Original article

Clinical and morphometric parameters of frailty for prediction of mortality following hepatopancreaticobiliary surgery in the elderly

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Background: **Although frailty is a known determinant of poor postoperative outcomes, it can be difficult to identify in patients before surgery. The authors sought to develop a preoperative frailty risk model to predict mortality among patients aged 65 years or more.**

Methods: **Clinical and morphometric data including total psoas area (TPA), total psoas volume (TPV) and psoas density (Hounsfield unit average calculation, HUAC) were collected for patients undergoing hepatopancreaticobiliary (HPB) surgery between 2012 and 2014. Multivariable Cox proportional hazards regression was used to identify preoperative risk factors associated with 1-year mortality.**

Results: **The median age of the 518 patients included in the study was 72 (i.q.r. 68–76) years; 55·6 per cent of patients were men, and half of the cohort had multiple co-morbidities (Charlson co-morbidity index (CCI) of 4 or more, 55·6 per cent). TPA cut-offs to define sarcopenia were 552·7 mm^2/m^2 in women and 702·9 mm^2/m^2 in men; cut-offs for TPV were 18·2 cm^3/m^2 in women and 26·2 cm^3/m^2 in men, whereas HUAC cut-offs were 31·1 HU in women and 33·3 HU in men. The overall 1-year mortality rate was 14·1 per cent. In multivariable analysis, risk factors associated with 1-year mortality included CCI of 4 or above (hazard ratio (HR) 2·91, 95 per cent c.i. 1·47 to 5·77; *P* = 0·002), malignant disease (HR 3·94, 1·17 to 13·30; *P* = 0·027) and sarcopenia by HUAC (HR 1·85, 1·10 to 3·10; *P* = 0·021). A weighted 25-point composite score was developed to stratify patients at risk of 1-year postoperative mortality. The 1-year mortality rate was noted to be 2·5 per cent among patients scoring 0–10 (low risk), 17·3 per cent among patients scoring 11–20 (intermediate risk) and 29·2 per cent among those scoring between 21 and 25 (high risk) (*P* < 0·001).**

Conclusion: **Clinical and morphometric measures of frailty accurately predict the risk of 1-year mortality following HPB surgery in elderly patients, and can be used to risk-stratify patients appropriately.**

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Introduction

Each year over 30 000 patients aged 65 years or more undergo hepatopancreaticobiliary (HPB) surgery in the USA[1]. Although surgery is the cornerstone of multimodal therapy for many HPB disease processes, postoperative outcomes can be compromised by the high morbidity rate associated with surgery[2,3]. In particular, a subset of elderly patients may be at higher risk of developing postoperative complications, as well as mortality owing to loss of physiological functional and physical reserves[4]. Given the potential heterogeneity in the ageing surgical population with regard to postoperative outcomes, there is great interest in developing more robust methodologies for risk stratification before surgery[4]. Accurate identification of elderly patients at risk of perioperative morbidity and mortality may identify appropriate patients for prehabilitation, as well as better inform patient and provider decisions regarding the potential benefits of surgery[5].

Frailty, defined as decreased physiological reserve, has been proposed as a potential means to assess a patient's overall health status[6,7]. The concept of frailty has, however, largely been applied only to non-surgical patients[8–10]. The small number of studies examining frailty among surgical patients has noted an association with postoperative complications, as well as longer length of stay and additional interventional procedures[4,11–13]. Many of these studies were limited in using subjective measures/indices, as well as cumbersome clinical measurements to assess frailty[4,12,13]. These proposed parameters are time-consuming and may therefore be impractical for use in the preoperative surgical setting[4,12,13]. Furthermore, the lack of standardized practices and external validation has limited the widespread use of frailty to quantify and assess patients undergoing complex surgery[4].

Recently sarcopenia, or muscle wasting, has been identified as an objective, easy to measure surrogate for frailty[14–19]. Sarcopenia may be associated with outcomes in patients undergoing several different surgical procedures[14–19]. Most often, sarcopenia has been defined by measuring total psoas area (TPA) or, less commonly, total psoas volume (TPV) or Hounsfield units average calculation (HUAC)[15–20]. There is debate, however, regarding which parameter is most appropriate for measurement of sarcopenia, with conflicting results among several studies[15–20]. Furthermore, previous studies[4,12,15–20] have not examined frailty using a combination of clinical and morphometric parameters. As such, there is a dearth of information on the assessment of frailty in elderly patients using conventional clinical risk-stratification factors combined with more objective measurements of sarcopenia[21]. Given this, the objective of the present study was to evaluate the ability of TPA, TPV and HUAC to predict 1-year mortality among a cohort of elderly patients undergoing HBP surgery. In addition, the authors sought to develop a preoperative risk-stratification tool that combined clinical and morphometric factors to predict and identify elderly patients at greatest risk for early death following HPB surgery.

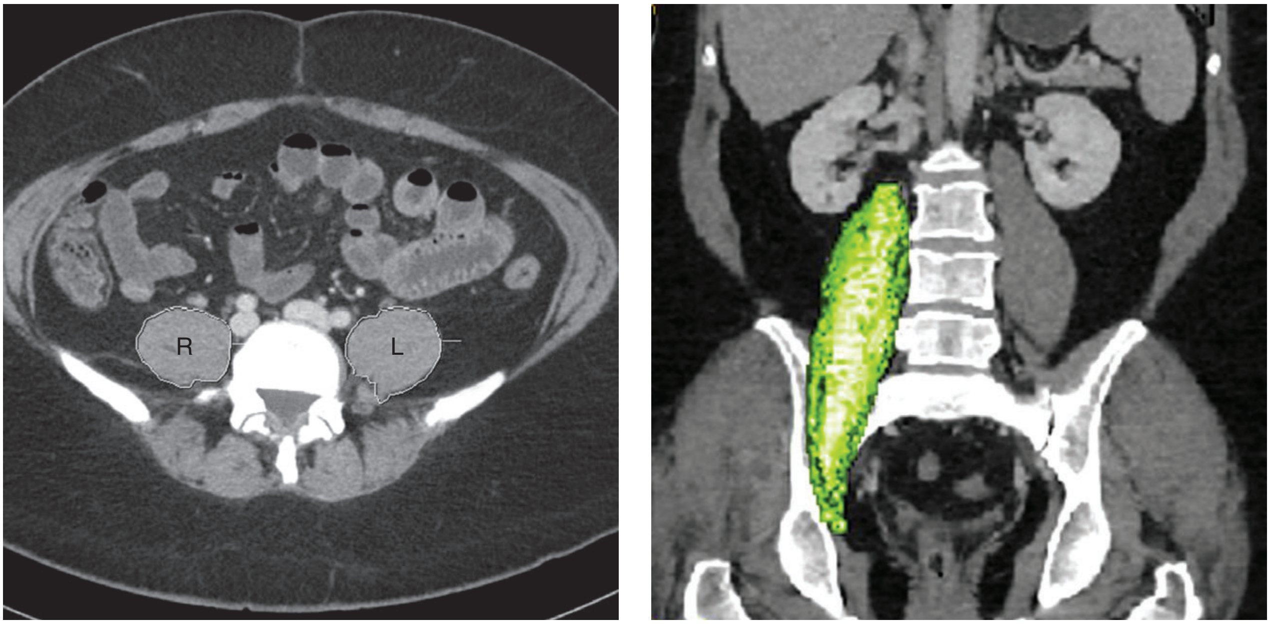
Methods

This cross-sectional study was performed using data from a prospectively maintained database of patients undergoing abdominal surgery at the Johns Hopkins Hospital. As described previously[22,23], information in this database is updated monthly and verified by institutional quality review. Patients undergoing liver or pancreatic surgery were identified using the ninth revision of the International Classification of Diseases – Clinical Manifestation (ICD-9-CM) procedure codes 50·22, 50·3, 52·51, 52·52, 52·53, 52·59, 52·6 and 52·7. To limit the analysis to elderly patients, only patients aged 65 years or more were included in the analyses. Additionally, to enhance the homogeneity of the patient population, only patients undergoing surgery on an elective basis were included in the study cohort. Further, as the primary outcome of the study was 1-year postoperative mortality, only patients undergoing surgery before 1 July 2014 were included in the analysis.

Sociodemographic and pathological data including age, sex, race, body mass index (BMI), American Society of Anesthesiologists (ASA) fitness grade and preoperative co-morbidity were collected for each patient[24]. Preoperative co-morbidity was defined according to the Charlson co-morbidity index (CCI), categorizing patients presenting with a CCI score of 4 or more as having severe co-morbidity[25]. BMI was categorized according to the World Health Organization classification (normal, less than 25 kg/m^2; overweight, 25–30 kg/m^2; obese, more than 30 kg/m^2), and preoperative anaemia was defined by sex-specific cut-offs of haemoglobin of less than 13·5 g/dl for men and less than 12·0 g/dl for women[26]. The study was approved by the Johns Hopkins University Institutional Review Board.

Image analysis

Preoperative (within 90 days) abdominal CT images were reviewed for patients who met inclusion criteria. Using the Ultravisual™ software package (Merge Emageon, Birmingham, Alabama, USA), sarcopenia was initially assessed by measuring TPA at the level of L3 where both iliac crests were clearly visible[16,17]. As described previously[15–17], measurements were performed in a semiautomated fashion with manual outlining of the psoas muscle borders (*Fig. 1a*). Similarly, TPV was assessed using AW Workstation Volume Viewer Software (GE Healthcare, Little Chalfont, UK)[15,19]. Specifically, TPV was calculated using three manual measurements at the level of L3 on the first image where both iliac crests were visible by hand-tracing the borders of the entire psoas muscle (*Fig. 1b*)[15,19]. Three measurements were performed to assess the total psoas length. All measurements were performed in a semiautomated fashion with the density threshold setting between −30 and 110 Hounsfield units (HU) to exclude vascular and fatty infiltration areas from the volumetric calculations[15,19]. TPA was normalized for height (height (cm) × height (cm)), and TPV was normalized for height calculated as (height (cm) × weight (kg))/3600)[15,19]. HUAC (a measure of muscle density and fatty infiltration) for the psoas muscle was calculated using the methodology described by Joglekar and colleagues[20]. Specifically, right and left psoas muscles were



a Measurement using TPA and HUAC **b** Measurement using TPV

Fig. 1 Sarcopenia measurement at level L3 using **a** total psoas area (TPA) and Hounsfield unit average calculation (HUAC) density measurement (L: TPA 15·6 cm^2, mean(s.d.) HUAC 51·15(29·56) HU; R: TPA 14·58 cm^2, mean(s.d.) HUAC 53·03(23·55) HU), and **b** total psoas volume (TPV)

evaluated, and the average calculation was used for the final HUAC calculation: right Hounsfield unit calculation = (right Hounsfield unit × right psoas area)/(total psoas area); left Hounsfield unit calculation = (left Hounsfield unit × left psoas area)/(total psoas area); and HUAC = (right Hounsfield unit calculation + left Hounsfield unit calculation)/2 (*Fig. 1a*)[20].

Statistical analysis

Continuous variables are reported as medians (i.q.r.), and categorical variables are shown as whole numbers with percentages; differences were assessed using the Kruskal–Wallis test and χ^2 test respectively. As reported and validated previously[14,15,27], to obtain sex-specific categorical cut-offs for sarcopenia, optimal stratification was assessed through a series of sensitivity analyses, and sarcopenia was defined in categorical analyses as the lowest quartile. TPA cut-offs used to define sarcopenia were 702·9 and 552·7 mm^2/m^2 among men and women respectively. Similarly, sarcopenia was defined as TPV of less than 26·2 cm^3/m^2 in men and as TPV lower than 18·2 cm^3/m^2 in women, whereas HUAC below 33·3 HU in men and HUAC of less than 31·1 HU in women was used to define sarcopenia. Overall survival was analysed using the Kaplan–Meier method, and differences in survival assessed with the log rank test.

To identify preoperative factors predictive of 1-year all-cause mortality, a multivariable Cox proportional hazards model was built. The inclusion of clinicopathological risk factors into the multivariable model was assessed using results from a stepwise backward selection methodology based on the Akaike information criterion (AIC), as well as using results from the Lasso regression (*Table S1*, supporting information). As similar variables were selected according to each methodology, the final multivariable model was built to include all clinically relevant preoperative variables in order to generate the most parsimonious as well as the most clinically applicable prediction model[28]. Model calibration was evaluated by Harrell's concordance index (C-index). Bootstrap validation was performed by drawing random samples from the original data set with replacement; specifically, 150 iterations were performed to assess for model overfitting[29,30]. Point estimates were reported as hazard ratios (HRs) with 95 per cent c.i. Regression coefficients obtained from the multivariable model were used subsequently to generate a weighted score to predict the probability of 1-year mortality. All tests were two-sided and $P < 0{\cdot}050$ was used to define statistical significance. Statistical analyses were performed using STATA® version 14·0 (StataCorp LP, College Station, Texas, USA) and R version 3·0·3 (http://www.r-project.org).

Table 1 Baseline characteristics of patients undergoing hepatopancreaticobiliary surgery

	Total ($n = 518$)	Hepatobiliary surgery ($n = 94$)	Pancreatic surgery ($n = 424$)	P†
Age (years)*	72·0 (68·0–76·0)	72·5 (68·0–77·0)	71·0 (68·0–76·0)	0·517‡
Sex ratio (F : M)	230 : 288	31 : 63	199 : 225	0·014
Ethnicity				0·235
White	435 (84·0)	75 (80)	360 (84·9)	
Black	39 (7·5)	11 (12)	28 (6·6)	
Other	44 (8·5)	8 (9)	36 (8·5)	
Charlson co-morbidity index				< 0·001
0–3	230 (44·4)	23 (24)	207 (48·8)	
≥ 4	288 (55·6)	71 (76)	217 (51·2)	
Body mass index (kg/m^2)*	25·8 (23·4–28·8)	26·0 (23·8–28·4)	25·7 (23·2–28·8)	0·560‡
ASA fitness grade	($n = 517$)	($n = 94$)	($n = 423$)	0·381
I–II	105 (20·3)	16 (17)	89 (21·0)	
III–IV	412 (79·7)	78 (83)	334 (79·0)	
Co-existing condition	($n = 445$)	($n = 84$)	($n = 361$)	
Congestive heart failure	7 (1·6)	0 (0)	7 (1·9)	0·198
Pulmonary disease	51 (11·5)	3 (4)	48 (13·3)	0·012
Peripheral vascular disease	36 (8·1)	8 (10)	28 (7·8)	0·593
Hypertension	268 (60·2)	53 (63)	215 (59·6)	0·551
Diabetes mellitus	114 (25·6)	23 (27)	91 (25·2)	0·681
Renal disease	18 (4·0)	4 (5)	14 (3·9)	0·711
Primary diagnosis				< 0·001
Benign	130 (25·1)	10 (11)	120 (28·3)	
Malignant	388 (74·9)	84 (89)	304 (71·7)	
Preoperative haemoglobin (g/dl)*	12·9 (11·8–14·2)	12·8 (11·8–14·3)	13·0 (11·8–14·2)	0·654‡
1-year mortality	73 (14·1)	19 (20)	54 (12·7)	0·059

Values in parentheses are percentages unless indicated otherwise; *values are median (i.q.r.). ASA, American Society of Anesthesiologists. †χ^2 test, except ‡Kruskal–Wallis test.

Results

A total of 518 patients met the inclusion criteria; their median age was 72 (i.q.r. 68–76) years, with a majority of patients being men (288, 55·6 per cent) and Caucasian (435, 84·0 per cent). A pancreatic resection was performed in 424 patients (81·9 per cent) and 94 patients had a hepatobiliary resection (18·1 per cent). Baseline characteristics of the patients are shown in *Table 1*.

Total psoas volume, total psoas area, Hounsfield unit average calculation and sarcopenia

Preoperative imaging was used to calculate morphometric parameters for sarcopenia among patients undergoing HPB surgery. In the study cohort, median (i.q.r.) TPA and TPV values corrected for height were 723·0 (618·5–891·8) mm^2/m^2 and 25·8 (20·9–31·7) cm^3/m^2 respectively. When stratified by sex, median TPA and TPV were both higher in men than in women (TPA: 852·6 (702·9–971·0) *versus* 635·3 (552·7–722·1) mm^2/m^2 respectively; TPV: 30·5 (26·2–35·5) *versus* 21·0 (18·2–24·1) cm^3/m^2) ($P < 0·001$). Similarly, median HUAC was 40·9 (32·5–47·3) HU, and was also higher in men: 41·1 (33·3–47·5) HU *versus* 40·5 (31·1–46·3) HU in women ($P = 0·291$).

Owing to this potential confounding by sex, sex-specific quartiles for each parameter were developed that categorized patients in the lowest sex-specific quartile as sarcopenic. Among patients with complete data, 25·3 per cent (112 of 445) were sarcopenic as defined by TPA, 25·0 per cent (117 of 468) had sarcopenia as defined by TPV, and 25·3 per cent (112 of 443) presented with sarcopenia as defined by the HUAC. Using all three parameters, the proportion of patients categorized before surgery as sarcopenic did not vary between patients undergoing hepatobiliary and those having pancreatic surgery.

Preoperative risk factors associated with 1-year all-cause mortality

Among all patients included in the study cohort, the all-cause 1-year mortality rate was 14·1 per cent. Of note, patients undergoing pancreatic or hepatobiliary procedures demonstrated a similar risk of death ($P = 0·059$). Patients categorized as sarcopenic using the measurements for TPV and HUAC demonstrated a 78 and 92 per cent greater risk of death respectively (TPV: HR 1·78, 95 per cent c.i. 1·05 to 3·00, $P = 0·031$; HUAC: HR 1·92, 1·15 to 3·22, $P = 0·013$). In contrast, sarcopenia defined by TPA tended to be

Table 2 Univariable analysis of factors associated with 1-year mortality after hepatopancreaticobiliary surgery in the elderly

		Univariable analysis	
	1-year mortality*	Hazard ratio†	*P*
Factors selected			
Sex			
F	26 of 230 (11·3)	1·00 (reference)	
M	47 of 288 (16·3)	1·41 (0·87, 2·28)	0·159
Charlson co-morbidity index			
0–3	12 of 230 (5·2)	1·00 (reference)	
≥ 4	61 of 288 (21·2)	4·58 (2·47, 8·52)	< 0·001
Diagnosis			
Benign	4 of 130 (3·1)	1·00 (reference)	
Malignant	69 of 388 (17·8)	6·40 (2·33, 17·53)	< 0·001
Sarcopenia by TPA			
No	40 of 333 (12·0)	1·00 (reference)	
Yes	21 of 112 (18·8)	1·62 (0·96, 2·75)	0·072
Sarcopenia by TPV			
No	43 of 351 (12·3)	1·00 (reference)	
Yes	21 of 117 (17·9)	1·78 (1·05, 3·00)	0·031
Sarcopenia by HUAC			
No	38 of 331 (11·5)	1·00 (reference)	
Yes	23 of 112 (20·5)	1·92 (1·15, 3·22)	0·013
Factors not selected			
Age (years)			
65–79	60 of 455 (13·2)	1·00 (reference)	
≥ 80	13 of 63 (21)	1·63 (0·89, 2·97)	0·111
ASA fitness grade			
I–II	10 of 105 (9·5)	1·00 (reference)	
III–IV	63 of 412 (15·3)	1·71 (0·88, 3·34)	0·113
Body mass index (kg/m^2)			
≤ 25	32 of 225 (14·2)	1·00 (reference)	
25–30	22 of 185 (11·9)	0·80 (0·46, 1·38)	0·421
> 30	13 of 86 (15)	0·93 (0·49, 1·77)	0·821
First haemoglobin at admission (g/dl)			
> 10	67 of 474 (14·1)	1·00 (reference)	
≤ 10	6 of 44 (14)	1·16 (0·51, 2·69)	0·720
Procedure type			
Hepatectomy	19 of 94 (20)	1·00 (reference)	
Pancreatectomy	54 of 424 (12·7)	0·61 (0·36, 1·03)	0·067

Values in parentheses are *percentages and †95 per cent c.i. TPA, total psoas area; TPV, total psoas volume; HUAC, Hounsfield unit average calculation; ASA, American Society of Anesthesiologists.

Table 3 Multivariable Cox proportional regression analysis of factors selected; results from multivariable analysis were used to generate a weighted risk-stratification score

	TPA		TPV		HUAC		
	Hazard ratio	*P*	Hazard ratio	*P*	Hazard ratio	*P*	Score
Sex							
F	1·00 (reference)		1·00 (reference)		1·00 (reference)		0
M	1·38 (0·81, 2·35)	0·231	1·42 (0·84, 2·38)	0·186	1·42 (0·84, 2·41)	0·193	3
Charlson co-morbidity index							
0–3	1·00 (reference)		1·00 (reference)		1·00 (reference)		0
≥4	2·98 (1·50, 5·91)	0·002	3·07 (1·51, 6·26)	0·002	2·91 (1·47, 5·77)	0·002	8
Diagnosis							
Benign	1·00 (reference)		1·00 (reference)		1·00 (reference)		0
Malignant	3·85 (1·13, 13·06)	0·030	3·52 (1·04, 11·96)	0·044	3·94 (1·17, 13·30)	0·027	10
Sarcopenia							
No	1·00 (reference)		1·00 (reference)		1·00 (reference)		0
Yes	1·60 (0·94, 2·71)	0·084	1·64 (0·97, 2·77)	0·064	1·85 (1·10, 3·10)	0·021	4
C-statistic	0·695 (0·640, 0·751)		0·684 (0·626, 0·742)		0·706 (0·647, 0·765)		

Values in parentheses are 95 per cent c.i. TPA, total psoas area; TPV, total psoas volume; HUAC, Hounsfield unit average calculation.

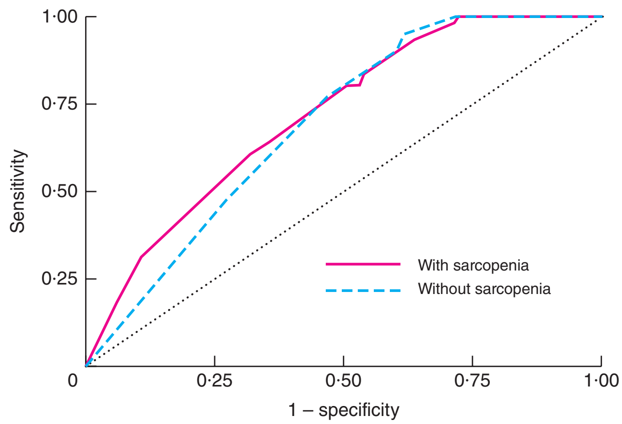
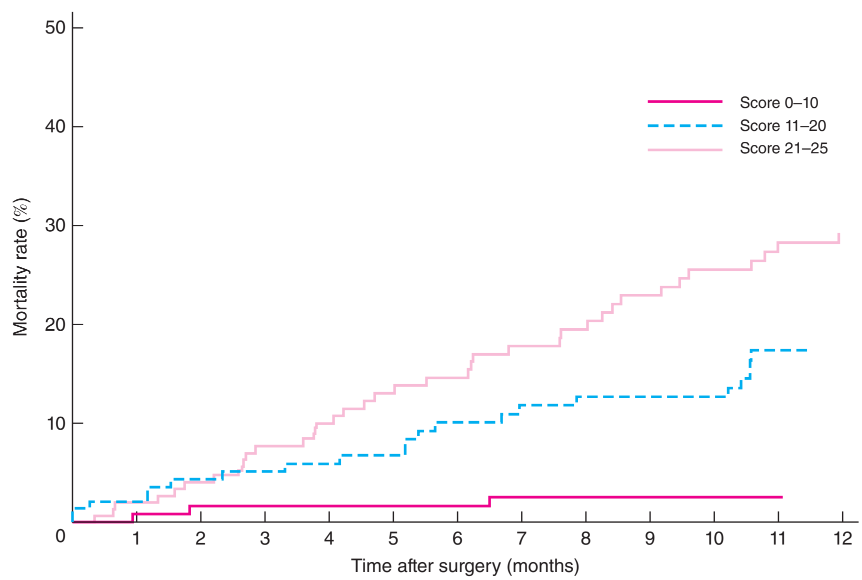


Fig. 2 Area under the receiver operating characteristic (ROC) curve demonstrating improved discrimination with inclusion of sarcopenia measured by Hounsfield unit average calculation (HUAC), from 0·69 without to 0·72 with sarcopenia

associated with 1-year survival (HR 1·62, 0·96 to 2·75, $P = 0{\cdot}072$) (*Table 2*).

To identify further factors predictive of 1-year mortality following HPB surgery, a multivariable Cox proportional hazards regression model was built adjusting for patient and disease characteristics. A stepwise backward selection model based on the AIC was used to select the most parsimonious model that included preoperative co-morbidity as defined by the CCI, indication for surgery (benign *versus* malignant) and sex (*Table 3*). To evaluate further the predictive effect of sarcopenia, TPV, TPA and HUAC were each subsequently added to the model. Selection of the final model was based on comparisons of discrimination via Harrell's C-statistics (*Table 3*). In multivariable analysis after adjusting for patient and disease characteristics, patients with severe preoperative co-morbidity, classified as CCI of 4 or above, demonstrated an almost threefold greater risk of mortality within 1 year after surgery (HR 2·91, 95 per cent c.i. 1·45 to 5·77; $P = 0{\cdot}002$), whereas patients having surgery for a malignant disease process demonstrated an almost fourfold increased risk of death after surgery (HR 3·94, 1·17 to 13·30; $P = 0{\cdot}027$). Of note, patients presenting with sarcopenia as defined by HUAC demonstrated an 85 per cent increased risk of mortality following surgery (HR 1·85, 1·10 to 3·10; $P = 0{\cdot}021$). The area under the receiver operating characteristic (AUROC) curve was used to quantify relative increments in the discriminatory ability of the final model with and without sarcopenia defined using HUAC (*Fig. 2*). The inclusion of sarcopenia improved the discriminatory ability of the prediction model ($P < 0{\cdot}001$). Bootstrap validation of the model with 150 iterations demonstrated minimal evidence of model overfit.



No. at risk

Score 0–10	138	130	122	120	117	110	108	105	101	99	96	94	93
Score 11–20	146	138	125	119	116	112	107	101	98	98	96	88	81
Score 21–25	159	148	134	124	119	112	106	98	94	89	84	79	76

Fig. 3 One-year survival among patients undergoing hepatopancreaticobiliary surgery stratified according to the risk-stratification weighted score: male sex, 3 points; Charlson co-morbidity index of 4 or more, 8 points; malignant disease, 10 points; and sarcopenia defined by Hounsfield unit average calculation (HUAC), 4 points. $P < 0{\cdot}001$ (log rank test)

Development of the risk-stratification score

Point estimates obtained from the final multivariable model (including sarcopenia defined by HUAC) were used to generate a 25-point weighted risk-stratification score for preoperative prediction of the risk of death in elderly patients undergoing HPB surgery. Specifically, each parameter was assigned a weighted score (male sex: 3 points; CCI of 4 or more, 8 points; malignant disease, 10 points; sarcopenia defined by HUAC, 4 points), and risk of death was categorized relative to the total score. The 1-year mortality rate was 2·5 per cent among patients scoring 0–10 (low risk), 17·3 per cent among patients scoring 11–20 (intermediate risk), and 29·2 per cent in those scoring between 21 and 25 (high risk) ($P < 0·001$) (*Fig. 3*).

Discussion

Although death following HPB surgery has decreased dramatically over the past two decades, recent reports[2,3,31] suggest that the mortality rate among elderly patients undergoing HPB procedures is still as much as fivefold greater than that for the overall population. Given the heterogeneity in physiological reserve and therefore post-operative outcomes within the ageing surgical population, appropriate risk stratification among the elderly is critical for improved prediction and potential avoidance of the high observed mortality[11,12,21]. Using a cohort of 518 patients aged 65 years or over, the present study identified preoperative morphometric and clinical parameters predictive of 1-year all-cause mortality following complex HPB surgery. Of note, among this elderly cohort, despite most patients being classified before surgery as high risk according to their ASA grade, there was significant heterogeneity in 1-year mortality risk. This study is important because it enabled development of an accurate risk-stratification tool with appropriate discrimination and calibration for identification of patients at greatest risk of 1-year mortality using clinical and morphometric data. In particular, with the inclusion of sarcopenia, a surrogate for patient frailty, the authors were able to identify those patients at greatest risk of death in the short term. Identification of such patients may assist in directing these individuals to interventions such as prehabilitation before operation[5].

Although the use of frailty measures to risk-stratify patients has been widely recognized for medical conditions, the use of similar metrics for surgical patients has remained limited at best. A small number of studies[4,11,12,21] have assessed the role of preoperative frailty among elderly patients undergoing surgery, but these studies have been limited in their approach, as most included only limited clinical measurements, as well as subjective definitions of frailty[4,10,13]. In the present study, sarcopenia, or muscle wasting, was used as a metric to measure preoperative patient frailty/physiological reserve. Although not widely used, previous research has demonstrated sarcopenia to be an accurate objective measure of frailty, with sarcopenic patients being at increased risk of postoperative complications and death[15–18,20]. The present study is unique in that it risk-stratifies patients undergoing HPB surgery using a clinical risk score that combines clinical and morphometric factors to assess patient frailty in an elderly population. In the past, the use of sarcopenia has been limited by disagreement in definitions regarding how to measure muscle mass/wasting[15,20]. For example, although previous research has suggested the use of TPA as a means of quantifying and measuring patient frailty, more recent work has suggested that TPV and psoas density (HUAC) may be more accurate methods to measure sarcopenia and therefore frailty[16,17,20,32]. In the present study, the use of psoas density was found to be a more accurate measure of patient frailty compared with either TPV or TPA, and also independently predicted early death at 1 year. In a report by Joglekar and co-workers[20] of patients undergoing pancreatic surgery, HUAC rather than other measures of sarcopenia was independently predictive of postoperative complications, and longer length of both hospital and intensive care unit stay. A measure of radiation attenuation, HUAC can be readily calculated from preoperative cross-sectional imaging that is performed routinely before HPB surgery[20]. Additionally, although TPA and TPV can sometimes be difficult to measure in obese patients, HUAC is able to account for fat infiltration, thereby facilitating assessment in these individuals[33–35]. Taken together, findings from the present study, as well as other published evidence, strongly suggest that preoperative radiological assessment of sarcopenia may help identify patients who are frail and therefore at high risk of mortality. In turn, such data may be used to facilitate healthcare decision-making, and allow surgeons, patients and care-givers to manage perioperative expectations better. For example, accurate preoperative identification of frail patients may allow identification of those individuals most at risk of postoperative complications and permit early intervention to improve short-term outcomes following HPB surgery[5].

The appropriate and accurate preoperative identification of frail patients is particularly important among elderly patients undergoing surgery[10–12,21]. Owing to substantial heterogeneity in disease presentation and variable physiological effects of ageing, standard indications and guidelines for treatment are often not generalizable to the elderly population[4]. Specifically, multiple chronic co-morbidities, polypharmacy, dysregulation of physiological systems, altered hormone function and decreased immune responses can all contribute to the variable presentation, and therefore outcomes, among older patients undergoing surgery[36–40]. Further, given that the proportion of elderly patients is expected to increase fourfold within the next 10 years, preoperative identification of and intervention for those elderly patients most at risk is critical[41]. Older, frail patients are at greater risk of developing postoperative complications that often result in significant functional disability requiring labour-intensive and costly support in the form of additional procedures, greater intensity of care and the need for nursing assistance at discharge[41].

In the present study, a 25-point composite score using four easy and readily available parameters to identify appropriately patients at greatest risk of 1-year mortality after surgery is proposed. Of note, the all-cause 1-year mortality rate ranged widely from 2·5 to 29·2 per cent among low- and high-risk patients respectively. Although previous studies[4,11,12,21] have proposed the assessment of frailty or physiological reserve via subjective clinical assessments such as exhaustion and decreased activity, this study combined morphometric and clinical parameters to develop an objective risk-stratification tool to identify frail, elderly patients. Specifically, sarcopenic patients (defined by HUAC) demonstrated an 85 per cent greater risk of mortality, and the inclusion of sarcopenia measured by HUAC increased the discriminative power of the model by about 3 per cent. This incremental increase is consistent with previous studies that have assessed the effect of frailty-specific parameters in predicting 1-year mortality[42]. For example, a recent systematic review[42] of patients undergoing cardiac surgery noted that the addition of frailty-specific parameters resulted in a mean incremental increase of 4 per cent in the discriminative power of conventional risk scores. These authors concluded that the use of composite frailty measures represents a more accurate method of identifying frail patients[42].

The present study has several limitations. The analyses were limited to HPB procedures. As such, future work is necessary to assess the performance of the proposed score among patients undergoing a wider variety of surgical procedures. In addition, it is possible that, owing to the omission of disease-specific parameters as well as additional postoperative measures including functional status and quality of life, certain important factors predictive of mortality were unaccounted for. Finally, given that the study was performed at a single centre, the risk-stratification score requires further external validation in an independent data set. Internal validation with bootstrapping techniques did, however, suggest a good model fit with minimal overfitting.

This study demonstrates that sarcopenia, as determined by HUAC, is an accurate measure of frailty among elderly patients undergoing complex HPB surgery, and is an independent predictor of 1-year mortality. In addition, a 25-point risk-stratification score that incorporates clinical and morphometric parameters accurately identified elderly patients at greatest risk of 1-year mortality following surgery. As such, the proposed score represents a convenient method to help clinicians identify elderly patients who are most likely to be frail and therefore at the highest risk of suffering an early death within 1 year of HPB surgery.

Disclosure

The authors declare no conflict of interest.

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Supporting information

Additional supporting information may be found in the online version of this article:

Table S1 Comparison of variables included in the Cox regression model (stepwise regression using the Akaike information criterion *versus* Lasso regression) with their corresponding regression coefficients (Word document)