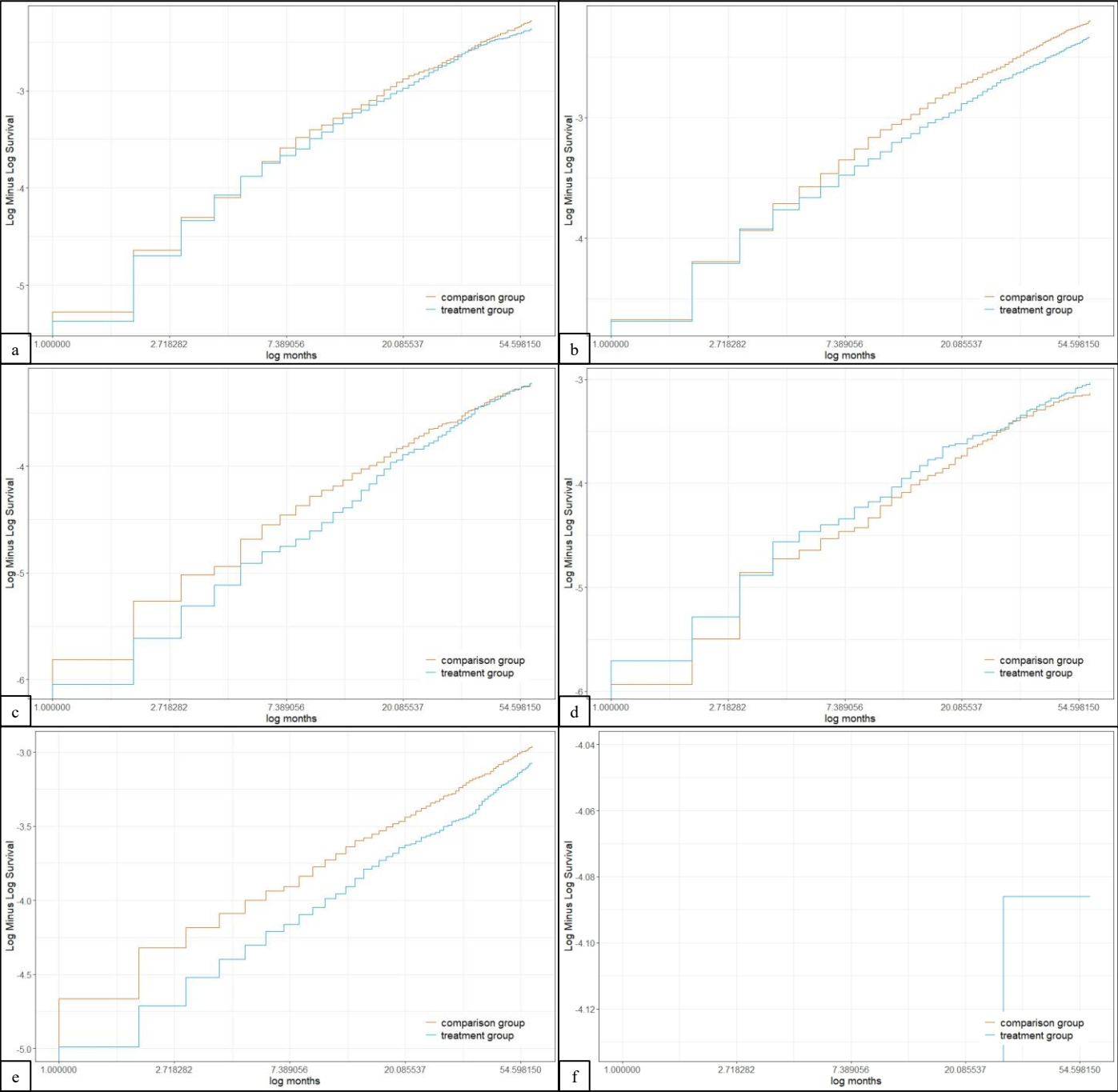
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Supporting Information

Additional supporting information can be found online in the Supporting Information section. **Figure S1:** Log-minus-log plots for each category: (a) Open Stomach, (b) Open Colorectum, (c) Open Hepatobiliary-pancreas, (d) Laparoscopic Stomach, (e) Laparoscopic Colorectum, and (f) Laparoscopic Hepatobiliary-pancreas [Correction added on 2 February 2026, after first online publication: Figure S1 has been replaced.]. **Table S1:** List of operation K codes using in this study. **Table S2:** List of ICD-10 codes using in this study. **Table S3:** Baseline characteristics between treatment and comparison groups for Open Stomach category before and after matching. **Table S4:** Baseline characteristics between treatment and comparison groups for Open Colorectum category before and after matching. **Table S5:** Baseline characteristics between treatment and comparison groups for Open Hepatobiliary-pancreas category before and after matching. **Table S6:** Baseline characteristics between treatment and comparison groups for Laparoscopic Stomach category before and after matching. **Table S7:** Baseline characteristics between treatment and comparison groups for Laparoscopic Colorectum category before and after matching. **Table S8:** Baseline characteristics between treatment and comparison groups for Laparoscopic Hepatobiliary-pancreas category before and after matching.



Supplementary Figure 1

	Code	Operation Name	
Gastric Cancer	K6551	Laparotomic Distal Gastrectomy	Simple Resection
	K6552		Cancer Resection
	K655-21	Laparoscopic Distal Gastrectomy	Simple Resection
	K655-22		Cancer Resection
	K655-23		Cancer Resection (Using Assistive Devices for Endoscopic Surgery)
	K655-41	Laparotomic Proximal Gastrectomy	Simple Resection
	K655-42		Cancer Resection
	K655-51	Laparoscopic Proximal Gastrectomy	Simple Resection
	K655-52		Cancer Resection
	K655-53		Cancer Resection (Using Assistive Devices for Endoscopic Surgery)
	K6571	Laparotomic Gastrectomy	Simple Resection
	K6572		Cancer Resection
	K6573		Cancer Resection (with Jejunostomy)
	K657-21	Laparoscopic Gastrectomy	Simple Resection
	K657-22		Cancer Resection
	K657-23		Cancer Resection (with Jejunostomy)
	K657-24		Cancer Resection (Using Assistive Devices for Endoscopic Surgery)
Small Bowel Cancer	K7161	Laparotomic Small Bowel Resection	Complicated
	K716-21	Laparoscopic Small Bowel Resection	Complicated
Colon Cancer	K7191	Laparotomic Colectomy	Partial Colectomy
	K7192		Hemicolectomy
	K7193		Total Colectomy, Sub-total Colectomy, or Cancer Resection
	K719-21	Laparoscopic Colectomy	Partial Colectomy, Hemicolectomy
	K719-22		Total Colectomy, Sub-total Colectomy
	K719-3	Laparoscopic Colon Cancer Resection	
Rectum Cancer	K7401	Laparotomic Proctectomy	Proctectomy
	K7402		Low Anterior Resection
	K7403		Super Low Anterior Resection
	K7404		Proctectomy with Transanal Intestinal Anastomosis
	K7405		Rectal Amputation
	K740-21	Laparoscopic Proctectomy	Proctectomy
	K740-22		Low Anterior Resection
	K740-23		Super Low Anterior Resection
	K740-24		Proctectomy with Transanal Intestinal Anastomosis
	K740-25		Rectal Amputation
Anal Canal Cancer	K7481	Anal Canal Cancer Resection	Anal Canal Cancer Resection
	K7482		Anal Canal Cancer Resection with Rectal Amputation
Hepatocellular Cancer	K6951 	Laparotomic Hepatectomy	Partial Resection with Simple Resection
	K6951 		Partial Resection with Multiple Resection
	K6952		Sub-segment Resection

	K6953		Lateral Segment Resection
	K6954		One Segment Resection (Excluding Lateral Resection)
	K6955		Two Segments Resection
	K6956		Over Three Segments Resection
	K6957		Over Two Segments Resection with Revascularization
	K695-21 イ	Laparoscopic Hepatectomy	Partial Resection with Simple Resection
	K695-21 □		Partial Resection with Multiple Resection
	K695-22		Subsegmentectomy
	K695-23		Lateral Segment Resection
	K695-24		One Segment Resection (Excluding Lateral Resection)
	K695-25		Two Segments Resection
	K695-26		Over Three Segments Resection
Pancreatic Cancer	K7021 イ	Laparotomic Pancreaticoduodenectomy	Spleen Resection
	K7021 □		Spleen Preserving
	K7022		Lymphadenectomy with Dissection of the Nerve Plexus
	K7023		Combined Resection of Surrounding Organs (Stomach, Colon, Kidney, Adrenal Gland)
	K7024		Pancreaticoduodenectomy with Revascularization
	K702-21	Laparoscopic Pancreaticoduodenectomy	Spleen Resection
	K702-22		Spleen Preserving
	K7031	Laparotomic Pancreatic Head Tumor Resection	Pancreatoduodenectomy
	K7032		Lymphadenectomy with Dissection of the Nerve Plexus or Duodenum Preserving Pancreas Head Resection
	K7033		Combined Resection of Surrounding Organs (Stomach, Colon, Kidney, Adrenal Gland)
	K7034		Pancreaticoduodenectomy with Revascularization
	K703-21	Laparoscopic Pancreatic Head Tumor Resection	Pancreatoduodenectomy
	K703-22		Lymphadenectomy with Dissection of the Nerve Plexus or Duodenum Preserving Pancreas Head Resection
	K704	Laparotomic Pancreatectomy	
Biliary Cancer	K6751	Laparotomic Gall Bladder Cancer Resection	Gall Bladder Cancer Resection (including Lymphadenectomy)
	K6752		with Over Subsegmentectomy
	K6753		with Over Lobectomy
	K6754		with Pancreatoduodenectomy
	K6755		with Pancreatoduodenectomy and Lobectomy
	K675-2	Laparoscopic Gall Bladder Cancer Resection	
	K6771	Biliary Cancer Resection	with Pancreatoduodenectomy and Lobectomy
	K6772		with Pancreatoduodenectomy and Revascularization
	K6773		Extrahepatic Biliary Resection
	K6774		Others
	K677-21	Hilar Biliary Cancer Resection	with Revascularization
	K677-22		without Revascularization

Supplementary Table 1

ICD-10 code	
Abdominal Gastroenterological Cancer	
C16	Malignant neoplasm of the stomach
C17	Malignant neoplasm of the small bowel
C18	Malignant neoplasm of the colon
C19	Malignant neoplasm of the rectosigmoid junction
C20	Malignant neoplasm of the rectum
C21	Malignant neoplasm of the anus and anal canal
C22	Malignant neoplasm of the liver and intrahepatic bile duct
C23	Malignant neoplasm of the gallbladder
C24	Malignant neoplasm of the bile duct
C25	Malignant neoplasm of the pancreas
Adhesive Bowel Obstruction	
K56.5	Bowel adhesion with obstruction [cord]
K56.6	Other and unspecified bowel obstruction
K56.7	Ileus, undetailed
K91.3	Postoperative bowel obstruction
Comorbidity	
I10,I11,I12,I13,I15	Hyper tension
I20,I21,I22,I23,I24,I25	Ischemic heart disease
I47,I48,I49	Arrhythmia
I50	Heart failure
E10,E11	Diabetes
J44	Chronic obstruction pulmonary disease
J45	Asthma
I60,I61,I62,I63,I64,I65,I66,I67,I68,I69	Cerebrovascular disease

Supplementary Table 2

	Before Matching			After Matching		
	Comparison	Treatment		Comparison	Treatment	
	n = 14 155	n = 17 344	ASD	n = 13 938	n = 13 938	ASD
Demographics						
Age (mean (SD))	70.7 (10.5)	70.6 (10.6)	0.01	70.7 (10.6)	70.7 (10.6)	<0.01
Male (%)	9 861 (69.7)	12 147 (70.0)	0.01	9 700 (69.6)	9 738 (69.9)	0.01
Height (cm) (mean (SD))	159.8 (9.2)	159.9 (9.1)	0.02	159.8 (9.2)	159.9 (9.1)	0.01
Weight (kg) (mean (SD))	56.8 (11.4)	56.9 (11.4)	0.01	56.8 (11.4)	56.9 (11.4)	0.01
BMI (mean (SD))	22.2 (3.5)	22.2 (3.5)	0.01	22.2 (3.5)	22.2 (3.5)	<0.01
Medical history						
Hypertension (%)	3 458 (24.4)	3 619 (20.9)	0.09	3 280 (23.5)	3 164 (22.7)	0.02
Arrhythmia (%)	644 (4.5)	757 (4.4)	0.01	623 (4.5)	632 (4.5)	<0.01
Heart failure (%)	386 (2.7)	541 (3.1)	0.02	385 (2.8)	404 (2.9)	0.01
Ischemic heart disease (%)	1 034 (7.3)	1 345 (7.8)	0.02	1 014 (7.3)	1 061 (7.6)	0.01
Diabetes (%)	2 149 (15.2)	2 670 (15.4)	0.01	2 115 (15.2)	2 138 (15.3)	0.01
COPD (%)	188 (1.3)	277 (1.6)	0.02	188 (1.3)	196 (1.4)	0.01
Asthma (%)	197 (1.4)	261 (1.5)	0.01	195 (1.4)	186 (1.3)	0.01
Cerebrovascular disease (%)	647 (4.6)	780 (4.5)	<0.01	634 (4.5)	627 (4.5)	<0.01
Medications						
Antithrombotic (%)	1 181 (8.3)	1 495 (8.6)	0.01	1 164 (8.4)	1 177 (8.4)	<0.01
Steroid (%)	281 (2.0)	335 (1.9)	<0.01	273 (2.0)	264 (1.9)	0.01
Hemodialysis (%)	110 (0.8)	114 (0.7)	0.01	103 (0.7)	93 (0.7)	0.01
Cancer Stage						
0 (%)	10 (0.1)	19 (0.1)	0.01	10 (0.1)	13 (0.1)	0.01
I (%)	5 265 (37.2)	5 881 (33.9)	0.07	5 131 (36.8)	5 036 (36.1)	0.01
II (%)	3 129 (22.1)	4 186 (24.1)	0.05	3 116 (22.4)	3 208 (23.0)	0.02
III (%)	3 942 (27.8)	5 204 (30.0)	0.05	3 928 (28.2)	3 974 (28.5)	0.01
IV (%)	1 809 (12.8)	2 054 (11.8)	0.03	1 753 (12.6)	1 707 (12.2)	0.01
Surgical Information						
High-volume Center (%)	11 379 (80.4)	12 990 (74.9)	0.13	11 163 (80.1)	10 949 (78.6)	0.04
Anesthesia Time (min) (mean (SD))	301 (95.8)	318.9 (97.6)	0.18	302.5 (95.3)	309.7 (94.2)	0.08

Supplementary Table 3

	Before Matching			After Matching		
	Comparison	Treatment	ASD	Comparison	Treatment	ASD
	n = 20 149	n = 19 867		n = 18 603	n = 18 603	
Demographics						
Age (mean (SD))	71.3 (11.4)	71 (11.3)	0.03	71 (11.5)	71 (11.3)	0.01
Male (%)	11 130 (55.2)	11 230 (56.5)	0.03	10 446 (56.2)	10 529 (56.6)	0.01
Height (cm) (mean (SD))	157.9 (9.8)	158.2 (9.7)	0.03	158.1 (9.7)	158.2 (9.7)	0.01
Weight (kg) (mean (SD))	55.5 (11.9)	55.6 (11.8)	0.02	55.6 (12)	55.7 (11.8)	0.01
BMI (mean (SD))	22.1 (3.7)	22.1 (3.6)	<0.01	22.1 (3.7)	22.1 (3.6)	<0.01
Medical history						
Hypertension (%)	4 601 (22.8)	4 413 (22.2)	0.02	4 084 (22.0)	4 090 (22.0)	<0.01
Arrhythmia (%)	823 (4.1)	842 (4.2)	0.01	773 (4.2)	789 (4.2)	<0.01
Heart failure (%)	629 (3.1)	647 (3.3)	0.01	591 (3.2)	603 (3.2)	<0.01
Ischemic heart disease (%)	1 268 (6.3)	1 314 (6.6)	0.01	1 215 (6.5)	1 229 (6.6)	<0.01
Diabetes (%)	3 117 (15.5)	3 293 (16.6)	0.03	3 001 (16.1)	3 048 (16.4)	0.01
COPD (%)	189 (0.9)	192 (1.0)	<0.01	178 (1.0)	180 (1.0)	<0.01
Asthma (%)	302 (1.5)	310 (1.6)	0.01	286 (1.5)	289 (1.6)	<0.01
Cerebrovascular disease (%)	932 (4.6)	953 (4.8)	0.01	878 (4.7)	889 (4.8)	<0.01
Medications						
Antithrombotic (%)	1 573 (7.8)	1 611 (8.1)	0.01	1 490 (8.0)	1 499 (8.1)	<0.01
Steroid (%)	648 (3.2)	572 (2.9)	0.02	518 (2.8)	550 (3.0)	0.01
Hemodialysis (%)	159 (0.8)	176 (0.9)	0.01	157 (0.8)	166 (0.9)	0.01
Cancer Stage						
0 (%)	321 (1.6)	268 (1.3)	0.02	225 (1.2)	260 (1.4)	0.02
I (%)	2 608 (12.9)	2 558 (12.9)	<0.01	2 400 (12.9)	2 394 (12.9)	<0.01
II (%)	6 472 (32.1)	6 389 (32.2)	<0.01	5 994 (32.2)	5 969 (32.1)	<0.01
III (%)	6 954 (34.5)	7 107 (35.8)	0.03	6 671 (35.9)	6 613 (35.5)	0.01
IV (%)	3 794 (18.8)	3 545 (17.8)	0.03	3 313 (17.8)	3 367 (18.1)	0.01
Surgical Information						
High-volume Center (%)	16 567 (82.2)	14 888 (74.9)	0.18	15 023 (80.8)	14 710 (79.1)	0.04
Anesthesia Time (min) (mean (SD))	267.4 (110.6)	277.8 (113.5)	0.09	273.7 (111.7)	276.1 (108.7)	0.02

Supplementary Table 4

	Before Matching			After Matching		
	Comparison	Treatment	ASD	Comparison	Treatment	ASD
	n = 13 876	n = 8 545		n = 8 534	n = 8 534	
Demographics						
Age (mean (SD))	69.5 (9.6)	69.4 (9.7)	0.02	69.5 (9.5)	69.4 (9.7)	0.01
Male (%)	8 715 (62.8)	5 623 (65.8)	0.06	5 597 (65.6)	5 612 (65.8)	<0.01
Height (cm) (mean (SD))	159.4 (9.3)	160.1 (9.3)	0.07	159.9 (9)	160.1 (9.3)	0.02
Weight (kg) (mean (SD))	57.5 (11.2)	57.9 (11.1)	0.04	57.8 (11.1)	57.9 (11.1)	0.01
BMI (mean (SD))	22.5 (3.5)	22.5 (3.4)	0.01	22.5 (3.5)	22.5 (3.4)	0.01
Medical history						
Hypertension (%)	3 647 (26.3)	2 298 (26.9)	0.01	2 223 (26.0)	2 294 (26.9)	0.02
Arrhythmia (%)	632 (4.6)	392 (4.6)	<0.01	390 (4.6)	392 (4.6)	<0.01
Heart failure (%)	332 (2.4)	239 (2.8)	0.03	241 (2.8)	237 (2.8)	<0.01
Ischemic heart disease (%)	929 (6.7)	632 (7.4)	0.03	625 (7.3)	628 (7.4)	<0.01
Diabetes (%)	3 640 (26.2)	2 477 (29.0)	0.06	2 480 (29.1)	2 467 (28.9)	<0.01
COPD (%)	156 (1.1)	100 (1.2)	<0.01	100 (1.2)	100 (1.2)	<0.01
Asthma (%)	193 (1.4)	105 (1.2)	0.01	107 (1.3)	105 (1.2)	<0.01
Cerebrovascular disease (%)	461 (3.3)	284 (3.3)	<0.01	291 (3.4)	283 (3.3)	0.01
Medications						
Antithrombotic (%)	1 415 (10.2)	912 (10.7)	0.02	898 (10.5)	911 (10.7)	0.01
Steroid (%)	358 (2.6)	206 (2.4)	0.01	206 (2.4)	206 (2.4)	<0.01
Hemodialysis (%)	82 (0.6)	67 (0.8)	0.02	65 (0.8)	65 (0.8)	<0.01
Cancer Stage						
0 (%)	160 (1.2)	131 (1.5)	0.03	127 (1.5)	126 (1.5)	<0.01
I (%)	2 266 (16.3)	1 300 (15.2)	0.03	1 302 (15.3)	1 300 (15.2)	<0.01
II (%)	3 942 (28.4)	2 680 (31.4)	0.06	2 677 (31.4)	2 674 (31.3)	<0.01
III (%)	3 969 (28.6)	2 386 (27.9)	0.02	2 407 (28.2)	2 386 (28.0)	0.01
IV (%)	3 539 (25.5)	2 048 (24.0)	0.04	2 021 (23.7)	2 048 (24.0)	0.01
Surgical Information						
High-volume Center (%)	7 988 (57.6)	5 384 (63.0)	0.11	5 378 (63.0)	5 373 (63.0)	<0.01
Anesthesia Time (min) (mean (SD))	495 (176.9)	495.7 (166.2)	0.01	495.8 (175.3)	495.8 (166.2)	<0.01

Supplementary table 5

	Before Matching			After Matching		
	Comparison	Treatment		Comparison	Treatment	
	n = 17 399	n = 3 039	ASD	n = 3 027	n = 3 027	ASD
Demographics						
Age (mean (SD))	67.6 (11.2)	67.7 (11.1)	0.01	67.7 (11.3)	67.7 (11.1)	0.01
Male (%)	11 475 (66.0)	2 033 (66.9)	0.02	2 032 (67.1)	2 022 (66.8)	0.01
Height (cm) (mean (SD))	160.7 (9.1)	160.6 (9)	<0.01	160.8 (9.1)	160.6 (9)	0.02
Weight (kg) (mean (SD))	58.7 (11.2)	59 (11.5)	0.03	59.2 (11.3)	58.9 (11.5)	0.02
BMI (mean (SD))	22.6 (3.3)	22.7 (3.4)	0.03	22.8 (3.3)	22.7 (3.4)	0.02
Medical history						
Hypertension (%)	3 415 (19.6)	724 (23.8)	0.1	716 (23.7)	720 (23.8)	<0.01
Arrhythmia (%)	622 (3.6)	107 (3.5)	<0.01	109 (3.6)	106 (3.5)	0.01
Heart failure (%)	292 (1.7)	82 (2.7)	0.07	88 (2.9)	81 (2.7)	0.01
Ischemic heart disease (%)	1 002 (5.8)	188 (6.2)	0.02	191 (6.3)	188 (6.2)	<0.01
Diabetes (%)	2 225 (12.8)	461 (15.2)	0.07	460 (15.2)	456 (15.1)	<0.01
COPD (%)	209 (1.2)	30 (1.0)	0.02	35 (1.2)	30 (1.0)	0.02
Asthma (%)	237 (1.4)	49 (1.6)	0.02	46 (1.5)	49 (1.6)	0.01
Cerebrovascular disease (%)	555 (3.2)	134 (4.4)	0.06	137 (4.5)	132 (4.4)	0.01
Medications						
Antithrombotic (%)	974 (5.6)	201 (6.6)	0.04	231 (7.6)	201 (6.6)	0.04
Steroid (%)	223 (1.3)	49 (1.6)	0.03	51 (1.7)	49 (1.6)	0.01
Hemodialysis (%)	66 (0.4)	16 (0.5)	0.02	11 (0.4)	15 (0.5)	0.02
Cancer Stage						
0 (%)	29 (0.2)	5 (0.2)	<0.01	3 (0.1)	5 (0.2)	0.02
I (%)	14 269 (82.0)	2 438 (80.2)	0.05	2 382 (78.7)	2 430 (80.3)	0.04
II (%)	1 791 (10.3)	339 (11.2)	0.03	371 (12.3)	339 (11.2)	0.03
III (%)	1 059 (6.1)	223 (7.3)	0.05	243 (8.0)	219 (7.2)	0.03
IV (%)	251 (1.4)	34 (1.1)	0.03	28 (0.9)	34 (1.1)	0.02
Surgical Information						
High-volume Center (%)	15 695 (90.2)	2 258 (74.3)	0.43	2 283 (75.4)	2 258 (74.6)	0.02
Anesthesia Time (min) (mean (SD))	379.2 (100.8)	416.5 (113.8)	0.35	417.7 (118.2)	415.1 (111.6)	0.02

Supplementary Table 6

	Before Matching			After Matching		
	Comparison	Treatment	ASD	Comparison	Treatment	ASD
	n = 35 328	n = 13 029		n = 13 027	n = 13 027	
Demographics						
Age (mean (SD))	68.6 (11.3)	68.9 (11.2)	0.03	68.8 (11.2)	68.9 (11.2)	0.01
Male (%)	19 886 (56.3)	7 337 (56.3)	<0.01	7 261 (55.7)	7 335 (56.3)	0.01
Height (cm) (mean (SD))	159.2 (9.4)	159.2 (9.5)	<0.01	159 (9.5)	159.2 (9.5)	0.02
Weight (kg) (mean (SD))	58 (11.7)	58.1 (11.9)	0.01	58 (11.7)	58.1 (11.9)	0.01
BMI (mean (SD))	22.8 (3.5)	22.8 (3.6)	0.01	22.8 (3.6)	22.8 (3.6)	<0.01
Medical history						
Hypertension (%)	7 834 (22.2)	2 805 (21.5)	0.02	2 721 (20.9)	2 804 (21.5)	0.02
Arrhythmia (%)	1 449 (4.1)	520 (4.0)	0.01	521 (4.0)	520 (4.0)	<0.01
Heart failure (%)	886 (2.5)	364 (2.8)	0.02	350 (2.7)	364 (2.8)	0.01
Ischemic heart disease (%)	2 001 (5.7)	769 (5.9)	0.01	724 (5.6)	769 (5.9)	0.02
Diabetes (%)	5 157 (14.6)	1 957 (15.0)	0.01	1 910 (14.7)	1 955 (15.0)	0.01
COPD (%)	377 (1.1)	108 (0.8)	0.03	104 (0.8)	108 (0.8)	<0.01
Asthma (%)	525 (1.5)	184 (1.4)	0.01	196 (1.5)	184 (1.4)	0.01
Cerebrovascular disease (%)	1 239 (3.5)	530 (4.1)	0.03	519 (4.0)	528 (4.1)	<0.01
Medications						
Antithrombotic (%)	2 121 (6.0)	853 (6.5)	0.02	844 (6.5)	851 (6.5)	<0.01
Steroid (%)	678 (1.9)	277 (2.1)	0.02	284 (2.2)	276 (2.1)	<0.01
Hemodialysis (%)	195 (0.6)	97 (0.7)	0.02	104 (0.8)	96 (0.7)	0.01
Cancer Stage						
0 (%)	1 270 (3.6)	489 (3.8)	0.01	477 (3.7)	489 (3.8)	<0.01
I (%)	11 824 (33.5)	4 182 (32.1)	0.03	4 182 (32.1)	4 181 (32.1)	<0.01
II (%)	9 331 (26.4)	3 488 (26.8)	0.01	3 416 (26.2)	3 488 (26.8)	0.01
III (%)	10 402 (29.4)	3 806 (29.2)	0.01	3 863 (29.7)	3 806 (29.2)	0.01
IV (%)	2 501 (7.1)	1 064 (8.2)	0.04	1 089 (8.4)	1 063 (8.2)	0.01
Surgical Information						
High-volume Center (%)	31 855 (90.2)	10 433 (80.1)	0.29	10 431 (80.1)	10 433 (80.1)	<0.01
Anesthesia Time (min) (mean (SD))	330.8 (117.3)	337.4 (120.4)	0.06	335.8 (122.2)	337.4 (120.3)	0.01

Supplementary Table 7

	Before Matching			After Matching		
	Comparison	Treatment	ASD	Comparison	Treatment	ASD
	n = 361	n = 102		n = 97	n = 97	
Demographics						
Age (mean (SD))	69.1 (10.1)	69.5 (9.4)	0.03	69.3 (11.4)	69.3 (9.6)	<0.01
Male (%)	265 (73.4)	77 (75.5)	0.05	72 (74.2)	72 (74.2)	<0.01
Height (cm) (mean (SD))	160.9 (8.5)	160.7 (8)	0.03	160.2 (8.6)	160.5 (8.1)	0.04
Weight (kg) (mean (SD))	62.7 (26.5)	60.9 (11.1)	0.09	60.5 (12.1)	60.8 (11.3)	0.03
BMI (mean (SD))	24.1 (10.9)	23.5 (3.5)	0.08	23.5 (3.9)	23.5 (3.5)	<0.01
Medical history						
Hypertension (%)	83 (23.0)	28 (27.5)	0.1	26 (26.8)	27 (27.8)	0.02
Arrhythmia (%)	7 (1.9)	8 (7.8)	0.28	4 (4.1)	4 (4.1)	<0.01
Heart failure (%)	10 (2.8)	4 (3.9)	0.06	4 (4.1)	4 (4.1)	<0.01
Ischemic heart disease (%)	22 (6.1)	5 (4.9)	0.05	4 (4.1)	5 (5.2)	0.05
Diabetes (%)	95 (26.3)	28 (27.5)	0.03	24 (24.7)	26 (26.8)	0.05
COPD (%)	5 (1.4)	0 (0.0)	0.17	97 (100.0)	97 (100.0)	<0.01
Asthma (%)	8 (2.2)	1 (1.0)	0.1	1 (1.0)	1 (1.0)	<0.01
Cerebrovascular disease (%)	8 (2.2)	4 (3.9)	0.1	2 (2.1)	4 (4.1)	0.12
Medications						
Antithrombotic (%)	32 (8.9)	14 (13.7)	0.15	14 (14.4)	12 (12.4)	0.06
Steroid (%)	6 (1.7)	2 (2.0)	0.02	2 (2.1)	2 (2.1)	<0.01
Hemodialysis (%)	6 (1.7)	1 (1.0)	0.06	1 (1.0)	1 (1.0)	<0.01
Cancer Stage						
I (%)	124 (34.3)	28 (27.5)	0.15	34 (35.1)	28 (28.9)	0.14
II (%)	176 (48.8)	59 (57.8)	0.18	52 (53.6)	54 (55.7)	0.04
III (%)	49 (13.6)	14 (13.7)	<0.01	11 (11.3)	14 (14.4)	0.09
IV (%)	12 (3.3)	1 (1.0)	0.24	0 (0.0)	1 (1.0)	0.1
Surgical Information						
High-volume Center (%)	249 (69.0)	87 (85.3)	0.4	85 (87.6)	82 (84.5)	0.09
Anesthesia Time (min) (mean (SD))	378.5 (131.5)	431.6 (141)	0.39	423.2 (125.3)	430.3 (142.8)	0.05

Supplementary Table 8