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Original Research

Psoas muscle density predicts elective colorectal surgical outcomes more accurately than psoas muscle area or indexed area

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ABSTRACT

Background: CT measurements of psoas muscle density (PMD) and area (PMA) (with or without indexing to height-squared or body-surface-area) are used interchangeably as sarcopenia measures - it is unknown which best correlates with surgical risk.
Objectives: 1.Determine the correlation between psoas muscle density, area, and indexed area;
2.Identify which psoas measures most strongly associated with surgical outcomes
Design: The University Hospital Geelong Colorectal database included all patients who underwent elective colorectal surgery from 2007 to 2014 (minimum five-years follow-up). Pre-operative CT scans were reviewed, psoas measures correlated with each other and with outcomes.
Setting: University Hospital Geelong is a regional referral hospital in Victoria, Australia.
Participants: This database listed 552 patients, 120 were excluded as pre-operative CT-films were not accessible, leaving 432 patients included.
Exposure: Psoas muscle density, area, and area indexed by height-squared and body-surface-area.
Measurements: Pearson correlations investigated correlations between psoas muscle measures. Logistic regression and ROC-analysis investigated each psoas measures association with peri-operative morbidity. Kaplan-Meier survival-analysis investigated the association of each psoas measure with long-term survival.
Results: Mean age was 70.4 years, 41 % were female.
Psoas muscle density correlated poorly with area (R^2=0.15). Unindexed psoas muscle area correlated well with area indexed by height-squared (R^2=0.950) and body-surface-area (R^2=0.938).
Long-term survival was associated with psoas muscle density (HR1.515(95 %CI 1.062–2.161)) and area (HR1.886(95 %CI 1.322–2.692)).
Increasing psoas muscle density (reduced sarcopenia) was associated with decreased major-complications (OR0.963(95 %CI 0.938–0.989)) and peri-operative mortality (OR0.903(95 %CI 0.847–0.962)), with ROC-curve AUC=0.829 indicating an accurate test. There was no association between psoas muscle area and major-complications (OR1.000(95 %CI 1.000–1.000)), nor peri-operative mortality (OR1.000(95 %CI 0.999–1.001)), with ROC-curves AUC=0.507–0.521.
Indexed area measures were not associated with outcomes.
Conclusions: Psoas muscle density and area did not correlate. Both were associated with long-term survival, but only density was associated major-complications and mortality. Indexing removed the correlation of area with long-term survival.

1. Introduction

Sarcopenia is a progressive and generalised loss of skeletal muscle mass and strength [1]. Sarcopenia commonly occurs in older adults, and is associated with increased morbidity and mortality after surgery [2–7]. Consequently, if assessed accurately, the presence of sarcopenia would be a useful indicator of surgical prognosis and enable better informed decision making by patients and their families.

A number of approaches have been described to estimate total body muscle mass as a marker of sarcopenia, including biometric, functional and radiological approaches [8]. Early total body muscle mass measurements relied on 24-hour urinary creatinine secretion, or muscle volume

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measurements from a whole body CT scan [9]. In the recent literature, there is a trend towards using single-level cross-sectional skeletal muscle imaging to assess sarcopenia. Although single-level measurements of multiple muscle groups have been reported to correlate well with total body muscle mass [10–12], a single-level measurement of the psoas major muscle at the L3 or L4 level is commonly used for simplicity [13]. Cross-sectional imaging of the psoas muscle provides a relatively simple and non-invasive approach to sarcopenia assessment. Cross-sectional psoas muscle measurement has an added advantage in surgery, in that many patients will have had a routine CT scan of that region for other clinical purposes.

Broadly, two approaches to measuring the psoas muscle to identify sarcopenia have been described in the literature [9]. Firstly psoas muscle density (PMD), which is a marker of muscle replacement by adipose and connective tissue, may be estimated from the mean radiological density of the muscle. Secondly psoas muscle cross-sectional area (PMA) can be measured as a marker of muscle size. PMD and PMA measurements have been used interchangeably in the literature as markers of sarcopenia, however there is no consensus on whether PMD and PMA correlate well with each other, or which provides the best prognostic information. This question is addressed in this cohort study.

Muscle size is affected not just by sarcopenia, but also by other factors including body size, sex and baseline musculature [9]. This is a challenge for implementing PMA as a marker of sarcopenia and attempts to address this include indexing psoas muscle area measurements to the patient's height-squared (PMA/H^2) or to their body-surface-area (PMA/BSA) [8]. Standardising body size by indexing to height squared was first described by Quetelet in 1835, and is still used today as the basis of the body mass index calculation (BMI = weight / height squared) [14]. The benefits from indexing PMA have not been examined in the literature however. The second question investigated in this cohort study concerns whether indexing PMA by H^2 or BSA enhances any correlation with surgical outcomes.

The study objective was to compare four commonly used psoas muscle measurements (PMD, PMA, PMA/H^2 and PMA/BSA) to assess sarcopenia, to identify whether these correlate together, and determine which psoas measure most accurately predicted outcomes in a cohort of patients undergoing elective surgery for colorectal cancer.

2. Method

This was a cohort study of all patients who underwent elective colorectal cancer resections between 2007 and 2014 at University Hospital Geelong (a regional referral hospital in Victoria, Australia) and had undergone a pre-operative staging CT scan. A cut-off date of 31 December 2014 was chosen at the time the colorectal database was originally collected, enabling a minimum follow up time of five years. This study involved reviewing this cohort's pre-operative CT scans and comparing psoas measurements with peri-operative morbidity and long-term survival, which was not available for patients admitted after 31 December 2014. A start date of 1 January 2007 was chosen as this was when electronic medical records were introduced at our institution, and radiological examinations prior to this were no longer accessible.

Demographic and some clinical data were obtained from the University Hospital Geelong colorectal database, and included date of birth, sex, age at admission, tumour site, nature of surgical resection, and cancer staging (TNM and Dukes). Peri-operative complications (with Clavien-Dindo classification) and peri-operative mortality (defined as death within 30 days, or prior to discharge from hospital) were also recorded in the database. Patients had lifelong clinical follow-up wherever possible. Long-term outcomes, including date of death after discharge were included in this database. When patients were lost to clinical follow-up, attempts were made to contact the patient, their family, or their general practitioner to identify their post-surgical outcomes.

Pre-operative CT scans were routinely performed on all patients as part of their cancer staging. These images were reviewed by one of the authors (LS). LS was blinded to patient outcomes and made radiological measurements of the psoas muscle (Fig. 1). Sagittal images were used to identify the mid third lumbar vertebra (L3) spinal level. Axial images at the selected mid-L3 spinal level were then used to measure the psoas muscle density and area bilaterally. The 'freedraw' function was used to manually circumscribe the bilateral psoas muscles, with the cross-sectional area and average density of these selections being automatically calculated. Height and weight data for indexing calculations were obtained from patients' medical records. Psoas muscle density (PMD) and psoas muscle area (PMA) were added to the Geelong colorectal database, as were psoas muscle indexed to height-squared (PMA/H^2) and body-surface-area (PMA/BSA). PMA/BSA was derived using the Mosteller equation:

$$BSA\left(m^2\right) = \sqrt{\frac{Height(cm)xWeight(kg)}{3600}}$$

Statistical analysis was planned in consultation with the Deakin University Biostatistics Unit. Descriptive statistical analyses were used to report demographic and clinical data. Pearson correlations were used to investigate the relationship between the different sarcopenia measures, scatter plots were then used to visualise these relationships.

Sarcopenia was treated as a continuous variable and logistic regression models were used to investigate how each sarcopenia measure (PMD, PMA, PMA/H^2, PMA/BSA) correlated with minor complications (Clavien-Dindo I-II), major complications (Clavien-Dindo IIIa-IVb), and peri-operative mortality. A separate logistic regression model was used to investigate the relationship between each sarcopenia measures and the dependent variables (complications and peri-operative mortality). The Hosmer & Lemeshaw test was used to assess the goodness of fit for the logistic regression models. A ROC curve analysis was conducted to examine the sensitivity and specificity of each psoas muscle measure for peri-operative mortality.

Kaplan-Meier survival curves were constructed to compare survival between sarcopenic and non-sarcopenic patients, as assessed by each of the radiological measures. Survival curves required dichotomisation - patients were defined as sarcopenic if they fell into the lowest sex-specific quartile for each measurement modality. Additional Kaplan-Meier survival curves were constructed for each psoas measure, using the original quartiles of distribution as a sensitivity analysis.SPSS 29.0.2.0 [20] was used for data analysis. A P-value of <0.05 was regarded as statistically significant in all analyses.

This study was approved by the Barwon Health Research Ethics Committee (QA/69,680/VICBH-2021–283,272(v2)). This research was conducted in accordance with the Helsinki Declaration of 1975 (as revised in 2000).

3. Results

There were 552 patients who underwent elective colorectal cancer resections at University Hospital Geelong during the study period (2007–2014). Of these patients, 120 were excluded on account of their pre-operative CT scan no-longer being accessible. This left a total of 432 patients included in this study.

The mean age of included patients was 70.4 years (SD12.0 years). These included 254 male (59 %) and 178 female (41 %) patients. Their most common co-morbidities are listed in supplementary Table 1. The most common was hypertension, which affected over half the patients (54 %) followed by diabetes mellitus which affected one-quarter. This table also presents the prevalence of co-morbidities for sarcopenic and non-sarcopenic patients (as defined by each of the four psoas muscle measures). In this cohort, co-morbidities were present more frequently in sarcopenic patients when sarcopenia was defined by PMD or PMA. The relationship between sarcopenia and co-morbidities was less clear when sarcopenia is defined by PMA/H^2 or PMA/BSA.

The operations performed are listed in supplementary Table 2. The majority of patients underwent an anterior resection (190/432, 44 %),

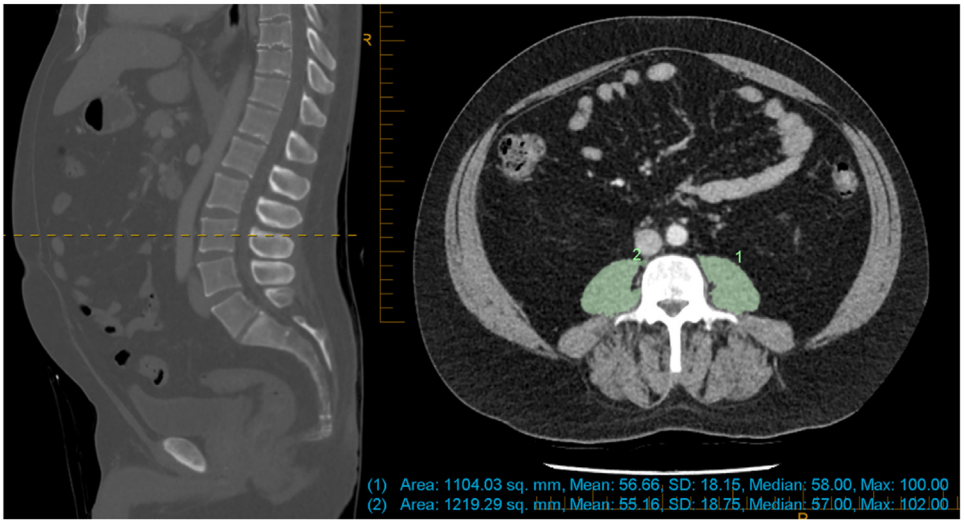

Fig. 1. Demonstration of technique used to obtain radiological measurements. Sagittal image on the left used to identify the L3 spinal level. Axial image on the right used to measure the area and density of the psoas muscle bilaterally.

Correlations

		Mean Psoas Muscle Density (HU)	Total Psoas Muscle Area (mm2)	Total Psoas Muscle Area indexed by Height Squared (mm2/m2)	PMA/BSA (mm2/m2)
Mean Psoas Muscle Density (HU)	Pearson Correlation	1	.148**	.175**	.231**
	Sig. (2-tailed)		.002	<.001	<.001
	N	432	432	377	373
Total Psoas Muscle Area (mm2)	Pearson Correlation	.148**	1	.950**	.938**
	Sig. (2-tailed)	.002		<.001	<.001
	N	432	432	377	373
Total Psoas Muscle Area indexed by Height Squared (mm2/m2)	Pearson Correlation	.175**	.950**	1	.942**
	Sig. (2-tailed)	<.001	<.001		<.001
	N	377	377	377	373
PMA/BSA(mm2/m2)	Pearson Correlation	.231**	.938**	.942**	1
	Sig. (2-tailed)	<.001	<.001	<.001	
	N	373	373	373	373

**. Correlation is significant at the 0.01 level (2-tailed).

Fig. 2. Correlations between sarcopenia muscle measurement types. PMD correlated poorly with PMA, PMA/H^2 and PMA/BSA. Indexing by height-squared or body-surface-area, had a small impact on PMA.

or right hemicolectomy (123/432, 28 %). Eleven of the 432 patients (2.5 %) died peri-operatively. Post-operative complications occurred in 222/432 (51 %) of patients; 72/432 (17 %) had major complications (Clavien-Dindo IIIa-IVb) and 150/432 (35 %) had minor complications (Clavien-Dindo I-II). Anastomotic leaks occurred in 19 (5.5 %) of the 348 patients who underwent surgery with a bowel anastomosis. After a median follow up time of 3.1 years (range 4 days-8.4 years, IQR1.3–5.0years), 138 (32 %) of patients had died. Median survival was 5.8 years (95 %CI 5.5–6.2 years).

3.1. Sarcopenia measurements

PMD and PMA were calculated for all 432 patients included in the study. There were 55 patients whose height was not recorded – thus PMA/H^2 could be calculated for 377 patients. Another four patients did not have weight recorded – thus PMA/BSA was calculated for 373 patients. Sarcopenia measurement results are summarised in supplementary Table 3.

Pearson correlations demonstrated that PMA correlated very closely with PMA/H^2 (R^2=0.950) and PMA/BSA (R^2=0.938). PMD correlated poorly with PMA (R^2=0.148), PMA/H^2 (R^2=0.175), and PMA/BSA (R^2=0.231) (Fig 2). Scatterplots visually demonstrating these relationships are provided as supplementary material (Supplementary Figures S1-S3). Age correlated best with PMD (R^2=0.153), then PMA (R^2=0.0.062), PMA/H^2 (R^2=0.029), and PMA/BSA (R^2=0.023).

3.2. The relationship between sarcopenia measurements and peri-operative outcomes

Peri-operative outcomes are summarised in Table 1. PMD was associated with major complications (Clavien-Dindo IIIa-IVb) (OR0.963, 95 %CI 0.938–0.989, $P = 0.006$) and peri-operative mortality (OR0.903, 95 %CI 0.847–0.962, $P = 0.002$); but showed no association with minor complications (OR0.998, 95 %CI 0.978–1.019, $P = 0.882$).

PMA, PMA/H^2 and PMA/BSA were not associated with mortality (respectively OR1.000(95 %CI 0.999–1.001), OR0.999 (95 %CI 0.995–1.004), and OR1.000 (95 %CI 0.997–1.003)), major complications (respectively OR1.000(95 %CI 1.000–1.000), OR1.001(95 %CI 0.999–1.002), and OR1.000(95 %CI 0.999–1.002)), or minor complications (respectively OR1.000(95 %CI 1.000–1.000), OR1.000(95 %CI 0.999–1.001), and OR1.000(95 %CI 0.999–1.001)).

A ROC curve for peri-operative mortality showed that PMD had the greatest sensitivity and specificity for peri-operative mortality, acting as a strong marker with AUC=0.829 ($P < 0.001$). Conversely PMA, PMA/H^2, and PMA/BSA were poor markers of peri-operative mortality with AUC 0.507–0.521 (P values 0.834 – 0.949) (Supplementary Figure 4).

3.3. Sarcopenia measurements as a predictor of long-term survival

Kaplan-Meier survival analysis demonstrated that patients with sarcopenia measured using PMD had reduced long-term survival compared

Table 1
Correlations between sarcopenia measurement type and peri-operative outcomes for patients included in the Geelong Hospital colorectal database, 2007–2014.

Sarcopenia measurement	Minor complication (Clavien-Dindo I-II)		Major complication (Clavien-Dindo IIIa-IVb)		Peri-operative mortality	
	OR (95 %CI)	P value	OR (95 %CI)	P value	OR (95 %CI)	P value
PMD (HU)	0.998 (0.978 - 1.019)	0.882	0.963 (0.938–0.989)	0.006	0.903 (0.847 - 0.962)	0.002
PMA (mm2)	1.000 (1.000 - 1.000)	0.976	1.000 (1.000 - 1.000)	0.795	1.000 (0.999 - 1.001)	0.914
PMA/H2 (mm2/m2)	1.000 (0.999 - 1.001)	0.857	1.001 (0.999 - 1.002)	0.482	0.999 (0.995 - 1.004)	0.737
PMA/BSA (mm2/m2)	1.000 (0.999 - 1.001)	0.644	1.000 (0.999 - 1.002)	0.437	1.000 (0.997 - 1.003)	0.823

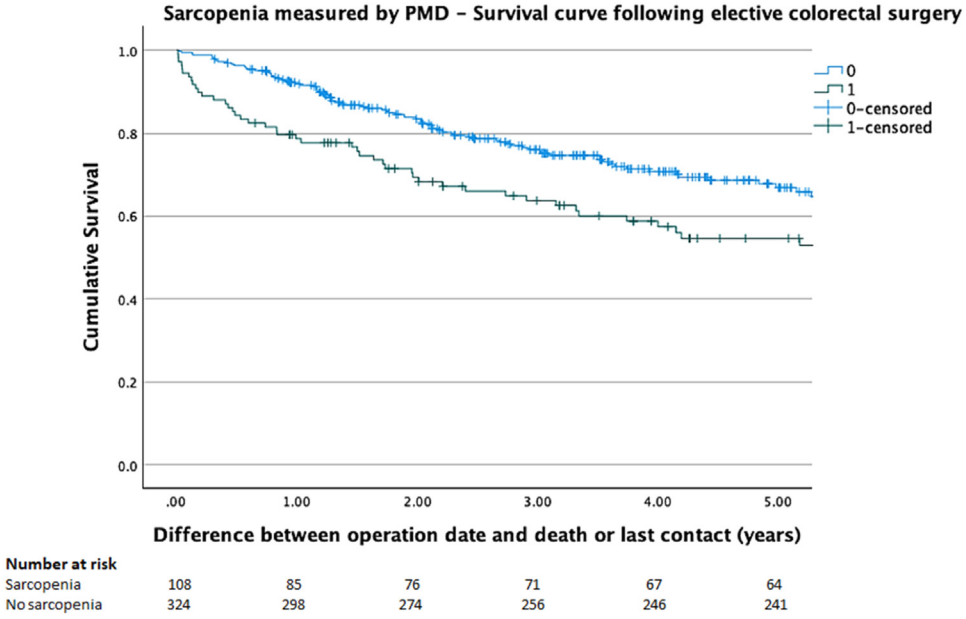

Fig. 3. Kaplan Meier survival curve demonstrating decreased long-term survival in sarcopenic patients as measured by PMD for patients included in the Geelong Hospital colorectal database, 2007–2014.

to non-sarcopenic patients (median 5.0 years 95 %CI 4.3–5.6years, vs 6.0 years 95 %CI 5.6–6.4years, $P = 0.021$). This is illustrated in Fig. 3. As sensitivity analysis, a Kaplan-Meier curve investigating survival across all four quartiles of the PMD distribution is also provided (Supplementary Figure 5), wherein the first quartile had the densest psoas muscle and the fourth the least dense (most sarcopenic). Survival generally decreased with each quartile, however there was some overlap of the second and third quartiles around the first year, and the first and second quartiles at five years. Log-rank test of equality of survival distribution for the different PMD quartiles was $P = 0.020$.

Similarly when sarcopenia was measured using PMA, patients with sarcopenia had a median survival of 4.8 years (95 %CI 4.1–5.5) vs 6.1 years (95 %CI 5.8–6.5) for non-sarcopenic patients ($P < 0.001$) (Fig. 4). In the Kaplan-Meier sensitivity analysis (Supplementary Figure 6), the first quartile had the largest psoas muscle and the fourth the smallest psoas muscle (most sarcopenic). Survival generally decreased by the quartile, however there was some overlap of the first three quartiles, for the first year, and of the second and third quartiles out to five years. The fourth quartile (smallest psoas muscle) had the worst survival throughout. Log-rank test of equality for survival across the PMA quartiles was $P < 0.001$

When using PMA/H^2 to define sarcopenia, there was no statistically significant difference in survival between those with and without sarcopenia (median survival 5.4 years 95 %CI 4.6–6.1 vs 6.0 years 95 %CI 5.6–6.4; $P = 0.069$) (Supplementary Figure 7). Supplementary Figure 8 demonstrates survival by quartile for PMA/H^2. Whilst the log-rank equality of distribution ($P = 0.002$) demonstrates that the four curves are unlikely to be the same, there is significant overlap between the quartiles, and the relationship is less clear than for PMD or PMA. Likewise when sarcopenia was defined by PMA/BSA, no statistically significant difference in survival was identified (median survival 5.0 years 95 %CI 4.4–5.6, vs 6.0 years 95 %CI 5.6–6.4; $P = 0.217$) (Supplementary Figure 9). Supplementary Figure 10 demonstrates survival by quartiles for PMA/BSA. Whilst the log-rank equality of distribution ($P = 0.014$) demonstrates that the four curves are unlikely to be the same, there is again significant overlap between the quartiles, and the relationship between PMA/BSA and survival is less clear than for PMD or PMA.

4. Discussion

The average age of the global population is increasing, as is the frequency of co-morbidities [15]. Consequently the demand for elective and emergency surgery is growing with the average operative risk for surgical candidates. There is an increasing need for accurate preoperative risk assessment to inform shared decision making around whether to proceed with surgery, or to recommend other clinical pathways instead. Sarcopenia is widely reported as a marker of operative risk, and numerous papers have found a correlation between sarcopenia and surgical morbidity [2–7]. Clinical implementation of sarcopenia assessment is impeded by the number of different approaches to measurements and the lack of clarity around which is the most effective. In this cohort study we have focused on two questions:

1. Do PMD and PMA correlate closely, and which is the better marker of operative risk?
2. Does indexing PMA improve the correlation with surgical outcomes?

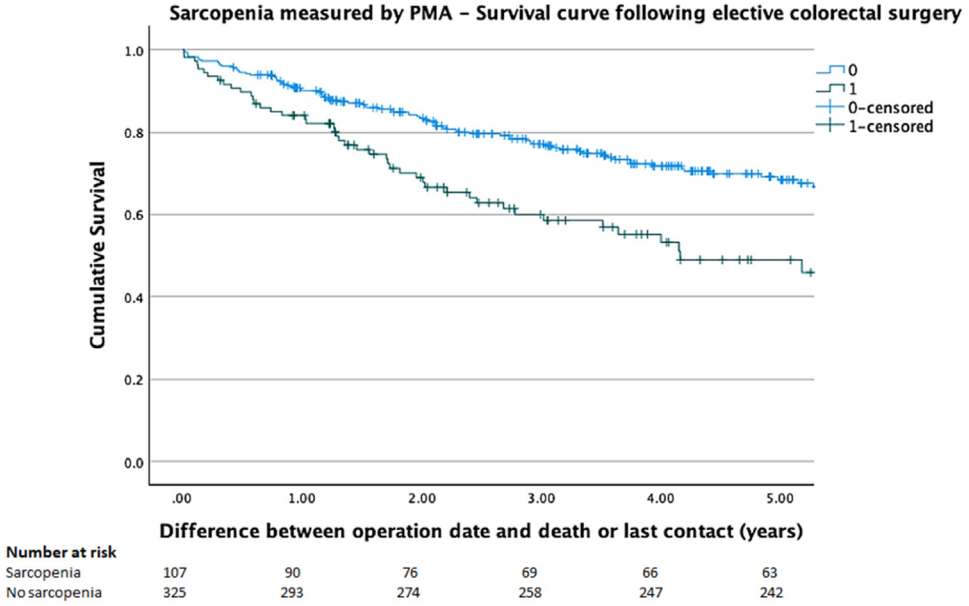

Fig. 4. Kaplan Meier survival curve demonstrating decreased long-term survival in sarcopenic patients as measured by PMA for patients included in the Geelong Hospital colorectal database, 2007–2014.

In this cohort of elective colorectal surgery patients, we found that PMD and PMA correlated poorly: R^2=0.15. Long-term survival following elective colorectal surgery was correlated both with PMD (HR1.515, 95 %CI 1.062–2.161) and PMA (HR1.886, 95 %CI 1.322–2.692). However only PMD was associated with peri-operative mortality (OR0.903, 95 %CI 0.847–0.962) and major-complications (OR0.963, 95 %CI 0.938–0.989). There was no association between PMA and peri-operative mortality (OR1.000, 95 %CI 0.999–1.001), nor major-complications (OR1.000, 95 %CI 1.000–1.000). Similarly a ROC curve demonstrated that PMD was an accurate marker of peri-operative mortality (AUC 0.829, $P < 0.001$), whilst PMA was not (AUC 0.507, $P = 0.949$). (Note that with dichotomisation of sarcopenia for survival curves, a HR above one indicates increased risk for sarcopenic patients; whilst treating sarcopenia as a continuous variable for peri-operative morbidity means that an OR below one indicates decreased risk for denser or larger (less sarcopenic) muscles).

These results suggest that PMD and PMA are not the same and should not be used interchangeably. They suggest that PMD is a more effective marker of operative risk than PMA, however confidence in this result must be tempered by it coming from a single cohort study, and the cohort being limited to elective colorectal cancer resection patients. The correlation between PMD and PMA has not been examined in the literature, nor their effectiveness as markers of operative risk directly compared. Repeating this analysis with other cohorts would be valuable for establishing whether, and in which circumstances, PMD is more effective than PMA as a marker of operative risk.

PMD is considered to relate to infiltration of the muscle with fat and connective tissue as part of sarcopenia, whilst PMA relates to muscles getting smaller in size [9]. An issue affecting PMA measurement is that muscle size does not just relate to sarcopenia – muscle size is affected by a number of factors including sex, body size, and baseline musculature. Whilst the effect of sex on muscle size can be addressed by comparing muscle size with patients of the same sex, variability in baseline musculature may be large when compared with the reduction in muscle size with sarcopenia - markedly reducing the signal to noise ratio when attempting to use PMA to measure sarcopenia. This may be the reason PMD appears a more effective marker of operative risk than PMA in this cohort.

The effect of different baseline muscle sizes on PMA measurement has been noted and indexing by height squared (or less often body surface area) has been implemented in the literature in an attempt to reduce the impact of body size on PMA [9]. Standardising body size by indexing to height squared was first described by Quetelet in 1835 and is the basis of the BMI calculation - it is well established that significant care needs to be taken when interpreting BMI measurements [14]. Whilst indexing PMA has been increasingly reported in the literature – we were unable to identify evidence in the literature supporting its effectiveness.

In this cohort indexing had a small effect numerically on PMA: PMA's correlation coefficient with PMA/H^2 was R^2=0.95 and with PMA/BSA was R^2=0.938. Like unindexed PMA, neither PMA/H^2 nor PMA/BSA correlated with peri-operative mortality or major-complications. However, whereas unindexed PMA had a statistically significant correlation with long-term survival (HR1.886, 95 %CI 1.322–2.692), neither PMA/H^2, nor PMA/BSA had a statistically significant relationship with long-term survival (with sarcopenia defined as the lowest quartile of measures, see supplementary Table 3). Kaplan-Meier survival curves were created comparing the lowest sex quartile with the upper three quartiles, as well as curves comparing each quartile for each psoas muscle measure. There appears to be much greater overlap of the quartiles when sarcopenia is defined by PMA/H^2 or PMA/BSA, than when sarcopenia is defined by PMD or PMA. It is also interesting to note that indexing reduced the correlation of PMA with age (as sarcopenia is thought to be progressive with age [16]): PMA vs age (R^2=0.0.062), PMA/H^2 vs age (R^2=0.029), and PMA/BSA vs age (R^2=0.023) (whilst PMD correlated better with age than any of the PMA measures: R^2=0.153). Furthermore, it is noteworthy that in this cohort, co-morbidities were more frequent in sarcopenic than non-sarcopenic patients identified using PMD or PMA; but this relationship was less clear when PMA/H^2 or PMA/BSA were used to define sarcopenia (see Supplementary Figure 1). Taken together, these results indicate that indexing PMA by height squared or body surface area has a small numerical impact on PMA, reduced the correlation with long-term survival (and, incidentally, with patient age), and did not result in PMA correlating with peri-operative morbidity. Indexing PMA adds significantly to the difficulty of measurement – as height (and weight for BSA) are required, in addition to the CT measurement. Our findings imply that the usefulness of indexing needs to be reconsidered, and the impact of indexing reported in future studies on muscle area. It may be that if area measurements are used, indexing should not be performed, or that improved approaches to indexing need to be developed.

Our results suggest that PMD is a more effective marker of operative risk than PMA, and that indexing PMA reduces (rather than improves) its effectiveness. These results have arisen from a single cohort of elective colorectal cancer resection patients. Given the importance

of effective psoas muscle measurement – it will be important to repeat these results in further cohorts to ensure that this cohort is representative of a broader population. Van Mourik et al. (2018) has reported intra-observer (correlation co-efficient 0.98) and inter-observer (correlation co-efficient 0.97) variance in the measurement of PMA [17]. PMA measurements in the literature have typically been performed by one observer and intra-observer variability has not been widely reported. This study could have been improved by both reporting intra-observer variability, and by having a second observer to enable inter-observer variability to be measured.

Future investigations could investigate simplifying PMD measurement by testing whether PMD needs to be measured from the L3 spinal level specifically to obtain useful prognostic information, or if simpler measurements can be taken between more easily identified anatomical landmarks (such as psoas muscle density at spinal levels between the iliac crest and costal margin).

Total skeletal muscle cross-sectional density (SMD) or area (SMA) are also reported as markers of operative risk. It has been established that SMA and PMA correlate poorly [18,19], however it has not been directly established which of these two is the more effective marker of operative risk. Given the effectiveness of PMD in this study, it would be valuable to compare SMA and SMD directly with PMD, to determine both the correlation with each other, and to identify which is the most effective marker of operative risk. SMA is usually indexed to height squared – given that indexing PMA to height squared was found to be counter-productive – the effectiveness of indexing SMA also needs to be assessed.

Whilst radiological sarcopenia measurements are an important factor to consider in surgical risk assessment, there are other factors that influence the risk of poor postoperative outcomes. Sandini et al's (2017) meta-analysis of 1,153,684 patients who had undergone major abdominal surgery found a strong association between frailty and major morbidity, short term mortality, and long-term mortality [20]. Meta-regression of their study demonstrated no association between age and post-operative morbidity or short term mortality once the effects of frailty were removed. Sandini et al's study treated sarcopenia as one component of frailty – finding that sarcopenia had a larger effect size (OR2.52, 95 %CI 1.32–4.80) in relation to major morbidity, than any other frailty domain, including functional tests. This current cohort study makes an important contribution in terms of optimising the measurement of psoas muscle for surgical risk assessment, however further work will be needed to correlate PMD with functional capacity and other frailty domains. This will enable examination of whether PMD should be used as a single marker, or in combination with other markers of frailty.

Routinely using the simplest and most effective measure of sarcopenia in risk assessments has potential to conserve resources, avert morbidity, and reduce mortality. The patients values, goals and preferences are critical to consider when recommending consideration of surgery; and being able to better inform patients of operative risks will enhance their ability to make informed decisions. PMD as a surgical risk marker warrants further consideration across a wide range of cohorts.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

CRediT authorship contribution statement

Louis Scarrold: Writing – review & editing, Writing – original draft, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Douglas Stupart:** Writing – review & editing, Writing – original draft, Supervision, Project administration, Formal analysis, Conceptualization. **David Watters:** Writing – review & editing, Supervision, Project administration, Methodology, Formal analysis, Conceptualization.

Disclosures of interest

On behalf of all authors, the corresponding author states that there is no conflict of interest.

Declaration of Generative AI and AI-assisted technologies in the writing process

No AI was used in the writing of this manuscript.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.tjfa.2025.100037.

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