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ARTICLE

Effect of Sarcobesity Index and Body Adipose Tissue Variables on Cardiopulmonary Exercise Testing Performance in Colorectal Surgery Setting: A Retrospective Cohort Study

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Abstract

Aims/Background The prognostic significance of body composition variables has become a popular area of research over the recent years. This study aimed to determine whether adipose tissue variables and sarcobesity index measured by computed tomography (CT) could predict cardiopulmonary exercise testing (CPET) performance and long-term mortality in patients undergoing major colorectal surgery.

Methods The Strengthening the Reporting of Cohort Studies in Surgery (STROCSS) statement standards were followed to conduct a retrospective cohort study of consecutive patients who had CPET prior to major colorectal surgery between January 2011 and January 2017. Receiver Operating Characteristic curve analysis was conducted to assess the discriminative performances of adipose tissue variables. The association between CT-derived adipose tissue variables (sarcobesity index, visceral adipose tissue, subcutaneous adipose tissue, and total adipose tissue) and CPET performance and mortality were assessed using regression analyses.

Results 457 patients were included. Total adipose tissue evaluated via 2-dimensional (2D) and 3-dimensional (3D) approaches predicted oxygen uptake ($\dot{V}O_2$) Rest, $\dot{V}O_2$ anaerobic threshold (AT), ventilatory equivalents for carbon dioxide ($\dot{V}E/\dot{V}CO_2$) AT, ventilatory equivalents for oxygen ($\dot{V}E/\dot{V}O_2$) AT, $\dot{V}O_2$ peak, exercise time, maximum work, peak metabolic equivalents (METS), peak respiratory rate (RER), and peak oxygen pulse. Sarcobesity index (2D and 3D) predicted $\dot{V}O_2$ Rest, $\dot{V}O_2$ AT, $\dot{V}E/\dot{V}CO_2$ AT, $\dot{V}O_2$ peak, maximum work, peak METS, maximum heart rate, and peak RER. Neither total adipose tissue nor sarcobesity index (2D and 3D) predicted 1-year, 3-year, or 5-year mortality. There was no difference in the discriminative performance of adipose tissue variables in predicting mortality.

Conclusion The CPET performance may be predicted by radiologically measured adipose tissue variables and sarcobesity index. However, the prognostic value of the variables may not be significant in this setting.

Key words: adipose tissue; sarcobesity; colorectal surgery; cardiopulmonary exercise test

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Introduction

The prognostic significance of body composition variables including skeletal muscle mass and adipose tissue (subcutaneous and visceral) has become a popular area of research over recent years (Kifjak et al, 2024; Lee et al, 2024; Mueller et al, 2024; Rai et al, 2024; Song et al, 2024; Wang et al, 2024). Owing to advances in medical technology, the body composition variables can be quantified by computed tomography (CT) (Kifjak et al, 2024; Lee et al, 2024; Mueller et al, 2024; Rai et al, 2024; Song et al, 2024; Wang et al, 2024). The fact that almost all patients undergoing major abdominal or thoracic surgery have a CT scan as part of their preoperative diagnostic pathway has enabled researchers to evaluate the prognostic significance of CT-derived body composition variables in different settings. The body composition variables have been shown to predict short-term and long-term outcomes after emergency abdominal surgery (Hajibandeh et al, 2024b; Wang et al, 2024), colorectal surgery (Rai et al, 2024; Song et al, 2024), liver surgery (Lee et al, 2024), pancreatic surgery (Mueller et al, 2024), and transplant surgery (Kifjak et al, 2024).

Among the body composition variables, while it is well-established that skeletal muscle mass is a strong predictor of postoperative morbidity (Hajibandeh et al, 2024a; Rai et al, 2024), the predictive significance of adipose tissue variables is controversial. Adipose tissue variables include visceral adipose tissue, subcutaneous adipose tissue, total adipose tissue, and sarcobesity index, the term used to describe a person who has both visceral obesity and low muscle mass (Parr et al, 2013). Sarcobesity index has been shown to be a better predictor of postoperative morbidity compared to adipose tissue alone (Conti et al, 2022; Feng et al, 2023; Pedrazzani et al, 2020).

The significance of body composition variables in predicting postoperative morbidity may raise the question of whether they may also have predictive significance in terms of other outcomes. Cardiopulmonary exercise testing (CPET) is a well-recognised tool widely used to provide an objective assessment of preoperative physical fitness (Levett et al, 2018; West et al, 2016). Identifying the predictors of CPET performance is a novel area of interest in research and the relationship between CT-derived body composition variables and pre-operative CPET performance has been demonstrated in some studies (Berkel et al, 2022; West et al, 2019). While it has been shown that psoas muscle mass variables are predictors of CPET performance (Hajibandeh et al, 2024a), whether or not CPET performance can be predicted by CT-derived adipose tissue measurements remains poorly understood. Moreover, it is not known whether combining adipose tissue variables and psoas muscle mass variables (sarcobesity index) would increase the predicted performance of body composition variables. Furthermore, whether a 3-dimensional (3D) approach in measuring adipose tissue variables is advantageous over a 2-dimensional (2D) approach remains controversial. Therefore, in this study, we aimed to determine whether in patients undergoing colorectal resection adipose tissue variables and sarcobesity index measured by CT can predict CPET performance.

Methods

Study Design and Reporting Standards

The design, protocol, and conduct of this study, which was a retrospective cohort study, followed the standards recommended by the Strengthening the Reporting of Cohort Studies in Surgery guideline. The study was completed in a teaching hospital in South Wales and followed the research ethics (Helsinki ethical principles). The patient's informed consent was waived by the Cardiff and Vale University Health Board (15/AIC/6352) and the University of South Wales Ethics Committee (LSE1636GREO). Consecutive patients who had CPET prior to major colorectal surgery between January 2011 and January 2017 were identified from a prospectively maintained hospital database. The colorectal procedures were (open or laparoscopic) abdominoperineal resection, anterior resection, panproctocolectomy, subtotal or total colectomy, sigmoid colectomy, Hartmann's procedure, transverse colectomy, and right or left hemicolectomy. We excluded patients who did not have available preoperative CT abdomen and pelvis scans.

Adipose Tissue Variables

Visceral adipose tissue, subcutaneous adipose tissue, total adipose tissue, and sarcobesity index measured via CT scan using 2D and 3D approaches were the studied adipose tissue variables. The selected variables were consistent with previous literature (Feng et al, 2023; Pedrazzani et al, 2020). The CT scan images were analysed in a semi-automated fashion by SYNAPSE software (V5.7.240.16413, FUJIFILM Medical Corp. Ltd., Tokyo, Japan) using density thresholds for abdominal fat (–190 to –30 HU). The technique and thresholds used for measuring abdominal fat were consistent with previous literature (Hsu et al, 2023). The sarcobesity index was determined by calculating the ratio of visceral adipose tissue and total psoas muscle area (cross-sectional area of both psoas muscles at L4 level) and volume (volume of both psoas muscles between the L1 and the roof of the acetabulum). The methods for calculating the sarcobesity index and measuring psoas muscle metrics were also consistent with previous literature (Hajibandeh et al, 2024a; Pedrazzani et al, 2020).

Primary Outcome

The primary outcome was CPET performance. Electromagnetically-braked cycle ergometer (Lode, Groningen, Netherlands) and a Medgraphics Ultima metabolic cart (MedGraphics™, Gloucester, UK) were used for conducting CPET. The average middle five of seven breaths were used for data collection. The test included three minutes of resting, three minutes of cycling in an unloaded freewheeling state (60 revolutions per minute), progressively ramped period of exercise (5–15 Watts. min^{-1} based on age, sex, height, and body mass), and three minutes recovery (Wasserman, 2012). The Medgraphics Breeze™ software (Breeze suite 6.1, Medical Graphics Corporation; St Paul, MN, USA) was used to automatically calculate peak oxygen uptake ($\dot{V}O_2$ peak), oxygen uptake efficiency slope (OUES) (Hollenberg and Tager, 2000) and peak oxygen pulse ($\dot{V}O_2$ peak/heart rate). Two

independent consultant anaesthetists manually interpreted the anaerobic threshold (AT) using the V-slope method (Beaver et al, 1986), and by comparison of ventilatory equivalents for oxygen ($\dot{V}E/\dot{V}O_2$) and carbon dioxide ($\dot{V}E/\dot{V}CO_2$) plots. Moreover, we determined the ventilatory equivalents for carbon dioxide at AT ($\dot{V}E/\dot{V}CO_2$-AT) and for oxygen at AT ($\dot{V}E/\dot{V}O_2$-AT). The $\dot{V}O_2$ AT and $\dot{V}O_2$ peak measures were divided by body mass to calculate allometric metrics (Welsman et al, 1996). If a patient was unable to perform a CPET because of their clinical status, the performance was as unable to perform CPET and if insufficient data was available for clear identification of the AT, it was recorded as unable to reach AT.

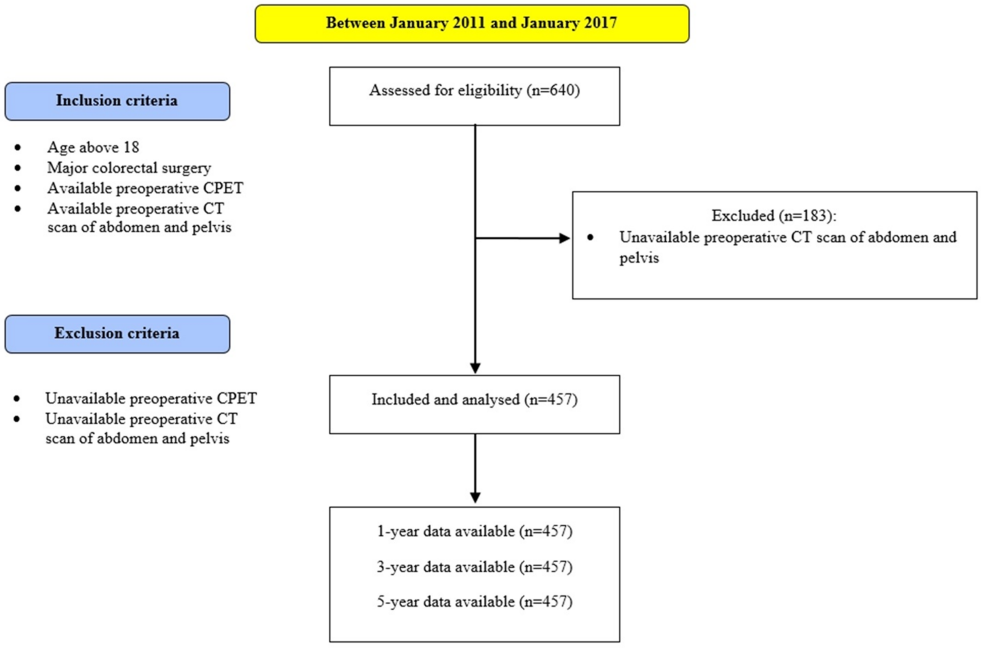

Fig. 1. Flow diagram for the study. CT, computed tomography; CPET, cardiopulmonary exercise testing.

Secondary Outcome

The secondary outcome was mortality (at 1-year, 3-year, and 5-year due to any cause after index operation). The matched data between hospital records and Office for National Statistics records were used to determine mortality.

Data Collection

The following data related to each patient was extracted into an electronic data extraction sheet: age, sex, body mass index), weight, height, American Society of Anesthesiologists physical status, comorbidities (diabetes, atrial fibrillation, ischemic or valvular heart disease, hypertension, asthma, chronic obstructive pulmonary disease, liver cirrhosis, renal insufficiency, cerebrovascular accident, peripheral arterial disease, and anaemia), smoking history, and outcome data. As mentioned previously, the above data items were obtained from electronic hospital records.

Table 1. Characteristics of patients at baseline.

Participants number	457
Male, % (n/total)	58% (267/457)
Female, % (n/total)	42% (190/457)
Weight, median (IQR)	79 (68–90)
Height, median (IQR)	169 (162–175)
Age, median (IQR)	72 (64–78)
Body mass index, median (IQR)	27 (25–31)
American Society of Anesthesiologists, % (n/total)	
I	3% (15/457)
II	60% (273/457)
III	36% (164/457)
IV	1% (3/457)
Comorbidities, % (n/total)	
Ischemic heart disease	11% (48/457)
Diabetes	17% (79/457)
Cerebrovascular accident	9% (40/457)
Hypertension	46% (211/457)
Chronic obstructive pulmonary disease	11% (48/457)
Atrial fibrillation	11% (51/457)
Peripheral arterial disease	4% (18/457)
Asthma	9% (43/457)
Valvular heart disease	5% (25/457)
Renal insufficiency	4% (20/457)
Anaemia	38% (174/457)
Liver cirrhosis	1% (3/457)
Smoking, % (n/total)	
Ex-smoker	51% (235/457)
Never smoked	37% (169/457)
Current smoker	12% (53/457)
Malignancy as indication for operation, % (n/total)	88% (402/457)
Surgical approach, % (n/total)	
Laparoscopic	44% (201/457)
Laparoscopic–assisted	12% (55/457)
Laparoscopic converted to open	16% (75/457)
Open	28% (126/457)
Procedure, % (n/total)	
Abdominoperineal resection	7% (30/457)
Anterior resection	33% (150/457)
Panproctocolectomy	1% (5/457)
Transverse colectomy	1% (4/457)
Extended hemicolectomy	6% (26/457)
Hemicolectomy	33% (150/457)
Subtotal colectomy	2% (7/457)
Sigmoid colectomy	6% (27/457)
Other	13% (58/457)

IQR, interquartile range; Ex-smoker, a person who has stopped smoking tobacco or nicotine products.

Statistical Analysis

The baseline characteristics data were summerised with simple descriptive statistics (interquartile range for continuous variables and percentages for dichotomous variables). Receiver Operating Characteristic (ROC) curve analysis was used to compare the discrimination of adipose tissue variables by calculating the Area Under the Curve (AUC) (DeLong et al, 1988). We used the statistical method reported by DeLong et al (1988) which involved calculating standard error and an exact Binomial Confidence Interval for the AUC and determining associated sensitivity and specificity for all possible threshold values. The association between the adipose tissue variables (independent variables) and outcomes (dependent variables) was assessed via regression analyses. The binary logistic regression model was used for dichotomous dependent variables such as mortality, ability to perform CPET, and inability to reach AT. Linear regression model was used for continuous dependent variables such as all CPET variables. The analyses, which were two-tailed with a 95% confidence level, were done using MedCalc® Statistical Software version 22.002 (MedCalc Software Ltd, Ostend, Belgium).

Results

Among 640 patients who had CPET before colorectal resection between January 2011 and January 2017, 183 patients were excluded because their preoperative CT scans were not available. Consequently, 457 patients with five-year follow-up data were studied. The study flow diagram is provided in Fig. 1 and characteristics of the included patients at baseline are shown in Table 1.

Adipose Tissue Measurements

The median visceral adipose tissue area was 197 cm^2 (interquartile range (IQR): 127–274) and the median visceral adipose tissue was 3632 cm^3 (IQR: 2424–5069). The median subcutaneous adipose tissue area was 221 cm^2 (IQR: 167–304) and the median subcutaneous adipose tissue volume was 4443 cm^3 (IQR: 3178–6279). The median total adipose tissue area was 452 cm^2 (IQR: 326–573) and the median total adipose tissue volume was 8289 cm^3 (IQR: 6103–10,856). The median sarcobesity index was 9.3 (IQR: 6.1–12.9) via 2D approach and 13.0 (IQR: 8.8–17.7) via 3D approach.

Primary Outcome (CPET Performance)

The results of regression analyses for the association between adipose tissue variables and CPET performance are shown in Tables 2,3.

Table 2. Association between sarcobesity index, adipose tissue measurements and CPET performance based on linear regression analysis.

CPET performance as a dependent variable	Independent variables															
	Visceral adipose tissue				Subcutaneous adipose tissue				Total adipose tissue				Sarcobesity index			
	2D		3D		2D		3D		2D		3D		2D		3D	
	Coefficient	*p*	Coefficient	*p*	Coefficient	*p*	Coefficient	*p*	Coefficient	*p*	Coefficient	*p*	Coefficient	*p*	Coefficient	*p*
$\dot{V}O_2$ rest	–0.00168	<0.001	–0.000086	<0.001	–0.002187	<0.001	–0.000103	<0.001	–0.001503	<0.001	–0.000073	<0.001	–0.04003	<0.001	–0.01433	0.005
$\dot{V}O_2$ AT	–0.00497	<0.001	–0.000268	<0.001	–0.0052	<0.001	–0.00025	<0.001	–0.004013	<0.001	–0.000198	<0.001	–0.1523	<0.001	–0.0680	<0.001
$\dot{V}O_2$ AT (allometric scaling)	–0.00249	0.615	0.00004	0.889	–0.00139	0.762	–0.000017	0.937	–0.00208	0.485	0.000003	0.986	–0.453	<0.001	–0.1915	0.002
$\dot{V}E/\dot{V}CO_2$ AT	–0.00009	0.973	–0.000022	0.883	–0.01001	<0.001	–0.01001	<0.001	–0.00399	0.011	–0.000227	0.003	0.1550	0.013	0.0786	0.018
$\dot{V}E/\dot{V}O_2$ AT	–0.00333	0.236	–0.000229	0.155	–0.00964	<0.001	–0.000419	<0.001	–0.00543	0.001	–0.00543	0.001	0.1034	0.115	0.0646	0.066
$\dot{V}O_2$ peak	–0.00509	0.012	–0.000213	0.067	–0.00944	<0.001	–0.000447	<0.001	–0.0058	<0.001	–0.000275	<0.001	–0.2912	<0.001	–0.1186	<0.001
$\dot{V}O_2$ peak (allometric scaling)	0.00419	0.639	0.000715	0.162	–0.0154	0.063	–0.000722	0.059	–0.00486	0.366	–0.000155	0.56	–0.960	<0.001	–0.380	0.001
$\dot{V}O_2$ peak/predicted $\dot{V}O_2$ peak	0.01452	0.081	0.001128	0.018	0.03971	<0.001	0.001681	<0.001	0.02197	<0.001	0.001118	<0.001	0.365	0.062	0.141	0.179
$\dot{V}O_2$ peak exercise time	0.1686	0.017	0.01305	0.001	0.1329	0.045	0.00666	0.029	0.1142	0.007	0.00676	0.001	–1.47	0.379	–0.831	0.355
Max work	0.0533	0.0533	0.00386	<0.001	0.0108	0.527	0.000589	0.457	0.0244	0.027	0.001331	0.015	–1.511	<0.001	–0.639	0.006
$\dot{V}O_2$ peak METS	–0.001293	0.031	–0.00005	0.146	–0.002695	<0.001	–0.000127	<0.001	–0.00159	<0.001	–0.000075	<0.001	–0.0784	<0.001	–0.03188	<0.001
$\dot{V}O_2$ peak Max HR	–0.0241	0.047	–0.000826	0.235	0.0063	0.576	0.000415	0.427	–0.00592	0.418	–0.000024	0.947	–0.803	0.004	–0.351	0.020
$\dot{V}O_2$ peak Max RER	–0.000095	0.17	–0.000005	0.234	–0.000125	0.054	–0.000006	0.052	–0.000091	0.029	–0.000004	0.049	–0.00549	0.001	–0.002705	0.002
$\dot{V}O_2$ peak Max $\dot{V}O_2$/HR	0.01193	<0.001	0.000732	<0.001	0.0054	<0.001	0.000284	<0.001	0.00657	<0.001	0.000336	<0.001	0.0273	0.443	0.0216	0.256

CPET, cardiopulmonary exercise testing; AT, anaerobic threshold; $\dot{V}O_2$, oxygen uptake; $\dot{V}E/\dot{V}O_2$, ventilatory equivalents for oxygen; $\dot{V}E/\dot{V}CO_2$, ventilatory equivalents for carbon dioxide; RER, respiratory rate; HR, hear rate; METS, metabolic equivalents; 2D, 2-dimensional; 3D, 3-dimensional.

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Table 3. Association between sarcobesity index, adipose tissue measurements and CPET performance based on binary logistic regression analysis.

Dependent variables	Independent variables															
	Visceral adipose tissue				Subcutaneous adipose tissue				Total adipose tissue				Sarcobesity index			
	2D		3D		2D		3D		2D		3D		2D		3D	
	OR (95% CI)	*p*	OR (95% CI)	*p*	OR (95% CI)	*p*	OR (95% CI)	*p*	OR (95% CI)	*p*	OR (95% CI)	*p*	OR (95% CI)	*p*	OR (95% CI)	*p*
Inability to perform CPET	1.0011 (0.9968, 1.0055)	0.622	1.0000 (0.9997, 1.0003)	0.989	1.0024 (0.9988, 1.0061)	0.208	1.0001 (0.9999, 1.0003)	0.272	1.0016 (0.9990, 1.0041)	0.246	1.0001 (0.9999, 1.0002)	0.435	1.1170 (1.0190, 1.2245)	0.018	1.0184 (0.9760, 1.0626)	0.401
Inability to reach AT	0.9978 (0.9947, 1.0010)	0.166	0.9999 (0.9997, 1.0000)	0.144	1.0010 (0.9984, 1.0036)	0.475	1.0001 (1.0000, 1.0002)	0.204	0.9997 (0.9979, 1.0015)	0.758	1.0000 (0.9999, 1.0001)	0.862	1.0258 (0.9593, 1.0968)	0.457	1.0210 (0.9918, 1.0511)	0.160
1-year mortality	0.9993 (0.9962, 1.0025)	0.673	1.0000 (0.9998, 1.0001)	0.657	0.9960 (0.9925, 0.9996)	0.02	0.9998 (0.9996, 1.0000)	0.024	0.9984 (0.9964, 1.0003)	0.097	0.9999 (0.9998, 1.0000)	0.082	1.0346 (0.9651, 1.1092)	0.338	1.0220 (0.9914, 1.0535)	0.162
3-year mortality	0.9982 (0.9959, 1.0004)	0.099	0.9999 (0.9998, 1.0000)	0.111	0.9985 (0.9963, 1.0006)	0.149	1.0000 (0.9999, 1.0000)	0.309	0.9987 (0.9974, 1.0001)	0.062	0.9999 (0.9999, 1.0000)	0.123	0.9954 (0.9462, 1.0471)	0.858	1.0042 (0.9779, 1.0312)	0.759
5-year mortality	0.9993 (0.9975, 1.0012)	0.481	1.0000 (0.9999, 1.0001)	0.577	0.9990 (0.9973, 1.0008)	0.273	1.0000 (0.9999, 1.0001)	0.462	0.9994 (0.9983, 1.0005)	0.29	1.0000 (0.9999, 1.0000)	0.422	1.0050 (0.9629, 1.0489)	0.820	1.0060 (0.9834, 1.0291)	0.607

CPET, cardiopulmonary exercise testing; OR, odds ratio; AT, anaerobic threshold; CI, confidence intervals; 2D, 2-dimensional; 3D, 3-dimensional.

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Table 4. Comparison of performance of 2D and 3D approaches in measuring adipose tissue variables in predicting mortality.

	1-year mortality		3-year mortality		5-year mortality	
	AUC (95% CI)	*p*-value*	AUC (95% CI)	*p*-value*	AUC (95% CI)	*p*-value*
Sarcobesity (2D)	0.548 (0.498 to 0.597)	0.528	0.507 (0.457 to 0.556)	0.903	0.617 (0.567 to 0.664)	0.197
Sarcobesity (3D)	0.513 (0.513 to 0.612)		0.516 (0.466 to 0.566)		0.605 (0.556 to 0.653)	
Total adipose tissue (2D)	0.582 (0.532 to 0.630)	0.523	0.570 (0.520 to 0.619)	0.405	0.542 (0.492 to 0.591)	0.674
Total adipose tissue (3D)	0.571 (0.521 to 0.620)		0.558 (0.508 to 0.607)		0.537 (0.487 to 0.586)	
Subcutaneous adipose tissue (2D)	0.603 (0.556 to 0.648)	0.759	0.554 (0.507 to 0.600)	0.378	0.538 (0.491 to 0.584)	0.726
Subcutaneous adipose tissue (3D)	0.597 (0.550 to 0.642)		0.547 (0.500 to 0.593)		0.535 (0.488 to 0.581)	
Visceral adipose tissue (2D)	0.538 (0.492 to 0.585)	0.705	0.571 (0.524 to 0.617)	0.459	0.531 (0.484 to 0.577)	0.491
Visceral adipose tissue (3D)	0.534 (0.487 to 0.580)		0.563 (0.516 to 0.609)		0.525 (0.478 to 0.571)	

CI, confidence interval; AUC, area under the curve; 2D, 2-dimensional; 3D, 3-dimensional.

**p*-value is related to the comparison of AUC between 2D and 3D approaches for each adipose tissue variable.

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Visceral Adipose Tissue and CPET Performance

2D approach. Visceral adipose tissue predicted $\dot{V}O_2$ Rest (Coeff: –0.00168, $p < 0.001$), $\dot{V}O_2$ AT (Coeff: –0.00497, $p < 0.001$), $\dot{V}O_2$ peak (Coeff: –0.00509, p: 0.012), exercise time (Coeff: 0.1686, p: 0.017), peak METS (Coeff: –0.001293, p: 0.031), maximum heart rate (Coeff: –0.0241, p: 0.047), and peak oxygen pulse (Coeff: 0.01193, $p < 0.001$). Visceral adipose tissue (2D approach) did not predict inability to perform CPET (odds ratio (OR): 1.0011, p: 0.622) and not reaching AT (OR: 0.9978, p: 0.166).

3D approach. Visceral adipose tissue predicted $\dot{V}O_2$ Rest (Coeff: –0.000086, $p < 0.001$), $\dot{V}O_2$ AT (Coeff: –0.000268, $p < 0.001$), % predicted $\dot{V}O_2$ peak (Coeff: 0.001128, p: 0.018), exercise time (Coeff: 0.01305, p: 0.001), maximum work (Coeff: 0.00386, $p < 0.001$), and peak oxygen pulse (Coeff: 0.000732, $p < 0.001$). Visceral adipose tissue (3D approach) did not predict inability to perform CPET (OR: 1.0000, p: 0.989) and not reaching AT (OR: 0.9999, p: 0.144).

Subcutaneous Adipose Tissue and CPET Performance

2D approach. Subcutaneous adipose tissue predicted $\dot{V}O_2$ Rest (Coeff: –0.002187, $p < 0.001$), $\dot{V}O_2$ AT (Coeff: –0.0052, $p < 0.001$), $\dot{V}E/\dot{V}CO_2$ AT (Coeff: –0.01001, $p < 0.001$), $\dot{V}E/\dot{V}O_2$ AT (Coeff: –0.00964, $p < 0.001$), $\dot{V}O_2$ peak (Coeff: –0.00944, $p < 0.001$), % predicted $\dot{V}O_2$ peak (Coeff: 0.03971, $p < 0.001$), exercise time (Coeff: 0.1329, $p = 0.045$), peak METS (Coeff: –0.002695, $p < 0.001$), peak RER (Coeff: –0.000125, $p = 0.054$), and peak oxygen pulse (Coeff: 0.0054, $p < 0.001$). Subcutaneous adipose (2D approach) did not predict inability to perform CPET (OR: 1.0024, $p = 0.208$) and not reaching AT (OR: 1.0010, $p = 0.475$).

3D approach. Subcutaneous adipose tissue predicted $\dot{V}O_2$ Rest (Coeff: –0.000103, $p < 0.001$), $\dot{V}O_2$ AT (Coeff: –0.00025, $p < 0.001$), $\dot{V}E/\dot{V}CO_2$ AT (Coeff: –0.01001, $p < 0.001$), $\dot{V}E/\dot{V}O_2$ AT (Coeff: –0.000419, $p < 0.001$), $\dot{V}O_2$ peak (Coeff: –0.000447, $p < 0.001$), % predicted $\dot{V}O_2$ peak (Coeff: 0.001681, $p < 0.001$), exercise time (Coeff: 0.00666, p: 0.029), peak METS (Coeff: –0.000127, $p < 0.001$), peak RER (Coeff: –0.000006, p: 0.052), and peak oxygen pulse (Coeff: 0.000284, $p < 0.001$). Subcutaneous adipose tissue (3D approach) did not predict inability to perform CPET (OR: 1.0001, p: 0.272) and not reaching AT (OR: 1.0001, p: 0.204).

Total Adipose Tissue and CPET Performance

2D approach. Total adipose tissue predicted $\dot{V}O_2$ Rest (Coeff: –0.001503, $p < 0.001$), $\dot{V}O_2$ AT (Coeff: –0.004013, $p < 0.001$), $\dot{V}E/\dot{V}CO_2$ AT (Coeff: –0.00399, p: 0.011), $\dot{V}E/\dot{V}O_2$ AT (Coeff: –0.00543, p: 0.001), $\dot{V}O_2$ peak (Coeff: –0.0058, $p < 0.001$), % predicted $\dot{V}O_2$ peak (Coeff: 0.02197, $p < 0.001$), exercise time (Coeff: 0.1142, p: 0.007), maximum work (Coeff: 0.0244, p: 0.027), peak METS (Coeff: –0.00159, $p < 0.001$), peak RER (Coeff: –0.000091, p: 0.029), and peak oxygen pulse (Coeff: 0.00657, $p < 0.001$). Total adipose tissue (2D approach) did not predict inability to perform CPET (OR: 1.0016, p: 0.246) and not reaching AT (OR: 0.9997, p: 0.758).

3D approach. Total adipose tissue predicted $\dot{V}O_2$ Rest (Coeff: –0.000073, $p <$ 0.001), $\dot{V}O_2$ AT (Coeff: –0.000198, $p < 0.001$), $\dot{V}E/\dot{V}CO_2$ AT (Coeff: –0.000227, p: 0.003), $\dot{V}E/\dot{V}O_2$ AT (Coeff: –0.00543, p: 0.001), $\dot{V}O_2$ peak (Coeff: –0.000275, $p < 0.001$), % predicted $\dot{V}O_2$ peak (Coeff: 0.001118, $p < 0.001$), exercise time (Coeff: 0.00676, p: 0.001), maximum work (Coeff: 0.001331, p: 0.015), peak METS (Coeff: –0.000075, $p < 0.001$), peak RER (Coeff: –0.000004, p: 0.049), and peak oxygen pulse (Coeff: 0.000336, $p < 0.001$). Total adipose tissue measured (3D approach) did not predict inability to perform CPET (OR: 1.0001, p: 0.435) and not reaching AT (OR: 1.0000, p: 0.862).

Sarcobesity Index and CPET Performance

2D approach. Sarcobesity index predicted $\dot{V}O_2$ Rest (Coeff: –0.04003, $p <$ 0.001), $\dot{V}O_2$ AT (Coeff: –0.1523, $p < 0.001$), $\dot{V}O_2$ AT (allometric scaling) (Coeff: –0.453, $p < 0.001$), $\dot{V}E/\dot{V}CO_2$ AT (Coeff: 0.1550, p: 0.013), $\dot{V}O_2$ peak (Coeff: –0.2912, $p < 0.001$), $\dot{V}O_2$ peak (allometric scaling) (Coeff: –0.960, $p < 0.001$), maximum work (Coeff: –1.511, $p < 0.001$), peak METS (Coeff: –0.0784, $p <$ 0.001), maximum heart rate (Coeff: –0.803, p: 0.004), and peak RER (Coeff: –0.00549, p: 0.001). Sarcobesity index (2D approach) predicted inability to perform CPET (OR: 1.1170, p: 0.018) but did not predict inability to reach AT (OR: 1.0258, p: 0.457).

3D approach. Sarcobesity index predicted $\dot{V}O_2$ Rest (Coeff: –0.01433, p: 0.005), $\dot{V}O_2$ AT (Coeff: –0.0680, $p < 0.001$), $\dot{V}O_2$ AT (allometric scaling) (Coeff: –0.1915, p: 0.002), $\dot{V}E/\dot{V}CO_2$ AT (Coeff: 0.0786, p: 0.018), $\dot{V}O_2$ peak (Coeff: –0.1186, $p < 0.001$), $\dot{V}O_2$ peak (allometric scaling) (Coeff: –0.380, p: 0.001), maximum work (Coeff: –0.639, p: 0.006), peak METS (Coeff: –0.03188, $p <$ 0.001), maximum heart rate (Coeff: –0.351, p: 0.020), and peak RER (Coeff: –0.002705, p: 0.002). Sarcobesity index (3D approach) did not predict inability to perform CPET (OR: 1.0184, p: 0.401) and not reaching AT (OR: 1.0210, p: 0.160).

Secondary Outcome (Mortality)

The risk of 1-year mortality was 7.4% (34 out of 457), 3-year mortality was 17.5% (80 out of 457), and 5-year mortality was 27.1% (124 out of 457). The results of regression analyses for the association between adipose tissue variables and mortality are shown in Table 3. Also, the discrimination of adipose tissue variables in predicting mortality is shown in Fig. 2.

Total Adipose Tissue and Mortality

One-year mortality. Total adipose tissue measured via 2D approach (OR: 0.9984, 95% CI 0.9964, 1.0003, p: 0.097) and 3D approach (OR: 0.9999, 95% CI 0.9998, 1.0000, p: 0.082) did not predict 1-year mortality. Total adipose tissue had an AUC of 0.582 (95% CI 0.532 to 0.630) when measured via 2D method and 0.571 (95% CI 0.521 to 0.620) when measured by 3D approach.

Three-year mortality. Total adipose tissue measured via 2D approach (OR: 0.9987, 95% CI 0.9974, 1.0001, p: 0.062) and 3D approach (OR: 0.9999, 95% CI 0.9999, 1.0000, p: 0.123) did not predict 3-year mortality. Total adipose tissue had

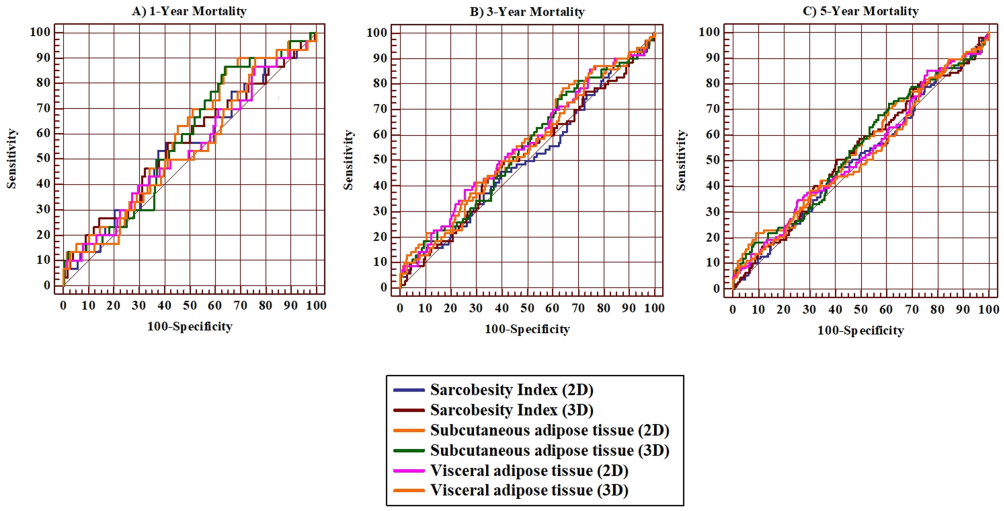

Fig. 2. Discrimination of adipose tissue variables in predicting (A) 1-year mortality, (B) 3-year mortality, (C) 5-year mortality.

an AUC of 0.570 (95% CI 0.520 to 0.619) when measured via 2D method and 0.558 (95% CI 0.508 to 0.607) when measured via 3D method.

Five-year mortality. Total adipose tissue measured via 2D approach (OR: 0.9994, 95% CI 0.9983, 1.0005, *p*: 0.29) and 3D approach (OR: 1.0000, 95% CI 0.9999, 1.0000, *p*: 0.422) did not predict 5-year mortality. Total adipose tissue had an AUC of 0.542 (95% CI 0.492 to 0.591) when measured via 2D method and 0.537 (95% CI 0.487 to 0.586) when measured via 3D approach.

Sarcobesity Index and Mortality

One-year mortality. Sarcobesity index measured via 2D approach (OR: 1.0346, 95% CI 0.9651 to 1.1092, *p*: 0.338) and 3D approach (OR: 1.0220, 95% CI 0.9914 to 1.0535, *p*: 0.162) did not predict 1-year mortality. The sarcobesity index had an AUC of 0.548 (95% CI 0.498 to 0.597) when measured via 2D method and 0.513 (95% CI 0.513 to 0.612) when measured via 3D approach.

Three-year mortality. Sarcobesity index measured via 2D method (OR: 0.9954, 95% CI 0.9462 to 1.0471, *p*: 0.858) and 3D method (OR: 1.0042, 95% CI 0.9779, 1.0312, *p*: 0.759) did not predict 3-year mortality. The sarcobesity index had an AUC of 0.507 (95% CI 0.457 to 0.556) when measured via 2D method and 0.516 (95% CI 0.466 to 0.566) when measured via 3D method.

Five-year mortality. Sarcobesity index measured via 2D method (OR: 1.0050, 95% CI 0.9629, 1.0489, *p*: 0.820) and 3D method (OR: 1.0060, 95% CI 0.9834, 1.0291, *p*: 0.607) did not predict 5-year mortality. The sarcobesity index had an AUC of 0.617 (95% CI 0.567 to 0.664) when measured via 2D method and 0.605 (95% CI 0.556 to 0.653) when measured via 3D method.

Comparison of ROC Curves

There was no difference in discriminative performance of visceral adipose tissue, subcutaneous adipose tissue, and sarcobesity index measured by 2D or 3D approaches in predicting mortality based on pairwise comparisons of ROC curves (Fig. 2, Table 4).

Discussion

We studied the significance of adipose tissue variables and sarcobesity index measured by CT in predicting CPET performance in a colorectal surgery setting. The results showed that radiological adipose tissue measurements (visceral adipose tissue, subcutaneous adipose tissue, total adipose tissue, and sarcobesity index) may predict CPET performance but not long-term mortality in colorectal surgery setting. Moreover, the predictive performance of visceral adipose tissue, subcutaneous adipose tissue, and sarcobesity index measured by 2D or 3D approaches were comparable.

Our findings are comparable with similar studies investigating the relationship between pre-operative CT characteristics and CPET performance. Berkel et al (2022) also demonstrated a significant correlation between body composition variables and aerobic fitness. However, their study had a small sample size and did not include the sarcobesity index as a variable and only demonstrated a significant relationship between visceral adipose tissue and CPET performance. Moreover, it has recently been demonstrated that CT-derived measurements of the psoas muscle can predict the successful completion of CPET before colorectal resections (Hajibandeh et al, 2024a).

Previous research has elicited conflicting results when evaluating the relationship between obesity and postoperative outcomes. Several studies have also concluded that obesity has no correlation with overall survival (Frostberg et al, 2021; Kuritzkes et al, 2018; Malietzis et al, 2016). One possible explanation for this is the theory that obesity confers some survival advantage, particularly in patients with cancer, owing to the patient having larger energy stores (Laird and Skipworth, 2022; Lennon et al, 2016). Therefore, in post-surgical patients this advantage may counteract the negative disease processes associated with obesity, such as coronary artery disease and hepatic steatosis.

There have been few studies to date specifically evaluating sarcobesity as a body composition variable in colorectal surgery patients (Conti et al, 2022; Feng et al, 2023; Malietzis et al, 2016; Pedrazzani et al, 2020). A recent study looking at body composition variables and outcomes following colorectal cancer surgery found that sarcobesity was only associated with worse overall 5-year survival in univariate analysis, and was not an independent risk factor (Conti et al, 2022). They did however find that sarcobesity was an independent risk factor for disease-free survival. A UK study found a significant correlation between sarcobesity and 30-day mortality, but no correlation with other body composition variables. Similar to our results, they also demonstrated that sarcopenia alone and not obesity or sarcobesity are associated with overall survival at a median follow-up time of 47.1 months (Malietzis et al, 2016). Therefore, although psoas muscle volume is a predictor of mortality, adipose tissue is not and possibly cancels out the predictive effect of muscle mass in sarcobesity. Given that CPET provides a measure of cardiorespiratory fitness which is an independent predictor of postoperative mortality (Rose et al, 2022), we may expect muscle volume, where terminal oxidative phosphorylation generates ATP, to be related. Unlike adipose tissue, muscle mass drives a strong

demand for mitochondrial oxygen uptake, and greater muscle mass is associated with both increased cardiorespiratory fitness and reduced mortality risk in patients (Nichols et al, 2019). Other studies have not only looked at sarcobesity in relation to mortality outcomes but also post-surgical complications. A study by Takano et al (2023) found that sarcobesity, and not visceral or subcutaneous obesity alone, is an independent risk factor for developing incisional hernia after colorectal cancer surgery.

This study showed that both 2D and 3D fat analysis techniques were comparable in predicting CPET performance meaning that 2D fat analysis could provide a quick and reliable tool for identifying high-risk patients requiring further CPET testing pre-operatively. This is a novel finding as the predictive performance of 2D and 3D approaches in the measurement of adipose tissue in patients undergoing colorectal surgery has not been compared previously. It was very interesting to observe that 3D approach was not advantageous in comparison to 2D approach. One possible explanation for this could be that a decrease or increase in adipose tissue variables happens proportionally throughout the body, hence both area and volume decrease proportionally. Consistent with these findings, a previous study suggested comparable predictive performance of psoas muscle mass measured by 3D and 2D approaches (Hajibandeh et al, 2024a).

The findings of the current study may have some implications for future research and preoperative practice. The main objective of the CPET is to identify patients who are at high risk for a major operation. On the other hand, performing CPET for all patients may not be cost-effective or may not be essential. Consequently, future studies should investigate whether the use of body composition variables such as sarcobesity index can be used for the selection of patients who benefit from CPET; those with alarming body composition metrics should undergo CPET and those with satisfactory body composition metrics may be considered as low or moderate risk of complications, hence they may proceed with surgery without CPET provided that the other aspects of preoperative anaesthetic assessment are satisfactory. The above hypothesis needs to be robustly evaluated in future studies.

The limitations of the current study include retrospective design, inevitable selection bias, exclusion of patients without available CT scan results, and potential selection bias due to the inclusion of those who were fit enough to undergo colorectal resection. Another source of selection bias may be the fact that we only investigated patients who underwent colorectal procedures in a single centre which can influence the generalizability of the results in other centres and in other surgical settings. Otherwise, systematic methodology, transparent analyses and reporting, reasonable sample size with no loss to follow-up, and appropriate radiological method in measurement of adipose tissue variables using both 2D and 3D approaches are the strengths of the current study.

Conclusion

The CPET performance may be predicted by radiologically measured adipose tissue variables and sarcobesity index in patients undergoing elective colorectal

resection. However, the prognostic value of adipose tissue variables may not be significant in this setting. The 3D measurement technique may not be advantageous compared with 2D technique.

Key Points

- Four hundred fifty-seven patients who had CPET before colorectal resection were studied.
- CPET performance may be predicted by radiologically measured adipose tissue variables.
- Radiologically measured adipose tissue variables may not predict long-term mortality.
- The 3D measurement technique may not be advantageous compared with 2D technique.

Availability of Data and Materials

The data and materials related to this study will be available upon reasonable request from the corresponding author.

Author Contributions

Conception and design: RGD, AC; Data collection: IG, WT, EK, AOBO, WJ, RGD, GAR, DMB; Analysis and interpretation: EK, WT, IG, AOBO, WJ, ShahinH, ShahabH, GAR, DMB, CM, RH, AC, RGD; Writing the article: EK, ShahabH, RGD; Critical revision for important intellectual content: All authors; Final approval of the article: All authors. All authors agreed to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Ethics Approval and Consent to Participate

The Cardiff and Vale University Health Board (15/AIC/6352) and the University of South Wales Ethics Committee (LSE1636GREO) approved the study. Due to the retrospective nature of the study, use of non-identifiable hospital data, and indirect patient involvement, the Cardiff and Vale University Health Board and the University of South Wales Ethics Committee waived the Patient's informed consent.

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Conflict of Interest

Damian M Bailey is Editor-in-Chief of *Experimental Physiology*, Chair of the Life Sciences Working Group, a member of the Human Spaceflight and Exploration Science Advisory Committee to the European Space Agency, a member of the Space Exploration Advisory Committee to the UK Space Agency, and a member of the National Cardiovascular Network for Wales and South East Wales Vascular Network. Damian M Bailey is also affiliated to the companies FloTBI Inc. and Bexorg Inc., focused on the technological development of novel biomarkers of brain injury in humans. All other authors declare no conflict of interest.

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