A Risk Model to Predict 90-Day Mortality among Patients Undergoing Hepatic Resection

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BACKGROUND: Reliable criteria to predict mortality after hepatectomy remain poorly defined. We sought to identify factors associated with 90-day mortality, as well as validate the "50-50" and peak bilirubin of >7 mg/dL prediction rules for mortality after liver resection. In addition, we propose a novel integer-based score for 90-day mortality using a large cohort of patients.

STUDY DESIGN: Data from 2,056 patients who underwent liver resection at 2 major hepatobiliary centers between 1990 and 2011 were identified. Perioperative laboratory data, as well as surgical and postoperative details, were analyzed to identify factors associated with liver-related 90-day death.

RESULTS: Indications for liver resection included colorectal metastasis (39%), hepatocellular carcinoma (19%), benign mass (17%), or noncolorectal metastasis (14%). Most patients had normal underlying liver parenchyma (71%) and resection involved ≥3 segments (36%). Overall morbidity and mortality were 19% and 2%, respectively. Only 1 patient fulfilled the 50-50 criteria; this patient survived and was discharged on day 8. Twenty patients had a peak bilirubin concentration >7 mg/dL and 5 died within 90 days; the sensitivity and specificity of the >7-mg/dL rule were 25% and 99.3%, respectively, but overall accuracy was poor (area under the curve 0.574). Factors associated with 90-day mortality included international normalized ratio (odds ratio = 11.87), bilirubin (odds ratio = 1.16), and serum creatinine (odds ratio = 1.87) on postoperative day 3, as well as grade of postoperative complications (odds ratio = 5.08; all $p < 0.05$). Integer values were assigned to each factor to develop a model that predicted 90-day mortality (area under the curve 0.89). A score of ≥11 points had a sensitivity and specificity of 83.3% and 98.8%, respectively.

CONCLUSIONS: The 50-50 and bilirubin >7-mg/dL rules were not accurate in predicting 90-day mortality. Rather, a composite integer-based risk score based on postoperative day 3 international normalized ratio, bilirubin, creatinine, and complication grade more accurately predicted 90-day mortality after hepatectomy. (J Am Coll Surg 2013;216:1049−1056. © 2013 by the American College of Surgeons)

Liver resection has become a more common procedure during the last several decades. In fact, as indications for liver resection expand[1-4] and perioperative management continues to improve, the use of hepatectomy for both benign and malignant disease will undoubtedly continue to increase. Although hepatic resection was historically associated with large-volume blood loss and a perioperative mortality of 10% to 20%,[5-7] more recently major academic centers have reported a mortality of <3%.[8-10] Other reports, however, have noted an almost 2-fold higher mortality when examining population-based data.[11] In addition, morbidity after hepatic resection has remained high, at about 20% to 40%.[4,10,12]

Several groups have attempted to establish reliable criteria to predict mortality after liver resection.[13-15] Balzan and colleagues proposed the "50-50 criteria" on postoperative day 5 as a simple, early, and accurate predictor of mortality after hepatectomy.[14] Specifically, the authors noted that the conjunction of prothrombin time <50% and serum bilirubin >50 μmol/L on postoperative day 5 was a strong predictor of mortality. In contrast, other

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investigators have advocated for a peak bilirubin of >7 mg/dL as a more accurate predictor of mortality after hepatectomy.[13] More recently, biochemical blood tests have been proposed as not only an accurate means to predict mortality, but perhaps even morbidity.[16] Reissfelder and colleagues reported that biochemical data can help to recognize patients more likely to have a surgery-related complication during the postoperative course.[16]

Notwithstanding these previous studies,[13-16] there remain limited data on the impact of biochemical blood tests after hepatic resection. In general, most studies have focused primarily on mortality rather than morbidity and, therefore, did not compare patients with and without surgery-related complications relative to biochemical parameters. In addition, virtually all previous studies were derived using data from single institutions and might therefore lack generalizability. As such, the aim of the current study was to describe the postoperative changes in biochemical blood tests among a large, multi-institutional international cohort of patients after liver resection. Specifically, we sought to identify factors associated with 90-day mortality, as well as validate the 50-50 and peak bilirubin of >7-mg/dL prediction rules.[13,14] In addition, we describe the impact and clinical significance of biochemical blood tests on the risk of post-resection morbidity. Finally, we present and validate a novel numeric score for prediction of 90-day mortality in a large cohort of patients from 2 major centers.

METHODS

Patients and data collection

Using a multi-institutional database, patients undergoing liver resection for benign and malignant disease at Johns Hopkins School of Medicine, Baltimore, MD or Ospedale San Raffaele, Milan, Italy between January 1991 and December 2011 were identified. Patients who underwent ablation only were excluded from the current study. The institutional review board of each institution approved the study. Standard demographic and clinicopathologic data were collected, including sex, age, and race. Indication for surgery and presence of underlying disease of the non-tumorous liver, presence of portal hypertension, and Child-Pugh score were recorded for all patients. Operative details, such as type of liver resection, intraoperative blood loss, and requirement for transfusion, were recorded. Among patients with a malignant diagnosis, patients were deemed to have resectable hepatic disease only if it was anticipated that the disease could be completely resected, at least 2 adjacent liver segments could be spared, vascular inflow and outflow could be preserved, and the volume of the liver remaining after resection would be adequate.[17] The extent of the hepatic resection was categorized as minor (≤3 segments) or major (≥4 segments).

Laboratory values including total serum bilirubin, prothrombin time, international normalized ratio (INR), albumin, and serum creatinine were recorded for all patients before surgery, as well as on days 1, 3, 5, 7, 10, and 14 after surgery. When identical laboratory samples were drawn multiple times on the same day, the highest value was recorded and used for the purposes of analyses. Postoperative complications occurring during the inpatient stay were noted and classified according to the Clavien-Dindo classification.[18] Data on the occurrence of postoperative liver-related sequelae were also recorded (eg, prolonged [>24 hours] ventilator support, ascites [defined according to the Child classification as absent, slight, and moderate per cross-sectional imaging and physical examination], intra-abdominal fluid collections, bleeding, pleural effusion, liver failure/insufficiency). Patients were followed until death or were censored at last date of follow-up.

Data analysis

Median values were used to describe continuous data, with discrete variables displayed as totals and frequencies. Comparisons of clinicopathologic characteristics were assessed using the chi-square test for dichotomous and categorical variables. Mann−Whitney U test was used to compare continuous variables. Ninety-day mortality was calculated from the date of operation.[19] Cumulative event rates were calculated using the method of Kaplan and Meier and survival curves were compared using the log-rank test. External validation of previously proposed mortality models was performed through calculation of sensitivity, specificity, and receiver-operating characteristic curves. Receiver-operating characteristic curves were drawn to graphically present the fit of the model to the data; area under the curve (AUC)/c-statistic was noted. In assessing the 50-50 criteria, a bilirubin ≥2.9 mg/dL and an INR ≥1.7 were used as conversion cut-off values.[13] Logistic regression analysis with forward selection was used to select factors to be added to the final prediction model. The new model was internally validated using n-fold cross-validation.[20] Statistical significance was defined as a 2-tailed $p < 0.05$. All data analyses were performed using SPSS statistical software package (version 17.0 for Microsoft Windows, 2008, SPSS Inc.).

RESULTS

Demographic and clinical characteristics

The study included 2,056 patients (Table 1). The majority of patients were male (n = 1,083 [52.7%]) and white (n = 1,749 [85.1%]). The most common

Table 1. Clinicopathologic Patient Data for 2,056 Patients Who Underwent Liver Resection

Patient data	All (n = 2,056)	Minor resection (n = 1,322)	Major resection (n = 734)
Age, y, median (IQR)	61 (51–70)	61 (51–70)	60 (49–70)
Sex ratio (male to female)	1,083:973	676:646	407:327
Diagnosis, n (%)			
Metastatic disease			
Colorectal primary	781 (38.0)	495 (37.4)	286 (39.0)
Other	281 (13.7)	210 (15.9)	71 (9.7)
Primary malignancy			
HCC	375 (18.2)	241 (18.2)	134 (18.3)
Cholangiocarcinoma	154 (7.5)	47 (3.6)	107 (14.6)
Carcinoma of gallbladder	47 (2.3)	32 (2.4)	15 (2.0)
Benign disease	376 (18.3)	283 (21.4)	93 (12.7)
Trauma	42 (2.0)	14 (1.1)	28 (3.8)
Pathology of underlying liver, n (%)			
None	1,464 (71.2)	939 (71.0)	525 (71.5)
Steatosis	204 (9.9)	123 (9.3)	81 (11.0)
Steatohepatitis	79 (3.8)	43 (3.3)	36 (4.9)
Fibrosis	121 (5.9)	76 (5.8)	45 (6.1)
Cirrhosis	188 (9.1)	141 (10.7)	47 (6.4)

HCC, hepatocellular carcinoma; IQR, interquartile range.

indication for liver resection was colorectal liver metastasis in 781 (38.0%) patients. Other common indications included various benign lesions (n = 376 [18.3%]), hepatocellular carcinoma (n = 375 [18.2%]), and resection of noncolorectal liver metastasis (n = 281 [18.2%]). Most patients did not have underlying liver disease (n = 1,464 [71.2%]) and a small subset did (steatosis, n = 204 [9.9%]; cirrhosis, n = 188 [9.1%]; fibrosis, n = 121 [5.9%]; and steatohepatitis, n = 79 [3.8%]).

The overwhelming majority of patients underwent resection only (n = 2,009 [97.7%]) and a small number of patients had resection plus ablation (n = 47 [2.3%]). The type of resection was minor in most patients (n = 1,322 [64.3%]) and major in 734 (35.7%) patients. The most frequently performed minor operation was a nonanatomical or wedge resection (n = 814 [39.6%]), and the most common major procedure was a right hepatectomy (n = 380 [18.5%]). Median estimated blood loss was 400 mL (interquartile range [IQR] 400 to 1,000 mL; for minor resection: 300 mL [IQR 150 to 600 mL] vs major resection: 600 mL [IQR 400 to 1,000 mL]; $p < 0.001$).

Postoperative course, complications, and mortality

After surgery, the median length of stay was 6 days (IQR 5 to 8 days; Johns Hopkins Hospital: median 5 days [IQR 4 to 6 days] vs Ospedale San Raffaele: median 7 days [IQR 6 to 10 days]). Of note, 494 (24.3%) patients had a length of stay <5 days and 231 (11.2%) patients had a length of stay >12 days.

There were 396 patients who experienced a complication for a morbidity of 19.3% (Table 2). Liver-specific complications included postoperative ascites (n = 51 [2.5%]), biliary leak (n = 65 [3.2%]), bleeding (n = 19 [0.9%]), abscess (n = 15 [0.7%]), and liver insufficiency/failure (n = 9 [0.5%]). Among patients with liver insufficiency/failure, 2 required extracorporeal liver support and subsequently underwent "rescue" liver transplantation. Among the 396 patients who experienced a complication, 250 (63.1%) had a minor/grade I to II complication, and 146 (36.9%) had a major/grade III to IV complication. Patients who experienced a complication had a longer hospital stay compared with patients who did not have a complication (median 6 days [IQR 4 to 7 days] vs 9 days [IQR 7 to 15 days], respectively; $p < 0.001$).

There were 32 deaths, for a mortality of 1.6%; 25 patients died during the index admission associated with the hepatic resection and another 7 patients died after discharge, but within 90 days of surgery. Ninety-day mortality was more common among older patients, patients with postoperative complications, and patients undergoing major hepatic resection (all $p < 0.05$; Table 1).

Posthepatectomy biochemical blood tests: association with morbidity and mortality

Overall, postoperative serum bilirubin differed among patients who underwent a minor vs major resection. Specifically, median postoperative bilirubin was higher

Table 2. Surgery-Related and Medical Morbidity

Morbidity	Minor resection (n = 1,322) n	%	Major resection (n = 734) n	%
Surgery-related morbidity				
Liver abscess	6	0.5	1	0.1
Cholangitis	1	0.1	2	0.3
Pleural effusion	27	2.0	20	2.7
Biliary fistula	34	2.6	15	2.0
Biloma	9	0.7	7	1.0
Sepsis	10	0.8	19	2.6
Hemorrhage	11	0.8	8	1.1
Wound infection	3	0.2	4	0.5
Intra-abdominal abscess	3	0.2	5	0.7
Portal vein thrombosis	0	0	2	0.3
Liver insufficiency	3	0.2	6	0.8
Medical morbidity				
Infectious	19	1.4	11	1.5
Cardiovascular	11	0.8	4	0.5
Pulmonary	14	1.1	5	0.7
Renal	1	0.1	4	0.5
Gastrointestinal	10	0.8	12	1.6
Hematologic	1	0.1	3	0.4
Other	22	1.7	17	2.3

Patients could have multiple complications.

on postoperative day 1 after major resection when comparing patients who underwent minor vs major resection (1.7 mg/dL [IQR 0.8 to 2.0 mg/dL] vs 2.2 mg/dL [IQR 1.2 to 2.2 mg/dL], respectively; $p < 0.001$; Fig. 1). These differences persisted on day 5 and even on day 7 after resection (both $p < 0.05$). Similarly, differences in serum albumin were noted when comparing patients who underwent a minor vs a major resection, with lower postoperative serum albumin levels among patients who had a major resection. The difference in median serum albumin levels decreased, but remained different even on day 7 after resection (minor resection: 3.5 g/dL [IQR 3.2 to 4.0 g/dL] vs major resection: 3.3 g/dL [IQR 3.0 to 3.6 g/dL]; $p < 0.001$). In contrast, there were no notable differences in serum creatinine or INR levels when comparing minor vs major resection (Fig. 1).

Of note, patients who had a complication were more likely to have aberrations in their biochemical blood tests after surgery (Fig. 2). Specifically, patients who experienced a complication had a higher median serum bilirubin on postoperative day 3 (no complication: 1.6 mg/dL [IQR 0.9 to 2.2 mg/dL] vs complication: 1.9 mg/dL [IQR 1.2 to 2.7 mg/dL] and postoperative day 5 (no complication: 1.4 mg/dL [IQR 1.0 to 2.0 mg/dL] vs complication: 1.7 mg/dL [1.2 to 2.2 mg/dL]). Serum albumin was also noted to be lower among patients who experienced a complication (postoperative day 3, no complication: 3.5 mg/dL [IQR 3.0 to 3.7 mg/dL] vs complication: 3.3 mg/dL [IQR 2.7 to 3.6 g/dL]; postoperative day 5: no complication, 3.8 mg/dL [IQR 3.2 to 4.0 g/dL] vs 3.4 g/dL [IQR 3.9 to 4.9 g/dL]; both $p < 0.05$). These differences in biochemical blood tests among patients who experienced a complication persisted even when patients were stratified according to minor vs major resection (Fig. 2). Among patients who underwent a major resection, median bilirubin was higher among patients who had suffered a complication (2.7 mg/dL vs 2.2 mg/dL; $p < 0.001$) and peaked on day 3, and decreasing to near-normal levels by postoperative day 7. Serum albumin levels fell to their lowest level on day 3; however, in contrast to median bilirubin levels, serum albumin levels were slower to recover when a complication developed in patients during the postoperative period. Among patients with a complication, INR and creatinine levels were also noted to be different. International normalized ratio levels peaked at day 5 and, similar to albumin, decreased back to a normal level slower among patients who had experienced a complication.

Validation of mortality prediction rules and proposed new model

Among 1,286 patients who had a hospital stay of $\geq$5 days, only a small subset had laboratory values that fulfilled the criteria of the 50-50 rule. Specifically, 60 (4.7%) patients had a bilirubin $\geq$2.9 mg/dL and 3 (0.2%) patients had an INR $\geq$1.7. Of note, only 1 patient had the requisite combination of both bilirubin $\geq$3 mg/dL and INR $\geq$1.7 on day 5. This patient survived and was discharged on day 8. Validation of the 50-50 rule was not attempted due to the small number of patients who fulfilled the criteria. In contrast, 20 patients had a peak bilirubin concentration >7 mg/dL and 5 died within 90 days. As such, the sensitivity of the >7-mg/dL rule was 25%, and the specificity was 99.3%. The AUC for the >7-mg/dL prediction rule was 0.574.

Given the lack of applicability of previous prediction rules, we identified other factors that were associated with mortality (Table 3). On multivariate analyses, 3 factors were noted to be strongly associated with risk of mortality: Clavien-Dindo complication classification, as postoperative day 3 INR and creatinine. A risk model for predicting 90-day mortality was constructed using these variables, as well as serum bilirubin on day 3 because of its empiric relation to liver function, its association with morbidity, and its pre-eminence in previous prediction rules.[13,14] These variables were used to derive a novel score that weighted each variable according its strength of

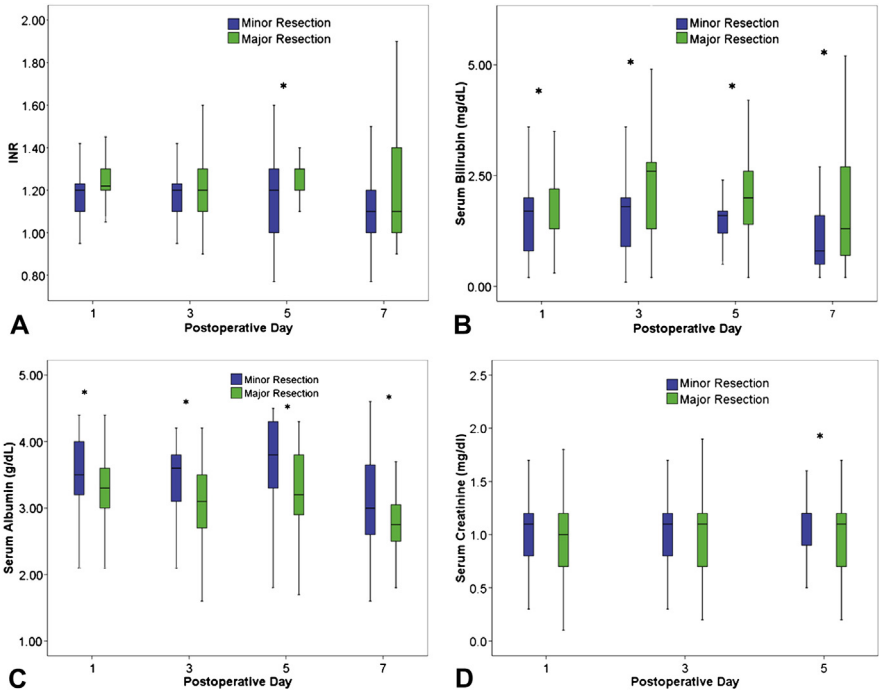


Figure 1. Laboratory values. (A) International normalized ratio (INR), (B) bilirubin, (C) albumin, and (D) creatinine during the course of the postoperative period stratified by extent of operation. Asterisks denote statistically significant difference.

association with mortality (day 3 INR × 2.5 + complication grade × 1.5 + day 3 serum bilirubin × 0.15 + day 3 serum creatinine × 0.5). The novel risk model showed a good fit to the data (Hosmer-Lemeshow goodness-of-fit test, chi-square$_{HL}$ 8.77; $p = 0.19$). In addition, the prediction rule performed well on receiver-operating characteristic curve analysis (AUC 0.927; Fig. 3). The mortality prediction rule was also applied separately to the data from Johns Hopkins (AUC 0.914) and Ospedale San Raffaele (AUC 0.936). The n-fold cross-validation of the prediction rule provided a Sommer's D statistics value of 0.787 (AUC 0.893). Additional n-fold cross-validation analyses were performed to investigate the performance of the score in patients with a normal vs abnormal underlying liver. Because of limited numbers, patients with steatosis, steatohepatitis, fibrosis, and cirrhosis were combined into one cohort. When comparing patients with a normal underlying liver vs patients with an abnormal underlying liver, the score performed similarly well among patients with a normal (AUC 0.887) vs abnormal underlying liver (AUC 0.885). When patients were stratified according to the number of points derived from the score, there was an incremental increased risk of death (<5.9 points: 0.2% vs 6.0 to 8.9 points: 1.2% vs 9.0 to 10.9 points: 34.3% vs ≥11 points: 83.3%; $p < 0.001$). Among patients who had ≥11 points, the prediction rule had a sensitivity of 83.3% and a specificity of 98.9%.

DISCUSSION

Liver resection has become an increasingly common procedure because of better patient selection, development of improved surgical techniques, and better perioperative care. Despite these improvements, hepatic resection can still be associated with perioperative mortality and a high incidence of morbidity.[11,13,14,21] Belghiti and colleagues reported an overall in-hospital mortality of 4.4% after liver resections among 747 patients treated at a major European hepatobiliary center.[21] In a separate study from a large center in the United States, Mullen and colleagues noted a 4.7% all-cause 90-day mortality after liver resection.[13] Morbidity similarly remains a problem after hepatic resection, with surgery-related morbidity being documented in 20% to 40% of patients after surgery.[7,16,22] Several previous groups have proposed prediction rules based on postoperative laboratory values to identify patients at the highest risk of mortality after liver resection.[13,14] Other groups have suggested that biochemical data might even help to recognize surgery-related complications early during the postoperative course.[16] The current study is important

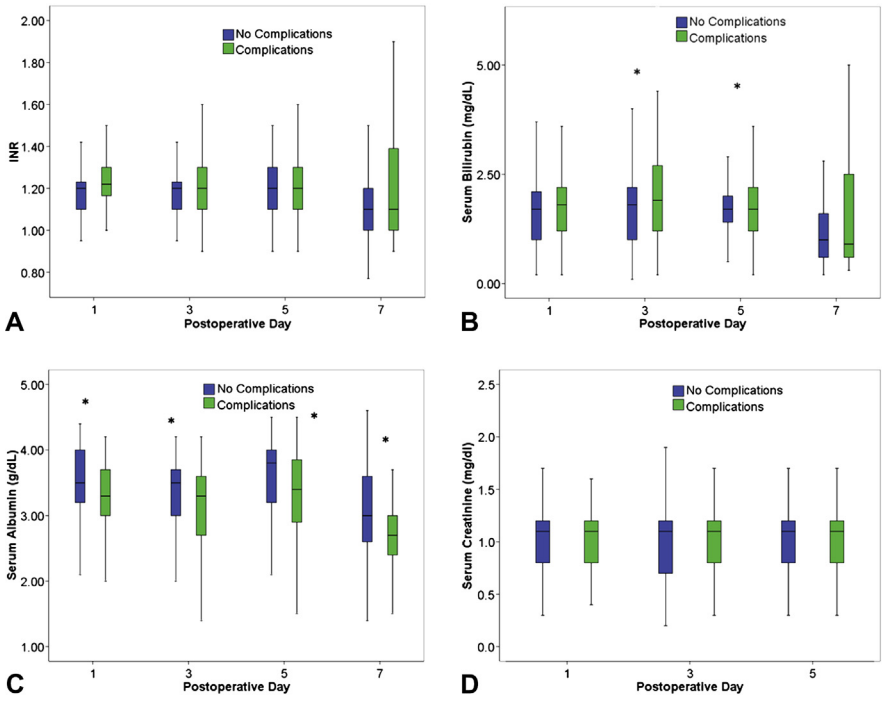


Figure 2. Laboratory values. (A) International normalized ratio (INR), (B) bilirubin, (C) albumin, and (D) creatinine during the course of the postoperative period stratified by the presence or absence of a postoperative complication. Asterisks denote statistically significant difference.

because it sought to externally validate previous mortality prediction rules in a large, international, dual-center cohort of patients. We found that previous prediction rules were not clinically applicable due to the very low number of patients who met the defined criteria. In addition, in the case of the >7-mg/dL rule—when a subset of patients actually did meet the criteria—the rule performed relatively poorly (AUC 0.574). Given this, we defined a broader set of parameters (eg, complication grade, as well as INR, creatinine, and bilirubin on postoperative day 3) that were used to derive a novel, weighted score to predict 90-day mortality. When applied to the current data and internally validated, the score was noted to perform well (AUC 0.893) with an incremental increased risk of death associated with a higher score.

Similar to the previous report from Reissfelder and colleagues,[16] we sought to examine the postoperative course of biochemical tests commonly obtained within routine clinical practice in a large set of patients undergoing hepatic resection. Serum bilirubin and INR are established laboratory parameters to evaluate hepatic function and have been the focus of most predictive rules examining outcomes after liver surgery.[13,14,23,24] As one might have expected, we noted that both bilirubin and INR were elevated among patients after major vs minor liver resection. Perhaps more interestingly, we also found that bilirubin and INR were elevated among patients who experienced a complication even after stratifying for the extent of resection. Reissfelder and colleagues had similarly noted that both of these laboratory parameters were significantly different among patients who experienced a complication.[16] In fact, not only did patients with a complication have higher serum bilirubin and INR levels, but these levels also took longer to normalize after a complication (Fig. 2). Taken together, these data confirm the biologic relevance and centrality of both

Table 3. Multivariate Logistic Regression Predicting the Risk of 90-Day Mortality

Variable	β	OR	95% CI	p Value	Numeric score
Serum INR day 3	2.47	11.87	1.57–89.69	0.02	2.5
Each complication grade increase	1.63	5.08	3.32–7.78	<0.001	1.5
Serum bilirubin day 3	0.15	1.16	0.80–1.70	0.42	0.15
Serum creatinine day 3	0.62	1.87	1.08–3.25	0.03	0.5

INR, international normalized ratio; OR, odds ratio.

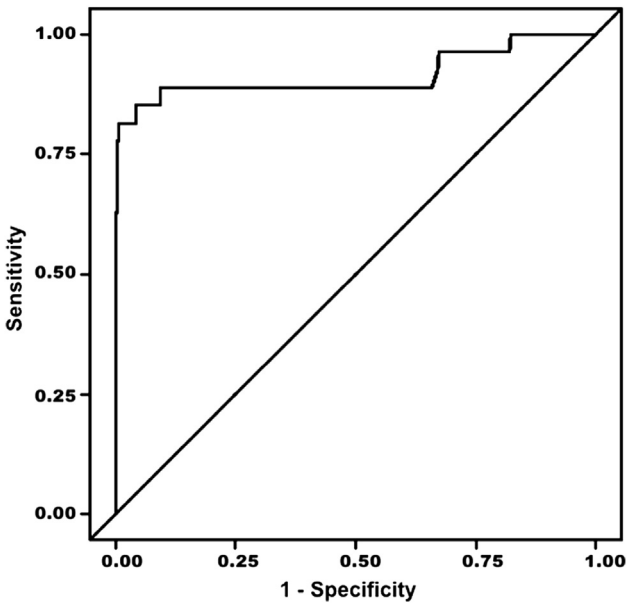


Figure 3. The receiver-operating characteristic (ROC) of the proposed composite prediction rule. The composite score consists of weighted values for grade of postoperative complication, as well as international normalized ratio, bilirubin, and creatinine on postoperative day 5. The composite rule performed well on ROC curve analysis (area under the curve [AUC] 0.927), as well as on n-fold cross-fold validation (AUC 0.893).

serum bilirubin and INR as parameters to assess patient outcomes after hepatic resection.

Given the importance of bilirubin and INR, it is not surprising that some groups have tried to use these parameters to predict mortality after liver resection.[12,14,24] Balzan and colleagues reported that a prothrombin time of 50% and serum bilirubin of 50 μmol/L on postoperative day 5 was a simple, early, and accurate predictor of mortality after hepatectomy.[14] The 50-50 rule has been criticized, however, for several reasons. Some investigators have questioned the value of using INR as a main predictor of mortality because it can be biased after liver resection by the administration of fresh-frozen plasma. Perhaps more importantly, the 50-50 rule seems to lack general applicability. For example, in the study by Mullen and colleagues, which included >1,000 patients, only 14 of 28 patients who died actually met the 50-50 criteria.[13] Similarly, in the current study, which contained >2,000 patients, only 1 patient had the requisite combination of both bilirubin ≥3 mg/dL and INR ≥1.7 on day 5. Other prediction models for mortality have therefore been proposed, with the >7-mg/dL rule probably being the most cited.[13] The >7 mg/dL is appealing in its simplicity, but is also problematic. By exclusively focusing on serum bilirubin, the prediction rule is largely applicable only to patients at risk for death related to liver insufficiency. In an era of preoperative volumetrics, increased use of portal vein embolization, and more parenchymal-sparing operations, liver insufficiency is increasingly uncommon.[3] In fact, only 9 (0.5%) patients in the current study had liver insufficiency/failure. In turn, although the specificity of the >7-mg/dL rule was high (99.3%), it had a low sensitivity (25%) and overall performance as a prediction rule (AUC 0.574).

Rather than relying on 1 or 2 laboratory values, risk models that use multiple laboratory factors to formulate a composite score might be more relevant and applicable to the clinical setting. One example of such a score is the Model for End-Stage Liver Disease (MELD) calculator. The MELD score was developed to predict survival in patients undergoing elective transjugular intrahepatic portosystemic shunt.[24] Subsequently, the MELD calculator has been shown to predict perioperative mortality after hepatic resection, with patients who have a biologic MELD score of >10 having a substantially higher risk of 90-day death.[25,26] Although the MELD score has largely been used to predict mortality among patients with cirrhosis undergoing resection, it is interesting to note that the prediction rule independently derived from data in the current study identified similar factors associated with outcomes (eg, creatinine, INR, and bilirubin). Unlike the MELD score, however, we also included grade of complication as an important factor in predicting mortality. Morbidity, especially severe complications, was noted to be strongly associated with 90-day mortality and, therefore, any prediction rule should include this parameter. Rather than emphasizing simplicity, prediction rules should focus on overall accuracy and clinical applicability. Our proposed prediction rule had both a high sensitivity and specificity, as well as overall accuracy. In addition, on internal n-fold cross-validation it continued to perform well (AUC 0.893).

The current study had several limitations. The study included patients undergoing hepatectomy for a wide range of indications. Although the overwhelming majority of patients did not have underlying liver disease, a small subset did have cirrhosis (9.1%). Given the small number of patients with cirrhosis, we did not perform stratified analyses to examine specifically the accuracy of the predictive rule in noncirrhotic vs cirrhotic patients. We did, however, examine the performance of the score among patients with a normal vs abnormal (ie, steatosis, steatohepatitis, fibrosis, and cirrhosis) liver. In addition, although we internally validated our proposed predictive rule by assessing its performance separately on to data from each institution, as well as n-fold cross-internal validation, the current prediction rule will need to be externally validated.

CONCLUSIONS

We found that previously proposed mortality prediction rules lacked clinical applicability and overall accuracy. Instead, we defined a numerical risk model based on grade of complication, as well as INR, serum bilirubin, and serum creatinine on postoperative day 3 that accurately predicted 90-day mortality among patients undergoing liver resection. Such a risk score that combines a number of clinical and laboratory parameters into a composite score can be useful to identify and stratify patients at high risk for 90-day mortality.

Author Contributions

Study conception and design: Hyder, Pulitano, Aldrighetti, Pawlik

Acquisition of data: Hyder, Pulitano, Firoozmand, Dodson, Wolfgang, Choti, Aldrighetti, Pawlik

Analysis and interpretation of data: Hyder, Pulitano, Firoozmand, Dodson, Wolfgang, Choti, Aldrighetti, Pawlik

Drafting of manuscript: Hyder, Pulitano, Dodson, Aldrighetti, Pawlik

Critical revision: Hyder, Pulitano, Firoozmand, Dodson, Wolfgang, Choti, Aldrighetti, Pawlik

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