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ORIGINAL SCIENTIFIC REPORT

Procedure-Specific Volume and Nurse-to-Patient Ratio: Implications for Failure to Rescue Patients Following Liver Surgery

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Abstract

Background The effect of various hospital characteristics on failure to rescue (FTR) after liver surgery has not been well examined. We sought to examine the relationship between hospital characteristics and FTR after liver surgery.
Methods The 2013–2015 Medicare-Provider Analysis and Review (MEDPAR) database was used to identify Medicare beneficiaries who underwent liver surgery. The effect of various hospital characteristics on FTR was compared among the highest mortality hospitals (HMH) and the lowest mortality hospitals (LMH).
Results Among 4902 patients undergoing hepatectomy, patients treated at HMH had a higher risk of FTR (OR 3.08, 95% CI 2.03–4.66). Hospital factors such as total number of beds (OR 0.80, 95% 0.56–1.15), operating rooms (OR 0.81, 95% 0.57–1.14), and overall hospital surgical volume (OR 0.88, 95% 0.61–1.25) were not associated with FTR (all $p > 0.05$). In contrast, hospitals with a greater nurse-to-patient ratio had a markedly lower risk of FTR following a complication (OR 0.70, 95% CI 0.54–0.91; $p = 0.007$) (Table 3). As volume of liver operations and nurse-to-patient ratio decreased the risk of FTR increased ($p > 0.001$). After risk-adjusting for patient characteristics, both the effect of surgical volume (adjusted OR 0.66, 95% CI 0.46–0.94; $p = 0.022$) and nurse-to-patient ratio (adjusted OR 0.68, 95% CI 0.51–0.90; $p = 0.008$) remained strongly associated with FTR.
Conclusion FTR rates varied considerably among hospital performing hepatectomy. Higher procedure-specific hepatectomy volume, as well as a higher nurse-to-patient ratio, accounted for a reduction in the FTR rates. These data highlight the importance of not only procedure volume, but also adequate nurse staffing in reducing FTR and improving mortality following complex procedures such as hepatectomy.

Introduction

In 2011, the Centers for Medicare and Medicaid Services (CMS) launched the Hospital Value-Based Purchasing program that tied hospital reimbursements to the quality of the healthcare services provided [1, 2]. There is an ongoing debate, however, regarding the optimal methods of measuring quality of care [3–6]. For patients undergoing surgery, the most frequently used measurements to assess patient outcomes are perioperative morbidity and mortality [7–9]. Patients undergoing liver surgery may experience high rates of postoperative complications (30–40%) and postoperative mortality (1–5%) [10]. Silber et al. observed

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that postoperative morbidity and mortality are often, not surprisingly, correlated [11]. Subsequently, one method that has been increasingly proposed to assess quality of care is failure to rescue (FTR), defined as the probability of death among patients who developed a perioperative complication during the index hospitalization [4, 9, 11]. Although many patient factors can influence postoperative mortality, FTR may be more closely associated with hospital characteristics making it a better indicator of system-based quality of care [11]. In turn, understanding the factors that influence FTR may help guide healthcare policy and quality initiatives.

Multiple risk factors for postoperative complications and death among patients undergoing liver surgery have been elucidated [8, 12–14]. The factors that impact FTR following hepatectomy are less well defined [9, 15, 16]. Spolverato et al. reported that hospital surgical volume was correlated with hospital FTR [9]. Specifically, patients treated at low-volume hospitals who experienced a complication had a 40% increased risk of death versus patients treated at high-volume facilities. In a separate study, Schneider et al. reported that FTR at high-volume versus low-volume hospitals was 29.7% versus 36.7%, respectively [16]. The impact and importance of other non-volume-based hospital characteristics on FTR among patients undergoing liver surgery are yet to be examined. Therefore, the objective of the current study was to define the relationship of hospital characteristics in addition to procedural volume relative to FTR following liver surgery.

Materials and methods

Data sources and study population

Using the Medicare Provider Analysis and Review (MEDPAR) Inpatient Files and the Denominator File, patients who underwent liver surgery between 2013 and 2015 were identified. Eligible patients who were 65 years and older who had complete clinical data in the registry were included. Data on hospital characteristics were obtained from the American Hospital Association (AHA) Annual Survey Database. Patients treated at hospitals that performed fewer than 36 liver surgeries within the 3-year period (i.e., less than one surgery per month) were excluded. The study was approved by the Institutional Review Board (IRB) of the Ohio State University.

Primary outcomes

The primary outcomes were the occurrence of any complication or serious complication during index hospitalization following surgery, 90-day readmission, failure to rescue (FTR), and overall postoperative mortality at 30, 60, and 90 days. Index complications were determined using all ICD-9-CM diagnosis and procedure codes from the index hospitalization [17–20]. As previously reported, serious complications were defined as the occurrence of at least one complication that extended the index length of stay beyond the 75th percentile of all patients in the cohort [21]. Readmission was defined as readmission to any hospital within 90 days after discharge from the index hospitalization. FTR was defined as the presence of at least one major complication during the index hospitalization and subsequent death within 90 days of discharge. Mortality was defined as patient death within 30, 60, and 90 days after discharge from the index operation. Information regarding patient death was obtained from the MEDPAR denominator file.

Hospital characteristics

The 2013–2015 AHA Annual Survey Database was used to identify several characteristics of the index hospitals, including location type, the number of hospital beds, intensive care beds, and operating rooms; data on the total number of yearly admissions, the daily patient census, the number of surgical operations, and the number of liver operations, and full-time employees and nurse-to-patient-ratio were also collected. The liver surgical volume was calculated using the unique Medicare National Provider Identifier Standard (NPI) numbers for each hospital to determine the operative volume for hepatic surgery between 2013 and 2015. The hepatic surgical volume was used as a continuous variable in all analyses. The nurse-to-patient ratio was defined as [nursing full-time equivalents (FTE) $\times$ 1768 $\div$ adjusted patient days] to determine the number of nurse hours per patient day [22]. The nurse-to-patient ratio was assessed as a continuous variable; other hospital-based data were assessed as a continuous function, as well as in quartiles, and then reported using the empiric cutoff values based on locally weighted scatterplot smoothing (LOWESS) analyses.

Statistical analysis

Hospitals were divided into tertiles based on actual 90-day mortality for all liver surgery patients. For the purposes of analyses, comparisons were made between the top and bottom tertile hospital categories. Patient characteristics and comorbidities were compared using the Pearson Chi-square test for categorical variables and the Kruskal–Wallis rank test for continuous variables. The incidence of index complications and serious complications: 90-day readmission, FTR patients who developed an index complication (death), and overall 30-, 60-, and 90-day mortality, were compared between the highest and lowest mortality hospitals. The influence of hospital characteristics on the risk-adjusted rate of FTR was determined using multivariate logistic regression analysis. Point estimates were reported as odds ratios (OR) with 95% confidence intervals (95% CI). The relative attenuation of the odds of FTR between the highest and lowest mortality hospitals was quantified using $[OR_F - OR_{FH}] \div [OR_F - 1]$, where OR_F is the odds of FTR in a high-mortality hospital compared to a low-mortality hospital without adding specific hospital characteristics as covariates and OR_{FH} is the odds of FTR after adjusting for the risk of specific hospital characteristics [23]. All results were adjusted for age, sex, race/ethnicity, number of comorbidities based on the Charlson Comorbidity Index, the number of previous, all-cause admissions 1 year prior to index hospitalization, admission priority, and the type of liver procedure (hepatic lobectomy, partial hepatectomy, and other destruction of liver lesion). Two-sided p values < 0.05 were used to evaluate statistical significance. All statistical analysis was performed with STATA 14.0 MP.

Results

Patient characteristics

A total of 4902 patients who underwent hepatic surgery were included in the analysis: 69.8% underwent partial hepatectomy ($n = 3422$), 19.0% ($n = 929$) underwent hepatic lobectomy, and 11.2% ($n = 551$) underwent open thermal destruction of the liver lesion (Table 1). Mean patient age was 71.9 years (standard deviation [SD] 5.5 years); 50.1% ($n = 2455$) of patients were male and 16.5% ($n = 810$) were non-white. Overall, 77.2% ($n = 3784$) of patients had more than three Charlson comorbid conditions; 15.0% ($n = 734$) had more than one previous admission in the year before the index operation. The majority of index admissions were elective (91.4%, $n = 4480$) and the average length of stay for the index hospitalization was 8.2 days (SD 8.1). Following surgery, 1117 (22.8%) patients had at least one complication during the index hospitalization; 584 (11.9%) patients had at least one serious complication. The incidence of 90-day readmission was 22.8% ($n = 1118$). The incidence of FTR following a complication was 17.6% ($n = 196$). Overall mortality was 2.8% ($n = 138$), 4.7% ($n = 229$), and 6.0% ($n = 296$) at 30, 60, and 90 days, respectively.

There were no differences in terms of patient age, gender, and race among patients treated at high- versus low-mortality hospitals (Table 1). Compared with patients at low-mortality hospitals (LMH), patients at high-mortality hospitals (HMH) were more likely to have > 3 comorbid conditions (LMH 80.8%, $n = 1442$ vs. HMH 74.9%, $n = 1178$; $p < 0.001$). While the number of previous all-cause admissions was comparable (≥ 2 previous admissions, LMH 14.7%, $n = 262$ vs. HMH 14.7%, $n = 231$; $p = 0.377$), patients at HMH were more likely to have a non-elective admission (LMH 6.1%, $n = 108$ vs. HMH 11.4%, $n = 180$; $p < 0.001$). Although the type of liver procedures performed were similar, patients at HMH were more likely to experience any complication (LMH 19.7%, $n = 352$ vs. HMH 27.2%, $n = 427$; $p < 0.001$), as well as a serious complication (LMH 10.4%, $n = 186$ vs. HMH 14.1%, $n = 221$; $p = 0.001$). In fact, patients undergoing liver surgery at a HMH had a 47% increased risk of experiencing a complication (risk adjusted, LMH 20.2% vs. HMH 26.8%; OR 1.47, 95% CI 1.17–1.86; $p = 0.001$) and a 28% increased risk of experiencing a serious complication during index hospitalization (risk adjusted, LMH 10.9% vs. HMH 13.4%; OR 1.28, 95% CI 1.02–1.62; $p = 0.037$) (Table 2). Interestingly, there were no differences in low- and high-mortality hospital 90-day readmission (risk adjusted, LMH 21.4% vs. HMH 24.1%; OR 1.17, 95% CI 1.00–1.38; $p = 0.050$).

The incidence of FTR following a complication, as well as mortality, during the index hospitalization did vary. Specifically, patients who underwent a liver resection of a HMH had a threefold increased risk of dying following a complication (risk adjusted, LMH 9.5% vs. HMH 23.5%; OR 3.08, 95% CI 2.03–4.66; $p < 0.001$). In addition, the risk of death within 30 (OR 3.31, 95% CI 2.16–5.08), 60 (OR 3.50, 95% CI 2.69–4.56), and 90 days (OR 3.70, 95% CI 2.84–4.80) following hepatic resection was also markedly higher (all $p < 0.001$).

Hospital characteristics and failure to rescue

Hospitals with higher liver operative volumes had a lower FTR risk among patients experiencing a postoperative complication (OR 0.71, 95% CI 0.51–0.99; $p = 0.042$). The association of other hospital-level factors relative to FTR was investigated. Of note, hospital factors such as geographic location, as well as total number of beds (OR 0.80, 95% 0.56–1.15), intensive care beds (OR 0.99, 95% 0.70–1.39), and operating rooms (OR 0.81, 95% 0.57–1.14) did not impact FTR (all $p > 0.05$). In addition, other factors such as the number of full-time employees (OR 0.73, 95% 0.53–1.00), admissions (OR 0.81, 95% 0.57–1.14), as well as overall hospital surgical volume (OR 0.88, 95% 0.61–1.25) were similarly not associated with the incidence of FTR among hospitals (all $p > 0.05$) (Table 2) (Supplementary Table 1). In contrast, risk of FTR was strongly associated with the nurse-to-patient ratio. Specifically, hospitals with a greater nurse-to-patient ratio had a markedly lower risk of FTR following a complication (OR 0.70,

Table 1 Patient characteristics across hospital tertiles based on overall mortality rates

Characteristic	Total	By tertiles of hospital mortality (%)			High versus low, p value
		Low-mortality	Medium-mortality	High-mortality	
Hospital, No	67	22	22	23	
Patient, No	4902	1785	1544	1573	
Age, mean (SD), year	71.9 (5.5)	71.5 (5.3)	72.1 (5.5)	72.2 (5.7)	< 0.001
Male, No. (%)	2455 (50.1)	891 (49.9)	759 (49.2)	805 (51.2)	0.466
Non-white race, No. (%)	810 (16.5)	286 (16.0)	240 (15.5)	284 (18.1)	0.117
Comorbidity, No. (%)					
0 conditions	248 (5.1)	81 (4.5)	87 (5.6)	80 (5.1)	0.458
1–2 conditions	870 (17.8)	262 (14.7)	293 (75.4)	315 (20.0)	
3 + conditions	3784 (77.2)	1442 (80.8)	1164 (75.4)	1178 (74.9)	
Prior admissions, No. (%)					
0 stay	2856 (58.3)	1054 (59.1)	906 (58.7)	896 (57.0)	0.377
1 stay	1312 (26.8)	469 (26.3)	397 (25.7)	446 (28.4)	
2 + stays	734 (15.0)	262 (14.7)	241 (15.6)	231 (14.7)	
Admission type, No. (%)					
Elective	4480 (91.4)	1676 (93.9)	1417 (91.8)	1387 (88.2)	< 0.001
Urgent	241 (4.9)	64 (3.6)	59 (3.8)	118 (7.5)	
Emergent	170 (3.5)	44 (2.5)	64 (4.2)	62 (3.9)	
Procedure type, No. (%)					
Hepatic lobectomy	929 (19.0)	307 (17.2)	328 (21.2)	294 (18.7)	0.429
Partial hepatectomy	3422 (69.8)	1289 (72.2)	1007 (65.2)	1126 (71.6)	
Other destruction of liver lesion	551 (11.2)	189 (10.6)	209 (13.5)	153 (9.7)	
Complication, No. (%)	1117 (22.8)	352 (19.7)	338 (21.9)	427 (27.2)	< 0.001
Serious complication, No. (%)	584 (11.9)	186 (10.4)	177 (11.5)	221 (14.1)	0.001
Length of stay, mean (SD), day	8.2 (8.1)	7.8 (6.6)	8.3 (9.6)	8.5 (8.0)	0.783
90-day readmission, No. (%)	1118 (22.8)	383 (21.5)	355 (23.0)	380 (24.2)	0.062
Complication, died (Fail-to-rescue), No. (%)	196 (17.6)	34 (9.7)	63 (18.6)	99 (23.2)	< 0.001
30-day mortality, No. (%)	138 (2.8)	25 (1.4)	41 (2.7)	72 (4.6)	<0.001
60-day mortality, No. (%)	229 (4.7)	41 (2.3)	69 (4.5)	119 (7.6)	< 0.001
90-day mortality, No. (%)	296 (6.0)	52 (2.9)	88 (5.7)	156 (9.9)	< 0.001

Table 2 Complications, readmission, failure to rescue, and mortality across hospitals performing hepatic surgery

Variable	Total	By tertiles of hospital mortality (%)			High versus low		
		Low-mortality	Medium-mortality	High-mortality	Odds ratio	95% CI	P value
Complications	22.8	20.2	21.7	26.8	1.47	1.17–1.86	0.001
Serious complications	11.9	10.9	11.5	13.4	1.28	1.02–1.62	0.037
90-Day readmission	22.8	21.4	23.0	24.1	1.17	1.00–1.38	0.050
Failure to rescue	17.5	9.5	18.5	23.5	3.08	2.03–4.66	<0.001
30-Day mortality	2.8	1.4	2.6	4.5	3.31	2.16–5.08	<0.001
60-Day mortality	4.7	2.3	4.4	7.5	3.50	2.69–4.56	<0.001
90-Day mortality	6.0	3.0	5.6	9.8	3.70	2.84–4.80	<0.001

95% CI 0.54–0.91; $p = 0.007$) (Table 3). In fact, as both the volume of liver operations and nurse-to-patient ratio decreased, the risk of FTR increased (Fig. 1a, b). In addition, even after risk-adjusting for patient characteristics, both the effect of surgical volume (adjusted OR 0.66, 95% CI 0.46–0.94; $p = 0.022$) and nurse-to-patient ratio

Table 3 Effect of hospital characteristics on rates of failure to rescue among patients undergoing hepatic surgery

Hospital characteristic	Unadjusted FTR rate (%)	Univariate analysis			Multivariate analysis		
		Odds ratio	95% CI	*P* value	Odds ratio	95% CI	*P* value
Location type							
Division	20.9	Ref	–	–	Ref	–	–
Metro	16.9	0.77	0.48–1.23	0.271	0.73	0.44–1.21	0.224
Total beds							
$\leq$ 685 (50 percentile)	19.2	Ref	–	–	Ref	–	–
$>$ 685 (50 percentile)	16.0	0.80	0.56–1.15	0.224	0.77	0.53–1.14	0.196
Intensive care beds							
$\leq$ 90 (50 percentile)	17.6	Ref	–	–	Ref	–	–
$>$ 90 (50 percentile)	17.4	0.99	0.70–1.39	0.934	0.95	0.65–1.37	0.764
No. of operation rooms							
$\leq$ 42 (50 percentile)	19.2	Ref	–	–	Ref	–	–
$>$ 42 (50 percentile)	16.1	0.81	0.57–1.14	0.231	0.80	0.55–1.18	0.260
Total admissions							
$\leq$ 31,748 (50 percentile)	19.1	Ref	–	–	Ref	–	–
$>$ 31,748 (50 percentile)	16.0	0.81	0.57–1.14	0.229	0.79	0.54–1.13	0.198
Average daily census							
$\leq$ 517 (50 percentile)	19.2	Ref	–	–	Ref	–	–
$>$ 517 (50 percentile)	16.1	0.81	0.57–1.14	0.227	0.80	0.55–1.17	0.247
Total surgical operations							
$\leq$ 26,807 (50 percentile)	18.6	Ref	–	–	Ref	–	–
$>$ 26,807 (50 percentile)	16.7	0.88	0.61–1.25	0.463	0.88	0.59–1.30	0.516
Hepatic volume							
$\leq$ 59 (50 percentile)	21.1	Ref	–	–	Ref	–	–
$>$ 59 (50 percentile)	15.9	0.71	0.51–0.99	0.042	0.66	0.46–0.94	0.022
Full-time employee							
$\leq$ 6534 (50 percentile)	20.3	Ref	–	–	Ref	–	–
$>$ 6534 (50 percentile)	15.6	0.73	0.53–1.00	0.051	0.72	0.50–1.04	0.078
Increased nurse-to-patient ratio							
$\leq$ 9.6 (median ratio)	20.0	Ref	–	–	Ref	–	–
$>$ 9.6 (median ratio)	14.9	0.70	0.54–0.91	0.007	0.68	0.51–0.90	0.008

(adjusted OR 0.68, 95% CI 0.51–0.90; $p = 0.008$) remained strongly associated with FTR.

The degree of difference in FTR associated with various hospital characteristics was further estimated after adjusting for specific hospital characteristics (Table 4). The inclusion of hepatic surgical volume in the estimation model demonstrated an 11.4% reduction in the odds of FTR among the lowest versus highest mortality hospitals (OR 2.84, 95% CI 1.86–4.34) (Table 4) (Fig. 2). Moreover, the addition of nurse-to-patient ratio in the model demonstrated a 9.7% reduction in the odds of FTR (OR 2.88, 95% CI 1.89–4.37). The combination of liver surgery volume and nurse-to-patient ratio was associated with an over 2.5-fold reduction in the odds of FTR between highest and lowest mortality hospitals (OR 2.63, 95% CI 1.73–4.00).

Discussion

As payment structures in the USA begin to place more emphasis on the value of care rather than volume of care, there has been greater interest in the methods to assess the quality of healthcare services [21, 24, 25]. For patients undergoing surgery, quality metrics have traditionally included postoperative morbidity and mortality. Hepatectomy has been associated with a higher incidence of postoperative complications (30–40%) and mortality (1–4%) than most other types of major gastrointestinal surgical procedures [10]. While the incidence of postoperative complications among surgical patients are generally similar among hospitals, several studies have demonstrated that FTR following a complication can vary considerably leading to differences in mortality.(26, 31) While the risk

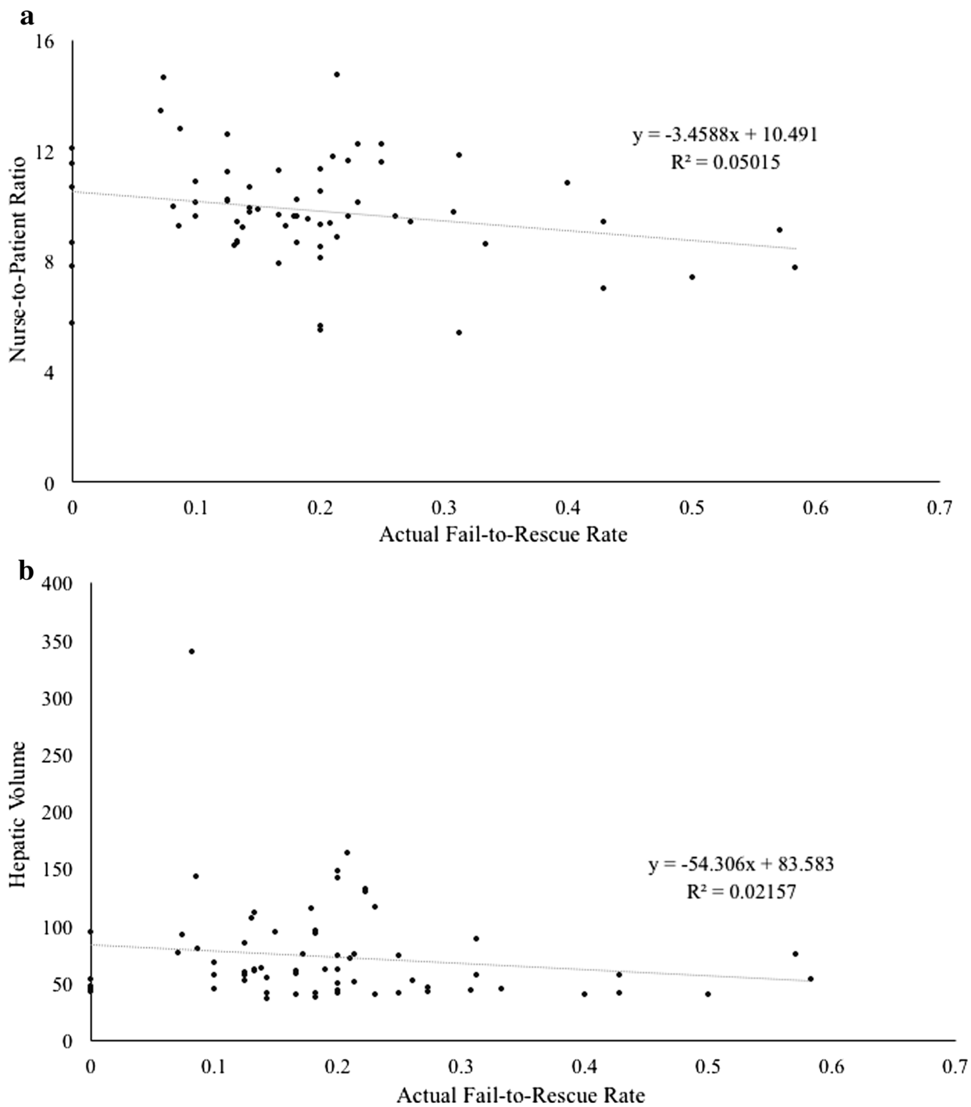


Fig. 1 **a** Relationship between nurse-to-patient ratio and failure to rescue. **b** The relationship between hepatic volume and failure-to-rescue rate

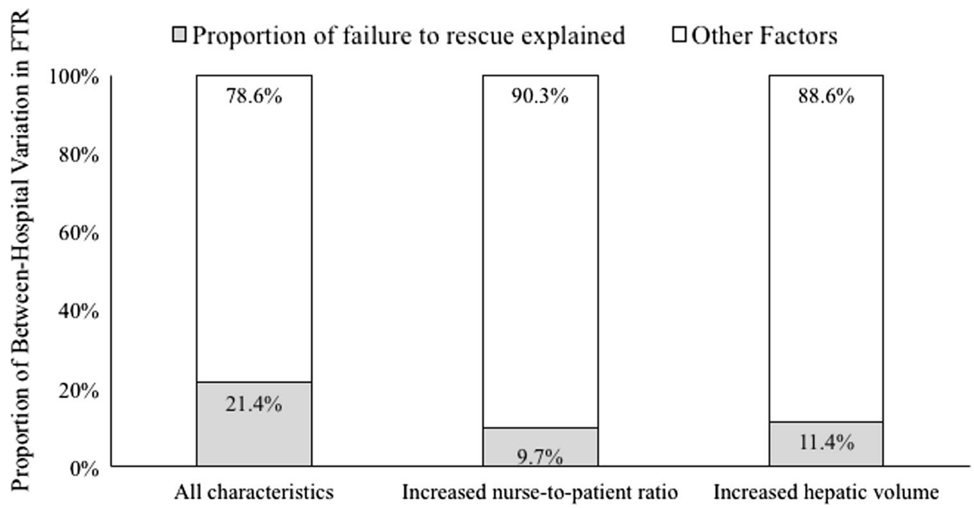
Table 4 Effect of each hospital characteristic on the odds of failure to rescue at a high-mortality hospital compared to a low mortality hospital

Hospital characteristic	FTR rate at low mortality hospital (%)	FTR rate at high-mortality hospital (%)	Odds ratio (95% CI) adjusted for hospital characteristic
All characteristics	10.3	22.2	2.63 (1.73–4.00)
Increased nurse-to-patient ratio	9.7	22.7	2.88 (1.89–4.37)
Increased hepatic volume	10.3	22.2	2.84 (1.86–4.34)

Odds ratio of failure to rescue in patients at high-mortality hospitals compared with low-mortality hospitals = 3.08

of a surgical complication is strongly linked to a number of patient- and procedure-specific factors, subsequent complication-related mortality may be explained by timely recognition of the complication and the ability to rescue patients from these complications [11, 26, 27]. In turn, FTR has been proposed as an important quality metric to assess performance and define variations in quality among hospitals [28–30]. As a result, FTR is increasingly being used to measure hospital quality of care in high-risk surgery, yet the factors associated with FTR have been less well defined

Fig. 2 Identifying sources of between-hospital variation in failure to rescue



[28, 31, 32]. The current study was important because we specifically investigated the impact of hospital characteristics on FTR following liver surgery. Of note, HMH had a much higher incidence of FTR. Perhaps not surprisingly, FTR following hepatectomy was strongly associated with liver-specific procedural volume. In contrast, FTR was not associated with overall hospital operative volume, total number of beds, or the number of operating rooms. These data suggest that the overall size and structural capacity of the hospital/medical center did not impact FTR for any given procedure such as hepatectomy. In contrast, unlike structural factors such as number of beds or operating rooms, nurse staffing levels did affect patient outcomes, FTR and risk of in-hospital death. In particular, as the nurse-to-patient ratio increased, there was a direct correlation with decreased FTR following liver resection (Fig. 1a).

While the risk of mortality following liver resection has dramatically decreased over the last several decades, morbidity remains high [8, 14, 24, 33]. As such, recent attention has focused on management of postoperative morbidity, as well as rescuing patients from complications to decrease the risk of complication-related deaths [9, 34, 35]. Some surgeons may have higher proficiency and advanced technical skills, and some hospitals may have superior perioperative management, leading to better outcomes [5, 16, 36]. Different mortality outcomes among hospitals may, however, be more related to the ability to recognize and manage postsurgical complications. As such, FTR may be a better indicator to understand the variability in surgical mortality seen among hospitals [37–39]. To this point, our group has previously reported that complication-related deaths following hepatectomy were high, as roughly one in seven (14.9%) patients died after experiencing at least one complication after hepatic surgery [9]. The current expanded on this previous work, as we demonstrated that FTR varied widely among different hospitals. Specifically, among the 4902 Medicare patients included in the current analytic cohort, patients who underwent hepatectomy at HMH had a threefold increased risk of dying after a complication (LMH 9.5% vs. HMH 23.5%, OR 3.08, 95% CI 2.03–4.66; $p < 0.001$). Collectively these data, as well as previous data reported from our group, strongly suggest that the risk of death following hepatic surgery can vary considerably among hospitals. In turn, the variability in mortality may largely be related to differences in FTR at hospitals.

The volume–outcomes relationship relative to mortality has been well established across a number of different surgical procedures [40–43]. More recently, the association of volume and outcomes has also been linked to FTR and the risk of death after experiencing a complication [16, 30, 34]. Spolverato et al. reported that the incidence of major morbidity following hepatectomy remained the same over the past decade, yet FTR decreased [9]. In addition, the rate of FTR was higher at low- and intermediate-volume hospitals compared with high-volume hospitals. In the current study, we similarly noted that hospitals with higher liver operative volumes had a lower FTR risk among patients experiencing a postoperative complication. In fact, patients who underwent an operation at a high liver volume hospital had a roughly 30% decreased risk of death if they experienced a complication in the postoperative period. Interestingly, the volume effect was procedure specific, as the overall size of the hospital (e.g., number of beds, discharges) and the general surgical volume (e.g., number of OR rooms, number of overall operative cases) were not associated with FTR after a liver operation. Some studies have suggested that large hospital size may be a surrogate for the availability of specialized services, advanced equipment or increased access to interventional services, which might in turn translate into better FTR rates [4, 28, 44]. Data from the current study would suggest, however, that these macrolevel hospital characteristics did not have an important impact on FTR following a complex surgical procedure such as liver resection. Rather, only procedure-specific volume was associated with FTR. In turn, these data indicated that the volume–outcome effect relative to FTR after hepatic resection was specific in nature at the procedure, rather than the hospital level.

Another mechanism to explain variations in FTR rates among hospitals may be related to differences in the timely recognition of a complication so that it can be more expeditiously and appropriately managed. To this point, another important finding of the current study was the relationship of nurse-to-patient ratio with FTR. Specifically, hospitals with a greater nurse-to-patient ratio had a markedly lower risk of FTR following a complication (Table 3). Rather than just procedural volume alone, the addition of nurse-to-patient ratio in the model demonstrated a 9.7% reduction in the odds of FTR such that the combination of liver surgery volume and nurse-to-patient ratio was associated with an over 2.5-fold reduction in the odds ratio for FTR among highest and lowest mortality hospitals. FTR may be related to nursing care as nurses are usually the individuals at the bedside monitoring patients and are among the first staff members to see and evaluate a patient. FTR often involves a patient under care for a noncritical medical condition who then begins to show signs of an impending issue or complication. Nurses are often the first provider to report the condition up the chain of command and initiate attempts to "rescue" the patient. As such, a lower nurse-to-patient ratio may impede this process and increase the likelihood of FTR. While several other studies have reported a positive correlation between nurse-to-patient ratio and the risk of postoperative mortality, to our knowledge, the current study is the first to describe the relationship between nurse-to-patient ratio and FTR among patients who underwent liver surgery [29, 45–48]. Understanding the relationship between nurse-to-patient ratio and FTR can help inform optimal healthcare resource allocation and utilization [49–51]. In particular, increasing nursing staffing for complex surgical patients, such as individuals undergoing hepatic resection, may be an important step toward optimizing perioperative care.

Several limitations should be considered when interpreting the current study. Given that Medicare was the data source, the results were derived largely from individuals $\geq$ 65 years (or younger Medicare beneficiaries) and therefore the result may not be generalizable or applicable to other non-Medicare populations of patients undergoing hepatectomy. While the use of Medicare data is well established in the literature and Medicare coding is generally highly accurate in the coding of most procedures, certain aspects of healthcare delivery such as leadership and governance structures, varied means of clinical oversight of outcomes cannot be captured by Medicare. In addition, the use of an administrative claims database provided limited information on certain health status factors at the time of admission, as well as surgical techniques (e.g., lymphadenectomy, associated surgical procedures) and disease severity (e.g., tumor size, number). However, these factors should not necessarily impact the examination of FTR, which was the primary study outcome. While the nurse-to-patient ratio may have varied depending on the unit in which the patient was receiving care, the overall nurse-to-patient ratio still reflected overall staffing levels. As such, the conclusion that lower nursing staff levels at the institutional level were associated with FTR rates remains an important and valid finding.

In conclusion, among patients undergoing hepatic surgery, marked differences were observed in the incidence of FTR following the development of a complication during index hospitalization at a low- versus high-mortality hospital. Higher procedure-specific hepatectomy volume, as well as a higher nurse-to-patient ratio accounted for 11.4% and 9.7% of the reduction in the FTR rates, respectively. These data highlight the importance not only of procedure volume, but also adequate nurse staffing in reducing FTR and improving mortality following complex procedures such as hepatectomy. Future studies should aim to identify other hospital characteristics that impact FTR to inform future organizational improvements to maximize quality of care for complex surgical patients.

Compliance with ethical standards

Conflict of interest All authors declare that they have no disclosures to report.

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