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2016 SSAT POSTER PRESENTATION

Minimally Invasive vs. Open Hepatectomy: a Comparative Analysis of the National Surgical Quality Improvement Program Database

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Abstract
Background While minimally invasive surgery (MIS) to treat liver tumors has increased, data on perioperative outcomes of MIS relative to open liver resection (O-LR) are lacking. We sought to compare short-term outcomes among patients undergoing MIS vs. O-LR in a nationally representative database.
Methods The National Surgical Quality Improvement Program database was used to identify patients undergoing hepatectomy between January 1 and December 31, 2014. Propensity score matching algorithm was used to balance differences in baseline characteristics among MIS and O-LR groups.
Results A total of 3064 patients were included in the study. After propensity matching, the baseline characteristics for O-LR and MIS groups were comparable (minimum p value=0.12). Incidence of superficial surgical site infections, intraoperative or postoperative blood transfusions, and pulmonary embolism was lower among patients in MIS group compared to O-LR ($p<0.02$). Liver failure and biliary leakage were also less frequent among patients undergoing MIS ($p<0.01$). Similarly, MIS was associated with a shorter length of hospital stay (LOS) compared to O-LR ($p<0.001$). Of note, 30-day postoperative mortality and readmission were comparable between the two groups.
Conclusions Patients undergoing MIS had a lower postoperative morbidity and shorter LOS compared with patients undergoing O-LR. MIS is safe and may be associated with improved short-term outcomes following hepatic surgery.

Keywords Liver surgery · Minimally invasive surgery · Laparoscopic surgery · Robotic surgery

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Introduction

Due to advances in preoperative imaging, patient selection, surgical techniques, and perioperative management, morbidity after liver surgery for both primary and metastatic hepatobiliary disease has decreased.[1–4] The centralization of liver resection in high-volume hospitals, improved operative proficiency, advanced technical skills, more careful case selection, as well as superior anesthetic care and perioperative management have improved safety of major hepatic resection.[3, 5–10] The lower incidence of complications and subsequent mortality has led to a progressive increase in the number of operation performed for both primary and secondary liver tumors in the USA from

2.4 to 3.3 per 100,000 adults in the last decade.[3] However, while mortality has significantly decreased, morbidity after major hepatobiliary procedures, including bleeding requiring transfusion, bile leakage, and hepatic failure, remains relatively high.[11] While the role of surgical resection for primary and metastatic liver disease and symptomatic benign liver tumors is clearly established[12–14], the operative approach remains less well defined.

Open liver resection has traditionally been considered the gold standard to treat liver tumors. However, patients and surgeons are interested in minimally invasive (MIS) surgery. Since the early 1990s, the MIS approach has been proposed for a variety of surgical procedures to treat lung, colorectal, pancreatic, and gastric cancer.[11, 15–21] The MIS approach has also been proposed in hepatopancreaticobiliary (HPB) surgery[11], including distal pancreatectomy, pancreaticoduodenectomy[22, 23], as well as hepatic resection.[24–27] While the MIS and open approach seem to confer similar oncological results, patients undergoing a MIS procedure may be less likely to experience wound complications and have a shorter length of hospital stay.[28, 29] However, to date, most studies that have evaluated postoperative outcomes of patients undergoing hepatic resection with a MIS approach have been derived from small single center datasets.[11, 30–32] Such data may not be representative of the larger experience with MIS hepatic resection across the USA. As such, we sought to define the relative outcomes of the open vs. MIS approach for liver surgery using the newly released Procedure Targeted Hepatectomy module of the American College of Surgeons-National Surgical Quality Improvement Program NSQIP (ACS-NSQIP). In particular, the aim of the present study was to characterize the overall utilization and short-term outcomes among patients undergoing MIS vs. open liver surgery in a nationally representative database.

Methods

Patient Selection

Patients who underwent curative intent liver surgery between January 1, 2014 and December 31, 2014 in hospitals voluntarily participating in the Procedure Targeted Hepatectomy module of the ACS-NSQIP dataset were identified. The ACS-NSQIP database includes data prospectively collected on a variety of clinicopathological characteristics, including demographics, comorbidities, indication, operative details, and 30-day postoperative morbidity and mortality for patients undergoing major surgical procedures. As previously described, the data were collected by trained surgical clinical reviewers (SCRs) in a standardized format and were made available in a de-identified form for research.[14, 33, 34] Appropriate approval was obtained from the Johns Hopkins Institutional Review Board.

Data on demographic, clinicopathological, tumor, and therapy-related variables were collected. Specifically, patient demographic and clinicopathological characteristics, including age, sex, American Society of Anesthesiologist (ASA) score, comorbidities, jaundice, hepatitis status, biliary stent, and neoadjuvant therapy were collected. Data regarding treatment details were also collected including operative approach (i.e., open, laparoscopic, robotic, other minimally invasive approaches, hybrid, and other), operative time, Pringle maneuver, blood transfusion, and drain placement. Data on type of liver resection, concomitant biliary reconstruction, operative time, estimated blood loss (EBL), transfusion, and length of hospital stay (LOS) were collected. Data on peri-operative morbidity and mortality, as well as reoperation and readmission, were also obtained. Complications were scored by Clavien-Dindo classification with major complications defined as grade ≥3.[29] Complications included bile leak, post-hepatectomy liver failure, surgical site infections, wound disruption, pneumonia, reintubation, pulmonary embolism, acute renal failure, urinary tract infection, stroke, cardiac arrest, myocardial infarction, bleeding requiring transfusion, deep venous thrombosis requiring therapy, and sepsis.

For the purposes of analyses, patients were classified into two groups: patients who underwent MIS (including laparoscopic, laparoscopic hand assist, or robotic procedures) and patients who underwent open surgery. Patients who underwent conversion to an open procedure were classified in the open group.

Statistical Analysis

Discrete variables were described as medians with interquartile range (IQR). Categorical variables were described as totals and frequencies. Univariate comparisons were assessed using the chi-squared or Wilcoxon-rank sum test as appropriate. The nearest neighbor-matching algorithm was used to predict a propensity score to create comparable cohorts of patients. The propensity score was calculated using a logistic regression model, with the treatment of interest (open vs. MIS liver resection) as the outcome measure. The propensity-matched cohorts were compared to assess the effect of MIS vs. open surgery on peri-operative outcomes. All analyses were carried out with STATA version 12.0 (StataCorp, College Station, TX) or R software for statistical computing, v. 3.2.2, with the additional packages "Hmisc" and "Matching." A p value <0.05 (two-tailed) was considered statistically significant.

Results

A total of 3064 patients who underwent hepatic resection for primary liver malignancies (n=854, 27.9 %), liver metastasis (n=1446, 47.2 %), or symptomatic benign liver tumors (n=614, 20.0 %) were included in the study (Table 1). The median age of the study group was 60 years (IQR=50–68) and 52.3 % (n=1604) of patients was female. The minority of patients had underlying viral hepatitis (n=312, 10.2 %) related to HBV infection (n=140, 4.6 %), HCV infection (n=154, 5.0 %), or a concomitant HBV and HCV infection (n=18, 0.6 %). Neoadjuvant chemotherapy was administered to 898 (39.0 % of the 2300 patients with primary or secondary cancer) patients. The majority of patients underwent a partial lobectomy (n=1882, 61.4 %), while 302 (9.9 %), 607 (19.8 %), and 273 (9.9 %) patients underwent total left hepatectomy, total right hepatectomy, and extended hepatectomy, respectively. The Pringle maneuver was performed on 788 (25.7 %) patients. A minority of patients (n=220, 7.2 %) underwent a liver resection with a concomitant biliary reconstruction. A total of 2452 (80.0 %) patients underwent an open liver resection, while 612 (20.0 %) had a MIS approach (laparoscopic: n=563, 92.0 %; robotic: n=49, 8.0 %). According to the ASA classification, 1969 (64.3 %) patients had severe systemic disease (ASA 3), 805 (26.3 %) mild systemic disease (ASA 2), and 210 (6.8 %) a life-threatening systemic disease (ASA 4), while 77 (2.5 %) patients had no systemic disease (ASA 1). Hypertension and diabetes were the most frequent comorbidities and occurred in 1314 (42.9 %) and 479 (15.6 %) patients, respectively.

As expected, some baseline characteristics differed between the open vs. MIS groups (Table 2). MIS patients were more likely to be male (open 50.6 % vs. MIS 59.3 %; p<0.001) and to have benign liver disease (open 18.3 % vs. MIS 32.1 %; p<0.001). In addition, MIS patients were more likely to undergo a partial lobectomy (open 56.5 % vs. MIS 81.1 %; p<0.001), while total left hepatectomy (open 10.6 % vs. MIS 7.0 %), total right hepatectomy (open 22.9 % vs. MIS 7.5 %), and extended hepatectomy (open 10.6 % vs. MIS 7.0 %) were mostly performed with an open approach (p<0.001). Pringle maneuver (open 29.3 % vs. MIS 11.4 %) and biliary reconstruction (open 8.6 % vs. MIS 2.0 %) were also performed more frequently in the open group compared to the MIS group (both p<0.001).

In the post-operative period, the most common complications were bleeding requiring transfusion (n=569, 18.6 %) and organ space surgical site infection (SSI) (n=228, 7.4 %); post-hepatectomy biliary leak and liver failure occurred in 250 (8.2 %) and 149 (4.9 %) patients, respectively. When post-operative outcomes were stratified by operative approach, MIS was associated with lower bleeding requiring transfusion (open 21.3 % vs. MIS 7.5 %; p<0.001), post-hepatectomy liver failure (open 5.8 % vs. MIS 1.3 %), and biliary leak (open 10.3 % vs. MIS 2.9 %) compared with the open approach (all p<0.001). Furthermore, superficial SSI (open 4.5 % vs. MIS 1.1 %; p<0.001), deep SSI (open 1.2 % vs. MIS 0.3 %; p=0.06), organ space SSI (open 8.4 % vs. MIS 3.6 %; p<0.001), and wound disruption (open 1.1 % vs. MIS 0 %; p=0.012) were all more common in open than MIS group. Similarly, patients who had undergone an open hepatic resection had a higher incidence of reintubation (open 3.0 % vs. MIS 1.1 %; p=0.011), pulmonary embolism (open 1.6 % vs. MIS 0.2 %; p=0.006), myocardial infarction (open 0.7 % vs. MIS 0 %; p=0.039), and deep venous thrombosis requiring medical therapy (open 2.5 % vs. MIS 1.0 %; p=0.025). In addition, sepsis (open 5.6 % vs. MIS 2.6 %; p<0.001), septic shock (open 2.5 % vs. MIS 1.0 %; p=0.020), return to operation room (open 3.2 % vs. MIS 1.6 %; p=0.036), LOS (open 6 days vs. MIS 3 days), and readmission (open 11.1 % vs. MIS 7.5 %; p=0.011) all occurred more frequently after an open vs. MIS approach.

Propensity Score Matching

Given the differences in the baseline characteristics of the open vs. MIS groups, propensity matching was utilized to minimize confounding by indication and create more comparable cohorts of open vs. MIS patients for further analytic purposes. After propensity matching for age, gender, viral hepatitis, pathology, neoadjuvant therapy, diabetes, smoker status, dyspnea, ventilator-dependent status, COPD, ascites, chronic heart failure, hypertension, acute renal failure, steroid use for chronic condition, weight loss, ASA status, type of resection, Pringle maneuver, and biliary reconstruction, the propensity-matched cohort included 609 patients who underwent an open liver resection and 609 patients who underwent a MIS liver resection. After propensity matching, the demographic and clinicopathological characteristics for the open vs. MIS groups were much more comparable (minimum p value 0.12; Table 1S).

When peri-operative outcomes were analyzed in the propensity-matched cohort, morbidity remained lower among patients who had the MIS approached compared with patients who had undergone an open resection (open 20.8 % vs. MIS 11.6 % p<0.001; Fig. 1). Specifically, the incidence of superficial SSI (open 3.1 % vs. MIS 1.2 %; p=0.017), intraoperative or postoperative blood transfusions (open 14.9 % vs. MIS 7.3 %; p=0.001), and pulmonary embolism (open 2.1 % vs. MIS 0.2 %; p=0.001) was lower among patients in MIS vs. open group (Fig. 2a). Post-hepatectomy liver failure (open 3.6 % vs. MIS 1.2 %; p=0.005) and biliary leakage (open 7.0 % vs. MIS 3.0 %; p=0.002) were also less frequent among patients undergoing MIS (Fig. 2b). Similarly, the MIS approach was associated with a shorter LOS compared with patients who had undergone an open surgical procedure (median LOS: open 5 days [IQR, 4–8] vs. MIS 3 days

Table 1 Demographic, clinicopathological characteristics, and outcomes of the study population

Variables	*N* (%)
All patients	3064 (100 %)
Age, median (IQR)	60 years (50–68)
Age	
<65 years	1928 (62.9 %)
≥65 years	1136 (37.1 %)
Gender	
Male	1460 (47.7 %)
Female	1604 (52.3 %)
Viral hepatitis	
Hepatitis B	140 (4.6 %)
Hepatitis C	154 (5.0 %)
Hepatitis B and C	18 (0.6 %)
None	2404 (78.5 %)
NA	348 (11.3 %)
Pathology	
Benign	614 (20.0 %)
Primary hepatobiliary cancer	854 (27.9 %)
Secondary cancer	1446 (47.2 %)
NA	150 (4.9 %)
Neoadjuvant therapy[a]	
No	1522 (61.0 %)
Yes	898 (39.0 %)
Diabetes	
Insulin	192 (6.2 %)
Non-insulin	287 (9.4 %)
No	2585 (84.4 %)
Current smoker	
No	2613 (85.3 %)
Yes	451 (14.7 %)
Dyspnea	
At rest	10 (0.3 %)
Moderate exertion	155 (5.1 %)
No	2899 (94.6 %)
Ventilator dependent	
No	3061 (99.9 %)
Yes	3 (0.1 %)
COPD	
No	2956 (96.5 %)
Yes	108 (3.5 %)
Ascites	
No	3040 (99.2 %)
Yes	24 (0.8 %)
CHF	
No	3049 (99.5 %)
Yes	15 (0.5 %)
Hypertension	
No	1750 (57.1 %)
Yes	1314 (42.9 %)

Table 1 (continued)

Variables	*N* (%)
Acute renal failure	
No	3062 (99.9 %)
Yes	2 (0.1 %)
Steroid use for chronic condition	
No	2950 (96.3 %)
Yes	114 (3.7 %)
Weight loss	
No	2933 (95.7 %)
Yes	131 (4.3 %)
ASA	
1—no systemic disease	77 (2.5 %)
2—mild systemic disease	805 (26.3 %)
3—severe systemic disease	1969 (64.3 %)
4—life-threatening systemic disease	210 (6.8 %)
NA	3 (0.1 %)
Type of resection	
Partial lobectomy	1882 (61.4 %)
Total left hepatectomy	302 (9.9 %)
Total right hepatectomy	607 (19.8 %)
Extended hepatectomy	273 (9.9 %)
Concurrent inter-operative ablation	
No	2633 (85.9 %)
Yes	414 (13.5 %)
NA	17 (0.6 %)
Minimally invasive approach	
No	2452 (80.0 %)
Yes	612 (20.0 %)
MI approach[b]	
Full laparoscopic	407 (66.5 %)
Laparoscopic with hand assistance	156 (25.5 %)
Full robotic	27 (4.4 %)
Robotic with hand assistance	22 (3.6 %)
Pringle maneuver	
No	2276 (74.3 %)
Yes	788 (25.7 %)
Biliary reconstruction	
No	2800 (91.4 %)
Yes	220 (7.2 %)
NA	44 (1.4 %)
Bleeding requiring transfusion	
No	2495 (81.4 %)
Yes	569 (18.6 %)
Post-hepatectomy liver failure	
No	2915 (95.1 %)
Yes	149 (4.9 %)
Bile leak	
No	2788 (91.8 %)
Yes	250 (8.2 %)
NA	26

Table 1 (continued)

Variables	N (%)
Superficial incisional SSI	
No	2947 (96.2 %)
Yes	117 (3.8 %)
Deep incisional SSI	
No	3033 (98.9 %)
Yes	31 (1.1 %)
Organ/space SSI	
No	2836 (92.6 %)
Yes	228 (7.4 %)
Wound disruption	
No	3039 (99.2 %)
Yes	25 (0.8 %)
Pneumonia	
No	2950 (96.3 %)
Yes	114 (3.7 %)
Reintubation	
No	2984 (97.4 %)
Yes	80 (2.6 %)
Pulmonary embolism	
No	3025 (98.7 %)
Yes	39 (1.3 %)
On ventilator >48 h	
No	2996 (97.8 %)
Yes	68 (2.2 %)
Acute renal failure	
No	3036 (99.1 %)
Yes	28 (0.9 %)
Urinary tract infection	
No	2996 (97.8 %)
Yes	68 (2.2 %)
Stroke/CVA	
No	3057 (99.8 %)
Yes	7 (0.2 %)
Cardiac arrest requiring CPR	
No	3039 (99.2 %)
Yes	25 (0.8 %)
Myocardial infarction	
No	3047 (99.4 %)
Yes	17 (0.6 %)
DVT requiring therapy	
No	2998 (97.8 %)
Yes	66 (2.2 %)
Sepsis	
No	2912 (95.0 %)
Yes	152 (5.0 %)
Septic shock	
No	2996 (97.8 %)
Yes	68 (2.2 %)
Reoperation	
No	2975 (97.1 %)
Yes	89 (2.9 %)
Length of stay, median (IQR)	6 days (4–8)
Readmission	
No	2740 (89.4 %)
Yes	315 (10.3 %)
NA	9 (0.3 %)
Overall morbidity	
No	2098 (68.5 %)
Yes	966 (31.5 %)
30-day mortality	
No	3017 (98.5 %)
Yes	47 (1.5 %)

[a] In patients with malignancies

[b] In patients who underwent minimally invasive liver resections

[IQR, 2–5]; $p<0.001$). In contrast, 30-day post-operative mortality and readmission were comparable between the two groups (both $p>0.05$; Table 3).

Discussion

During the last several decades, there has been an increased interest in the MIS approach in different surgical fields including colorectal, gastric, urologic, and gynecological procedures.[35–38] In addition, interest in laparoscopic hepatic resection has grown since the International "Louisville Statement" regarding laparoscopic liver surgery was published in 2009. However, the role of MIS has not been clearly defined due to the slow adaptation of laparoscopic liver surgery, probably due to the perceived technical complexity of liver surgery and the high risk of difficult-to-control bleeding.[39] Moreover, the majority of evidence in favor of the MIS approach for hepatobiliary surgery has been derived from reports by specialized, tertiary hepatobiliary centers, limiting the general applicability of the findings.[11, 40] The current study is important because we analyzed outcomes of the MIS approach using the 2014 Procedure Targeted Hepatectomy module of ACS-NSQIP that included more than 3000 patients who underwent liver resection at 92 participating hospitals. More importantly, using propensity score matching to mitigate the confounding effect of differing preoperative characteristics among open vs. MIS patients, we noted that the MIS approach was associated with fewer transfusions and less overall morbidity including less surgical site infection and shorter LOS.

The overall utilization of the MIS approach among liver surgeons was noted to be relatively low. In fact, only one in

Table 2 Comparison between open liver resection and minimally invasive liver resection groups before propensity score matching

Variables	Open	MIS	*p* value
Number of patients	2452	612	–
Age			>0.99
<65 years	1543 (62.9 %)	385 (62.9 %)	
≥65 years	909 (37.1 %)	227 (37.1 %)	
Gender			<0.001
Male	1241 (50.6 %)	363 (59.3 %)	
Female	1211 (49.4 %)	249 (40.7 %)	
Viral hepatitis			0.39
Hepatitis B	108 (5.0 %)	32 (5.7 %)	
Hepatitis C	115 (5.3 %)	39 (7.0 %)	
Hepatitis B and C	15 (0.7 %)	3 (0.5 %)	
None	1919 (89.0 %)	485 (84.8 %)	
Pathology			<0.001
Benign	423 (18.3 %)	191 (32.1 %)	
Primary hepatobiliary cancer	719 (31.0 %)	135 (22.7 %)	
Secondary cancer	1176 (50.7 %)	270 (45.3 %)	
Neoadjuvant therapy*			0.08
No	1244 (62.1 %)	278 (66.7 %)	
Yes	759 (37.9 %)	139 (33.3 %)	
Diabetes			0.48
Insulin	158 (6.4 %)	34 (5.6 %)	
Non-insulin	235 (9.6 %)	52 (8.5 %)	
No	2059 (84.4 %)	526 (85.9 %)	
Current smoker			0.30
No	2083 (84.9 %)	530 (86.6 %)	
Yes	369 (15.1 %)	82 (13.4 %)	
Dyspnea			0.83
At rest	8 (0.3 %)	2 (0.3 %)	
Moderate exertion	127 (5.2 %)	28 (4.6 %)	
No	2317 (94.5 %)	582 (95.1 %)	
Ventilator dependent			0.39
No	2449 (99.9 %)	612 (100.0 %)	
Yes	3 (0.1 %)	0	
COPD			0.92
No	2366 (96.5 %)	590 (96.4 %)	
Yes	86 (3.5 %)	22 (3.6 %)	
Ascites			0.92
No	2433 (99.2 %)	607 (99.2 %)	
Yes	19 (0.8 %)	5 (0.8 %)	
CHF			0.52
No	2439 (99.5 %)	610 (99.7 %)	
Yes	13 (0.5 %)	2 (0.3 %)	
Hypertension			0.045
No	1378 (56.2 %)	372 (60.8 %)	
Yes	1074 (43.8 %)	240 (39.2 %)	
Acute renal failure			0.48
No	2450 (99.9 %)	612 (100.0 %)	
Yes	2 (0.1 %)	0	
Steroid use for chronic condition			0.44
No	2364 (96.4 %)	586 (95.8 %)	
Yes	88 (3.6 %)	26 (4.2 %)	
Weight loss			0.023
No	2337 (95.3 %)	596 (97.4 %)	
Yes	115 (4.7 %)	16 (2.6 %)	
ASA			0.003
1—no disturb	70 (2.9 %)	7 (1.1 %)	
2—mild disturb	612 (24.9 %)	193 (31.5 %)	
3—severe disturb	1589 (64.8 %)	380 (62.1 %)	
4—life-threatening	178 (7.4 %)	32 (5.3 %)	
Type of resection			<0.001
Partial lobectomy	1386 (56.5 %)	496 (81.1 %)	
Total left hepatectomy	259 (10.6 %)	43 (7.0 %)	
Total right hepatectomy	561 (22.9 %)	46 (7.5 %)	
Extended hepatectomy	246 (10.0 %)	27 (4.4 %)	
Concurrent inter-operative ablation			0.027
No	2090 (85.7 %)	543 (89.2 %)	
Yes	348 (14.3 %)	66 (10.8 %)	
Pringle maneuver			<0.001
No	1734 (70.7 %)	542 (88.6 %)	
Yes	718 (29.3 %)	70 (11.4 %)	
Biliary reconstruction			<0.001
No	2204 (91.4 %)	596 (98.0 %)	
Yes	208 (8.6 %)	12 (2.0 %)	
Bleeding requiring transfusion			<0.001
No	1929 (78.7 %)	566 (92.5 %)	
Yes	523 (21.3 %)	46 (7.5 %)	
Post-hepatectomy liver failure			<0.001
No	2311 (94.2 %)	602 (98.8 %)	
Yes	141 (5.8 %)	7 (1.2 %)	
Bile leak			<0.001
No	2200 (89.7 %)	588 (97.1 %)	
Yes	232 (10.3 %)	18 (2.9 %)	
Superficial incisional SSI			<0.001
No	2342 (95.5 %)	605 (98.9 %)	
Yes	110 (4.5 %)	7 (1.1 %)	
Deep incisional SSI			0.06
No	2423 (98.8 %)	610 (99.7 %)	
Yes	29 (1.2 %)	2 (0.3 %)	
Organ/space SSI			<0.001
No	2246 (91.6 %)	590 (96.4 %)	
Yes	206 (8.4 %)	22 (3.6 %)	
Wound disruption			0.012
No	2427 (98.9 %)	612 (100.0 %)	
Yes	25 (1.1 %)	0	

Table 2 (continued)

Variables	Open	MIS	*p* value
Pneumonia			0.11
No	2354 (96.0 %)	596 (97.4 %)	
Yes	98 (4.0 %)	16 (2.6 %)	
Reintubation			0.011
No	2379 (97.0 %)	605 (98.9 %)	
Yes	73 (3.0 %)	7 (1.1 %)	
Pulmonary embolism			0.006
No	2414 (98.5 %)	611 (99.8 %)	
Yes	38 (1.6 %)	1 (0.2 %)	
On ventilator greater than 48 h			<0.001
No	2386 (97.3 %)	610 (99.7 %)	
Yes	66 (2.7 %)	2 (0.3 %)	
Acute renal failure			0.09
No	2426 (98.9 %)	610 (99.7 %)	
Yes	26 (1.1 %)	2 (0.3 %)	
Urinary tract infection			0.09
No	2392 (97.6 %)	604 (98.7 %)	
Yes	60 (2.5 %)	8 (1.3 %)	
Stroke/CVA			0.57
No	2447 (99.8 %)	610 (99.7 %)	
Yes	5 (0.2 %)	2 (0.3 %)	
Cardiac arrest requiring CPR			0.13
No	2429 (99.1 %)	610 (99.7 %)	
Yes	23 (0.9 %)	2 (0.3 %)	
Myocardial infarction			0.039
No	2435 (99.3 %)	612 (100.0 %)	
Yes	17 (0.7 %)	0 (0 %)	
DVT requiring therapy			0.025
No	2392 (97.5 %)	606 (99.0 %)	
Yes	60 (2.5 %)	6 (1.0 %)	
Sepsis			<0.001
No	2316 (94.4 %)	596 (97.4 %)	
Yes	136 (5.6 %)	16 (2.6 %)	
Septic shock			0.020
No	2390 (97.5 %)	606 (99.0 %)	
Yes	62 (2.5 %)	6 (1.0 %)	
Reoperation			0.036
No	2373 (96.8 %)	602 (98.4 %)	
Yes	79 (3.2 %)	10 (1.6 %)	
Length of stay, median (IQR)	6 days (5–8)	3 days (2–5)	<0.001
Readmission			0.011
No	2174 (88.9 %)	566 (92.5 %)	
Yes	269 (11.1 %)	46 (7.5 %)	
Overall morbidity			<0.001
No	1580 (79.2 %)	540 (88.3 %)	
Yes	872 (35.6 %)	72 (11.7 %)	
30-day mortality			0.019
No	2408 (98.2 %)	606 (99.5 %)	
Yes	44 (1.8 %)	3 (0.5 %)	

*In patients with malignancies

five liver operations performed at NSQIP participating hospitals was done using a MIS approach. In a study of the Nationwide Inpatient Sample (NIS) database, Ejaz et al. reported on open vs. MIS outcomes among patients undergoing major pancreatic and hepatic resections between 2000 and 2011.[11] In that study, the authors noted a very low utilization of the MIS with only about 4 % of hepato-pancreatic cases performed using an MIS approach. Furthermore, an increased trend in the overall use of the MIS approach only increased from 2.3 % in 2000 to 7.5 % in 2011.[11] The reason for the higher utilization of the MIS approach reported in the current study is likely multifactorial. Data in the current study were more contemporary (2014) and therefore may reflect a temporal increasing trend in implementation of the MIS approach over time. In addition, in contrast to NIS, data derived from ACS-NSQIP probably represent a sub-selection of higher performing, larger academic and private hospitals where the penetration of the MIS approach may be more prevalent. Interestingly, of the 612 patients who underwent a MIS approach, 67 % had a total laparoscopic procedure, 25 % had a hand-assisted laparoscopic operation, and 8 % had a robotic approach. These data indicate that use of the robot for liver surgery at many hospitals remains low. In addition, we noted that more than two thirds of patients who underwent a MIS approach had a malignant liver tumor as indication for surgery. In a separate series of patients undergoing hepatectomy, Nguyen et al. noted that about 50 % of MIS hepatectomy were for malignant tumors.[41] Collectively, these data suggest that more and more surgeons are routinely using an MIS approach to treat

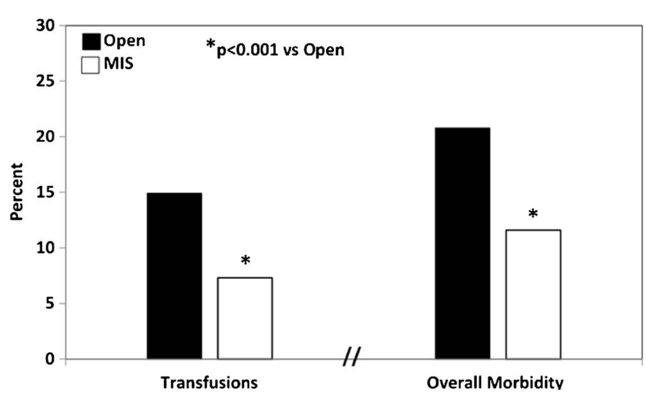

Fig. 1 Transfusion and overall morbidity in MIS (n=609) and open (n=609) groups after propensity matching

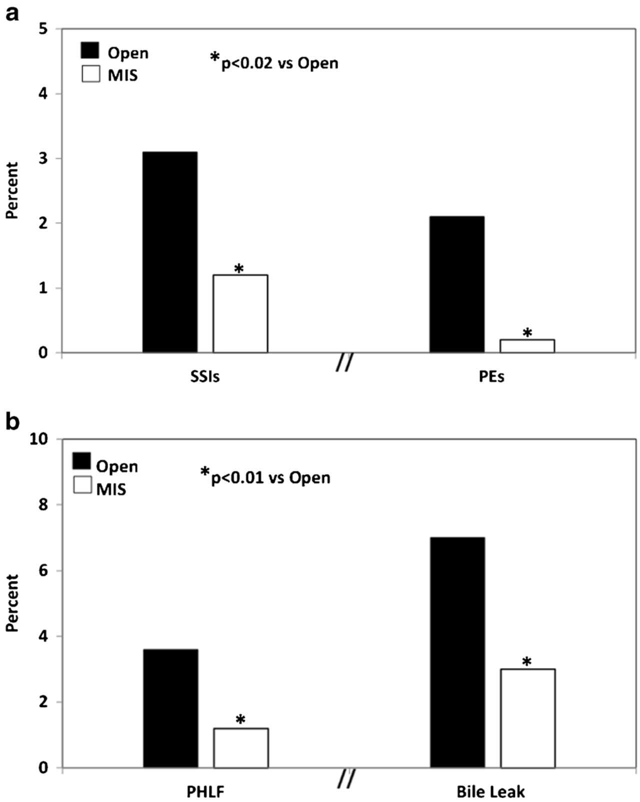

Fig. 2 **a** Superficial site infections (SSIs) and pulmonary embolism (PEs) in MIS (n=609) and open (n=609) groups after propensity matching. **b** Post-hepatectomy liver failure (PHLF) and bile leak rates in MIS (n=609) and open (n=609) groups after propensity matching

Table 3 Comparison between short-term outcomes of open liver resection and minimally liver resection groups after propensity score matching

Variables	Open	MIS	*p* value
Number of patients	609	609	–
Transfusions intra-postoperative			0.001
No	526 (86.4 %)	563 (92.5 %)	
Yes	83 (13.6 %)	46 (7.5 %)	
Post-hepatectomy liver failure			0.005
No	584 (96.4 %)	599 (98.8 %)	
Yes	22 (3.6 %)	7 (1.2 %)	
Bile leak			0.002
No	561 (93.0 %)	582 (98.8 %)	
Yes	42 (7.0 %)	18 (3.0 %)	
Superficial incisional SSI			0.017
No	590 (96.9 %)	602 (98.8 %)	
Yes	19 (3.1 %)	7 (1.2 %)	
Deep incisional SSI			>0.99
No	607 (99.7 %)	607 (99.7 %)	
Yes	2 (0.3 %)	2 (0.3 %)	
Organ/space SSI			0.42
No	589 (97.2 %)	584 (96.4 %)	
Yes	17 (2.8 %)	22 (3.6 %)	
Wound disruption			0.08
No	606 (99.5 %)	609 (100.0 %)	
Yes	3 (0.5 %)	0 (0 %)	
Pneumonia			0.15
No	600 (98.5 %)	593 (97.4 %)	
Yes	9 (1.5 %)	16 (2.6 %)	
Reintubation			0.62
No	600 (98.5 %)	602 (98.9 %)	
Yes	9 (1.5 %)	7 (1.1 %)	
Pulmonary embolism			0.001
No	596 (97.9 %)	608 (99.8 %)	
Yes	13 (2.1 %)	1 (0.2 %)	
On ventilator greater than 48 h			0.02
No	599 (98.4 %)	607 (99.7 %)	
Yes	10 (1.6 %)	2 (0.3 %)	
Acute renal failure			0.41
No	605 (99.3 %)	607 (99.7 %)	
Yes	4 (0.7 %)	2 (0.3 %)	
Urinary tract infection			0.64
No	599 (98.4 %)	601 (98.7 %)	
Yes	10 (1.6 %)	8 (1.3 %)	
Stroke/CVA			>0.99
No	607 (99.7 %)	607 (99.7 %)	
Yes	2 (0.3 %)	2 (0.3 %)	
Cardiac arrest requiring CPR			0.65
No	606 (99.5 %)	607 (99.7 %)	
Yes	3 (0.5 %)	2 (0.3 %)	
Myocardial infarction			0.08
No	606 (99.5 %)	609 (100.0 %)	
Yes	3 (0.5 %)	0	
DVT requiring therapy			0.10
No	596 (97.9 %)	603 (99.0 %)	
Yes	13 (2.1 %)	6 (1.0 %)	
Sepsis			0.15
No	601 (99.7 %)	593 (97.4 %)	
Yes	8 (1.3 %)	16 (2.6 %)	
Septic shock			0.76
No	604 (99.2 %)	603 (99.0 %)	
Yes	5 (0.8 %)	6 (1.0 %)	
Reoperation			0.46
No	602 (98.8 %)	599 (98.4 %)	
Yes	7 (1.2 %)	10 (1.6 %)	
Length of stay, median (IQR)	5 days (4–8)	3 days (2–5)	<0.001
Readmission			0.74
No	558 (92.1 %)	561 (92.6 %)	
Yes	48 (7.9 %)	45 (7.4 %)	

Table 3 (continued)

Variables	Open	MIS	*p* value
Overall morbidity			<0.001
No	482 (79.2 %)	538 (88.4 %)	
Yes	127 (20.8 %)	71 (11.6 %)	
30-day mortality			0.48
No	604 (99.2 %)	606 (99.5 %)	
Yes	5 (0.8 %)	3 (0.5 %)	

malignant tumors of the liver. This observation could be related to increasing evidence of oncological equivalence of the MIS approach.[40, 42] In particular, the MIS approach has been associated with decreased blood loss, overall complication rates, and LOS with comparable 5-year overall and disease-free survival.[42]

Prior to propensity score matching, several preoperative clinical, as well as operative, characteristics were different among patients undergoing open vs. MIS approach. Particularly, the MIS group included more patients with benign pathologies and those who underwent a minor hepatectomy. In contrast, Pringle maneuver and biliary reconstruction were performed more frequently in the open group compared to the MIS group. To account for some of these baseline differences, previous studies had utilized a case-matched study design to compare open vs. MIS liver surgery and had reported that MIS was associated with better peri-operative outcomes.[42] The use of a case-matched approach can, however, be limited due to inability to identify appropriate controls, as well as the ability to match only a limited number of variables.[43] In contrast, we utilized the much more robust methodology of propensity matching, which allows for better balancing of many covariates into a score that can be used to identify comparable matched groups.[44] Of note, after propensity matching, no significant differences were noted among the open and MIS groups in terms of demographic and clinicopathological baseline characteristics (Table 1S). Importantly, even after propensity matching, overall morbidity was lower among patients who underwent an MIS vs. an open liver resection. Specifically, the incidence of SSI as well as liver-related complications such as bile leak were less frequent among patients undergoing MIS than open surgery. In addition, MIS was associated with a shorter LOS compared with an open approach (median LOS: open 5 days vs. MIS 3 days; $p<0.001$). Interesting, however, the 30-day postoperative mortality and readmission were comparable between the two groups (both $p>0.05$).

The current study had several potential limitations. As with all retrospective studies, there undoubtedly was some residual selection bias/confounding despite the propensity matching. The increased percentage of liver failure and bile leaks in the open group suggests that this group may have had a higher fraction of more complex surgeries and disease states. However, the differences for most outcomes, while statistically significant, were not that large when comparing the open vs. MIS groups. Moreover, no hospital- or surgeon-specific variables were available to assess the impact of volume or experience on MIS peri-operative outcomes. In the current study, we combined patients undergoing laparoscopic and robotic liver resections into the MIS group. While this did not permit an assessment of robot-specific outcomes, previous single center data from Tsung et al. reported no differences among patients undergoing laparoscopic vs. robotic resections with regard to peri-operative outcomes including blood loss, transfusion rate, margin status, postoperative peak bilirubin, postoperative intensive care unit admission rate, LOS, and 90-day mortality.[42] Finally, our analysis was limited to 30-day outcomes although 90-day outcomes due to the restrictions of the NSQIP database.

In conclusion, utilization of MIS for liver tumors remains relatively low, as only one in five cases were performing using this approach. The indications for the MIS approach were, however, broad as many patients with both benign and malignant tumors underwent a MIS procedure. Even after propensity matching to ensure minimal residual bias, patients who underwent an MIS approach had a lower postoperative morbidity and shorter LOS compared with patients undergoing open liver surgery. When feasible, the MIS approach to the resection of both benign and malignant tumors should be strongly considered.

Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no competing interests.

Authors' Contributions All authors designed the work, revised the manuscript critically for important intellectual content, approved the final version to be published, and agreed to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. Fabio Bagante, Gaya Spolverato, and Timothy M. Pawlik analyzed and interpreted data. Fabio Bagante, Gaya Spolverato, and Timothy M. Pawlik drafted the work.

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