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Bile leak incidence, risk factors and associated outcomes in patients undergoing hepatectomy: a contemporary NSQIP propensity matched analysis

Charles C. Vining[1] · Kristine Kuchta[2] · Amr I. Al Abbas[3] · Phillip J. Hsu[4] · Pierce Paterakos[2] · Darryl Schuitevoerder[4] · Divya Sood[4] · Kevin K. Roggin[4] · Mark S. Talamonti[2] · Melissa E. Hogg[2]

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Abstract

Background Despite advances in surgical technique, bile leak remains a common complication following hepatectomy. We sought to identify incidence of, risk factors for, and outcomes associated with biliary leak.

Study design This is an ACS-NSQIP study. Distribution of bile leak stratified by surgical approach and hepatectomy type were identified. Univariate and multivariate factors associated with bile leak and outcomes were evaluated.

Results Robotic hepatectomy was associated with less bile leak (5.4% vs. 11.4%; $p<0.001$) compared to open. There were no significant differences in bile leak between robotic and laparoscopic hepatectomy (5.4% vs. 5.3%; $p=0.905$, respectively). Operative factors risk factors for bile leak in patients undergoing robotic hepatectomy included right hepatectomy [OR 4.42 (95% CI 1.74–11.20); $p=0.002$], conversion [OR 4.40 (95% CI 1.39–11.72); $p=0.010$], pringle maneuver [OR 3.19 (95% CI 1.03–9.88); $p=0.044$], and drain placement [OR 28.25 (95% CI 8.34–95.72); $p<0.001$]. Bile leak was associated with increased reoperation (8.7% vs 1.7%, $p<0.001$), 30-day readmission (26.6% vs 6.8%, $p<0.001$), 30-day mortality (2% vs 0.9%, $p<0.001$), and complications (67.2% vs 23.4%, $p<0.001$) for patients undergoing MIS hepatectomy.

Conclusion While MIS confers less risk for bile leak than open hepatectomy, risk factors for bile leak in patients undergoing MIS hepatectomy were identified. Bile leaks were associated with multiple additional complications, and the robotic approach had an equal risk for bile leak than laparoscopic in this time period.

Keywords Hepatectomy · Bile leak · Minimally invasive · Outcomes

Hepatectomy is the primary therapy to manage various liver pathologies [1, 2]. Despite advances in surgical technique, bile leak remains a common complication associated with morbidity following hepatectomy [3]. Reported incidences of bile leak ranges from 3.6 to 12.8% [4–7]. Previously reported independent risk factors for bile leak include repeat hepatectomy, prolonged operative time, preoperative chemotherapy, major hepatectomy, and biliary reconstruction [4, 8].

In the past 2 decades, utilization of minimally invasive approaches to hepatectomy have increased, and advances in techniques have decreased morbidity after hepatectomy, including bile leak [9–13]. Laparoscopic approaches to hepatectomy have become established as a safe and feasible approach for resection of both benign and malignant hepatic lesions [14, 15]. Compared to open hepatectomy, laparoscopic hepatectomy has demonstrated reduced complication rates, blood loss, frequency of transfusions, time to first flatus, and length of stay, with no increase in operation time or mortality [9–11]. In one multicenter study, laparoscopic hepatectomy has also demonstrated lower rates of bile leaks compared to open hepatectomy [16].

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✉ Melissa E. Hogg
MHogg@Northshore.org

1 Department of Surgery, Penn State Health Milton S. Hershey Medical Center, Hershey, USA

2 Department of Surgery, NorthShore University HealthSystem, Walgreens Building—Floor 2, 2650 Ridge Road, Evanston, IL 60201, USA

3 Department of Surgery, University of Texas Southwestern, Dallas, USA

4 Department of Surgery, University of Chicago, Chicago, USA

Use of robotic hepatectomy is also increasing, with potential advantages including improved dexterity with wristed instruments, 3D optics, integrated stapling, and a stable platform [12, 17–20]. Robotic hepatectomy may confer advantages in cases where tumor location would make laparoscopic approaches challenging (i.e. superior-posterior tumors) [19]. However, robotic hepatectomy has been associated with longer operating times with no improvement in outcomes compared to laparoscopic hepatectomy [12, 21]. Moreover, the evidence level for robotic hepatectomy was graded as low to very low by the 2018 international consensus statement, given the lack of randomized-controlled trials [20]. It is unknown whether robotic hepatectomy is associated with increased risk of bile leak compared to open or laparoscopic approaches.

Herein, we sought to identify the incidence of bile leak stratified by surgical approach and hepatectomy type, elucidate risk factors for bile leak in patients undergoing hepatectomy, and decipher outcomes associated with bile leak. The hypothesis was surgical approach and hepatectomy type influence the incidence of bile leak.

Methods

Study design

This is a retrospective cohort study using the American College of Surgeons National Surgical Quality Improvement Project (ACS-NSQIP) database from 2014 to 2019. The ACS-NSQIP database is a validated, risk adjusted, outcomes-based program used to detect and modify surgical care based on 30-day patient outcomes. More than 150 variables are collected in the ACS-NSQIP program including preoperative, intra-operative and post-operative factors, and 30-day postoperative morbidity and mortality. The hepatectomy-targeted participant user file (PUF) additionally contains 45 variables specific to liver directed operations such as use of pringle, postoperative bile leak, type of hepatectomy and biliary reconstruction. The hepatectomy-targeted PUF is merged with the main ACS-NSQIP PUF utilizing the unique "case id" variable. To ensure the quality of the ACS-NSQIP, certified and trained surgical clinical reviewers (SCR) gather, input and maintain data to ensure quality. The ACS-NSQIP performs audits of participating sites and SCRs are required to undergo annual certification examinations. Written informed consent is not required and this study is exempt from institutional review board approval.

Patient selection

Using the ACS-NSQIP, patients were identified in the hepatectomy-targeted PUF using the current procedure terminology codes for hepatectomy. These included CPTs: 47120 (partial hepatectomy), 47130 (right hepatectomy), 47125 (left hepatectomy), and 47122 (trisegmentectomy). Patients were grouped based on their operative approach [open, minimally invasive (laparoscopic and robotic), laparoscopic and robotic] and based on hepatectomy performed [partial and major (right, left, trisegmentectomy)].

Outcomes

Baseline preoperative, operative and postoperative characteristics amongst patients who underwent open, minimally invasive, laparoscopic and robotic hepatectomy were compared. Bile leak is defined in the ACS-NSQIP as a clinical diagnosis of bile leak with either: (1) a drain continued on or after post-operative day three; (2) a percutaneous drain is placed; (3) reoperation is performed or (4) there is spontaneous wound drainage. Additionally, bile leak is defined as persistent drainage with either: (1) a drain continued on, or after post-operative day three; (2) a percutaneous drain is placed or (3) reoperation is performed. Risk factors associated with bile leak were identified on univariable and multivariable logistic regression analysis. Postoperative outcomes associated with bile leak were identified.

Statistical analysis

Baseline characteristics of patients undergoing hepatectomy were evaluated. Continuous variables were reported as mean with standard deviation and assessed with the independent samples *t* test, if normally distributed. If the continuous variable data was skewed, it was reported as median with interquartile range and assessed with Wilcoxon rank-sum test. Frequencies with percentages were used to report categorical variables assessed with chi-square or Fisher's exact tests.

Patients were stratified by type of hepatectomy. The rate of bile leak based on operative approach was assessed using chi-square and Fisher's exact tests. Univariate and multivariable logistic regression analysis was used to identify risk factors for bile leak in patients undergoing hepatectomy. Results were reported as odds ratios (OR) with 95% confidence intervals (CI). Variables included in the final multivariate models were selected based on a backward selection method with a significance level of $p < 0.10$ to stay in the model.

Univariate conditional logistic regression was used to perform a propensity score matched analysis. Propensity score matching (PSM) was based on a logistic regression model including covariates that were statistically significant on multivariable analysis including: age, sex, race, BMI, Steroid use, American Society of Anesthesiology (ASA), pathology, biliary stent, neoadjuvant therapy, type of hepatectomy, concurrent cholecystectomy, concurrent excision of a bile duct tumor, concurrent ablation, Pringle, tumor size, and drain placement. Each robotic case was matched to up to five open cases using a greedy matching algorithm without replacement and a caliper of 0.2 times the standard deviation of the logit of the propensity score. Each robotic case was also matched separately to up to five laparoscopic cases in a similar fashion, with the addition of conversion to open approach to the propensity score. The quality of PSM was assessed visually with mirrored overlapping histograms of the logit of the propensity score. All statistical analyses were performed using SAS 9.4 (SAS Institute, Cary, NC), with two-sided tests and statistical significance set at $p<0.05$.

Results

Baseline characteristics

Preoperative characteristics of patients undergoing hepatectomy

A total of 25,592 patients were identified who underwent elective non-emergent hepatectomy. Excluding patients who underwent multivisceral procedures, missing Bile Leak and who underwent biliary reconstruction, 21,342 patients entered the analysis. Of these, 15,162 (71%) were open, 5512 (25.8%) were laparoscopic and 668 (3.1%) were robotic. The mean age of all patients was 59 years old. Patients who underwent robotic hepatectomy were more likely to be female (56.1% vs 48.7%, $p<0.001$), had a higher mean BMI (29.3 vs 28.5 kg/m^2, $p=0.001$), had less weight loss > 10% (1.2% vs 3.2%, $p=0.003$), had less bleeding disorders (1.5% vs 3.3%, $p=0.010$), less likely to have malignant pathology (78.9% vs 66.3%, $p<0.001$), and less likely to undergo portal vein embolization (0.1% vs 4.3%, $p<0.001$) or chemotherapy (29.6% vs 18.3%; $p<0.001$) compared to open surgery (Table 1).

Operative characteristics of patients undergoing hepatectomy

Patients who underwent robotic hepatectomy were less likely to undergo concurrent cholecystectomy (21.7% vs. 34.1%; $p<0.001$), concurrent ablation (6.1% vs. 14.7%; $p<0.001$) including microwave ablation (MVA) (3% vs. 6.4%; $p<0.001$) and radiofrequency ablation (RFA) (2.4% vs 7.2%; $p<0.001$), less likely to undergo transfusion (12.1% vs. 17.2%; $p=0.001$). Also, robotic hepatectomy were less likely to have had drains placed (28.3% vs. 44.9%; $p<0.001$). Of note, overall operative time did not vary significantly between robotic and open hepatectomy (Table 2).

Postoperative characteristics of patients undergoing hepatectomy

Robotic hepatectomy was associated with decreased postoperative bile leak (5.4% vs 11.4%; $p<0.001$), had decreased median length of stay (3 days vs. 5 days; $p<0.001$), decreased readmission (7.2% vs. 9.6%; $p=0.039$) and was less likely to have any complication (19.6% vs 31.8%; $p<0.001$) compared to open hepatectomy (Table 3).

Operative characteristics of patients undergoing minimally invasive hepatectomy

Compared to laparoscopic, robotic hepatectomies were less likely to be open assist (16.8% vs 20.8%; $p=0.014$), be converted to open (7.6% vs 14.8%; $p<0.001$), undergo ablation (6.1% vs 10.6%; $p=0.003$), and use the pringle maneuver (9.3% vs 15.9%; $p<0.001$). Robotic hepatectomies were longer (mean 230 ± 114 min vs 198 ± 110 min; $p<0.001$) and had more transfusions (12.1% vs. 7.9%; $p<0.001$).

Incidence of bile leak by approach

Distribution of bile leak by surgical approach and hepatectomy type

Of all hepatectomies performed, 14,901 were partial, 6441 were major, 1406 were trisegmentectomy, 1767 were left hepatectomy and 3268 were right hepatectomy. The associated bile leak was 7.1%, 15.5%, 18.8%, 11.1% and 16.4%, respectively.

Compared to open hepatectomy, those who underwent robotic hepatectomy were less likely to develop a bile leak overall (5.4% vs 11.4%; $p<0.001$) and if they underwent a partial hepatectomy (3.3% vs 8.6%; $p<0.001$) (Table 4).

Compared to laparoscopic hepatectomy, those underwent robot hepatectomy were more likely to develop a bile leak if they underwent a major hepatectomy (17.7% vs 10.8%, $p=0.043$), and right hepatectomy (25% vs 13.1%, $p=0.019$) (Table 4).

Annual trends of bile leak by surgical approach

During the study period, robotic and laparoscopic hepatectomy accounted for 2–5% and 23–27% of all hepatectomies,

Table 1 Preoperative baseline characteristics of patients undergoing hepatectomy

	All patients	Robotic	Open	*p* value (robotic vs. open)	Laparoscopic	*p* value (robotic vs. laparoscopic)
Total number	21342	668 (3.1%)	15162 (71.0%)	–	5512 (25.8%)	–
Age, years [Mean ± SD]	59 ± 14	59 ± 14	59 ± 14	0.6807	59 ± 14	0.9275
Female gender [N (%)]	10717 (50.2)	375 (56.1)	7378 (48.7)	**0.0002**	2964 (53.8)	0.2469
White race [N (%)]ǂ	13625 (80.3)	496 (80.0)	9722 (81.3)	0.4259	3407 (77.8)	0.2232
BMI, kg/m^2 [Mean ± SD]ǂ	28.6 ± 6.3	29.3 ± 6.5	28.5 ± 6.2	**0.0007**	28.7 ± 6.4	**0.0224**
Diabetes [N (%)]	3830 (17.9)	129 (19.3)	2680 (17.7)	0.2789	1021 (18.5)	0.6211
COPD [N (%)]	761 (3.6)	31 (4.6)	509 (3.4)	0.0737	221 (4.0)	0.4359
CHF [N (%)]	68 (0.3)	3 (0.4)	49 (0.3)	0.4828	16 (0.3)	0.4518
Hypertension [N (%)]	9849 (46.1)	323 (48.4)	7009 (46.2)	0.2809	2517 (45.7)	0.1878
Steroid use [N (%)]	677 (3.2)	25 (3.7)	491 (3.2)	0.4727	161 (2.9)	0.2405
Weight loss > 10% of body weight [N (%)]	627 (2.9)	8 (1.2)	488 (3.2)	**0.0033**	131 (2.4)	0.0523
Bleeding disorder [N (%)]	665 (3.1)	10 (1.5)	501 (3.3)	**0.0097**	154 (2.8)	**0.0489**
ASA [Mean ± SD]	2.8 ± 0.6	2.7 ± 0.6	2.8 ± 0.6	**0.0007**	2.8 ± 0.6	0.1608
Preoperative serum albumin, g/dL [Mean ± SD]ǂ	4.0 ± 0.5	4.0 ± 0.5	4.0 ± 0.5	0.3169	4.1 ± 0.5	**0.0298**
Pathology [N (%)]						
Malignant	16028 (75.1)	443 (66.3)	11962 (78.9)	**< 0.0001**	3623 (65.7)	0.7622
Hepatocellular carcinoma	3935 (18.4)	119 (17.8)	2649 (17.5)	0.8193	1167 (21.2)	**0.0435**
Cholangiocarcinoma	1472 (6.9)	45 (6.7)	1173 (7.7)	0.3426	254 (4.6)	**0.0155**
Metastatic tumor	9930 (46.5)	248 (37.1)	7608 (50.2)	**< 0.0001**	2074 (37.6)	0.8006
Benign	5314 (24.9)	225 (33.7)	3200 (21.1)	**< 0.0001**	1889 (34.3)	0.7662
Hepatic adenoma	922 (4.3)	51 (7.6)	500 (3.3)	**< 0.0001**	371 (6.7)	0.3817
Hemangioma	745 (3.5)	29 (4.3)	418 (2.8)	**0.0155**	298 (5.4)	0.2455
Focal nodular hyperplasia	449 (2.1)	20 (3.0)	191 (1.3)	**0.0001**	238 (4.3)	0.1062
Biliary or hepatic cyst	993 (4.7)	47 (7.0)	483 (3.2)	**< 0.0001**	463 (8.4)	0.2263
Viral hepatitis [N (%)]ǂ	2783 (14.5)	88 (14.4)	1828 (13.5)	0.5242	867 (17.2)	0.0808
Biliary stent [N (%)]	377 (1.8)	7 (1.0)	315 (2.1)	0.0650	55 (1.0)	0.9024
Neoadjuvant therapy [N (%)]						
PVE	697 (3.3)	1 (0.1)	646 (4.3)	**< 0.0001**	50 (0.9)	**0.0410**
Preoperative chemotherapy	5672 (26.6)	122 (18.3)	4493 (29.6)	**< 0.0001**	1057 (19.2)	0.5706
Any preoperative therapy	6434 (30.1)	134 (20.1)	5143 (33.9)	**< 0.0001**	1157 (21.0)	0.5768

Bold indicates statistical significance

ǂ Missing data

respectively. In this time period (2014–2019), open hepatectomies grew by 156% which is comparable to the laparoscopic growth 173%. However, robotic hepatectomies had a 432% growth during this period. More of the growth was observed in the major hepatectomies with an increase in 285%. There is no statistically significant trend ($p > 0.05$) in bile leak based on approach or procedure during the 2014–2019 time frame (data not shown).

Although not statistically significant with the small robotic sample size, the bile leak trends show a spike in 2016 and 2017 for partial and major hepatectomy. For robotic major hepatectomy, there were no bile leaks in 2014 and 2015 however the rate in 2016–2017 was 22.2% and 42.3%. It decreased in 2018 and 2019 to 3.8% and 15%, respectively ($p = 0.790$). (Fig. 1). For robotic partial hepatectomy, the bile leak rate was 2.6%, 3.3%, 7.8%, 3.8%, 1.6% and 2.8% ($p = 0.376$) (Fig. 2).

Table 2 Operative baseline characteristics of patients undergoing hepatectomy

	All patients	Robotic	Open	*p* value (robotic vs. open)	Laparoscopic	*p* value (robotic vs. laparoscopic)
Type of surgery				**< 0.0001**		**0.0446**
Partial	14901 (69.8)	572 (85.6)	9662 (63.7)		4667 (84.7)	
Major trisegmentectomy	1406 (6.6)	10 (1.5)	1254 (8.3)		142 (2.6)	
Major left	1767 (8.3)	30 (4.5)	1401 (9.2)		336 (6.1)	
Major right	3268 (15.3)	56 (8.4)	2845 (18.8)		367 (6.7)	
Concurrent procedures [N (%)]						
Cholecystectomy	6536 (30.6)	145 (21.7)	5168 (34.1)	**< 0.0001**	1223 (22.2)	0.7772
Excision of bile duct tumor	61 (0.3)	3 (0.4)	54 (0.4)	0.5194	4 (0.1)	**0.0315**
Chole or BD tumor	6591 (30.9)	148 (22.2)	5217 (34.4)	**< 0.0001**	1226 (22.2)	0.9594
Minimally invasive approach [N (%)]						
Open assist	1259 (20.4)	112 (16.8)	–	–	1147 (20.8)	**0.0143**
Unplanned conversion	868 (14.0)	51 (7.6)	–	–	817 (14.8)	**< 0.0001**
Concurrent intraop ablation [N (%)]						
Microwave	1254 (5.9)	20 (3.0)	964 (6.4)	**0.0004**	270 (4.9)	**0.0279**
RFA	1378 (6.5)	16 (2.4)	1097 (7.2)	**< 0.0001**	265 (4.8)	**0.0047**
Any intraop ablation	2851 (13.4)	41 (6.1)	2223 (14.7)	**< 0.0001**	587 (10.6)	**0.0003**
Pringle [N (%)]	5333 (25.0)	62 (9.3)	4395 (29.0)	**< 0.0001**	876 (15.9)	**< 0.0001**
Liver texture [N (%)]				**0.0030**		0.3415
Normal	5886 (27.6)	161 (24.1)	4299 (28.4)		1426 (25.9)	
Abnormal (cirrhotic, congested, fatty)	5472 (25.6)	201 (30.1)	3751 (24.7)		1520 (27.6)	
Not documented	9984 (46.8)	306 (45.8)	7112 (46.9)		2566 (46.6)	
Tumor size, cm [N (%)]‡				0.1830		0.4268
< 2	5704 (30.9)	181 (31.9)	3843 (29.5)		1680 (34.6)	
2–5	7857 (42.6)	248 (43.7)	5592 (42.9)		2017 (41.6)	
≥ 5	4904 (26.6)	138 (24.3)	3609 (27.7)		1157 (23.8)	
Drain placed [N (%)]	8589 (40.2)	189 (28.3)	6805 (44.9)	**< 0.0001**	1595 (28.9)	0.7289
Operative time, minutes [Mean ± SD]	226 ± 109	230 ± 114	236 ± 107	0.1815	198 ± 110	**< 0.0001**
Transfusion [N (%)]	3121 (14.6)	81 (12.1)	2607 (17.2)	**0.0006**	433 (7.9)	**0.0002**

Bold indicates statistical significance

Table 3 Postoperative baseline characteristics of patients undergoing hepatectomy

	All patients	Robotic	Open	*p* value (robotic vs. open)	Laparoscopic	*p* value (robotic vs. laparoscopic)
Bile leak [N (%)]	2049 (9.6)	36 (5.4)	1722 (11.4)	**< 0.0001**	291 (5.3)	0.9047
Reoperation [N (%)]	505 (2.4)	13 (1.9)	422 (2.8)	0.1952	70 (1.3)	0.1516
30-day readmission	1852 (8.7)	48 (7.2)	1452 (9.6)	**0.0389**	352 (6.4)	0.4276
30-day mortality	213 (1.0)	6 (0.9)	166 (1.1)	0.6314	41 (0.7)	0.6645
LOS, days [Median (Q1-Q3)]	5 (3–7)	3 (2–4)	5 (4–7)	**< 0.0001**	3 (2–5)	**0.0033**
Any complication [N (%)]	5894 (27.6)	131 (19.6)	4814 (31.8)	**< 0.0001**	949 (17.2)	0.1239

Bold indicates statistical significance

Table 4 Distribution of bile leak by surgical approach and hepatectomy

	All	Partial	Major	Trisegmentectomy	Left	Right
All						
Total N	21342	14901	6441	1406	1767	3268
Total bile leak	2049	1051	998	265	196	537
% Bile leak (%)	9.6	7.1	15.5	18.8	11.1	16.4
Robot						
Total N	668	572	96	10	30	56
Total bile leak	36	19	17	0	3	14
% Bile leak (%)	5.4	3.3	17.7	0.0	10.0	25.0
Open						
Total N	15162	9662	5500	1254	1401	2845
Total bile leak	1722	832	890	247	168	475
% Bile leak (%)	11.4	8.6	16.2	19.7	12.0	16.7
p value robot vs. open	**< 0.0001**	**< 0.0001**	0.6874	0.2248	0.7154	0.1002
Lap						
Total N	5512	4667	845	142	336	367
Total bile leak	291	200	91	18	25	48
% Bile leak (%)	5.3	4.3	10.8	12.7	7.4	13.1
p value robot vs. lap	0.9047	0.3193	**0.0433**	0.6084	0.4910	**0.0188**

Bold indicates statistical significance

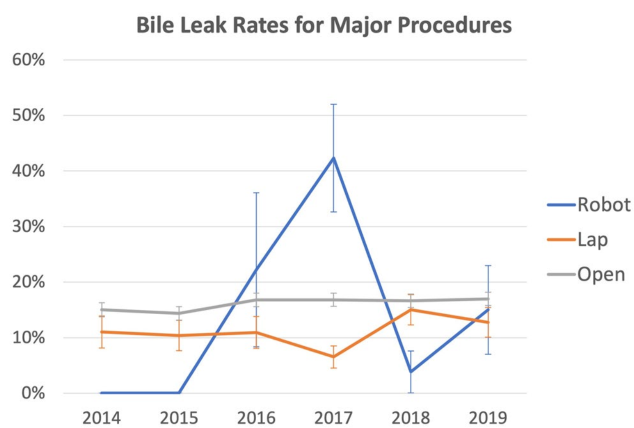

Fig. 1 Bile leak rates for major hepatectomy from 2014 to 2019 stratified by surgical approach

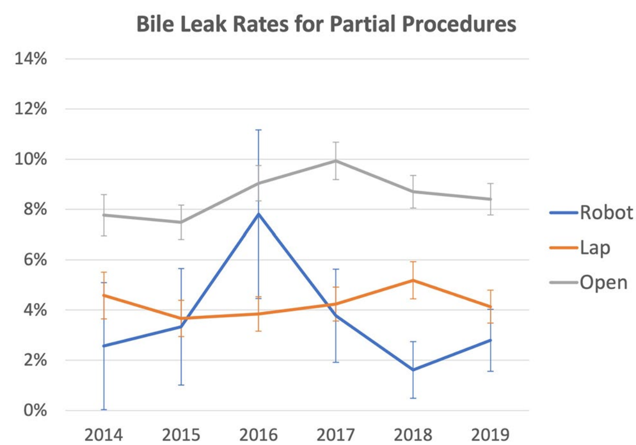

Fig. 2 Bile leak rates for partial hepatectomy from 2014 to 2019 stratified by surgical approach

Multivariable analysis of factors associated with bile leak stratified by hepatectomy type and surgical approach

Hepatectomy type

All hepatectomies

Preoperative risk factors associated with bile leak in patients undergoing hepatectomy included increasing age [OR 1.01 (95% CI 1.00–1.01); $p = 0.021$], preoperative use of a biliary stent [OR 2.52 (95% CI 1.93–3.3); $p < 0.001$]. Benign pathology appeared to have protective factors for bile leak with odds ratios between 0.57 and 0.60 (Table 5).

Operative risk factors that increased the risk of bile leak in patients undergoing hepatectomy were concurrent cholecystectomy or bile duct tumor excision [OR 1.32 (95% CI 1.19–1.47); $p < 0.001$], conversion from minimally invasive to open [OR 1.75 (95% CI 1.32–2.30); $p < 0.001$], concurrent ablation [OR 1.26 (95% CI 1.09–1.47); $p = 0.002$], use of pringle [OR 1.22 (95% CI 1.09–1.37); $p = 0.001$], drain placement [OR 8.62 (95% CI 7.51–9.88), $p < 0.001$], larger tumors [OR 1.2 (95% CI 1.03–1.40), p = 0.017], abnormal liver texture [OR 1.19 (95% CI 1.03–1.38), $p = 0.018$] and transfusion [OR 1.89 (95% CI 1.68–2.13); $p < 0.001$]. Additionally, compared to patients undergoing a partial hepatectomy, right hepatectomy [OR 1.68 (95% CI 1.47–1.91);

Table 5 Multivariable analysis of risk factors associated with bile leak in patients undergoing hepatectomy

	All patients		Partial hepatectomy		Major hepatectomy	
	OR (95% CI)	*p* value	OR (95% CI)	*p* value	OR (95% CI)	*p* value
Preoperative						
Age, per year increase	1.00 (1.00–1.01)	**0.0210**	–	–	1.01 (1.00–1.01)	**0.0391**
BMI, per kg/m^2	–	–	–	–	1.01 (1.00–1.02)	**0.0358**
Diabetes, yes vs. no	0.82 (0.71–0.94)	**0.0046**	0.78 (0.65–0.93)	**0.0057**	–	–
ASA, per unit increase	–	–	1.16 (1.02–1.31)	**0.0207**	–	–
Pathology						
Hepatic adenoma, yes vs. no	0.57 (0.40–0.80)	**0.0011**	0.49 (0.31–0.75)	**0.0013**	–	–
Hemangioma, yes vs. no	0.60 (0.43–0.85)	**0.0033**	–	–	0.57 (0.34–0.96)	**0.0351**
Focal nodular hyperplasia, yes vs. no	0.60 (0.36–1.00)	0.0510	**0.50 (0.26–0.95)**	**0.0353**	–	**–**
Biliary or hepatic cyst, yes vs. no	–	–	–	–	1.69 (1.20–2.39)	**0.0026**
Viral hepatitis, yes vs. no	0.81 (0.69–0.94)	**0.0070**	–	–	–	–
Biliary stent, yes vs. no	2.52 (1.93–3.30)	**< 0.0001**	2.49 (1.71–3.63)	**< 0.0001**	2.55 (1.78–3.65)	**< 0.0001**
Operative						
Surgical approach						
Open vs. robotic	1.46 (1.00–2.12)	0.0502	1.91 (1.18–3.09)	**0.0085**	0.75 (0.42–1.33)	0.3265
Lap vs. robotic	0.92 (0.62–1.36)	0.6595	1.22 (0.74–2.01)	0.4345	0.63 (0.34–1.15)	0.1334
Type of surgery						
Major triseg vs. partial	1.76 (1.48–2.09)	**< 0.0001**	–	–	–	–
Major left vs. partial	1.13 (0.94–1.35)	0.1873	–	–	–	–
Major right vs. partial	1.68 (1.47–1.91)	**< 0.0001**	–	–	–	–
Major left vs. major triseg	–	–	–	–	0.57 (0.46–0.71)	**< 0.0001**
Major right vs. major triseg	–	–	–	–	0.89 (0.74–1.06)	0.1766
Concurrent chole or BD tumor, yes vs. no	1.32 (1.19–1.47)	**< 0.0001**	1.43 (1.25–1.65)	**< 0.0001**	1.20 (1.03–1.39)	**0.0158**
Conversion, yes vs. no	1.75 (1.32–2.30)	**< 0.0001**	1.96 (1.43–2.69)	**< 0.0001**	–	–
Concurrent intraop ablation, yes vs. no	1.26 (1.09–1.47)	**0.0020**	1.24 (1.04–1.49)	**0.0173**	1.28 (1.01–1.61)	**0.0371**
Pringle, yes vs. no	1.22 (1.09–1.37)	**0.0006**	1.24 (1.07–1.44)	**0.0044**	1.23 (1.05–1.43)	**0.0101**
Liver texture, abnormal vs. normal	1.19 (1.03–1.38)	**0.0177**	1.21 (1.00–1.48)	**0.0529**		
Tumor size, cm						
2–5 vs. < 2	1.06 (0.92–1.22)	0.4213	1.13 (0.95–1.35)	0.1656	–	–
≥ 5 vs. < 2	1.20 (1.03–1.40)	**0.0168**	1.37 (1.12–1.67)	**0.0020**	–	–
Drain placement, yes. vs. no	8.62 (7.51–9.88)	**< 0.0001**	9.50 (8.00–11.29)	**< 0.0001**	6.75 (5.59–8.15)	**< 0.0001**
Transfusion, yes vs. no	1.89 (1.68–2.13)	**< 0.0001**	1.95 (1.65–2.30)	**< 0.0001**	1.79 (1.54–2.09)	**< 0.0001**

Bold indicates statistical significance

$p < 0.001$], and trisegmentectomy [OR 1.76 (95% CI 1.48–2.09), $p < 0.001$] were associated with an increased risk of bile leak (Table 5).

Partial hepatectomy

Preoperative risk factors for bile leak in patients undergoing partial hepatectomy include increasing American Society of Anesthesiology (ASA) physical status classification [OR 1.16 (95% CI 1.02–1.31); $p = 0.021$] and preoperative biliary stent [OR 2.49 (95% CI 1.71–3.63); $p < 0.001$]. Adenomas and focal nodular hyperplasia pathology also appeared protective against bile leak. Operative risk factors for bile leak include open hepatectomy (versus robotic) [OR 1.91 (95% CI 1.18–3.09); $p = 0.009$], concurrent cholecystectomy or bile duct tumor excision [OR 1.43 (95% CI 1.25–1.65); $p < 0.001$], conversion [OR 1.96 (95% CI 1.43–2.69); $p < 0.001$], intraop ablation [OR 1.24 (95% CI 1.04–1.49), $p = 0.017$], pringle maneuver [OR 1.24 (95% CI 1.07–1.44), $p = 0.004$], tumors ≥ 5 cm (compared to < 2 cm) [OR 1.37 (95% CI 1.12–1.67); $p < 0.002$], drain placement [OR 9.5 (95% CI 8–11.2), $p < 0.001$] and transfusion [OR 1.95 (95% CI 1.65–2.3), $p < 0.001$] (Table 5).

Major hepatectomy

Preoperative risk factors for bile leak in patients undergoing major hepatectomy included increasing age [OR 1.01

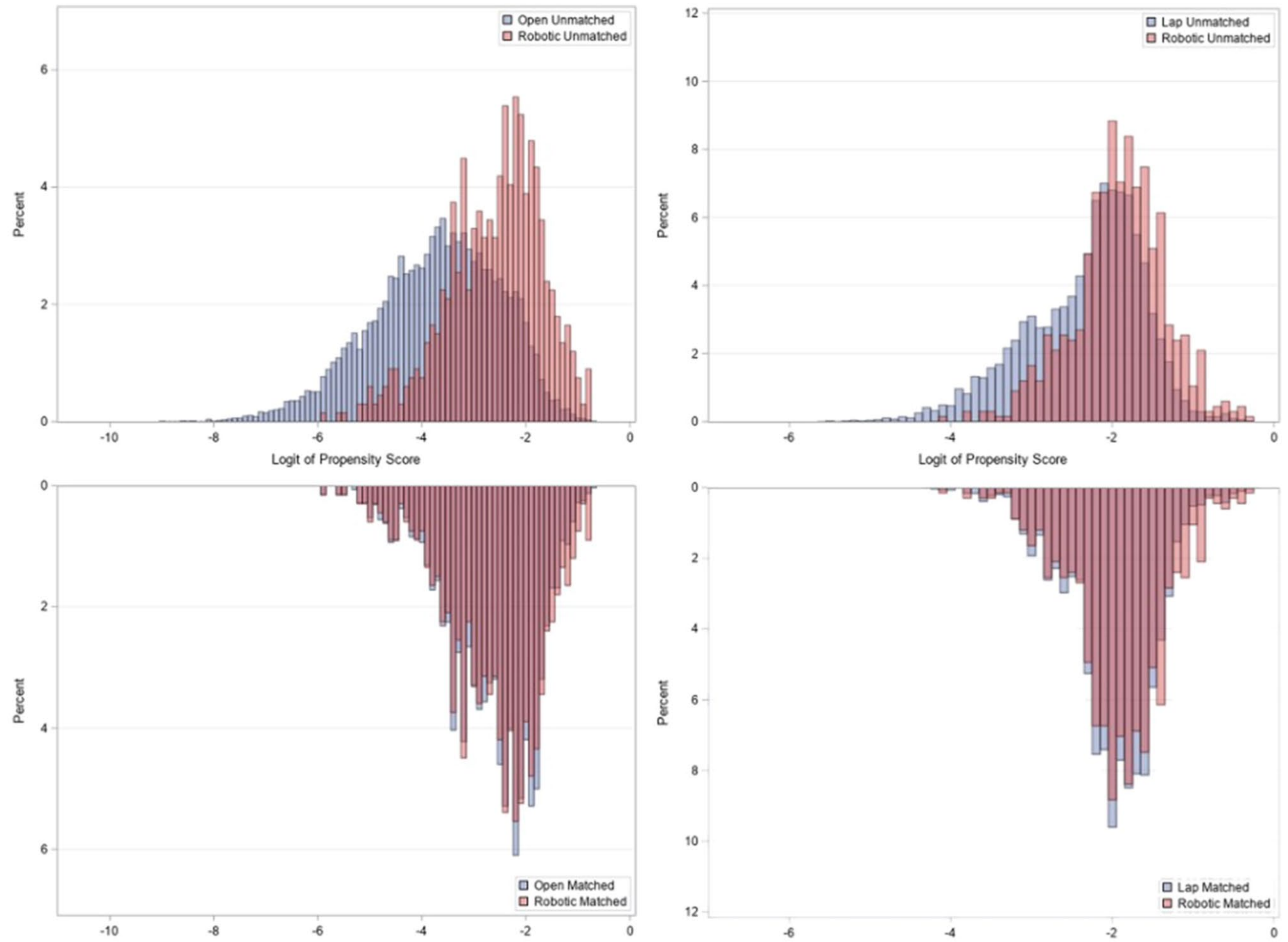

Fig. 3 Mirrored overlapping histograms of the logit of the propensity scores for open and robotic and open and laparoscopic: unmatched and matched

(95% CI 1.00–1.01); $p=0.039$], body mass index (BMI) [OR 1.01 (95% CI 1.00–1.02), $p=0.036$], biliary/hepatic cyst pathology [OR 1.69 (95% CI 1.2–2.39); $p=0.003$], and preoperative biliary stent [OR 2.55 (95% CI 1.78–3.65); $p<0.001$]. Hemangioma was protective against bile leak. Operative risk factors for bile leak included concurrent cholecystectomy or bile duct tumor excision [OR 1.20 (95% CI 1.03–1.39); $p=0.016$], concurrent ablation [OR 1.28 (1.01–1.61); $p=0.037$] or pringle [OR 1.23 (95% CI 1.05–1.43); $p=0.010$], drain placement [OR 6.75 (95% CI 5.59–8.15), $p<0.001$] and transfusion [OR 1.79 (95% CI 1.54–2.09), $p<0.001$] (Table 5).

Propensity score matched analysis

PSM on 16 covariates were used to adjust for selection bias and confounding variables. Of the 21,342 (668 robotic, 15,162 open, and 5512 laparoscopic) cases eligible for matching, 3482 (668 robotic, 3199 open, and 3064 laparoscopic) were able to be matched. Distributions of the logit of the propensity scores for open and laparoscopic cases were different than robotic cases before PSM but were very similar after PSM. Additionally, none of the covariates used for matching were significantly different after PSM, indicating good quality matching (Fig. 3). Although the open approach

Table 6 Propensity score matched analysis

	All patients		Partial hepatectomy		Major hepatectomy	
	OR (95% CI)	*p* value	OR (95% CI)	OR (95% CI)	*p* value	OR (95% CI)
Open vs. robotic	1.22 (0.84–1.77)	0.2910	1.56 (0.96–2.55)	0.0748	0.79 (0.43–1.45)	0.4455
Lap vs. robotic	0.86 (0.59–1.25)	0.4130	1.16 (0.70–1.90)	0.5708	0.55 (0.30–1.03)	0.0637

Table 7 Multivariable analysis of risk factors associated with bile leak in patients undergoing minimally invasive hepatectomy

	Minimally invasive hepatectomy		Robotic hepatectomy		Laparoscopic hepatectomy	
	OR (95% CI)	*p* value	OR (95% CI)	*p* value	OR (95% CI)	*p* value
Preoperative						
Age, per year increase	1.01 (1.00–1.02)	**0.0045**	–	–	–	–
Female, yes vs. no	–	–	0.39 (0.17–0.93)	**0.0331**		
Hypertension, yes vs. no	–	–	–	–	1.32 (1.02–1.70)	**0.0337**
Steroid use, yes vs. no	2.04 (1.17–3.56)	**0.0118**	–	–	2.10 (1.15–3.85)	**0.0161**
ASA, per unit increase	–	–	–	–	–	–
Pathology						
Cholangiocarcinoma, yes vs. no	–	–	5.37 (1.73–16.65)	**0.0036**	–	–
Hepatic adenoma, yes vs. no	–	–	–	–	0.52 (0.27–0.99)	**0.0478**
Hemangioma, yes vs. no	–	–	–	–	0.46 (0.22–0.97)	**0.0416**
Biliary or hepatic cyst, yes vs. no	–	–	6.04 (1.86–19.60)	**0.0027**	–	–
Biliary stent, yes vs. no	2.41 (1.05–5.52)	**0.0382**	2.24 (0.92–5.46)	0.0752	–	–
Operative						
Surgical approach						
Lap vs. robotic	0.97 (0.66–1.43)	0.8693	–	–	–	–
Type of surgery						
Major triseg vs. partial	2.02 (1.16–3.53)	**0.0134**	1.66 (0.04–73.83)	0.7930	1.95 (1.11–3.43)	**0.0200**
Major left vs. partial	1.32 (0.86–2.03)	0.2089	1.59 (0.34–7.47)	0.5593	1.21 (0.77–1.91)	0.413
Major right vs. partial	2.04 (1.46–2.85)	**< 0.0001**	4.42 (1.74–11.20)	**0.0017**	1.72 (1.19–2.49)	**0.0040**
Concurrent chole or BD tumor, yes vs. no	1.43 (1.11–1.85)	**0.0059**	–	**–**	1.49 (1.13–1.94)	**0.0040**
Conversion, yes vs. no	1.51 (1.14–1.99)	**0.0037**	4.04 (1.39–11.72)	**0.0102**	1.47 (1.10–1.96)	**0.0088**
Pringle, yes vs. no	1.76 (1.33–2.31)	**< 0.0001**	3.19 (1.03–9.88)	**0.0442**	1.71 (1.28–2.28)	**0.0002**
Tumor size, cm						
2–5 vs. < 2	1.19 (0.87–1.64)	0.2768	0.33 (0.11–0.99)	**0.0473**	1.39 (0.99–1.95)	0.0537
≥ 5 vs. < 2	1.47 (1.04–2.08)	**0.0286**	1.06 (0.36–3.11)	0.9202	1.72 (1.18–2.50)	**0.0051**
Drain placement, yes. vs. no	9.51 (7.12–12.70)	**< 0.0001**	28.25 (8.34–95.72)	**< 0.0001**	8.44 (6.27–11.37)	**< 0.0001**
Transfusion, yes vs. no	2.13 (1.58–2.88)	**< 0.0001**	–	–	2.33 (1.69–3.21)	**< 0.0001**

Bold indicates statistical significance

for partial hepatectomy was associated with a significantly higher risk than robotic on multivariable analysis for partial hepatectomy, it was no longer significant after PSM [OR 1.56 (95% CI 0.96–2.55), $p = 0.075$] (Tables 6, 7).

Minimally invasive hepatectomy

There was no difference in bile leak on multivariate analysis for laparoscopic vs. robotic approach [OR 0.97 (95% CI 0.66–1.43); $p = 0.869$]. Operative factors risk factors for bile leak in patients undergoing robotic hepatectomy included right hepatectomy [OR 4.42 (95% CI 1.74–11.20); $p = 0.002$], conversion [OR 4.40 (95% CI 1.39–11.72); $p = 0.010$], pringle maneuver [OR 3.19 (95% CI 1.03–9.88); $p = 0.044$] and drain placement [OR 28.25 (95% CI 8.34–95.72); $p < 0.001$]. Small tumors < 2 cm were protective against bile leaks.

Outcomes associated with bile leak

Outcomes amongst patients who developed bile leak and those that did not were compared. Of all patients who underwent hepatectomy, those who developed bile leak were more likely to undergo reoperation (8.7% vs 1.7%, $p < 0.001$), be readmitted within 30-days (26.6% vs 6.8%, $p < 0.001$), die within 30-days (2% vs 0.9%, $p < 0.001$) and have longer hospital stay (median 7 vs 5 days, $p < 0.001$). Those who developed bile leak were more likely to develop any complication (67.2% vs 23.4%, $p < 0.001$), a surgical complication (58.9% vs 16.4%, $p < 0.001$) including bleeding requiring transfusion (31% vs 12.9%, $p < 0.001$), and need for invasive intervention postoperatively (38.6% vs 3.8%, $p < 0.001$), wound complications (6.7% vs 3.1%, $p < 0.001$) including dehiscence (1.5% vs 0.4%, $p < 0.001$) and superficial skin infection (5.4% vs 2.8%, $p < 0.001$) and medical complications (33.1% vs 9.7%, $p < 0.001$) (Table 8).

Table 8 Postoperative outcomes associated with bile leak

	All hepatectomy	All with bile leak	*p* value	Partial hepatectomy	Partial w/bile leak	*p* value	Major hepatectomy	Major w/bile leak	*p* value
Total patients [N]	19293	2049	–	13850	1051	–	5443	998	–
Reoperation [N (%)]	327 (1.7)	178 (8.7)	**< 0.0001**	178 (1.3)	89 (8.5)	**< 0.0001**	149 (2.7)	89 (8.9)	**< 0.0001**
30-day readmission [N (%)]	1307 (6.8)	545 (26.6)	**< 0.0001**	883 (6.4)	279 (26.5)	**< 0.0001**	424 (7.8)	266 (26.7)	**< 0.0001**
30-day mortality [N (%)]	173 (0.9)	40 (2.0)	**< 0.0001**	87 (0.6)	12 (1.1)	**0.0482**	86 (1.6)	28 (2.8)	**0.0069**
LOS, days [Median (Q1-Q3)]	5 (3–6)	7 (5–11)	**< 0.0001**	4 (3–6)	6 (5–10)	**< 0.0001**	5 (4–7)	8 (6–13)	**< 0.0001**
Any complication [N (%)]	4518 (23.4)	1376 (67.2)	**< 0.0001**	2661 (19.2)	647 (61.6)	**< 0.0001**	1857 (34.1)	729 (73)	**< 0.0001**
Surgical complication [N (%)]	3158 (16.4)	1207 (58.9)	**< 0.0001**	1790 (12.9)	562 (53.5)	**< 0.0001**	1368 (25.1)	645 (64.6)	**< 0.0001**
Bleeding requiring transfusion	2486 (12.9)	635 (31.0)	**< 0.0001**	1339 (9.7)	255 (24.3)	**< 0.0001**	1147 (21.1)	380 (38.1)	**< 0.0001**
Reoperation	327 (1.7)	178 (8.7)	**< 0.0001**	178 (1.3)	89 (8.5)	**< 0.0001**	149 (2.7)	89 (8.9)	**< 0.0001**
Need for invasive intervention postoperatively	736 (3.8)	791 (38.6)	**< 0.0001**	469 (3.4)	382 (36.3)	**< 0.0001**	267 (4.9)	409 (41.0)	**< 0.0001**
Wound [N (%)]	591 (3.1)	137 (6.7)	**< 0.0001**	391 (2.8)	74 (7.0)	**< 0.0001**	200 (3.7)	63 (6.3)	**0.0001**
Dehiscence	72 (0.4)	31 (1.5)	**< 0.0001**	41 (0.3)	20 (1.9)	**< 0.0001**	31 (0.6)	11 (1.1)	0.0546
Superficial SSI	534 (2.8)	110 (5.4)	**< 0.0001**	358 (2.6)	55 (5.2)	**< 0.0001**	176 (3.2)	55 (5.5)	**0.0004**
Medical complication [N (%)]	1879 (9.7)	679 (33.1)	**< 0.0001**	1080 (7.8)	288 (27.4)	**< 0.0001**	799 (14.7)	391 (39.2)	**< 0.0001**
Cardiac arrest	95 (0.5)	18 (0.9)	**0.0220**	43 (0.3)	7 (0.7)	0.0856	52 (1.0)	11 (1.1)	0.6648
Sepsis	323 (1.7)	213 (10.4)	**< 0.0001**	215 (1.6)	111 (10.6)	**< 0.0001**	108 (2.0)	102 (10.2)	**< 0.0001**
Septic shock	130 (0.7)	92 (4.5)	**< 0.0001**	73 (0.5)	34 (3.2)	**< 0.0001**	57 (1.0)	58 (5.8)	**< 0.0001**
DVT	209 (1.1)	77 (3.8)	**< 0.0001**	109 (0.8)	23 (2.2)	**< 0.0001**	100 (1.8)	54 (5.4)	**< 0.0001**
UTI	340 (1.8)	67 (3.3)	**< 0.0001**	222 (1.6)	37 (3.5)	**< 0.0001**	118 (2.2)	30 (3.0)	0.1043
Acute renal failure	94 (0.5)	46 (2.2)	**< 0.0001**	52 (0.4)	18 (1.7)	**< 0.0001**	42 (0.8)	28 (2.8)	**< 0.0001**
Ventilator > 48 h	178 (0.9)	104 (5.1)	**< 0.0001**	96 (0.7)	38 (3.6)	**< 0.0001**	82 (1.5)	66 (6.6)	**< 0.0001**
Pulmonary embolism	181 (0.9)	37 (1.8)	**0.0002**	100 (0.7)	19 (1.8)	**0.0001**	81 (1.5)	18 (1.8)	0.4565
Unplanned reintubation	245 (1.3)	98 (4.8)	**< 0.0001**	129 (0.9)	37 (3.5)	**< 0.0001**	116 (2.1)	61 (6.1)	**< 0.0001**
Pneumonia	454 (2.4)	143 (7.0)	**< 0.0001**	286 (2.1)	53 (5.0)	**< 0.0001**	168 (3.1)	90 (9.0)	**< 0.0001**
Stroke/CVA	22 (0.1)	6 (0.3)	**0.0465**	13 (0.1)	2 (0.2)	0.2862	9 (0.2)	4 (0.4)	0.1291
Myocardial infarction	126 (0.7)	40 (2.0)	**< 0.0001**	80 (0.6)	18 (1.7)	**< 0.0001**	46 (0.8)	22 (2.2)	**0.0001**

Table 8 (continued)

	All hepatectomy	All with bile leak	*p* value	Partial hepatectomy	Partial w/bile leak	*p* value	Major hepatectomy	Major w/bile leak	*p* value
Liver failure (Grade A, B or C)	497 (2.6)	277 (13.5)	**< 0.0001**	174 (1.3)	87 (8.3)	**< 0.0001**	323 (5.9)	190 (19.0)	**< 0.0001**

Bold indicates statistical significance

This was similar for patients undergoing partial hepatectomy however there was no increased risk of cardiac arrest (Table 8). The outcomes for patients undergoing major hepatectomy were also similar with no statistically significant difference in urinary tract infection, CVA/Stroke or pulmonary embolism (Table 8).

Discussion

This is the largest study to date to investigate the rate of postoperative bile leak in patients undergoing hepatectomy, stratified by type of hepatectomy and operative approach. Additionally, factors associated with postoperative bile leak and subsequent outcomes were identified. Based on this large retrospective cohort study, bile leak is associated with significant postoperative complications including but not limited to reoperation, readmission, 30-day mortality and length of stay. On multivariable analysis, robotic hepatectomy is associated with a decreased incidence of bile leak for those undergoing partial hepatectomy, with no difference for major hepatectomy. While there were differences between the open approach and robotics, on propensity score matched analysis there were no significant differences in bile leak rates.

Risk factors for the development of bile leak have been evaluated previously. Most recently in 2019, Spetzler et al. identified pre-operative chemotherapy within 4 weeks of hepatectomy, biliary-digestive anastomosis and major liver resection as risk factors for bile leak on multivariate analysis [8]. These results are consistent with the current findings that major hepatectomy was a risk factor for the development of bile leak. However, we identified additional factors for increased risk of bile leak on multivariable analysis including increasing age, biliary/hepatic cyst pathology, pre-operative biliary stent, concurrent cholecystectomy or bile duct tumor excision, drain placement, conversion, concurrent ablation, pringle and transfusion. A multi-center prospective study from eleven institutions reported in 2015 also identified variables associated with bile leak including the use of a drain and blood loss > 300 mL [22]. Although this was a multicenter study and classified bile leaks by International Study Group for Liver Surgery (ISGLS) grade [3], the number of patients and variables investigated to be associated with bile leak were significantly less than those reported in the current study.

The development of postoperative bile leak is problematic and is associated with additional morbidity and mortality. Spetzler et al. reported an increased incidence of surgical site infection, post-hepatectomy liver failure, 90-day mortality, and length of stay associated with bile leak [8]. Similarly, these data demonstrate an increased incidence of 30-day mortality, superficial skin infection and length of stay with bile leak. Additionally, this study demonstrated an increase in reoperation, 30-day readmission, surgical, wound and medical complications. Brooke-Smith et al. demonstrated that bile leak was associated with increased length of hospital stay, liver failure, and post-operative hemorrhage [22]. Moreover, Martin et al. reported increased perioperative morbidity associated with bile leak following hepatectomy on multivariable logistic regression however did not specify the type of morbidity. When they identified risk factors for mortality following hepatectomy, bile leak was not significant on multivariable logistic regression [23]. This is inconsistent with the results of the present study which demonstrated an increased 30-day mortality associated with bile leak (however this data was not risk adjusted).

A consensus statement on robotic hepatectomy was published in 2018 however the levels of recommendations are weak and based on a low level of evidence [20]. It concluded that robotic hepatectomy is as safe and feasible as traditional open hepatectomy with increased operative time, less blood less, decreased length of stay, and decreased complications. It also concluded that robotic hepatectomy is as safe and feasible as traditional laparoscopic hepatectomy with similar overall complication rates and length of stay however it is associated with increased operative time, blood loss and cost. When evaluating partial hepatectomy, robotic hepatectomy was as safe and feasible as laparoscopic hepatectomy and open hepatectomy with increased operative time compared to laparoscopic hepatectomy and similar blood loss, postoperative complications and cost. Regarding major hepatectomy, robotic hepatectomy was as safe and feasible as laparoscopic hepatectomy and open hepatectomy with increased operative time compared to laparoscopic hepatectomy with similar blood loss and postoperative complications [20]. In the current study, the incidence of bile leak was significantly increased in patients undergoing open partial hepatectomy compared to robotic partial hepatectomy. Furthermore, on multivariable analysis, the robotic approach decreased the incidence of bile leak for partial hepatectomy, but this did not hold true on propensity score matched analysis.

In patients who underwent a laparoscopic hepatectomy the unplanned conversion to open was higher than for robotic hepatectomy. Although robotic hepatectomy has a higher incidence of leak early on (2014–2017), this difference was less stark in later years, and there was no significant difference in terms of bile leak between the laparoscopic and robotic approaches on multivariable analysis. The major factor to consider here is the maturation of these minimally invasive platforms: ~25% of hepatectomies during 2014–2017 were performed laparoscopically while only ~2% were performed robotically showing the adoption of this platform for liver surgery is well behind laparoscopy; however, surgical approach data is not available prior to 2014 to assess earlier trends.

The exact reason why this leak rate is higher initially is unknown, but two possibilities include surgeon learning curve and technical factors of the robotic platform. For robot, the trend of bile leak curves is less clear (Figs. 1, 2), and the adoption is growing which may reflect surgeons inexperienced with the technology. The decrement in later years could be owing to these surgeons either reaching their learning curve or abandoning the technique. Additionally, technical factors related to bile leak could represent techniques coming through parenchyma or placing stitches. The latter may have increased leak with less experience with robotic suturing. Additionally, since the robotic platform is newer compared with open and laparoscopy, the instruments available to come through the parenchyma are limited in comparison. The advent and more widespread use of a wider variety of robotic instruments to come through the parenchyma likely plays a role in the decrease in bile leak in later years. The use of robotic major hepatectomy should be used cautiously, and only if the operative surgeon is proficient with robotic hepatectomy techniques including sewing and coming through parenchyma, has experience performing major, and has adequate volume. Data from high volume robotic hepatectomy centers demonstrate that the incidence of bile leak with the robotic platform can be minimal. In a study on their first 100 robotic hepatectomies, Sucandy et al. and reported a bile leak rate of only 2%, including a bile leak rate of 5.9% in patients undergoing formal right hepatectomy suggesting this platform is acceptable and may be beneficial if used appropriated by trained personnel [24]. These bile leak curves also suggests that surgeons who use the laparoscopic platform may be beyond their learning curve which has been reported to range from 15 to 160 cases depending on the type of hepatectomy and outcome of interest [25].

This study has several limitations. Due to the inherent nature of large database studies, the potential for observer bias exists as data is collected and entered retrospectively. The ACS-NSQIP aims to minimize bias by SCR training and audits however this potential remains. The lack of institution volume and surgeon data in NSQIP limits the conclusions that can be drawn from this dataset, and this may be the most important factor. This study incorporated a multivariable logistic regression to identify variables associated with bile leak however unknown factors are likely to contribute to the development of bile leak and subsequent outcomes that cannot be accounted for in the model. Bile leak identification and mitigation strategies such as the use of sealants, the air-leak test and application of hydrogen-peroxide cannot be determined. Although the ACS-NSQIP is a multi-institutional database, there is likely a disproportionate contribution from large teaching hospitals resulting in intrinsic selection bias. Also, ACS-NSQIP is primarily fed by institutions within the United States and is not utilized by all institutions. The ACS-NSQIP does not incorporate the ISGLS definition of bile leak [3] and therefore incidence, risk factors and associated outcomes cannot be stratified by ISGLS bile leak grade. The definition of bile leaks in ACS-NSQIP can have inherent error; however, this should be systematic and apply to all platforms. The use of drains along with the definition of bile leak within ACS-NSQIP is also hard to completely control for using administrative databases. Additionally, the specifics of predictor variables such as biliary/hepatic cyst and bleeding disorder are not available and so conclusions from findings related to these variables should be drawn sparingly. Finally, the ACS-NSQIP does not report on oncologic outcomes and therefore the long-term impact of bile leak and associated complications cannot be correlated with survival.

Conclusions

This is the largest study to date to report on bile leak incidence stratified by type of hepatectomy and operative approach. Risk factors for bile leak were identified and outcomes associated with bile leak were reported. Bile leak is a significant complication of hepatectomy and associated with multiple subsequent complications. Improved bile leak mitigation strategies are required to decrease the incidence of bile leak and associated complications. The use of the minimally invasive approach to hepatectomy has been reported as safe and feasible, especially with partial hepatectomies;however, it may be associated with an increased risk of bile leak in major robotic hepatectomies early in the platform's adoption, ultimately down trending in the last two years of this analysis. Further studies are required before a definitive conclusion regarding the safety and efficacy of robotic major hepatectomy can be made.

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