Received:
17 May 2018

Revised:
22 August 2018

Accepted:
29 August 2018

<https://doi.org/10.1259/bjr.20180451>

Cite this article as:

Halpenny DF, Goncalves M, Schwitzer E, Golia Pernicka J, Jackson J, Gandelman S, et al. Computed tomography-derived assessments of regional muscle volume: Validating their use as predictors of whole body muscle volume in cancer patients. *Br J Radiol* 2018; **91**: 20180451.

FULL PAPER

Computed tomography-derived assessments of regional muscle volume: Validating their use as predictors of whole body muscle volume in cancer patients

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Objective: Evaluate the accuracy of CT-derived regional skeletal muscle volume (SMV) measurements to predict whole body SMV in patients with melanoma.

Methods: 148 patients with advanced melanoma who underwent whole body positron emission tomography/CT were studied. Whole body SMV was measured on CT and used as the reference standard. CT-derived regional measures of SMV were obtained in the thorax, abdomen, pelvis, and lower limbs. Models were developed on a discovery cohort (n=98), using linear regression to model whole body SMV as a function of each regional measure, and clinical factors. Predictive performance of the derived models was evaluated in a validation cohort (n = 50) by estimating the explained variation (R^2) of each model.

Results: In the discovery cohort, all regional SMV measurements were significantly associated with whole body

SMV [β 1 range: 0.673–1.153, all $p < 0.001$]. The magnitude of association was greatest for pelvic regional measurements ($\beta = 1.153$, [95% confidence interval (0.989, 1.317)]). Prediction algorithms incorporating clinical variables and regional SMVs were developed to estimate whole body SMV from regional assessments. Using the validation cohort to predict whole body SMV, the R^2 values for the pelvic, abdominal and thoracic regional measurements were 0.89, 0.86, 0.78.

Conclusion: Regional measures of SMV are strong predictors of whole body SMV in patients with advanced melanoma.

Advances in knowledge: The first study utilizing whole body imaging as a reference standard validating the use of regional SMVs in cancer patients, including validating the use of regional SMVs outside of traditionally assessed areas.

INTRODUCTION

Measures of body composition, including assessments of skeletal muscle, are independent predictors of outcomes in cancer patients.^{1–5} Anthropometric measures such as body mass index (BMI), are surrogates for body composition but cannot accurately categorize between adipose tissue and skeletal muscle. This has led investigators to move beyond BMI and utilize image based measures of body composition.

Dual energy X-ray absorptiometry (DXA), e.g. utilizes differences in the attenuation values of tissues at varying X-ray energies to differentiate between lean body mass,

fat mass and bone mass.⁶ Although commonly used DXA cannot accurately assess differences between visceral and subcutaneous adipose tissue as well as muscular components of lean tissue.⁷ CT is a widely used imaging technique in the oncology setting. Due to its ability to precisely discriminate between tissue subtypes, a growing number of groups have started to leverage clinically available CT images to assess *in vivo* body composition⁸ in multiple cancer types.^{5,9–14}

The vast majority of CT images in the oncology setting only include a limited portion of the patient's anatomy in

the field of view, *e.g.* individual CT exams will routinely evaluate the chest, abdomen and pelvis (rather than whole body CT). Consequently, investigators have been unable to utilize available scans to assess whole body composition. Instead, muscle area is typically measured at the level of the third lumbar vertebra (L3), which is used as a surrogate of whole body muscle.^{8,9} Of importance, in cancer patients, the technique of using CT-based regional measurement at L3 to predict whole body composition has only been validated against DXA, and not whole body MRI or CT imaging.⁹ Cross-sectional regional measurements have been validated against whole body MRI in healthy controls¹⁵ and against a cadaveric model.¹⁶ However, validation in healthy cohorts or cadaveric specimens is likely not applicable to patients with solid tumors due to the potential for considerably altered host energy balance that may be reflected in body composition.^{17–19} Burgeoning interest in utilizing regional CT to assess whole body composition in the oncology setting highlights the critical importance of validating the use of a regional measurement of muscle volume as a predictor of whole body muscle volume in patients with cancer.

Accordingly, we leveraged whole body CT images obtained during positron emission tomography (PET)/CT studies, in patients with advanced melanoma. Advanced melanoma is frequently characterized by multiorgan visceral and cutaneous dissemination, necessitating whole body imaging. Our primary objective was to evaluate the accuracy of select regional assessments (*i.e.* lower thorax, abdomen, pelvis, thigh and calf) to predict whole body muscle volume. A secondary objective was to develop and validate prediction algorithms to allow the estimation of whole body muscle volume from a limited regional assessment of muscle volume in the thorax, abdomen or pelvis.

METHODS AND MATERIALS

The Institutional Review Board approved this retrospective study and waived the requirement for informed consent.

Patient cohorts and setting

Patients ($n = 148$) with melanoma were studied. Patients with melanoma were selected as they represented the largest homogeneous group of patients who undergo whole body PET/CT at Memorial Sloan Kettering Cancer Center (MSKCC). Major inclusion criteria were: (1) distant metastases, in-transit/satellite metastases, or lymph node metastases, (2) availability of whole body PET/CT imaging without major image degrading artifact. Patients were excluded from analysis if their whole body images contained major image degrading artifact, *e.g.* streak artifact from metal implants, or if their entire body was not included in the field of view. Given the potential confounding influence of sex on body composition assessment, equal distribution of males versus females was included, once 74 females had been enrolled no further females were selected for analysis and only males were subsequently selected to complete the cohort of 148 patients. Using a retrospective design, all potential participants were identified and screened for eligibility using a key word search of institutional databases utilizing the terms “melanoma” and “positron emission tomography”. Eligibility was confirmed with a subsequent medical

Figure 1. Coronal image from a whole body CT demonstrating a color-coded map of voxels with mean HU values within the range -29 and $+150$ (colored green on this image). Using this technique a volumetric measurement of all tissues falling within this range can be generated. The HU range -29 and $+150$ is not specific for muscle and therefore non-muscular soft tissue need to be manually excluded (Figure 2). Note: the mid lower limbs and distal upper limbs are not visible due to the angled position of the limbs. HU, Hounsfield unit.

chart review and review of imaging on the institutional picture archive and communication system.

Image acquisition and analysis

All patients underwent PET-CT using Siemens Biograph (Siemens/CPS Innovations, Knoxville, TN) or Discovery LS, 690, ST or STE PET-CT scanners (GE Medical Systems, Milwaukee, WI). Unenhanced diagnostic CT was performed from the skull vertex to the toes without intravenous contrast, using tube voltage of 120 kVp; tube current of 100 mA; a pitch of 0.984; slice thickness of 3.75 mm; slice spacing of 3.27 mm; field of view of 700 mm. Each consecutive PET-CT was reviewed on picture archive and communication system software (Centricity, GE Healthcare, Milwaukee, WI). Using commercially available software (Aquarius Intuition, Terarecon, Foster City, CA), images were analyzed for the presence of muscle by two radiologists in consensus (DH, AP). Hounsfield unit (HU) thresholds of -29 and $+150$ were applied to the entire image volume (skull vertex to toes) as previously described.²⁰ A color-coded map of voxels with mean HU values within the range -29 and $+150$ was generated (Figure 1). Using this HU threshold, there is significant overlap between muscle and certain non-muscular soft tissues (*e.g.* the abdominopelvic viscera, brain, portions of the bone marrow). The color-coded image volume was interrogated for non-muscular soft tissues within the HU range of -29 and $+150$; these areas were manually excluded. Cardiac muscle and organs containing smooth muscle were also excluded. An image

containing only skeletal muscle was generated (Figure 2) which yielded a volumetric calculation of whole body skeletal muscle. This image was saved as a template and then used to obtain regional measurements of skeletal muscle volume (SMV).

Six regional measurements of muscle volume were obtained at the following levels: 10th thoracic vertebral body (T10), third lumbar vertebral body (L3), mid-pelvis (first image on which the sacroiliac joints no longer contacted the rest of the bony pelvis), proximal thigh (first image on which the ischial tuberosity was no longer visible), distal thigh (12 cm above the upper part of the patella), mid-calf (12 cm inferior to the patella). Using the saved template, eight consecutive images at a given regional level were included to provide a measurement of muscle volume, while all muscle cranial and caudal to these eight images were excluded. PET-CT measures of body composition end points were: whole body SMV, whole body skeletal muscle mass (SMV x skeletal muscle density).²¹

Anthropometric measurements and clinical variables

Weight, height, BMI and body surface area coinciding with the selected PET-CT imaging were abstracted from the electronic medical record. Clinical variables included age, sex, tumor stage, Eastern Cooperative Oncology Group score, prior as well as concurrent anticancer therapy, and steroid use and dose.

Statistical analysis

We conducted a small pilot study in 10 patients to obtain preliminary estimates of the standard deviation (SD) of several of the measurements (whole body muscle volume, regional muscle volume in the abdomen, regional muscle volume in the thorax). This pilot study resulted in estimates of approximately SD = 4733 cm³ for whole body muscle volume and SD = 51 and 44 cm³ for the thorax and abdominal regions, respectively. Given a correlation of 0.70–0.85 (the expected range) between a region level and whole body muscle volume, a sample size of 98 patients was needed to yield 80% power using two-sided 0.05 level tests in separate linear regression analyses for each region level measurement.

Linear regression was used to evaluate all univariate associations. $p < 0.05$ was considered statistically significant. We modeled the natural logarithm of each measurement and included quadratic terms for age at diagnosis and BMI in order to capture the functional form of the relationship between these variables and the anatomical measurements. Pearson correlation coefficients

(ρ) were estimated to provide an additional description of the correlation between the region level and whole body muscle volume measurements. Multivariate models were developed within the same regression framework using backward elimination. Interactions between variables were considered and included in the models when there was evidence of a statistically significant multiplicative relationship. We developed three prediction models for whole body smooth muscle volume. One was based on the anatomical level with the highest estimated regression coefficient between regional muscle volume and whole body muscle volume (the mid-pelvic level), one was based on the region most frequently used in the literature (the L3 level),^{15,22} and one model was based on the other region (aside from L3 and pelvis) which is routinely included in clinical CT assessments (the lower thorax/T10 level).

We estimated measurements in an additional 50 patients who were not included in the model development phase in order to validate our predictive models. Model performance was assessed on these 50 patients using the R^2 statistic, the coefficient of multiple determination. R^2 measures the percentage of variation in the whole body muscle measurements that is captured by the prediction model. Values close to 1 suggest a model that has good predictive accuracy while values close to 0 suggest a model with poor predictive accuracy. We refit the models including all patients and present results for the prediction models based on all 148 observations.

15 cases were selected at random and the measurement of whole body muscle volume repeated by each reader, enabling assessment of inter reader and intra reader variability. We used intra-class correlation coefficients (ICC) from two-way random effects models for these purposes. Intra- and interobserver variability was excellent for both readers. For interobserver variability, the ICC was 0.999 [95% CI (confidence interval) 0.998–1.000]. For intraobserver variability, the ICC for reader 1 (AP) was for 0.999 (95% CI 0.998–1.000) and 1.000 (95% CI 0.999–1.000) for reader 2 (DH).

Variables were considered statistically significant at the $p = 0.05$ level. All analyses were done in Stata/SE 13.1 for Windows (Copyright StataCorp LP, College Station, TX).

RESULTS

Patient characteristics are summarized in Table 1. Median age and BMI was 64 years (range 15–91 years) and 26.5 kg m⁻² (range 17.5–44.3 kg m⁻²), respectively. WHO BMI classification was as follows: 5 (3%) patients were underweight (BMI <18.5 kg m⁻²), 59 (40%) were overweight (BMI 25–29.9 kg m⁻²) and 35 (24%) were obese (BMI >30 kg m⁻²). 72 (49%) patients had distant metastatic disease, 76 (51%) had either regional nodal metastases and/or in transit/satellite metastases. Median whole body muscle volume was 21,878 cm³ (range 13,056–40,795 cm³) and median whole body muscle mass was 23.2 kg (range 13.8–43.2 kg) (Table 2 summarizes the range of whole body and regional muscle volumes, and whole body muscle masses).

Figure 2. Axial upper abdominal image from a whole body CT before and after manual exclusion of all non-skeletal muscle elements.

Table 1. Patient characteristics

Characteristics	Median (range)	n (%)
No. of participants		148 (100)
Age, yrs		
At diagnosis	58 (11, 86)	
At scan	64 (15, 91)	
BMI, kg m ⁻²	26.5 (17.5, 44.3)	
Height, cm	169 (146, 188)	
BSA, m ²	1.9 (1.4, 28.7)	
Gender		
Male		74 (50.0)
Race		
Non-Hispanic White		135 (91.2)
African American		2 (1.4)
Asian		3 (2.0)
Unknown		8 (5.4)
AJCC overall stage		
III		4 (2.7)
IIIA		16 (10.8)
IIIB		15 (10.1)
IIIC		39 (26.4)
IV		74 (50.0)
Primary site		
Extremities		74 (50.0)
Head/neck		21 (14.2)
Trunk		33 (22.3)
Unknown		20 (13.5)
Previous cancer diagnosis		
Yes		26 (17.6)
ECOG		
0		123 (83.7)
1		21 (14.3)
2		3 (2.0)
Prior treatment		
Surgery		140 (94.6)
Radiation therapy		46 (31.1)
Chemotherapy		57 (38.5)
Immunotherapy		44 (29.7)
No prior treatment for melanoma		4 (2.7)
Current treatment		
Radiation therapy		2 (1.4)
Chemotherapy		12 (8.2)
Immunotherapy		15 (10.1)
Systemic steroids		20 (13.5)

AJCC, American Joint Committee on Cancer; BMI, body mass index; BSA, body surface area; ECOG, Eastern Cooperative Oncology Group;

Univariate associations

Table 3 and Figure 3 present the univariate associations between clinical variables/anthropometric measurements and whole body muscle volume in the discovery set ($n = 98$ patients). All regional muscle volume measurements were significantly associated with whole body muscle volume [(β) 0.673–1.153 p 's < 0.001]; the highest correlations with whole body muscle volume were observed for the regional measurement in the pelvic region [$\rho = 0.84$, $\beta = 1.153$, (95% CI 0.989–1.317)], the L3 level, the most commonly used regional slice, [$\rho = 0.90$, $\beta = 0.936$, (95% CI 0.845–0.947)], and the proximal thigh [$\rho = 0.85$, $\beta = 0.997$, (95% CI 0.867, 1.128)].

Predictive models

The univariate associations were used to develop models for predicting whole body muscle volume at the T10, L3 and pelvic level (summarized in Tables 4 and 5 and supplementary material respectively). The models for each regional level are summarized in equation form below.

T10 level:

$$\text{Females : Estimated muscle volume}_{\text{Total}} = \exp \{ 6.6 + 0.6 \log(\text{thorax volume}) + 0.1/5 \text{ age dx} 0.002/25 \text{ age dx}^2 - 0.013 \log(\text{thorax volume}) \text{ age dx} + 0.010 \text{ BMI} \}$$

$$\text{Males : Estimated muscle volume}_{\text{Total}} = \exp \{ 6.8 + 0.6 \log(\text{thorax volume}) + 0.1/5 \text{ age dx} 0.002/25 \text{ age dx}^2 - 0.013 \log(\text{thorax volume}) \text{ age dx} + 0.010 \text{ BMI} \}$$

L3 level:

$$\text{Females: Estimated muscle volume}_{\text{Total}} = \exp \{ 4.15 + 0.94 \log(\text{abdomen volume}) + 0.20/5 \text{ age dx} - 0.002/25 \times \text{age dx}^2 - 0.03 \log(\text{abdomen volume}) \times \text{age dx} + 0.006 \times \text{BMI} \}$$

$$\text{Males : Estimated muscle volume}_{\text{Total}} = \exp \{ 4.35 + 0.94 \log(\text{abdomen volume}) + 0.20/5 \text{ age dx} 0.002/25 \text{ age dx}^2 - 0.03 \log(\text{abdomen volume}) \text{ age dx} + 0.006 \text{ BMI} \}$$

Pelvic level:

$$\text{Females : Estimated muscle volume}_{\text{Total}} = \exp \{ 4.23 + 0.87 \log(\text{pelvis volume}) + 0.04/5 \text{ age dx} 0.003/25 \text{ age dx}^2 + 0.003 \text{ BMI} \}$$

$$\text{Males : Estimated muscle volume}_{\text{Total}} = \exp \{ 6.12 + 0.61 \log(\text{pelvis volume}) + 0.045 \text{ age dx} 0.003/25 \text{ age dx}^2 + 0.003 \text{ BMI} \}$$

Age dx = age at diagnosis; exp = e (the exponential function); thorax volume = muscle volume from limited regional thoracic measurement; abdomen volume = muscle volume from limited regional abdominal measurement; pelvis volume = muscle volume from limited regional pelvic measurement; BMI = Body Mass Index.

Table 2. Whole body muscle volumes, whole body muscle masses and regional muscle volumes

Characteristics	All patients, median (range)	Males, median (range)	Females, median (range)
Whole body muscle volume, cm ³	21,878 (13,056–40,795)	27,183 (16,577–40,795)	18,217 (13,056–32,400)
Whole body muscle mass, kg	23.2 (13.8–43.2)	28.8 (17.6–43.2)	19.3 (13.8–34.3)
T10 muscle volume, cm ³	239 (127–495)	284 (141–450)	193 (127–495)
L3 muscle volume, cm ³	335 (185–629)	411 (185–629)	299 (205–581)
Pelvis muscle volume, cm ³	545 (302–925)	621 (302–925)	505 (308–795)
Upper thigh muscle volume, cm ³	685 (385–1235)	797 (482–1235)	624 (385–1114)
Lower thigh muscle volume, cm ³	488 (203–855)	530 (310–855)	434 (203–815)
Mid calf muscle volume, cm ³	332 (152–601)	365 (226–601)	300 (152–520)

L3, third lumbar vertebral body; T10, tenth thoracic vertebral body;

Figure 4 presents the assessment of the performance of the L3/abdominal regional muscle volume model in predicting whole body muscle volume in the validation cohort (Figures 5 and 6 depict the performance of the T10/thoracic, and the pelvic regional muscle volume models in predicting whole body muscle volume). The R^2 values for pelvis, abdominal (L3 level) and thoracic (T10 level) slices were 0.89, 0.86, and 0.78, respectively.

Table 3. Univariate associations between clinical variables/anthropometric measurements and whole body muscle volume in the discovery cohort

Characteristics	Regression coefficient (β)	95% CI	p-value
Sex			<0.001
Male	0.360	(0.282, 0.439)	
Age at diagnosis, 5 year increments			
Linear	0.083	(0.014, 0.180)	0.093
Quadratic	−0.003	(−0.008, 0.001)	0.054
Age at scan, 5 year increments	−0.011	(−0.029, 0.007)	0.217
BMI			
Linear	0.132	(0.051, 0.213))	0.002
Quadratic	−0.002	(−0.003, −0.001)	0.005
Metastatic disease			0.793
Yes	−0.014	(−0.180, 0.040)	
Regional measures of muscle volume			
T10	0.673	(0.564, 0.783)	<0.001
L3	0.936	(0.845, 1.027)	<0.001
Pelvis	1.153	(0.989, 1.317)	<0.001
Proximal thigh	0.997	(0.867, 1.128)	<0.001
Distal thigh	0.683	(0.527, 0.840)	<0.001
Calf	0.793	(0.647, 0.939)	<0.001

BMI, body mass index; T10, 10th thoracic vertebral body; L3, 3rd lumbar vertebral body; CI, confidence interval;

DISCUSSION

The primary purpose of this study was to use whole body CT images to determine the accuracy of regional measurements of muscle volume to predict whole body muscle volume in patients with advanced melanoma. This is the first study to evaluate regional CT images against whole body volumes in cancer patients, eliminating any confounding factors presented by using alternate modalities for the reference method. Our results indicate a high degree of concordance between the selected regional and whole body assessments, with the regional measures obtained in the abdomen, pelvis and upper thigh being the strongest predictors of whole body muscle volume. Regression models based on regional measures of muscle volumes in the pelvis, abdomen and thorax accurately predicted whole body muscle volumes in a validation set of patients with advanced melanoma. These data have important implications for ongoing studies utilizing CT to assess body composition in patients with cancer, indicating that regional CT images from the thorax, abdomen, pelvis and lower limbs can be validly used to study the effects of muscle mass on cancer outcomes.

Figure 3. Depicts the univariate associations between regional muscle volume measurements and whole body muscle volume.

Table 4. Predicting total muscle volume from the thorax measurement/T10

Characteristics	Regression coefficient (β)	95% CI	p-value
Intercept	6.567	(5.055, 8.079)	<0.001
Thorax	0.556	(0.275, 0.838)	0.155
Sex			<0.001
Male	0.252	(0.200, 0.305)	
Age at diagnosis, 5 year increments			
Linear	0.095	(−0.036, −0.227)	0.155
Quadratic	−0.002	(−0.004, −0.0004)	0.016
Thorax x age at diagnosis	−0.013	(−0.037, 0.011)	0.303
BMI			
Linear	0.010	(0.200, 0.305)	<0.001

BMI, body mass index; CI, confidence interval; T10, 10th thoracic vertebral body;

Low muscle mass is recognized as an important biomarker in oncologic populations and has been associated with increased mortality^{1,2} and increased risk of treatment complications across a variety of cancer types. While anthropometric measures such as BMI are widely available in the clinical setting, they cannot accurately detect low muscle, especially among the overweight and obese. Consequently, the use of CT as a research tool to measure regional muscle in cancer patients has grown.^{8,22} However, to our knowledge no study has validated the assessment of regional muscle in cancer patients using whole body cross-sectional imaging as the reference standard.

Table 5. Predicting total muscle volume from the abdominal measurement/L3

Characteristics	Regression coefficient (β)	95% CI	p-value
Intercept	4.146	(2.503, 5.788)	<0.001
Abdomen	0.939	(0.659, 1.220)	<0.001
Sex			
Male	0.201	(0.157, 0.245)	<0.001
Age at diagnosis, 5 year increments			
Linear	0.197	(0.050, 0.343)	0.009
Quadratic	-0.002	(-0.003, -0.001)	0.003
Abdomen x age at diagnosis	-0.028	(-0.052, -0.003)	0.026
BMI			
Linear	0.006	(0.003, 0.009)	<0.001

Figure 4. Relationship between expected muscle volume (based on regional measurement of L3 muscle volume), and observed whole body muscle volume. This model has an R^2 of 0.86.

In addition to providing the first validation of regional muscle measurement in cancer patients using whole body CT as the reference method, our results add to the existing literature in several important ways. A large portion of muscle mass is located in the appendices (~40%), particularly the lower limbs. Previous studies assessing muscle mass or lean body mass have shown a strong correlation between regional muscle measurements in the abdomen and whole body muscle. To our knowledge, there has been no *in vivo* assessment of the correlation between muscle mass in the lower extremities and whole body muscle mass using cross-sectional imaging. Our results show that the correlation between whole body muscle mass and regional measurements in the abdomen and pelvis are either as strong or stronger (depending on the level assessed) when compared to measurements in the appendices, further validating the use of abdominopelvic measures of muscle mass.

Figure 5. Relationship between expected muscle volume (based on regional measurement of T10 muscle volume), and observed whole body muscle volume. This model has an R^2 of 0.78.

Figure 6. Relationship between expected muscle volume (based on regional measurement of pelvic muscle volume), and observed whole body muscle volume. This model has an R^2 of 0.89.

In addition, although the degree of association between regional muscle volume in the lower thorax and whole body muscle volume was the lowest for all measured anatomical regions, the strength of correlation at the T10 level can still be considered high. This is important, as certain cancer populations, *e.g.* those with lung cancer, may only be imaged with chest CT (rather than a CT of the chest, abdomen and pelvis). Our results support the use of lower thoracic regional measures of muscle volumes if abdominopelvic images are not available.

This study has some important limitations. CTs were excluded when the entire patient was not included in the field of view. This is more likely to happen in patients who are obese, or in those who are unable to comply with instructions at the time of scanning, meaning that these populations are possibly under represented in our cohort. In general, the population of cancer patients that undergo wholebody PET/CT is limited, most of the common indications for PET/CT require a truncated assessment from the neck to the thighs. We selected a population of patients with melanoma as this represents the largest homogenous group of patients that undergo whole body PET/CT at MSKCC. Although ideally we would have assessed a group with a broader array of cancer types, this was not possible for the above reasons. One potential benefit of having focused on melanoma is that the age

range of our cohort is wide (as is typical for a cohort of patients with melanoma), which may make our results more generalizable to a larger population than if we had focused on a cancer which disproportionately affects older adults. An additional limitation is the low number of non-White participants in the study, which may limit its applicability to other racial groups. Due to the size of the study population, there were a limited number of variables that could be included in our model for predicting whole body muscle volume. We chose sex, BMI and age as the clinical variables to build into our model as we believed that these would have the most significant impact on muscle volume, however we acknowledge that other clinical variables may have impacted on the correlation between regional and total body muscle volume. Where possible we opted to use fixed osseous landmarks to measure regional muscle (*e.g.* L3 vertebral body), however in the lower limbs this was not possible given the lack of bony landmarks in the mid thigh/calf (*e.g.* in the thigh we opted to measure muscle 12 cm above the upper part of the patella). It is possible that using a distance halfway between two bony landmarks (rather than a fixed distance) would reflect differences in patients of varying sizes/heights, however we decided to use the method outlined above as we felt it was more reproducible.

In conclusion, using whole body CT demonstrated strong correlations between regional measurements of muscle volume and whole body muscle volume in patients with advanced melanoma. This study has important implications for ongoing research using regional CT images to assess muscle in cancer patients, validating the use of this technique and providing a tool to accurately estimate whole body muscle volume in the oncology setting.

CONFLICT OF INTEREST STATEMENT

Darragh Halpenny, Marcus Goncalves, Emily Schwitzer, Jennifer Golia Pernicka, Jasmyne Jackson, Stephanie Gandelman, Chaya Moskowitz, Michael Postow, Marina Mourtzakis, Bette Caan, Lee Jones and Andrew Plodkowski declare that they have no conflict of interest relevant to the submitted work.

FUNDING

This research was funded in part through the National Institutes of Health/National Cancer Institute Cancer Center Support Core Grant P30 CA008748 and by the National Cancer Institute of the National Institutes of Health under Award Number R25CA020449.

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