



Modern trends in minimally invasive versus open hepatectomy for colorectal liver metastasis: an analysis of ACS-NSQIP

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Abstract

Background Surgical resection of colorectal liver metastasis (CRLM) provides the best opportunity for prolonged survival. Eligibility for metastasectomy has expanded with technical advancements including parenchymal-sparing hepatectomy (PSH). Meanwhile, enthusiasm for minimally invasive surgery (MIS) has increased, though this approach may be preferentially utilized for technically straightforward cases. The purpose of this study is to characterize modern trends in open versus MIS approaches to partial hepatectomy and anatomic hepatectomy for CRLM within a nationwide cohort.

Methods The American College of Surgeons' National Surgical Quality Improvement Program (ACS-NSQIP) was used to investigate trends in MIS versus open hepatectomy for CRLM from 2015 to 2019. We examined baseline clinicopathologic and disease-related characteristics and compared trends in treatments over the study period.

Results A total of 7457 patients undergoing hepatectomy for CRLM were identified (1367 MIS, 6090 open). Patients had similar clinicopathologic features between the two groups. Patients undergoing MIS resection less frequently received neoadjuvant therapy (51.1% vs 64.0%, $p < 0.001$) or concurrent intraoperative ablation (15.0% vs 21.3%, $p < 0.001$). Patients with tumors < 2 cm (34.9% vs 26.8%, $p < 0.001$) or only one to two tumors (82.8% vs 65.0%, $p < 0.001$) more commonly underwent MIS. MIS and open partial hepatectomies both significantly increased over the study period, but open partial hepatectomy increased at a greater rate than MIS ($p < 0.001$). Rates of anatomic resections have remained the same, with a greater proportion performed using an open approach (34.9% vs 16.4%, $p < 0.001$). Rates of operations consisting of > 1 concurrent partial hepatectomy are stable, but significantly more likely to be performed open ($p < 0.001$).

Conclusions Hepatectomy for CRLM has increased from a rise in partial hepatectomy, potentially translating to increased use of PSH. Current trends suggest MIS approaches appear to be increasing, but selectively implemented for patients with less technically demanding disease characteristics. Educational efforts should be directed towards increased dissemination of parenchymal-sparing MIS techniques for more complex resections.

Keywords Colorectal liver metastasis · Parenchymal-sparing · Minimally invasive surgery · Hepatectomy

ACS-NSQIP Disclaimer: The American College of Surgeons National Surgical Quality Improvement Program and the hospitals participating in the ACS NSQIP are the source of the data used herein; they have not verified and are not responsible for the statistical validity of the data analysis or the conclusions derived by the authors.

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Colorectal cancer is the fourth most common cancer in the USA [1]. The liver is the most common site of metastasis, occurring in approximately 50% of affected individuals [2–4]. While the majority of patients with colorectal liver metastasis (CRLM) have unresectable disease,

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advancements in perioperative management and improved surgical strategies, such as parenchymal sparing hepatectomy (PSH), have extended the eligibility for patients to undergo metastatectomy [2, 3, 5]. Five-year survival rates have recently been reported to be as high as 60%, compared to an accepted number of less than 30% in the 1980s, with approximately 20% achieving cure [2, 3, 6]. With modern management, to include PSH, salvageability is maintained in the case of recurrence. Up to 25% of patients may therefore undergo re-resection and achieve long-term survival [2, 7].

Minimally invasive surgery (MIS) is playing an increasing role in the management of CRLM. Retrospective data supports less blood loss and reduced length of stay (LOS) with an MIS approach, as well as non-inferior oncologic outcomes and mortality compared to open resection [8, 9]. In a recent single-institution randomized controlled trial, Fretland et al. demonstrated fewer postoperative complications, greater cost-effectiveness, and equivalent rate of negative resection margins in the laparoscopic compared to open arm [10]. Despite the apparent rise of both MIS and PSH techniques, which have undoubtedly revolutionized the care of patients with CRLM, existing literature characterizing trends in operative approach over the last decade is lacking. An analysis of the American College of Surgeons' National Quality Improvement Program (ACS-NSQIP) registry investigated patterns in concurrent partial lobectomy and ablation for 2014 cases, but did not incorporate characteristics such as tumor size or number into the study and included resections for both benign and malignant pathologies, limiting the ability to draw conclusions regarding trends in CRLM treatment specifically [11]. Another study of patients within the Veterans Affairs health system analyzed trends in management of CRLM from 1998 to 2012, but did not stratify patients by operative approach (i.e., liver resection only, ablation, or a combination) [4]. With the evolving management of CRLM in an expanding pool of patients eligible for resection, a more recent and detailed examination of operative approach patterns in the context of tumor-specific disease characteristics is warranted.

In this study, we sought to characterize modern trends in an open versus MIS approach to partial hepatectomy and anatomic hepatectomy for CRLM within a nationwide cohort. We hypothesized that while the use of MIS and partial hepatectomy would increase over time, an open approach with possible anatomic resection would predominate for patients with technically demanding disease characteristics.

Materials and methods

Data were obtained from the American College of Surgeons' National Surgical Quality Improvement Program (ACS-NSQIP) registry, a risk-adjusted, outcomes-based database,

using the Hepatectomy Procedure Targeted Participant User File (PUF). As the ACS-NSQIP database is de-identified and publicly available, Institutional Review Board approval was not required.

Study design and cohort definitions

Data were assessed between the years of 2015–2019. Patients older than 18 undergoing hepatectomy (CPT 47120, 47125, 47122, 47130) for a known diagnosis of metastatic colorectal cancer, defined as a categorical variable within the Hepatectomy PUF, were included. All patients had an operative approach (MIS or open) recorded. Patients were defined as undergoing MIS if they underwent laparoscopic, laparoscopic with open assist, robotic with open assist, or other minimally invasive approach. Patients were defined as undergoing an open approach if they underwent a planned open resection or unexpected conversion from an initial MIS approach.

Patients were assigned to either an anatomic (CPT 47125, 47122, or 47130) or partial resection (CPT 47120) study group based on procedure coding. It was noted if one or greater concurrent partial hepatectomies were performed. In this study a partial hepatectomy was considered a PSH, though some exceptions to this generalization exist, which nevertheless aligns with most literature and was necessary within the constraints of the dataset [5, 12, 13].

Variables

Baseline demographic details were collected including age, sex, body mass index (BMI), functional status prior to surgery, and comorbidities such as diabetes, bleeding disorders, and pre-existing hepatitis. Pre-operative lab values and year of resection were additionally assessed. Relevant operative details analyzed included principle operative procedure, adjunct procedures, case urgency, and operative time. Liver-specific preoperative factors such as neoadjuvant therapy and biliary stenting were considered, as well as intraoperative details of hepatectomy including concurrent ablation, inflow occlusion during resection (i.e., Pringle maneuver), biliary reconstruction, and size and number of hepatic lesions treated.

Predictors of undergoing open or MIS resection were evaluated based on the above clinicopathologic factors.

Analysis of trends

To examine trends in management of CRLM over time, we evaluated frequency over the years of partial versus anatomic resection, and whether resection was performed via a MIS or open approach. Specifics of treatment over time were assessed, including receipt of neoadjuvant therapy,

tumor size, concurrent partial hepatectomy, and intraoperative ablation.

Statistical analysis

Statistics were calculated using SPSS (version 22, IBM Corp, Released 2013, Armonk, NY) and SAS Software v9.4 (SAS Institute Inc., Cary, NC). Clinicopathologic data and trends were analyzed via either student's *T*-test or Mann–Whitney *U*-test for continuous variables and Chi-square test for categorical variables. Rate of change was evaluated with a student's *T*-test. Multivariable logistic regression was performed to evaluate predictors of undergoing open versus MIS resection based on preoperative patient and disease characteristics.

Results

A total of 22,531 patients underwent hepatectomy at participating ACS-NSQIP institutions between 2012 and 2019. After applying our study criteria, a total of 7457 patients underwent either MIS ($n = 1367$) or open ($n = 6090$) hepatectomy for CRLM and were included in our analysis (Fig. 1). Of note, 4.22% ($n = 257$) of the open hepatectomies were due to conversion from MIS. This subgroup was included in the open group as per our predefined cohorts in the methods section.

Clinicopathologic factors and treatments

Univariate analysis of demographics, pre-operative characteristics, and hepatic-specific variables for patients undergoing an MIS versus open resection are summarized in Table 1. Demographics and comorbidities of patients in either resection group were similar, though a greater proportion of patients in the open resection group had a pre-operative bleeding disorder (4.2% vs. 2.6%, $p = 0.01$). While several differences in pre-operative laboratory values were noted,

these do not appear to be clinically significant. A greater proportion of patients undergoing an open resection received neoadjuvant therapy (NAT) (64.0% vs 51.1%, $p < 0.001$), with larger (> 5 cm, 22.3% vs 12.8%, $p < 0.001$) and more numerous tumors (> 2 tumors, 35.0% vs 17.2%, $p < 0.001$).

Regarding operative factors, a greater proportion of patients undergoing an MIS resection underwent a partial versus anatomic hepatectomy as the principle operative procedure than patients receiving an open resection (83.6% vs. 65.1%, $p < 0.001$). The most common principle operative procedure after partial hepatectomy was a right hepatectomy for both open (18.5%) and MIS (8.9%) resections. While additional procedures were numerous, concurrent partial hepatectomy (15.1% and 6.1%), cholecystectomy (20.9% and 3.5%), and diagnostic ultrasound (7.5% and 7.6%) were frequently reported for open and MIS resections, respectively. A greater proportion of open than MIS resections included > 1 concurrent partial hepatectomies (31.5% vs. 22.2%, $p < 0.001$) and ablation (21.3% vs. 15.0%, $p < 0.001$). More patients undergoing open resection required inflow occlusion during the operation (31.5% vs. 16.4%, $p < 0.001$) and biliary reconstruction (1.9% vs. 0.9%, $p = 0.01$) than the MIS group.

Multivariable logistic regression modeling was used to determine independent predictors of operative approach (Table 2). Asian race was independently associated with receiving an MIS resection (OR 2.13, 95% CI 1.56–2.91), as was undergoing a single partial hepatectomy (OR 2.33, 95% CI 1.74–3.12), and having a tumor < 2 cm (OR 1.58, 95% CI 1.22–2.04). However, receiving neoadjuvant chemotherapy (OR 0.73, 95% CI 0.62–0.87), undergoing concurrent intraoperative ablation (0.71, 95% CI 0.56–0.89), or requiring inflow occlusion during resection (OR 0.43, 95% CI 0.35–0.53) were associated with decreased odds of an MIS approach. Other factors, including number of CRLM, were not independently associated with operative approach.

Fig. 1 Patient flow diagram

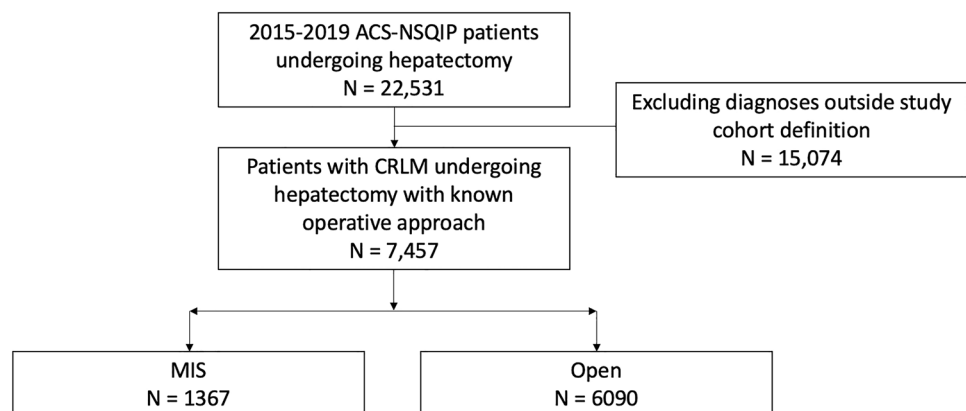


Table 1 Univariate analysis of demographics and clinicopathologic factors with missing data

Variable	Operative approach		<i>p</i> -value
	MIS <i>n</i> = 1367 (%)	Open <i>n</i> = 6090 (%)	
Demographics			
Year			0.1
2015	225 (16.5)	1076 (17.7)	
2016	242 (17.7)	1234 (20.3)	
2017	269 (19.7)	1165 (19.1)	
2018	306 (22.4)	1252 (20.6)	
2019	325 (23.8)	1363 (22.4)	
Missing	None	None	
Age (years), median (IQR)	60 (18)	59 (17)	0.01
Missing	None	None	
Sex			0.3
Male	782 (57.2)	3571 (58.6)	
Female	585 (42.8)	2519 (41.4)	
Missing	None	None	
Race			<0.001
American Indian or Alaska Native	4 (0.3)	25 (0.4)	
Asian	82 (6.0)	207 (3.4)	
Black or African American	85 (6.2)	407 (6.7)	
Native Hawaiian or Pacific Islander	3 (0.2)	12 (0.2)	
White	826 (60.4)	3892 (63.9)	
Missing	367 (26.9)	1547 (25.4)	
Hispanic Ethnicity			0.5
Yes	64 (4.7)	285 (4.7)	
No	974 (71.2)	4425 (72.7)	
Missing	329 (24.1)	1380 (22.7)	
Transfer status			0.8
Admitted from home	1362 (99.6)	6070 (99.7)	
Other	5 (0.4)	20 (0.3)	
Missing	None	None	
Discharge destination			<0.001
Home	1333 (97.5)	5767 (94.7)	
Expired	11 (0.8)	46 (0.8)	
Others	21 (1.5)	249 (4.1)	
Missing	2 (0.2)	28 (0.4)	
BMI, median (IQR)	27.7 (7.5)	27.7 (7.5)	0.9
Missing, <i>n</i> (%)	7 (0.5)	44 (0.7)	
Functional status prior to surgery			0.2
Independent	1357 (99.3)	6054 (99.4)	
Dependent	9 (0.7)	23 (0.4)	
Missing, <i>n</i> (%)	1 (0.1)	13 (0.2)	
Ventilator dependent prior to surgery	0 (0)	1 (0.02)	1.0
Missing	None	None	
Pre-operative transfusion	1 (0.1)	19 (0.3)	0.2
Missing	None	None	
Pre-operative sepsis	0 (0)	34 (0.6)	0.01
Missing	None	None	
ASA			0.2
Class 1	6 (0.4)	16 (0.3)	
Class 2	275 (20.1)	1226 (20.1)	

Table 1 (continued)

Variable	Operative approach		<i>p</i> -value
	MIS <i>n</i> = 1367 (%)	Open <i>n</i> = 6090 (%)	
Class 3	985 (72.1)	4317 (70.9)	
Class 4/5	101 (7.4)	512 (8.4)	
Missing	0 (0)	19 (0.3)	
Comorbidities			
Diabetes			0.5
Non-insulin requirement	154 (11.3)	626 (10.3)	
Insulin-dependent	65 (4.7)	311 (5.1)	
No	1148 (84.0)	5153 (84.6)	
Missing	None	None	
Smoking	174 (12.7)	833 (13.7)	0.4
Missing	None	None	
Dyspnea			0.9
At rest	2 (0.1)	7 (0.1)	
Moderate exertion	53 (3.9)	227 (3.7)	
No	1312 (96.0)	5856 (96.2)	
Missing	None	None	
Chronic obstructive pulmonary disease (COPD)	33 (2.4)	157 (2.6)	0.8
Missing	None	None	
Ascites	2 (0.2)	10 (0.2)	1.0
Missing	None	None	
Congestive heart failure (CHF)	2 (0.2)	14 (0.2)	0.8
Missing	None	None	
Hypertension	591 (43.2)	2573 (42.2)	0.5
Missing	None	None	
Renal failure	1 (0.07)	2 (0.03)	0.5
Missing	None	None	
Dialysis	0 (0)	14 (0.2)	0.1
Missing	None	None	
Open wound infection	5 (0.4)	31 (0.5)	0.7
Missing	None	None	
Steroid use pre-op	43 (3.2)	161 (2.6)	0.3
Missing	None	None	
Recent weight loss	44 (3.2)	226 (3.7)	0.4
Missing	None	None	
Bleeding disorders	35 (2.6)	259 (4.2)	0.01
Missing	None	None	
Hepatitis B/C	22 (1.6)	85 (1.4)	0.4
None/other	1174 (85.9)	5164 (84.8)	
Missing	171 (12.5)	841 (13.8)	
Pre-operative labs, median (IQR)			
Sodium	140 (3)	140 (3)	0.6
Missing, <i>n</i> (%)	47 (3.4)	177 (2.9)	
Creatinine	0.8 (0.3)	0.8 (0.3)	0.1
Missing, <i>n</i> (%)	29 (2.1)	133 (2.2)	
Pre-op albumin	4.1 (0.5)	4.0 (0.6)	0.01
Missing, <i>n</i> (%)	192 (14.0)	847 (13.9)	
Pre-op bilirubin	0.5 (0.3)	0.5 (0.4)	0.02
Missing, <i>n</i> (%)	99 (7.2)	412 (6.8)	
Pre-op white blood cell count (WBC)	6.0 (2.6)	6.2 (2.7)	0.01

Table 1 (continued)

Variable	Operative approach		<i>p</i> -value
	MIS <i>n</i> = 1367 (%)	Open <i>n</i> = 6090 (%)	
Missing, <i>n</i> (%)	25 (1.8)	103 (1.7)	
Pre-op hematocrit (Hct)	40.0 (5.5)	39.5 (6)	0.01
Missing, <i>n</i> (%)	19 (1.4)	99 (1.6)	
Pre-op platelet level	211 (87)	208 (90)	0.1
Missing, <i>n</i> (%)	31 (2.3)	105 (1.7)	
Pre-op international normalized ratio (INR)	1.0 (0.09)	1.0 (0.11)	<0.001
Missing, <i>n</i> (%)	240 (17.6)	957 (15.7)	
Pre-op aspartate aminotransferase (AST)	24 (13)	25 (14)	<0.001
Missing, <i>n</i> (%)	157 (11.5)	672 (11.0)	
Operative details			
Principle operative procedure (CPT)			<0.001
Partial hepatectomy (47120)	1142 (83.6)	3964 (65.1)	
Trisegmentectomy (47122)	40 (2.9)	587 (9.6)	
Total left hepatectomy (47125)	63 (4.6)	415 (6.8)	
Total right hepatectomy (47130)	122 (8.9)	1124 (18.5)	
Missing	None	None	
Additional procedures			
Secondary procedure			<0.001
Partial hepatectomy (47120)	58 (4.2)	700 (11.5)	
Ablation of 1 or more liver tumors (47380)	17 (1.2)	286 (4.7)	
Cholecystectomy (47600)	33 (2.4)	969 (15.9)	
Diagnostic ultrasound (76998)	72 (5.3)	349 (5.7)	
Other	773 (56.6)	2339 (38.4)	
Missing	414 (30.3)	1447 (23.8)	
Tertiary procedure			<0.001
Partial hepatectomy (47120)	14 (1.0)	294 (4.8)	
Cholecystectomy (47600)	14 (1.0)	489 (8.0)	
Diagnostic ultrasound (76998)	60 (4.4)	304 (5.0)	
Other	399 (29.2)	1846 (30.3)	
Missing	880 (64.4)	3157 (51.9)	
Emergency case	1 (0.1)	10 (0.2)	0.7
Missing	None	None	
Operative time, median (IQR)	200 (149)	238 (142)	<0.001
Missing, <i>n</i> (%)	1 (0.1)	0 (0)	
Liver specific factors			
Pre-operative biliary stent	7 (0.5)	66 (1.1)	0.2
Missing	9 (0.7)	47 (0.8)	
Neoadjuvant Therapy	695 (50.8)	3882 (63.7)	<0.001
Missing	7 (0.5)	27 (0.4)	
Type of neoadjuvant therapy			<0.001
Preoperative systemic chemotherapy alone	667 (48.8)	3399 (55.8)	
Preoperative systemic chemotherapy and other	20 (1.5)	318 (5.2)	
Unspecified	8 (0.6)	165 (2.7)	
Missing	672 (49.1)	2208 (36.3)	
Liver texture			<0.001
Cirrhotic	24 (1.8)	167 (2.7)	
Congested	18 (1.3)	202 (3.3)	
Fatty	262 (19.2)	1043 (17.1)	
Fibrosis	9 (0.7)	51 (0.9)	

Table 1 (continued)

Variable	Operative approach		<i>p</i> -value
	MIS <i>n</i> = 1367 (%)	Open <i>n</i> = 6090 (%)	
Normal	354 (25.9)	1713 (28.1)	
Missing	700 (51.2)	2914 (47.9)	
Number of concurrent partial hepatectomy			<0.001
0	648 (47.4)	2402 (39.4)	
1	404 (29.6)	1722 (28.3)	
> 1	301 (22.0)	1901 (31.2)	
Missing	14 (1.0)	65 (1.1)	
Concurrent intraoperative ablation	204 (14.9)	1289 (21.2)	<0.001
Missing	11 (0.8)	29 (0.5)	
Inflow occlusion during resection (i.e., Pringle)	224 (16.4)	1918 (31.5)	<0.001
Missing	None	None	
Biliary reconstruction	12 (0.9)	114 (1.9)	0.02
Missing	20 (1.5)	64 (1.0)	
Drain placement	343 (25.1)	2498 (41.0)	<0.001
Missing	15 (1.1)	16 (0.3)	
Number of tumors treated			<0.001
1–2	1100 (80.5)	3786 (62.2)	
3–5	188 (13.8)	1546 (25.4)	
6–8	26 (1.9)	319 (5.2)	
> 8	14 (1.0)	174 (2.9)	
Missing	39 (2.8)	265 (4.3)	
Tumor size			<0.001
< 2 cm	460 (33.7)	1569 (25.8)	
2–5 cm	688 (50.3)	2986 (49.0)	
> 5 cm	168 (12.3)	1308 (21.5)	
Missing	51 (3.7)	227 (3.7)	

Analysis of trends over time

Trends in management of CRLM were examined by year (Table 3). Both MIS ($p=0.001$) and open ($p=0.034$) partial hepatectomy increased in frequency during the study period, though open partial hepatectomy increased at a greater rate ($p<0.001$) (Fig. 2). Meanwhile, rates of anatomic resections did not change over the study period for either an MIS ($p=0.9$) or open ($p=0.5$) approach. Rates of ≥ 1 concurrent partial hepatectomy were stable over the study period for both MIS ($p=0.9$) and open ($p=0.5$) resections, but as discussed previously comprise a greater proportion of open than MIS resections ($p<0.001$).

Though a greater proportion of patients undergoing open versus MIS resection had a concurrent intraoperative ablation, only rates of MIS ablation significantly increased in time ($p=0.04$). Similarly, only rates of MIS resection of

mid-sized tumors (2–5 cm) increased ($p=0.01$), though large tumors (> 5 cm) favor open resection and these rates did not change over time for either approach. Rates of neoadjuvant therapy increased for patients receiving an open resection only ($p<0.001$).

Discussion

In this study, we examined a nationwide cohort of 7457 patients who underwent an open or MIS hepatectomy for CRLM. While patients undergoing either approach had similar demographics and preoperative comorbidities, patients undergoing open resection had larger, more numerous tumors. Additionally, a greater proportion of patients undergoing open hepatectomy received NAT and concurrent intraoperative ablation. Overall, hepatectomies

Table 2 Multivariable logistic regression of demographics and clinicopathologic factors

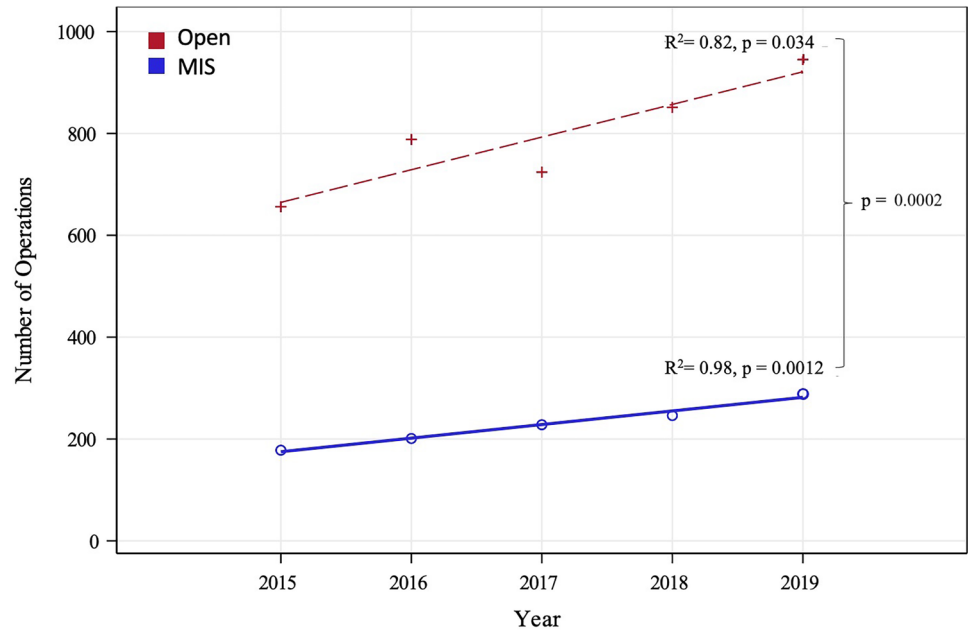
Variable	OR (95% CI)	<i>p</i> -value
Year		
2015	0.99 (0.77, 1.27)	0.9
2016	1.01 (0.79, 1.29)	0.9
2017	1.14 (0.89, 1.47)	0.3
2018	1.03 (0.81, 1.31)	0.8
2019	REF	
Age	1.010 (1.003, 1.017)	0.01
Race		
American Indian or Alaska Native	0.60 (0.17, 2.12)	0.4
Asian	2.13 (1.56, 2.91)	<0.001
Black or African American	1.08 (0.82, 1.44)	0.6
Native Hawaiian or Pacific Islander	1.03 (0.26, 4.02)	0.9
White	REF	
Comorbidities		
Bleeding disorders	0.88 (0.57, 1.35)	0.6
Pre-operative labs		
Pre-op albumin	0.96 (0.79, 1.18)	0.7
Pre-op white blood cell count (WBC)	0.96 (0.92, 0.99)	0.01
Pre-op hematocrit (Hct)	1.02 (1.01, 1.04)	0.04
Pre-op aspartate aminotransferase (AST)	0.997 (0.992, 1.001)	0.1
Principle operative procedure (CPT)		
Partial hepatectomy (47,120)	2.33 (1.74, 3.12)	<0.001
Trisegmentectomy (47,122)	0.65 (0.36, 1.17)	0.2
Total left hepatectomy (47,125)	1.19 (0.75, 1.90)	0.5
Total right hepatectomy (47,130)	REF	
Neoadjuvant Therapy		
Preoperative systemic chemotherapy alone	0.73 (0.62, 0.87)	<0.001
Preoperative systemic chemotherapy and other	0.39 (0.21, 0.71)	0.002
Not specified	0.50 (0.21, 1.20)	0.1
None	REF	
Number of concurrent partial hepatectomies		
0	1.38 (1.10, 1.73)	0.005
1	1.06 (0.84, 1.35)	0.6
> 1	REF	
Concurrent intraoperative ablation	0.71 (0.56, 0.89)	0.003
Inflow occlusion during resection (i.e., Pringle)	0.43 (0.35, 0.53)	<0.001
Biliary reconstruction	0.59 (0.22, 1.54)	0.3
Drain placement	0.56 (0.47, 0.67)	<0.001
Number of tumors treated		
1–2	1.80 (0.84, 3.88)	0.1
3–5	0.94 (0.43, 2.03)	0.9
6–8	1.01 (0.41, 2.45)	0.9
> 8	REF	
Tumor size		
<2 cm	1.58 (1.22, 2.04)	<0.001
2–5 cm	1.22 (0.96, 1.56)	0.1
>5 cm	REF	

Table 3 Frequency by operative approach over time

Year	MIS, <i>n</i> = 1367 (%)	Open, <i>n</i> = 6090 (%)	<i>p</i> -value
2015			
Partial resection	178 (79.1)	656 (61.0)	<0.001
≥ 1 concurrent partial resection	138 (61.6)	693 (65.1)	0.3
Intraoperative ablation	29 (13.0)	207 (19.3)	0.026
Neoadjuvant therapy	136 (60.7)	674 (62.9)	0.5
Tumor size			<0.001
< 2 cm	88 (40.9)	290 (28.1)	
2–5 cm	103 (47.9)	539 (52.3)	
> 5 cm	24 (11.2)	202 (19.6)	
2016			
Partial resection	201 (83.1)	788 (63.9)	<0.001
≥ 1 concurrent partial	131 (54.6)	760 (62.5)	0.02
Intraoperative ablation	40 (16.7)	281 (22.8)	0.035
Neoadjuvant therapy	128 (53.3)	782 (63.5)	0.003
Tumor size			<0.001
< 2 cm	90 (38.5)	305 (25.9)	
2–5 cm	110 (47.0)	608 (51.6)	
> 5 cm	34 (14.5)	265 (22.5)	
2017			
Partial resection	228 (84.8)	724 (62.2)	<0.001
≥ 1 concurrent partial	146 (55.3)	669 (58.2)	0.4
Intraoperative ablation	43 (16.1)	279 (24.1)	0.005
Neoadjuvant therapy	130 (48.5)	741 (63.8)	<0.001
Tumor size			0.002
< 2 cm	78 (30.1)	291 (25.9)	
2–5 cm	146 (56.4)	570 (50.7)	
> 5 cm	35 (13.5)	264 (23.5)	
2018			
Partial resection	246 (80.4)	851 (68.0)	<0.001
≥ 1 concurrent partial	177 (58.6)	755 (60.8)	0.5
Intraoperative ablation	46 (15.3)	251 (20.2)	0.060
Neoadjuvant therapy	153 (50.3)	817 (65.3)	<0.001
Tumor size			<0.001
< 2 cm	96 (32.7)	340 (28.0)	
2–5 cm	160 (54.4)	584 (48.0)	
> 5 cm	38 (12.9)	292 (24.0)	
2019			
Partial resection	289 (88.9)	945 (69.3)	<0.001
≥ 1 concurrent partial	113 (35.0)	746 (55.1)	<0.001
Intraoperative ablation	46 (14.2)	271 (20.0)	0.016
Neoadjuvant therapy	148 (45.7)	868 (64.4)	<0.001
Tumor size			<0.001
< 2 cm	108 (34.4)	343 (26.1)	
2–5 cm	169 (53.8)	685 (52.2)	
> 5 cm	37 (11.8)	285 (21.7)	
Total			
Partial resection	1142 (83.5)	3964 (65.1)	<0.001
≥ 1 concurrent partial	705 (52.1)	3623 (60.1)	<0.001
Intraoperative ablation	204 (15.0)	1289 (21.3)	<0.001
Neoadjuvant therapy	695 (51.1)	3882 (64.0)	<0.001
Tumor size			<0.001

Table 3 (continued)

Year	MIS, <i>n</i> = 1367 (%)	Open, <i>n</i> = 6090 (%)	<i>p</i> -value
< 2 cm	460 (34.9)	1569 (26.8)	
2–5 cm	688 (52.3)	2986 (50.9)	
> 5 cm	168 (12.8)	1308 (22.3)	

Fig. 2 Frequency of MIS versus open partial hepatectomy by year

increased in number over the years, but open partial hepatectomy increased at a greater rate than MIS ($p < 0.001$). Despite an overall increase in frequency of hepatectomy, anatomic resections have remained stable in number over the study period regardless of operative approach, with open resection predominating.

In recent years, there has been an increase in the proportion of patients with CRLM who are eligible to undergo curative-intent hepatectomy [14]. This is, in part, due to improvements in perioperative management and more effective chemotherapeutic regimens, but also because of an expanded use of PSH, which allows for resection of bilobar disease while retaining an adequate future liver remnant [3, 7, 12–16]. In our examination of the ACS-NSQIP database, the total number of hepatectomies significantly increased over the study period, but interestingly anatomic resections remained stable. Thus, the overall increase in hepatectomies can be likely attributed to a rise in non-anatomic resections or partial hepatectomies, and could be related to the wider trend of increased use of PSH. In this context, it is particularly notable that open partial hepatectomy is increasing at a faster rate than MIS. Furthermore, the majority of concurrent partial hepatectomies performed over the study period were completed open, and 31.5% of open cases required multiple concurrent partial hepatectomies versus only

22.2% of MIS cases. In total, these trends possibly reflect the increasing use of PSH across the field and demonstrate that most of these cases are done open. Certain partial hepatectomies, particularly single, peripheral lesions, may be less technically demanding than an anatomic resection, and therefore feasibly accomplished with any approach, MIS or open. Performing PSH for multiple, deep lesions within the liver, however, can be technically very challenging and time consuming, especially with an MIS approach. This situation often leads surgeons to choose open hepatectomy [17].

In a similar trend, our data indicate greater disease complexity among patients receiving an open resection. Patients in the open resection cohort had larger and more numerous tumors, as well as increased use of preoperative chemotherapy and/or concurrent intraoperative ablation. The higher proportion of patients who underwent NAT in the open resection cohort is likely related to efforts at conversion to resectable from borderline or unresectable disease, and these cases are technically demanding even if converted to resectable disease [18, 19]. Operative time was also longer for an open hepatectomy, potentially another marker of greater disease burden, as this is in contrast to most literature citing longer operative times in MIS groups [20, 21].

Multivariable analysis demonstrated several independent predictors of undergoing a minimally invasive operation,

including performance of partial hepatectomy (OR 2.3) as the principle operative procedure. MIS resections appear to be preferentially performed for small tumors (< 2 cm, OR 1.6) as a single partial hepatectomy (OR 1.4). As discussed previously and in concordance with prior literature, PSH can be technically difficult, often requiring deep and accurate dissection with ultrasound guidance, and therefore such resections may be more difficult to perform via a MIS approach [16, 22]. In addition, the need for variable port placements in bilobar or multiple PSH can additionally make the MIS approach less optimal. Unfortunately, we are unable to comment on the depth or anatomic location of hepatic metastases, as neither are collected variables of the ACS-NSQIP database, but these are certainly other aspects which may impact choice of operative approach [5]. Therefore, while multiple single institution reports are focused on expanding the reach of MIS hepatectomy, this nationwide observational cohort demonstrates that the majority of complex hepatectomies, to include multiple PSH, appear to be performed open [23, 24].

As the field attempts to broaden the application of MIS hepatectomy, there have been multiple initiatives from organizations such as the Society of American Gastrointestinal and Endoscopic Surgeons (SAGES) and the International Laparoscopic Liver Society (ILLS) to expand MIS capabilities. Given the intentional move towards PSH for resection of CRLM, our findings support a clear need for greater educational efforts promoting minimally invasive PSH. For minimally invasive PSH to have an expanded role in the management of CRLM, it is necessary for surgeons to improve proficiency with ultrasound-guided, precise parenchymal dissection. Modern laparoscopic tools such as the ultrasonic surgical aspirator (CUSA®, Plainsboro, NJ, USA) facilitate fine dissection deep in the parenchyma for isolation of vessels and biliary structures to avoid major hepatectomy [25]. Without utilizing such techniques and technology to facilitate dissection, an MIS anatomic major hepatectomy may be technically easier than a deep PSH, and surgeons may have to choose between MIS major hepatectomy or open PSH. Robotic surgery may have the potential to expand MIS resections for CRLM in the setting of comparable oncologic outcomes, with purported benefits including improved visualization, articulating instruments, and a potentially shorter learning curve compared to laparoscopy [26–29]. For robotic surgery to gain a more widespread role in the management of CRLM, however, future education must be directed at development of techniques for performing multiple deep partial hepatectomies, just as with laparoscopic surgery.

Our study has several limitations. The ACS-NSQIP lacks granularity regarding certain aspects of management of CRLM, including specific chemotherapy regimens and clinical decision-making guiding treatment selection.

This registry does not include important hepatic disease characteristics, such as depth, Couinaud segment, relation to vascular or biliary structures, and molecular biology of the tumor(s) that may inform decisions on operative approach. It similarly does not include post-excisional data about the specimen to include margin status. These missing factors are especially limiting when discussing selection of a minimally invasive and/or parenchymal-sparing operation, which may favor superficial tumors in anterior segments. However, the intent of this study was to characterize national trends in operative approach, and surrogates for disease complexity in the context of available procedure coding were used and provide valuable insight into selection for MIS and/or partial hepatectomy. In addition, the CPT codes used to characterize the types of hepatectomies performed similarly lack granularity and thus we made extrapolations between partial hepatectomy and PSH given the data available. Finally, the ACS-NSQIP registry is not a perfect indicator of proportion of procedures per year from participating institutions, and findings are not necessarily generalizable to non-participating institutions. Nevertheless, this analysis of trends across such a large cohort, including data from institutions of varied volume and geographic region, provides valuable and updated information about trends in CRLM management across the USA.

In conclusion, in this study we demonstrate an increase in hepatectomy for CRLM over the 2015–2019 study period of the ACS-NSQIP database, largely due to a rise in PSH in the form of partial hepatectomy. While MIS operations increased in number during this time, these approaches seem to be preferentially utilized for patients with less technically demanding disease characteristics such as small and/or few tumors requiring single partial hepatectomy. These results represent a call to action for further development and dissemination of parenchymal-sparing MIS techniques for more complex resections.

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Declarations

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