



Is resident assistance equivalent to fellows during hepatectomy?

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Abstract

Objective Hepatectomy is a complex operative procedure frequently performed at academic institutions with trainee participation. The aim of this study was to determine the effect of assistant's training level on outcomes following hepatectomy.

Methods A retrospective review of a prospective, single-institution ACS-NSQIP database was performed for patients that underwent hepatectomy (2013–2016). Patients were divided by trainee assistant level: hepatopancreatobiliary (HPB) fellow versus general surgery resident (PGY 4–5). Demographic, perioperative, and 30-day outcome variables were compared using Chi-Square/Fisher's exact, Mann–Whitney *U* test, and multivariable regression. Cases involving a senior-level general surgery resident or HPB fellow as first assistant were included ($n = 352$). Those with a second attending, junior-level resident, or no documented assistant were excluded ($n = 39$).

Results Patients undergoing hepatectomy with an HPB fellow as primary assistant had more frequent preoperative biliary stenting, longer operative time, and more concomitant procedures including biliary reconstruction, resulting in a higher rate of post-hepatectomy liver failure (PHLF) (15% vs. 8%, $P = 0.044$). However, trainee level did not impact PHLF on multivariable analysis (OR 0.60, 95% CI [0.29–1.25], $P = 0.173$). Fellows assisted with proportionally more major hepatectomies (45% vs. 31%; $P = 0.010$) and resections for hepatobiliary cancers (31% vs. 19%, $P = 0.014$). On stratified analysis of major and minor hepatectomies, outcomes were similar between trainee groups.

Conclusion Fellows performed higher complexity cases with longer operative time. Despite these differences, outcomes were similar regardless of assistant training level. Resident and HPB fellow participation in operations requiring liver resection provide comparable quality of care.

Keywords Hepatectomy · Education · Residency and internship · Liver disease

Abbreviations

ACS-NSQIP	American College of Surgeons National Surgical Quality Improvement Program
DVT	Deep venous thrombosis
HPB	Hepatopancreatobiliary
ISGLS	International Study Group of Liver Surgery
MELD	Model for End-Stage Liver Disease Score
PGY	Post-graduate-year
PHLF	Post-hepatectomy liver failure

The development of autonomous and competent surgeons relies heavily on operative experience and case volume during training [1]. According to the National Inpatient Sample, nearly 70% of all inpatient surgeries in the United States are performed at teaching hospitals [2]. Trainee experience must be balanced with patient safety, and a number of entities have examined this issue. Prior studies have demonstrated a slight increase in postoperative morbidity, but overall equal or decreased mortality when a surgical resident was involved in the operation [3–5]. These data support ongoing trainee participation while addressing safety and quality concerns. However, these conclusions are drawn from heterogeneous patient populations undergoing a wide range of operations of varying complexity. It is uncertain whether these broad findings can be accurately applied to a more specific population, namely those undergoing hepatectomy.

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Hepatectomy remains one of the more complex operations performed by surgeons today. Substantial improvements in postoperative outcomes after liver resection have been made in the past several decades. This is partially due to improved patient selection and operative techniques, as well as increased referral of these complex cases to high-volume tertiary centers and teaching hospitals where subspecialists practice. Despite these advances, total (minor + major) morbidity after major hepatectomy has been reported as high as 33% [6].

Outcomes for patients undergoing hepatopancreatobiliary (HPB) surgery have been examined several ways. Prior studies have shown that resident participation or performance of HPB surgery at a teaching hospital was associated with decreased mortality, but equal or only slightly higher postoperative morbidity [1, 7]. The relationship between specialized training of the attending surgeon and outcomes has also been studied. Analysis of over 1100 patients undergoing hepatectomy revealed that surgeons with specialized HPB training had significantly fewer postoperative complications when compared to surgeons with other areas of specialized training or general surgeons [8].

While the effects of resident participation and attending specialization have been documented, there is limited understanding of the effects of HPB fellow versus resident participation during hepatectomy. One study compared postoperative mortality and morbidity for patients that underwent hepatectomy in the presence of a fellowship program or residency program. However, actual trainee participation in the procedure was not taken into account. They determined the presence of a surgical residency program was associated with significantly decreased morbidity and mortality, but this benefit was not seen in the presence of a fellowship program [9].

According to the Americas Hepato-Pancreatico-Biliary Association, it is recommended that HPB fellows perform a minimum of 25 hepatectomies during training, whereas participation in only five liver operations is required by the Accreditation Council for Graduate Medical Education to graduate from general surgery residency [10, 11]. Thus, trainees at various levels must participate in these cases to different degrees, not only to gain proficiency in the operation, but to graduate from their training program. In many institutions, HPB fellows and residents coexist. Therefore, the purpose of this study is to gain a better understanding of the perioperative and postoperative implications for patients undergoing hepatectomy when a surgical resident versus a HPB fellow participates in the operation.

Methods

Study population

After approval from the Indiana University Institutional Review Board, our single-institution's prospectively maintained American College of Surgeons National Surgical Quality Improvement Program (ACS-NSQIP) database was queried to generate all consecutive hepatectomy cases ($n = 391$) performed between January 2013 and December 2016 at Indiana University Health-University Hospital. Data were supplemented through review of electronic medical records. All cases were performed primarily by the attending surgeon, with either a HPB fellow (post-completion of general surgery residency) or senior-level (PGY 4–5) general surgery resident assisting. After exclusion of cases involving a second attending ($n = 13$), a junior-level general surgery resident (PGY 1–3; $n = 24$), or without a trainee assistant documented ($n = 2$), 352 study subjects remained. Hepatectomies in which a PGY 1–3 general surgery resident served as first assistant were excluded to allow for the most homogeneous comparison of trainee participation (PGY 4–5 general surgery resident versus HPB fellow). At this institution, postoperative care is directed by the attending surgeon guiding a senior-level general surgery resident or a HPB fellow on the service.

Study design

Preoperative demographics, perioperative factors, and postoperative 30-day outcomes were gathered from the ACS-NSQIP database. First assistant level of training documented in operative records served as the basis for the two comparison groups.

1. Preoperative variables: All were available through the ACS-NSQIP database except for Model for End-Stage Liver Disease score (MELD). Scores were calculated with a widely available MDCalc online calculator utilizing preoperative laboratory values within 6 months prior to surgery [12]. Laboratory values were from the immediate preoperative office visit. Race was categorized as Caucasian vs. Other due to the high proportion of Caucasian patients in the study group.
2. Perioperative variables: The designation of major versus minor hepatectomy was determined through operative records. Major hepatectomy was defined as resection of three complete liver segments or right posterior sectionectomy [13]. All other cases were designated as minor hepatectomy.

3. Postoperative outcomes: All were tracked prospectively for 30-days after surgery and available through the ACS-NSQIP database. Post-Hepatectomy Liver Failure (PHLF) was defined by the International Study Group of Liver Surgery (ISGLS) guidelines [14]. This grading system utilizes a comprehensive review of liver function (international normalized ratio, presence of hepatic encephalopathy), renal or pulmonary dysfunction, and interventions required [14].

Statistical analysis was performed using SPSS software, version 24 (IBM corporation; Armonk, NY) and R, version 3.5.2 (R Foundation for Statistical Computing). Categorical variables were analyzed with Chi-square or Fisher's exact test. Continuous data were analyzed using the Mann–Whitney *U* test. Descriptive statistics including median, range, and frequencies were also calculated. Differences between the resident and fellow groups in regards to identified preoperative and perioperative confounding variables were examined using logistic regression. Variables with significant differences between the two groups and with significant associations with an outcome as identified by logistic regression (or Poisson/negative binomial regression for continuous outcome variables) were included as covariates in a multiple regression model, for that outcome. An α -level of 0.05 determined statistical significance.

Results

All hepatectomies

Between January 2013 and December 2016, 352 patients underwent hepatectomy at Indiana University Health–University Hospital in which a PGY 4–5 general surgery resident ($n=202$) or HPB fellow ($n=150$) was the first assistant (Fig. 1). Eight attending surgeons performed these operations, with the majority ($n=362$, 96%) performed by 5 high-volume HPB surgeons. Over the course of the study, the number of hepatectomies performed by the HPB fellow remained relatively unchanged (2013, $n=45$; 2014, $n=30$; 2015, $n=38$; 2016, $n=37$), while the overall hepatectomy volume and number performed by PGY 4–5 general surgery residents increased (2013, $n=72$; 2014, $n=52$; 2015, $n=103$; 2016, $n=125$). Preoperative patient features were similar between groups, except for a greater frequency of preoperative biliary stenting among patients for fellow-assisted hepatectomy (13% vs. 4%; $P<0.001$). Liver-specific variables including a history of viral hepatitis, MELD score, and history of neoadjuvant chemotherapy and/or radiation were similar between resident- and fellow-assisted hepatectomies. Several perioperative factors differed significantly between groups. Patients that had an HPB fellow assisting in their hepatectomy had more concomitant procedures (median 3 vs. 2, $P<0.001$), and more frequently required biliary-enteric anastomosis (14% vs. 5%, $P=0.002$). Thus,

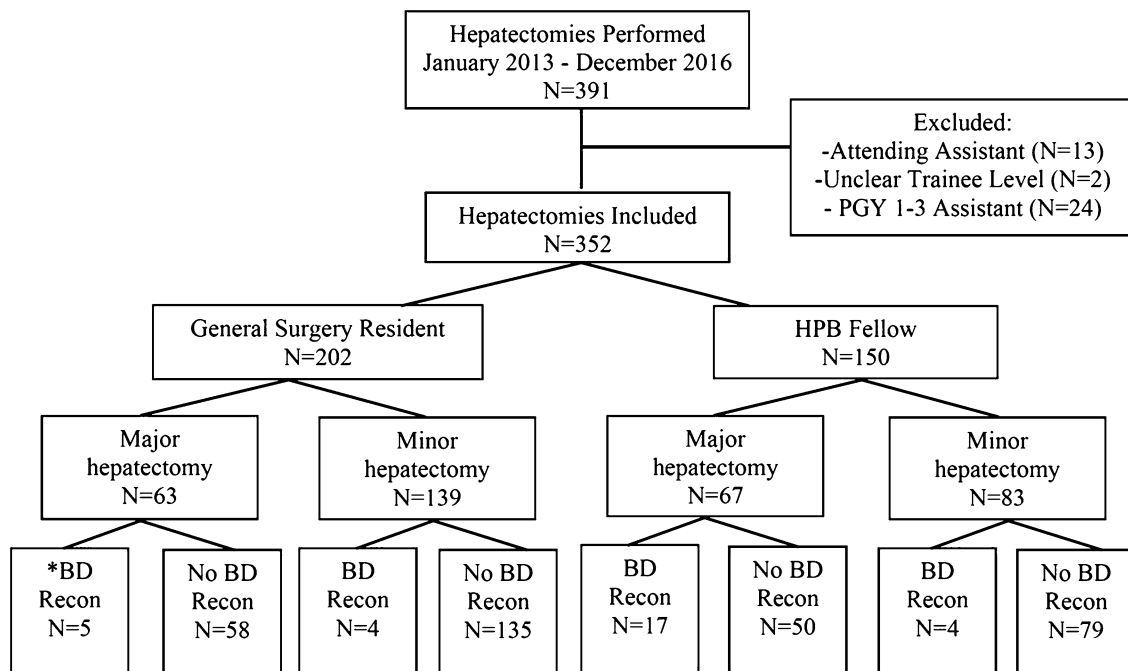


Fig. 1 Flow diagram of case characteristics by trainee assistant group. *BD Recon (Bile Duct Reconstruction)

operative times were longer for patients of fellow-assisted operations (median 214.5 min vs. 181.0 min, $P < 0.001$). Patients that had an HPB fellow as first assistant more frequently had primary hepatobiliary cancers (31% vs. 19%; $P = 0.014$). Among primary hepatobiliary cancers, the most common were hepatocellular carcinoma ($n = 41$), cholangiocarcinoma ($n = 22$), and gallbladder adenocarcinoma ($n = 17$). However, when all cancers were considered, the proportion of patients with malignant pathology was similar between hepatectomies with fellow and resident first assistants (73% vs. 68%; $P = 0.378$). These and other perioperative data are summarized in Table 1.

Table 2 summarizes all postoperative outcomes including the incidence of infectious, cardiopulmonary, vascular, and renal complications. The rate of these complications was similar for patients that had an HPB fellow versus a resident serving as first assistant. Overall 30-day morbidity, mortality, readmission rate, and need for surgical or other invasive interventions (i.e., endoscopic stenting, percutaneous drainage procedures, etc.) after surgery also did not differ. The

unadjusted rate of post-hepatectomy liver failure (PHLF) was significantly greater for patients of fellow-assisted cases compared to those involving residents on univariable analysis (15% vs. 8%; $P = 0.044$). Yet, on multivariate analysis trainee level was not a significant predictor of PHLF (OR [95% CI] 0.60 [0.29–1.25]; $P = 0.173$).

All hepatectomies—stratified by PGY status

Outcomes for all hepatectomies were further stratified by PGY status (PGY 4 [$n = 122$] vs. PGY 5 [$n = 80$] vs. HPB Fellow [$n = 150$]), with a few differences observed. There was a significant difference in the rate of surgical site infections ($P = 0.011$), overall 30-day morbidity ($P = 0.034$), and postoperative length of stay ($P < 0.001$) between groups. Pairwise comparisons were performed for each PGY combination. For these above-mentioned morbidities, instances where a PGY 4 resident or HPB fellow served as first assistant resulted in more favorable outcomes. All other postoperative outcomes were similar between groups. (Table 3).

Table 1 Baseline group comparison of preoperative and perioperative variables for all hepatectomies

	Fellow ($n = 150$)	Resident ($n = 202$)	<i>P</i> value
Preoperative			
Age (years)	61.0 (22.3–86.1)	58.0 (21.4–88.6)	0.386
Gender-male, <i>n</i> (%)	70 (47)	92 (46)	0.835
Race-white, <i>n</i> (%)	136 (91)	184 (91)	0.892
Body mass index	27.5 (17.1–54.2)	28.0 (16.7–54.1)	0.544
ASA	3 (2–4)	3 (1–4)	0.332
Diabetes, <i>n</i> (%)	23 (15)	34 (17)	0.706
Tobacco, <i>n</i> (%)	19 (13)	40 (20)	0.076
COPD, <i>n</i> (%)	8 (5)	10 (5)	0.872
Hypertension, <i>n</i> (%)	73 (49)	90 (45)	0.444
> 10% body weight loss, <i>n</i> (%)	10 (7)	14 (7)	0.923
MELD	7 (6–22)	7 (6–24)	0.909
Biliary stent, <i>n</i> (%)	20 (13)	8 (4)	<0.001
Neoadjuvant therapy, <i>n</i> (%)	33 (22)	58 (29)	0.155
Viral hepatitis, <i>n</i> (%)	9 (6)	13 (6)	0.867
Perioperative			
Operative approach-open, <i>n</i> (%)	105 (70)	134 (66)	0.467
Operative time (min)	214.5 (49.0–516.0)	181.0 (57.0–494.0)	<0.001
# Concomitant procedures	3 (0–9)	2 (0–7)	<0.001
Pringle maneuver performed, <i>n</i> (%)	17 (11)	15 (7)	0.207
Operative drains left in place, <i>n</i> (%)	63 (42)	110 (55)	0.021
Biliary reconstruction, <i>n</i> (%)	21 (14)	9 (5)	0.002
Liver texture-normal, <i>n</i> (%)	67 (53)	87 (57)	0.454
Any malignant pathology, <i>n</i> (%)	109 (73)	138 (68)	0.378
Primary hepatobiliary malignancy, <i>n</i> (%)	46 (31)	39 (19)	0.014
Major hepatectomy, <i>n</i> (%)	67 (45)	63 (31)	0.010

Continuous variables listed as median (range)

ASA American Society of Anesthesiology Physical Status Classification, COPD Chronic Obstructive Pulmonary Disease, MELD Model for End-Stage Liver Disease Score

Table 2 Postoperative outcomes for all hepatectomies

	Univariable analysis			Multivariable analysis	
	Fellow (<i>n</i> = 150)	Resident (<i>n</i> = 202)	<i>P</i> -value	OR/IR [95% CI]	<i>P</i> -value
Length of hospital stay (days)	6 (1–46)	5 (1–60)	0.244	1.04 [0.90–1.20]	0.597
Total # postoperative intubation	0 (0–2)	0 (0–2)	0.569	0.96 [0.35–2.60]	0.931
SSI, <i>n</i> (%)	16 (11)	21 (10)	0.935	1.25 [0.57–2.73]	0.580
Pneumonia, <i>n</i> (%)	4 (3)	4 (2)	0.728	1.05 [0.25–4.53]	0.944
Urinary tract infection, <i>n</i> (%)	4 (3)	3 (2)	0.465	0.58 [0.14–2.42]	0.460
Sepsis, <i>n</i> (%)	6 (4)	12 (6)	0.414	1.64 [0.58–4.65]	0.351
Septic shock, <i>n</i> (%)	6 (4)	4 (2)	0.335	0.77 [0.20–2.98]	0.707
Renal insufficiency, <i>n</i> (%)	0 (0)	2 (1)	0.510	4.76 [0.22–105.88]	0.321
Acute renal failure, <i>n</i> (%)	2 (1)	2 (1)	1.000	0.77 [0.13–4.75]	0.783
Myocardial infarction, <i>n</i> (%)	0 (0)	1 (0.5)	1.000	3.04 [0.10–92.32]	0.522
DVT, <i>n</i> (%)	6 (4)	3 (2)	0.178	0.39 [0.10–1.48]	0.168
Pulmonary embolism, <i>n</i> (%)	3 (2)	1 (0.5)	0.316	0.32 [0.05–2.22]	0.247
Cardiac arrest, <i>n</i> (%)	1 (1)	4 (2)	0.399	2.49 [0.37–16.51]	0.349
Intubation > 48 h, <i>n</i> (%)	5 (3)	3 (2)	0.293	0.68 [0.16–2.81]	0.591
≥ 1 complication, <i>n</i> (%)	45 (30)	52 (26)	0.377	1.10 [0.53–2.30]	0.802
30-day mortality, <i>n</i> (%)	2 (1)	2 (1)	0.764	0.77 [0.13–4.76]	0.783
90-day mortality, <i>n</i> (%)	2 (1)	3 (2)	1.000	1.10 [0.21–5.97]	0.912
≥ 1 unplanned readmission, <i>n</i> (%)	16 (11)	18 (9)	0.581	1.01 [0.49–2.09]	0.986
≥ 1 Unplanned re-operation, <i>n</i> (%)	5 (3)	7 (4)	0.946	0.88 [0.28–2.81]	0.833
Need for invasive procedure, <i>n</i> (%)	20 (13)	23 (11)	0.581	1.07 [0.53–2.12]	0.854
Bile leak, <i>n</i> (%)	13 (9)	14 (7)	0.545	1.19 [0.48–2.88]	0.706
Post-hepatectomy liver failure	22 (15)	16 (8)	0.044	0.60 [0.29–1.25]	0.173

Continuous data expressed as median (range)

SSI all surgical site infections (superficial, deep, organ space), DVT deep venous thrombosis; OR Odds ratio, IR incidence ratio, CI confidence interval

Major hepatectomy

One hundred and thirty patients underwent major hepatectomy over the 4-year time period (HPB fellow assistant *n* = 67, general surgery resident assistant *n* = 63). Similar to our analysis of all patients that underwent hepatectomy, patients that had an HPB fellow as first assistant more frequently required preoperative biliary stenting. Additionally, more patients in the HPB fellow group had a history of hypertension. All other preoperative demographics, comorbidities, and liver-specific variables were similar between groups. Regarding perioperative factors, when the HPB fellow served as assistant, operative time again was longer, a greater number of concomitant procedures were performed including biliary-enteric anastomosis, drains were less frequently left in the operative field, and primary HPB malignancy was more frequently the indication for resection (Supplementary Table 1).

Despite these differences, all postoperative outcomes were similar between groups on both univariable and multivariable analyses (Table 4).

Minor hepatectomy

Two hundred and twenty-two patients underwent minor hepatectomy in which an HPB fellow (*n* = 83) or senior general surgery resident (*n* = 139) was first assistant. Fewer patients in the HPB fellow group used tobacco, but all other demographics and preoperative variables were similar between patient groups. Perioperative factors did not differ between patients undergoing fellow- and resident-assisted minor hepatectomy, with the exception of a greater number of concomitant procedures for patients in the HPB fellow group as shown in Supplemental Table 2. There was a greater incidence of postoperative deep venous thrombosis (DVT) for patients when a HPB fellow was assistant on univariable (6% vs. 1%; *P* = 0.028) and multivariable analyses (OR [95% CI]: 0.16 [0.03–0.96], *P* = 0.047). No other outcome measures differed between patients in the two trainee groups (Table 5).

Table 3 Postoperative outcomes for all hepatectomies—stratified by PGY year

	Overall <i>P</i> -value (ANOVA or χ^2)	OR/IR PGY 5 (vs. PGY 4)	OR/IR fellow (vs. PGY 4)	OR/IR fellow (vs. PGY 5)
Length of hospital stay (days)	<0.001	1.43*	1.04	0.73*
Total # postoperative intubation	0.222	3.44	1.70	0.49
SSI	0.011	3.66*	1.15	0.31*
Pneumonia	0.383	3.29	1.39	0.42
Urinary tract infection	0.489	2.25	2.47	1.10
Sepsis	0.174	2.15	0.75	0.35
Septic shock	0.432	3.18	1.82	0.57
Renal insufficiency	0.080	9.54	0.47	0.05
Acute renal failure	0.456	0.22	0.94	4.24
Myocardial infarction	0.558	0.39	0.29	0.74
DVT	0.227	2.16	3.61	1.67
Pulmonary embolism	0.698	0.30	1.86	6.15
Cardiac arrest, <i>n</i> (%)	0.517	1.52	0.47	0.31
Intubation > 48 h	0.601	2.39	1.91	0.80
≥ 1 complication at 30-days	0.034	2.84	1.08	0.38
30-day mortality	0.922	1.32	1.43	1.08
90-day mortality	0.646	2.40	1.34	0.56
≥ 1 unplanned readmission	0.959	0.96	0.88	0.91
≥ 1 unplanned re-operation	0.916	0.74	0.82	1.11
Need for invasive procedure	0.365	1.79	1.08	0.60
Bile leak	0.070	3.74	1.45	0.39
Post-hepatectomy liver failure	0.158	2.48	2.06	0.83

**P* < 0.05

SSI all surgical site infections; superficial, deep, organ space, DVT deep venous thrombosis, OR Odds ratio, IR incidence ratio, CI confidence interval

Discussion

While trainee participation is unlikely to be the sole or primary determinant of morbidity for patients undergoing hepatectomy, in an era of informed and transparent patient decision-making and quality control, examining the potential effect of trainee participation is justified. In the present study, we evaluated 352 patients that underwent liver resection at Indiana University Health-University Hospital over a 4-year period (2013 to 2016). A specialized HPB fellow or PGY 4–5 general surgery resident was the first assistant in each operation. Overall, case characteristics and degree of difficulty varied between HPB fellows and senior-level surgery residents, but outcomes did not differ between groups. Fellows assisted with cases of higher complexity, involving larger resections of liver parenchyma and more frequent biliary reconstruction on patients that more frequently required preoperative biliary stenting. These factors likely account for the significantly longer operative times and greater frequency of PHLF for patients after fellow-assisted cases when all hepatectomies were considered on univariable analysis. However, on multivariable analysis, trainee level did not predict PHLF. The overall rate of PHLF in the present study

(10.8%) was similar to the ~9% incidence described in the literature [15–17].

Multiple factors increase a patient's risk of PHLF: a history of liver disease (including viral hepatitis or cirrhosis), certain medical comorbidities, postoperative hemorrhage, and several intra-operative factors including performance of a major liver resection [18]. We stratified our patient cohort into those who underwent major versus minor hepatectomy and performed separate stratified analyses. The 130 patients that had major hepatectomy were divided nearly equally amongst fellows (*n* = 67) and residents (*n* = 63). However, differences in perioperative factors still existed between patients in this subgroup. Again, fellows assisted with more biliary reconstructions and concomitant procedures, with resulting longer operative time. Despite these differences, all outcome measures were the same for patients undergoing hepatectomy with a HPB fellow or general surgery resident assisting.

The most homogeneous patient group in terms of preoperative and perioperative factors included those who underwent minor hepatectomy. A total of 222 patients underwent minor hepatectomy, 83 of which were fellow-assisted with the remaining 139 involving a senior general surgery

Table 4 Postoperative outcomes for major hepatectomies

	Univariable analysis			Multivariable analysis	
	Fellow (<i>n</i> = 67)	Resident (<i>n</i> = 63)	<i>P</i> -value	OR/IR [95% CI]	<i>P</i> -value
Length of hospital stay (days)	7 (2–46)	7 (1–60)	0.567	1.09 [0.87–1.36]	0.470
Total # postoperative intubation	0 (0–2)	0 (0–1)	0.276	0.46 [0.10–2.17]	0.322
SSI, <i>n</i> (%)	12 (18)	10 (16)	0.757	1.18 [0.40–3.46]	0.765
Pneumonia, <i>n</i> (%)	4 (6)	2 (3)	0.681	0.59 [0.10–3.43]	0.560
Urinary tract infection, <i>n</i> (%)	2 (3)	1 (2)	1.000	0.60 [0.07–5.04]	0.637
Sepsis, <i>n</i> (%)	4 (6)	4 (6)	1.000	0.88 [0.20–3.93]	0.870
Septic shock, <i>n</i> (%)	5 (8)	2 (3)	0.442	0.63 [0.11–3.60]	0.600
Renal insufficiency, <i>n</i> (%)	0 (0)	0 (0)	–	–	–
Acute renal failure, <i>n</i> (%)	2 (3)	1 (2)	1.000	0.60 [0.07–5.00]	0.637
Myocardial infarction, <i>n</i> (%)	0 (0)	0 (0)	–	–	–
DVT, <i>n</i> (%)	1 (2)	2 (3)	0.611	1.84 [0.22–15.30]	0.571
Pulmonary embolism, <i>n</i> (%)	3 (5)	1 (2)	0.620	0.42 [0.06–3.02]	0.391
Cardiac arrest, <i>n</i> (%)	0 (0)	1 (2)	0.485	3.64 [0.13–97.95]	0.446
Intubation > 48 h, <i>n</i> (%)	3 (5)	1 (2)	0.620	0.61 [0.08–4.93]	0.647
≥ 1 complication, <i>n</i> (%)	27 (40)	24 (38)	0.797	0.84 [0.29–2.41]	0.740
30-day mortality, <i>n</i> (%)	2 (3)	1 (2)	1.000	0.60 [0.07–5.00]	0.637
90-day mortality, <i>n</i> (%)	2 (3)	2 (3)	1.000	1.06 [0.17–6.65]	0.954
≥ 1 unplanned readmission, <i>n</i> (%)	9 (13)	7 (11)	0.687	1.09 [0.37–3.26]	0.877
≥ 1 unplanned re-operation, <i>n</i> (%)	3 (5)	3 (5)	1.000	0.81 [0.17–3.88]	0.790
Need for invasive procedure, <i>n</i> (%)	13 (19)	10 (16)	0.598	0.88 [0.32–2.40]	0.797
Bile leak, <i>n</i> (%)	10 (15)	8 (13)	0.713	1.12 [0.36–3.51]	0.843
Post-hepatectomy liver failure	16 (24)	11 (18)	0.367	0.76 [0.29–1.94]	0.563

Continuous data expressed as median (range)

SSI all surgical site infections (superficial, deep, organ space), DVT deep venous thrombosis; OR Odds ratio; IR incidence ratio; CI confidence interval

resident. The only differences detected were a higher rate of tobacco use amongst patients for resident-assisted cases, and a higher rate of DVT after operations in which an HPB fellow was the assistant. Regarding tobacco use, this amounted to 7 versus 27 tobacco-users for fellow-assisted and resident-assisted cases, respectively. This did not translate to a clinically significant impact, with no difference in cardiopulmonary or wound complications postoperatively. Though there was a statistically significantly higher rate of DVT for fellow-assisted versus resident-assisted minor hepatectomies, the absolute number of patients affected was very low (5 vs. 1 patient). Circumstances that commonly contribute to the development of postoperative DVT (malignancy; longer surgical time; factors affecting mobility including open surgery, longer hospitalization, etc.) were similar between groups in this stratified analysis, so likely did not contribute to this finding. One possible explanation would be differences in compliance with sequential compression devices or medical DVT prophylaxis in the perioperative period. However, the retrospective nature of this study limits the ability to examine this fully. Thus, the reason for this difference in rate of postoperative DVT remains unclear.

Prior studies have addressed concerns regarding case allocation between residents and fellows, and whether or not the current operative volume for general surgery residents is sufficient to gain proficiency in these specialized cases. Two studies have shown that the average number of liver resections performed by general surgery residents has slowly increased over time; but case numbers are still low, with an average of < 4 major liver resections and < 10 total liver cases performed by graduating general surgery residents [1, 19]. Each of these studies also demonstrated a gradual decline in the number of complex biliary or choledochenterostomy procedures performed by general surgery residents. The present study paralleled this finding, as general surgery residents assisted with significantly fewer biliary anastomoses compared to fellows. While the uptrend in endoscopic treatment of biliary disease may contribute to this decline in biliary operative experience for choledocholithiasis, our data show that case allocation to specialized trainees over general surgery residents may be a contributing factor. Similar results were demonstrated in a comparison of operative volume before and after induction of an HPB fellowship program at a single high-volume institution. On

Table 5 Postoperative outcomes for minor hepatectomies

	Univariable analysis			Multivariable analysis	
	Fellow (<i>n</i> = 83)	Resident (<i>n</i> = 139)	<i>P</i> -value	OR/IR [95% CI]	<i>P</i> -value
Length of hospital stay (days)	4 (1–30)	4 (1–31)	0.662	1.01 [0.84–1.22]	0.924
Total # postoperative intubation	0 (0–1)	0 (0–2)	0.620	1.74 [0.36–8.23]	0.485
SSI, <i>n</i> (%)	4 (5)	11 (8)	0.374	1.95 [0.55–7.00]	0.306
Pneumonia, <i>n</i> (%)	0 (0)	2 (1)	0.530	4.36 [0.18–103.47]	0.365
Urinary tract infection, <i>n</i> (%)	2 (2)	2 (1)	0.631	0.64 [0.10–3.98]	0.632
Sepsis, <i>n</i> (%)	2 (2)	8 (6)	0.328	2.29 [0.52–10.23]	0.278
Septic shock, <i>n</i> (%)	1 (1)	2 (1)	1.000	1.05 [0.11–9.83]	0.967
Renal insufficiency, <i>n</i> (%)	0 (0)	2 (1)	0.530	1.00 [0.01–101.06]	1.000
Acute renal failure, <i>n</i> (%)	0 (0)	1 (1)	1.000	2.77 [0.09–88.51]	0.566
Myocardial infarction, <i>n</i> (%)	0 (0)	1 (1)	1.000	2.77 [0.08–88.16]	0.566
DVT, <i>n</i> (%)	5 (6)	1 (1)	0.028	0.16 [0.03–0.96]	0.047
Pulmonary embolism, <i>n</i> (%)	0 (0)	0 (0)	–	–	–
Cardiac arrest, <i>n</i> (%)	1 (1)	3 (2)	1.000	1.62 [0.22–12.04]	0.638
Intubation > 48 h, <i>n</i> (%)	2 (2)	2 (1)	0.631	0.68 [0.10–4.39]	0.682
≥ 1 complication, <i>n</i> (%)	18 (22)	28 (20)	0.784	1.49 [0.51–4.36]	0.464
30-day mortality, <i>n</i> (%)	0 (0)	1 (1)	1.000	2.77 [0.09–90.08]	0.566
90-day mortality, <i>n</i> (%)	0 (0)	1 (1)	1.000	2.77 [0.09–89.87]	0.566
≥ 1 unplanned readmission, <i>n</i> (%)	7 (8)	11 (8)	0.891	0.97 [0.36–2.61]	0.959
≥ 1 unplanned re-operation, <i>n</i> (%)	2 (2)	4 (3)	1.000	1.08 [0.21–5.42]	0.926
Need for invasive procedure, <i>n</i> (%)	7 (8)	13 (9)	0.817	1.39 [0.51–3.85]	0.523
Bile leak, <i>n</i> (%)	3 (4)	6 (4)	1.000	1.21 [0.27–5.37]	0.799
Post-hepatectomy liver failure	6 (7)	5 (4)	0.337	0.45 [0.13–1.58]	0.212

Continuous data expressed as median (range)

SSI All surgical site infections (superficial, deep, organ space), DVT Deep Venous Thrombosis; OR Odds Ratio; IR Incidence Ratio; CI Confidence Interval

average, liver and pancreatic case numbers did not change, but complex biliary operative exposure decreased for surgical residents after the start of the HPB fellowship. Despite these changes, the average complex biliary exposure for general surgery residents was still greater than that of the national average, and HPB operative experience as a whole was not affected. This prior study concluded that, in the appropriate high-volume setting, both HPB fellows and general surgery residents can gain an appropriate level of experience in complex HPB surgery [20]. Moving forward, it is important to keep this trend in mind when allocating cases, to ensure that the gap does not continue to widen, as to ensure appropriate exposure of both HPB fellows and general surgery trainees to these procedures.

Conversely, these differences in case difficulty and pathology in which a general surgery resident versus an HPB fellow serve as assistant is not entirely unexpected. The goal of general surgery residency is to develop broadly trained, competent surgeons that can operate on most surgical disease seen in the community. This requires participation in a variety of procedures with a range of difficulty, including liver resection. On the contrary, HPB fellowship is focused

on the development of technical and problem-solving skills needed to treat the most complex liver, biliary, and pancreatic pathology. As previously discussed, these cases are frequently referred to university settings where outcomes in previous studies have proven to be superior. While it is imperative that general surgery trainees participate in both major and minor hepatectomy—with and without biliary-enteric anastomosis—based on current referral and practice patterns, it is likely necessary and appropriate for HPB fellows to have a comparatively greater exposure to the most complex cases.

Outcomes between patients undergoing a variety of procedures in which a fellow versus general surgery resident serves as assistant have been examined prior. Our institution previously examined patient outcomes after pancreatoduodenectomy when a HPB fellow versus a resident is first assistant. With the exception of a slightly higher rate of postoperative pancreatic fistula in the resident-assisted cohort, all other postoperative and perioperative measures were similar between groups. This prior study by Carr et al. also performed a stratified analysis by PGY status, and found a significantly higher rate of postoperative pancreatic

fistula among PGY-5 residents when compared to PGY-4 and HPB-fellow assistants [21]. This most closely parallels our stratified analysis in the current study, with a higher overall morbidity rate, incidence of surgical site infection, and postoperative length of stay trending toward the PGY-5 group. Linn et al. demonstrated no difference in postoperative outcomes, but longer operative times for residents compared to fellows performing minimally invasive surgery [22]. This was in contrast to another study examining outcomes for ventral hernia repair based on post-graduate-year (PGY) level. They revealed increasing operative time with increasing PGY level through fellowship, with overall similar postoperative outcomes. They hypothesized that differences in autonomy or degree of participation in the operating room, as well as case complexity with increasing PGY level, may have contributed to this difference [23]. In the present study, we demonstrated that for patients undergoing hepatectomy, operative time was significantly longer when the HPB fellow was assisting than when a general surgery resident was first assistant. While this may be explained by differences in case complexity, one can also speculate differences in degree of participation or autonomy between fellows and residents contributing to this operative time difference. These factors together may also contribute to the significant findings from the present study's stratified analysis, but cannot be definitively known on a retrospective analysis.

The incidence of major outcomes of interest post-hepatectomy in the present study were in line with the published literature. The present study revealed an overall 30-day mortality and morbidity of 1.1% and 27.6%, respectively. These figures are comparable to a study of > 4000 cases of liver resection by Kingham et al. with a reported 1.6% mortality and 20% overall morbidity [24], as well as a large, multi-institutional study by Virani et al. with reported 2.6% and 22.6% 30-day mortality and morbidity, respectively [25]. Similarly, our rate of unplanned reoperation (3.4%) was proximate to that found in the same multi-institutional study (5.2%) [25]. These findings suggest that, despite trainee participation in these complex cases, major outcomes are still on par with national quality metrics, and these data further support including these cases in both general surgical and specialized HPB fellow training experiences.

This study has several limitations. Although most postoperative variables were collected prospectively as part of the NSQIP initiative, incomplete data were supplemented through retrospective review of the electronic medical record. The degree of resident versus fellow participation in each procedure is difficult to ascertain on a retrospective review. However, this was specifically addressed by assessing only PGY 4–5 general surgery residents in comparison to HPB fellows as each attending surgeon agreed that intraoperative assistance and postoperative care management did not vary between senior residents and fellows. Future studies

may focus on more standardized definitions for the degree of trainee participation in the operating room, as well as a protocol-based management algorithm to decrease variations in postoperative care in an effort to mitigate these limitations.

Conclusion

We examined 352 patients that underwent liver resection at a single institution, wherein a PGY 4–5 surgical resident or an HPB fellow served as first assistant. HPB fellows assisted with a greater proportion of the most complex operations, with more concomitant procedures performed including biliary-enteric anastomosis, and longer operative time. Despite these differences, overall outcomes after hepatectomy were similar, regardless of trainee level of assistance. Our findings support ongoing participation of both general surgery residents and HPB fellows in complex liver surgery with no risk/benefit disparity for the patient.

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Compliance with ethical standards

Disclosures RE Simpson, KL Carpenter, CY Wang, CM Schmidt II, EM Kilbane, CL Colgate, MG House, NJ Zyromski, CM Schmidt, A Nakeeb, and EP Ceppa have no conflicts of interest or financial ties to disclose.

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