CT-Derived Body Composition Assessment as a Prognostic Tool in Oncologic Patients: From Opportunistic Research to Artificial Intelligence–Based Clinical Implementation

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CT-based body composition measures are well established in research settings as prognostic markers in oncologic patients. Numerous retrospective studies have shown the role of objective measurements extracted from abdominal CT images of skeletal muscle, abdominal fat, and bone mineral density in providing more accurate assessments of frailty and cancer cachexia in comparison with traditional clinical methods. Quantitative CT-based measurements of liver fat and aortic atherosclerotic calcification have received relatively less attention in cancer care but also provide prognostic information. Patients with cancer routinely undergo serial CT examinations for staging, treatment response, and surveillance, providing the opportunity for quantitative body composition assessment to be performed as part of routine clinical care. The emergence of fully automated artificial intelligence–based segmentation and quantification tools to replace earlier time-consuming manual and semiautomated methods for body composition analysis will allow these opportunistic measures to transition from the research realm to clinical practice. With continued investigation, the measurements may ultimately be applied to achieve more precise risk stratification as a component of personalized oncologic care.

Metrics of body composition have been extensively studied and have consistently been found to serve as important prognostic markers in patients with a variety of health conditions, including cancer [1–4]. These metrics include measurements of frailty, skeletal muscle, abdominal fat, bone mineral density (BMD), and atherosclerotic calcification [1]. In 2008, motivated by the consensus that "a consensus operational definition provides an opportunity for increased research" [5], an expert group developed a standard definition of cachexia, describing it as "a complex metabolic syndrome associated with underlying illness and characterized by loss of muscle with or without loss of fat mass" [5]. Determination of the presence of cachexia in patients with cancer has traditionally relied on patient weight or BMI. Over the past decade, it has become clear that determining the presence of cachexia is complex and may instead be better performed by body composition analysis using CT images [6]. For example, one study of oncologic patients found skeletal muscle depletion and low skeletal muscle attenuation on CT to be independently associated with poor prognosis, regardless of overall body weight [7]. CT-based body composition metrics thus have the potential to help perform risk stratification for patients with cancer and to tailor decisions regarding oncologic treatment.

Traditional clinical assessments of patient frailty are not easily implemented at population scale. In comparison, body composition parameters derived from CT scans can be readily extracted in an opportunistic manner without additional testing, as oncologic patients frequently undergo serial CT examinations as part of routine care for a range of indications, including baseline staging, assessment of response to therapy, and monitoring for recurrent disease after treatment. Although research to date has primarily investigated body composition measures obtained from baseline CT examinations (e.g., initial staging examinations), such measures, as observed on successive scans, may also serve as novel prognostic indicators.

Until recently, CT-based body composition analyses required time-consuming manual or semiautomated segmentation approaches. However, fully automated artificial intelligence (AI) algorithms have emerged that rapidly perform these analyses, facilitating population-level application of body composition measures. This review describes the potential

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role of body composition measures derived from abdominal CT scans in patients with cancer. We focus on the use of abdominal CT because the most commonly studied CT-based body composition markers are extracted from the upper abdomen [1, 8–11]. Nonetheless, these principles also largely apply to thoracic CT scans. For each tissue type presented (muscle, fat, bone, liver, and vasculature), we summarize the method for CT-based quantification and discuss its relevance to oncologic imaging (Table 1 and Fig. 1).

Body Composition Measures

Skeletal Muscle Quantity and Quality

Skeletal muscle is among the most studied regions in the field of body composition analysis. Sarcopenia is an overarching generic term for muscle loss or poor muscle quality and encompasses both myopenia (i.e., a decrease in skeletal muscle bulk) and myosteatosis (i.e., the presence of excess inter- and intramuscular adipose tissue, considered as a measure of skeletal muscle quality). Both of these processes have been linked to poor outcomes in a variety of oncologic outcomes [2, 12, 7], and at times these terms are used interchangeably. Nonetheless, decreases in muscle bulk and muscle quality have shown distinct biologic implications [13], supporting the use of myopenia and myosteatosis as distinct terms. The broader term "sarcopenia" is most commonly used in the context of the loss of skeletal muscle (myopenia) that occurs with aging [2, 14, 15].

Quantitative CT-based assessment of skeletal muscle includes the cross-sectional area of skeletal muscle (expressed as square centimeters), used to measure myopenia, and the mean attenuation of skeletal muscle (expressed as Hounsfield units), used to measure myosteatosis, with both measurements typically obtained at the level of the L3 vertebral body. Use of a manual ROI results in measuring the mean attenuation from a limited volume of muscle. In comparison, the use of a semiautomated or fully automated method allows inclusion of much larger volumes of skeletal muscle in the segmentation that is used for attenuation measurement [14–16]. Automated segmentations should include all skeletal muscle found within the psoas, paraspinal, and body wall musculature at the L3 level. The cross-sectional area can be normalized by patient height to provide a skeletal muscle index. Skeletal muscle assessment can alternatively be measured at the L1 level (or other thoracolumbar levels) [17, 18], to allow quantification from chest CT scans. The use of IV contrast material has a small effect on muscle attenuation measurements; when skeletal muscle quantification is performed using contrast-enhanced scans, adjustments can be applied to facilitate comparisons with data generated from unenhanced scans [19, 20].

Variation exists in the inclusion of intermuscular adipose tissue (IMAT) within the muscle segmentation when assessing myopenia and myosteatosis. Nonetheless, inclusion of IMAT within automated segmentations results in improved agreement between manual and automated measurements [21]. The inclusion of IMAT within automated segmentation also results in more rapid decreases with age in CT-based attenuation measurements [16] (Fig. 2) and appears to increase the prognostic utility of sarcopenia measurements for a variety of oncologic and nononcologic outcomes [17, 22].

Studies across multiple cancer types have shown the prognostic utility of the presence of sarcopenia (most commonly myopenia). For example, patients with advanced sarcoma [23], pancreatic cancer [24, 25], colorectal cancer [26], cervical cancer [27], esophageal cancer [28], ovarian cancer [29], and prostate cancer [30] have all been shown to have lower overall survival (OS) in the presence of myopenia established by a CT scan. In a study of patients undergoing colorectal cancer surgery, Pędziwiatr et al. [31] found that use of a laparoscopic (rather than open) surgical approach and an enhanced recovery after surgery (ERAS) protocol mitigated the negative impact of myopenia and myosteatosis on survival. This study illustrates a way in which knowledge of sarcopenia can be used to guide treatment approaches and improve outcomes. In addition to being a harbinger of worse survival, myopenia has been associated with a higher rate of complications from cancer treatment. This association has manifested as severe chemotherapy toxicity in patients with colon cancer and esophagogastric cancer [32, 33], increased dose-limiting toxicity from targeted tyrosine kinase inhibitor therapy in patients with renal cancer [34], increased postoperative complications after surgical resection of esophageal [28] or gastric cancer [35], and increased treatment-related mortality in patients with otherwise potentially curable hepatocellular carcinoma [36]. Finally, numerous studies have shown longitudinal changes in muscle mass during cancer treatment [37–39]; further investigation is needed to understand the prognostic implications of such changes.

HIGHLIGHTS

- *CT-based body composition measures of skeletal muscle, abdominal fat, and bone mineral density provide useful opportunistic information on frailty and cancer cachexia.*
- *CT-based measurements of atherosclerotic calcification and liver fat have received less attention in cancer care but may also have useful prognostic utility.*
- *Fully automated AI-based methods should transform opportunistic CT-based body composition assessment from the research realm to the clinic.*

TABLE 1: CT-Based Body Composition Measurements With Potential Application as Prognostic Markers in Oncologic Patients

Tissue	Measure(s)
Skeletal muscle	Muscle cross-sectional area Muscle mean attenuation
Adipose tissue	Visceral fat cross-sectional area Subcutaneous fat cross-sectional area Subcutaneous fat mean attenuation Ratio of visceral to subcutaneous fat areas
Bone	Bone mineral density
Liver	Hepatic steatosis Liver volume[a]
Abdominal aorta	Agatston calcium score Calcium mass or volume

[a]Not presented in this review.

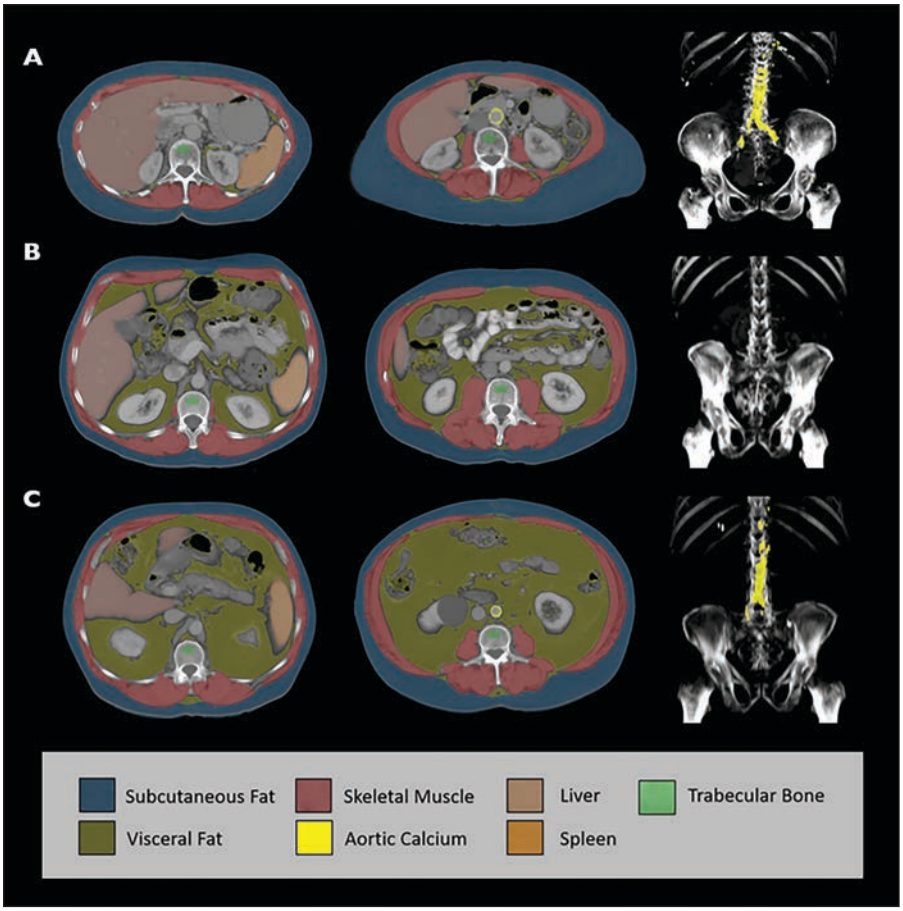


Fig. 1—Examples of baseline CT-based body composition assessment in patients with colorectal cancer.
A–**C,** Results of fully automated segmentation of various body tissues and organs using artificial intelligence (AI)-based algorithm for analysis of contrast-enhanced abdominal CT scans are shown for 79-year-old woman (**A**), 49-year-old man (**B**), and 63-year-old man (**C**) with colorectal cancer. Details regarding specific AI segmentation algorithms have been previously described [16, 62, 66, 86, 91]. Key specifies colors used to indicate segmentations of various tissues and organs. For each patient, first image in row is axial image obtained at L1 level, second image in row is axial image obtained at L3 level, and third image in row is coronal maximum-intensity-projection image showing calcified aortoiliac plaque. Quantification of segmentations of various tissues in terms of cross-sectional area, volume, or attenuation may hold prognostic value. In terms of survival risk, patient in **C** likely has worst overall combination of CT-based body composition parameters, with sarcopenic myosteatosis (muscle attenuation, 29 HU), fat distribution (subcutaneous adipose tissue [SAT], 137 cm^2; visceral adipose tissue [VAT], 344 cm^2; and ratio of visceral to subcutaneous adipose tissue [VSR], 2.5), and aortic calcium load (Agatston score, 10,273), compared with patient in **A** (muscle attenuation, 24 HU; SAT, 149 cm^2; VAT, 7 cm^2; VSR, 0.05; aortic Agatston score, 4089) and patient in **B** (muscle attenuation, 41 HU; SAT, 125 cm^2; VAT, 184 cm^2; VSR. 1.5; aortic Agatston score, 0). Patient in **C** did not have metastatic disease at diagnosis but died several years later, whereas patient in **A** remains alive 9 years after diagnosis and patient in **B** remains alive 4 years after diagnosis (despite having metastatic disease at presentation).

Studies have used varying criteria to define the presence of sarcopenia. Nonetheless, demographic factors such as age and sex are typically used in defining a normal skeletal muscle mass. A study by Wu et al. [40] used two different cutoffs, developed from populations from different geographic regions, for determining the presence or absence of sarcopenia based on the skeletal muscle index in a group of 146 patients with pancreatic cancer. One cutoff resulted in a baseline prevalence of sarcopenia of 66% and no significant association of sarcopenia with OS; the other cutoff resulted in a prevalence of 11% and a significant association with OS [40]. An additional study of patients with colorectal cancer found differences between men and women in terms of the association of skeletal muscle mass and mortality [41]. These studies illustrate the importance of establishing patient-specific definitions for sarcopenia as well as for other body composition measures for such measurements to become widely accepted as prognostic biomarkers. Automated quantitative tools used for determining CT-based muscle measurements in large patient cohorts will also need to consider variables such as age and sex when assessing the presence of sarcopenia.

In terms of myosteatosis, in a meta-analysis of 40 published studies, Aleixo et al. [2] found myosteatosis (i.e., decreased skeletal muscle attenuation) to be associated with shorter oncologic survival, with a 75% overall increase in mortality risk. The decrease in OS was observed in gastrointestinal, gynecologic, pancreatic, hepatic, renal, and hematologic malignancies. The parameters used to define myosteatosis were heterogeneous across studies. Myosteatosis was most often assessed for the psoas major muscle at the level of L3. The meta-analysis also observed that a range of muscle attenuation cutoffs have been used to define myosteatosis; the most commonly applied cutoff has been less than 41 HU in the presence of a BMI of less than 25 or less than 33 HU in the presence of a BMI of 25 or more. Studies have also varied in terms of whether different cutoffs were used in men and women. In another systematic review of patients with colorectal cancer, Valle et al. [42] also showed the prognostic utility of CT-based myosteatosis assessment [42]. Measures of myosteatosis may be preferable to measures of muscle area in clinical practice given the simplicity, reproducibility, and robust prognostic utility of such measures [1, 10, 17].

The combination of increased adipose tissue and low skeletal muscle mass and/or attenuation, known as sarcopenic obesity, appears to have distinct prognostic implications. For example, Prado et al. [4] reported lower functional status and poorer survival attributes among patients with sarcopenic obesity than among those with sarcopenia without obesity. Other studies have identified sarcopenic obesity as an independent risk factor for mortality in patients with gastric cancer [43] and a predictor of worse survival in patients who have undergone pancreaticoduodenectomy [24] and patients with nonmetastatic rectal cancer [44]. Although sarcopenic obesity typically has been evaluated at baseline in oncologic populations, one study showed that in

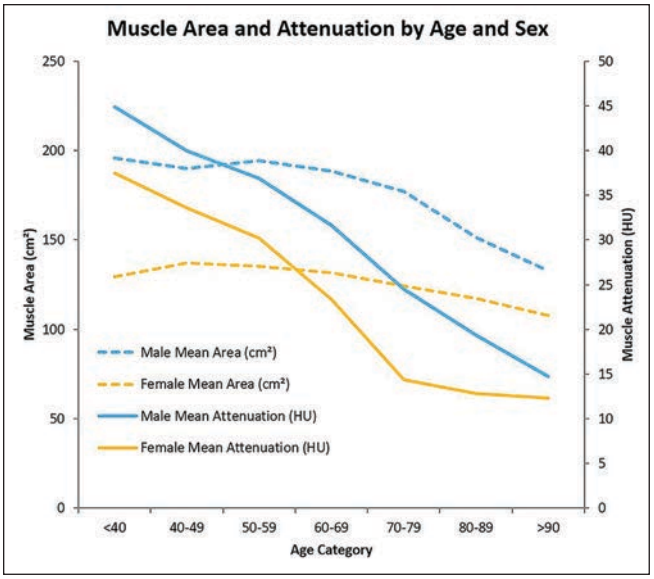


Fig. 2—Age and sex variation of automated CT-based skeletal muscle measures in adults. Graph shows data derived from cohort of asymptomatic adults using automated deep learning tool for skeletal muscle quantification at L3 level. Mean muscle cross-sectional area (*dashed lines*) varies less with age compared with mean muscle attenuation (*solid lines*), but both show overall consistent differences by sex. (Reprinted with permission from [16])

premenopausal patients with breast cancer, weight gain after adjuvant chemotherapy led to the posttreatment development of sarcopenic obesity [45].

As automated acquisition of CT-based body composition metrics becomes more widely available, sarcopenia assessment could become part of routine clinical cancer care. However, considerable work remains to standardize definitions, establish patient-specific thresholds, and show quality evidence on even larger scales than those presently available.

Abdominal Fat Volume and Distribution

As adipose tissue has an important role in physiology beyond serving as a passive store of energy, adipose tissue evaluation is a key component of body composition analysis. CT-based adipose tissue metrics may serve as more powerful markers than conventional metrics such as weight or BMI. Although methods have varied across the literature [46], visceral fat quantification in general involves the use of software to segment the intraabdominal compartment and calculate the cross-sectional area (expressed as square centimeters) of tissue having the attenuation values of fat (i.e., values of −150 to −50 HU) [47]. Measurements of fat volume performed using a single CT slice have been shown to correlate closely with fat volumes obtained from the total abdominal compartment [48]. Cross-sectional measurements have been performed at levels ranging from L1 to L4, including at the level of the umbilicus. The subcutaneous fat volume can also be quantified by segmenting a given level from the abdominal wall musculature to the skin. The visceral fat area and subcutaneous fat area can be combined to derive the total fat area [47]. Commercially available software products (e.g., FatSeg [Biomedical Imaging Group], OsiriX [Pixmeo], ImageJ [NIH], and SliceOmatic [TomoVision]) for semiautomated fat quantification appear to have excellent agreement, supporting comparisons of results from studies using these different software programs [49]. Although cutoff values have been proposed for establishing the presence of high visceral fat content [47], thresholds that can be widely applied across populations have not yet been established.

It is crucial to recognize the subcutaneous and visceral adipose tissue compartments as distinct entities with biologic differences. Subcutaneous fat purportedly represents "good" fat, whereas visceral fat purportedly represents "bad" fat. Fat quantification should thus use compartment-specific analyses, which is not possible with the use of BMI.

Increased levels of visceral adipose tissue have shown varying impacts in oncologic populations, both in terms of survival and the risk of complications. For example, increased visceral fat has been linked to reduced survival in patients with metastatic castrate-resistant prostate cancer on chemotherapy [50]; shorter distant disease-free survival in patients with breast cancer receiving neoadjuvant chemotherapy, particularly when such patients are postmenopausal [51]; and increased risk for lymph node metastases in patients who underwent resection for pancreatic adenocarcinoma as well as shortened survival among such patients who have nodal metastases [52]. However, other studies have shown increased visceral fat to be potentially beneficial or neutral. For example, one study of patients with colon cancer found an association of increased visceral adipose tissue with fewer lymph node metastases and better OS [53]. An additional large cohort study of patients with gynecologic malignancies found no significant association between visceral adiposity and patient survival [54]. In addition to its association with survival, increased visceral adiposity has been linked to treatment complications, such as those occurring after pancreatic surgery [55].

Subcutaneous adiposity has been evaluated using various metrics in oncologic patients. A study of patients with colorectal cancer found that the CT-based subcutaneous fat area, but not the visceral fat area, was independently associated with improved disease-free survival [56]. A study of patients with head and neck cancer treated with definitive chemoradiation found an association of high subcutaneous fat volume with locoregional control, metastasis-free survival, and OS [57]. Low subcutaneous fat volume was found to be associated with poor survival outcomes in patients with multiple myeloma [58]. The ratio of the visceral fat area to the subcutaneous fat area may also have prognostic utility. One study found that a high ratio of visceral fat to subcutaneous fat was an independent risk factor for surgical site infection after gastrectomy in patients with gastric cancer [59]. Finally, studies of the attenuation of subcutaneous fat have provided mixed results. In a study of men with high-risk prostate cancer who underwent radiation and androgen deprivation therapy, lower attenuation of subcutaneous fat was found to be associated with biochemical failure [60]. However, a study of patients with hepatocellular carcinoma found that increased attenuation of subcutaneous fat was negatively associated with survival [61]. Subcutaneous fat attenuation may be affected by various factors, including anasarca and the overall fat volume, possibly reducing the reliability of the metric.

Abdominal fat distribution shows clear differences, on average, between men and women. Lee et al. [62] used a fully automated tool to extract data on adiposity for a sample of 8852

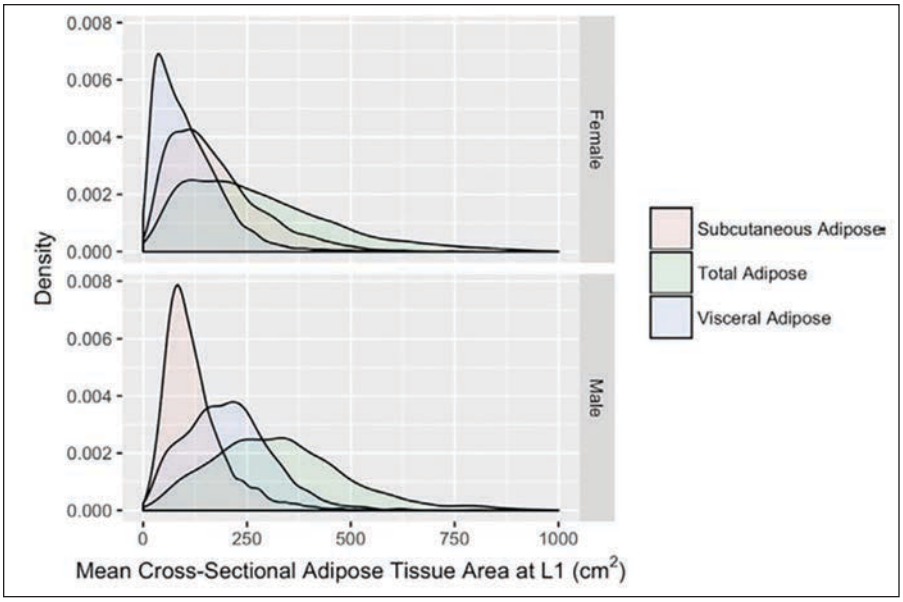


Fig. 3—Sex variation of automated CT-based subcutaneous and visceral fat in adults. Density plot compares distributions (*solid lines*) of subcutaneous, visceral, and total adipose tissue area at L1 vertebral level in cohort of asymptomatic adults by use of automated deep learning tool for skeletal muscle quantification at L1 level. In general, subcutaneous fat is greater in women, and visceral fat is greater in men. This distinction is obscured if measures of patient weight or body mass index are considered. (Reprinted with permission from [62])

asymptomatic adults and found significantly higher visceral adipose levels and significantly higher ratios of visceral to subcutaneous adipose in men than in women. Specifically, the mean ratio of visceral to subcutaneous fat was three times higher in men than in women (Fig. 3).

An overweight or obese state, as measured by BMI, has traditionally been considered a negative prognostic factor in patients with cancer. However, increased survival among overweight and mildly obese patients has also been reported on the basis of BMI, leading to what has been described as an obesity paradox [63]. Nonetheless, the conclusion that a mild increase in weight may be protective could be incorrect for multiple reasons. BMI is a crude metric for assessing adiposity [64] that does not distinguish between lean muscle mass and fat [63] or take into account the adipose tissue distribution. As Lennon et al. [63] indicated, in addition to having limitations associated with the use of BMI, studies suggesting a possible favorable prognostic impact of obesity are prone to confounding, detection bias, reverse causality, and selection bias.

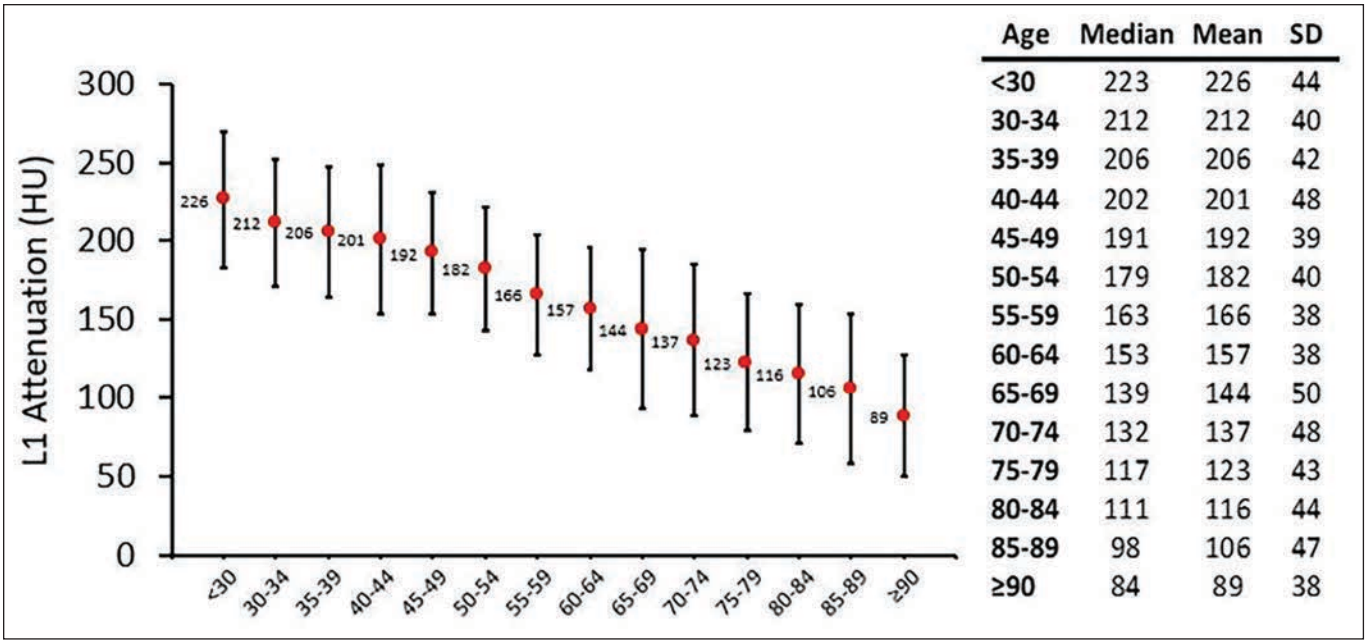
Bone Mineral Density

The most commonly used manual opportunistic metric for assessing BMD on CT is the mean attenuation of the trabecular bone at the level of the L1 vertebral body as assessed by ROI placement [65]. Automated tools can easily mimic this manual ROI placement in the trabecular space [66]. The attenuation value cutoffs commonly used to suggest osteoporosis range from less than 100 HU to less than 110 HU; a cutoff of less than 90 HU is associated with a significantly increased risk of prevalent and future osteoporotic fractures [67, 68]. Unlike skeletal muscle and adipose tissue measures, BMD assessment is highly sensitive to the specific kilovoltage setting [69]. Software has been developed to derive from abdominal CT scans femoral neck T scores that are equivalent to measurements obtained from dual-energy x-ray absorptiometry [70]; despite the use of software, this process may be more labor intensive than vertebral trabecular ROI placement. As with muscle attenuation, CT-based BMD measures are age dependent (Fig. 4A) [71]. In addition, premenopausal women show slightly increased BMD compared with age-matched men, a comparison that is reversed in postmenopausal patients (Fig. 4B).

Osteoporosis, the most common metabolic disease, is characterized by a decrease in BMD. Osteoporosis is highly prevalent worldwide and predominantly affects older individuals. A recent meta-analysis found among older patients a worldwide prevalence of osteoporosis of 22% [72]. In addition to the role of BMD in indicating risk for osteoporotic fractures, evidence indicates that BMD alone and in combination with other associated body composition metrics may be useful in the assessment of patients with cancer. This metric can be easily extracted from CT scans of the thorax or abdomen that are obtained for other indications [71].

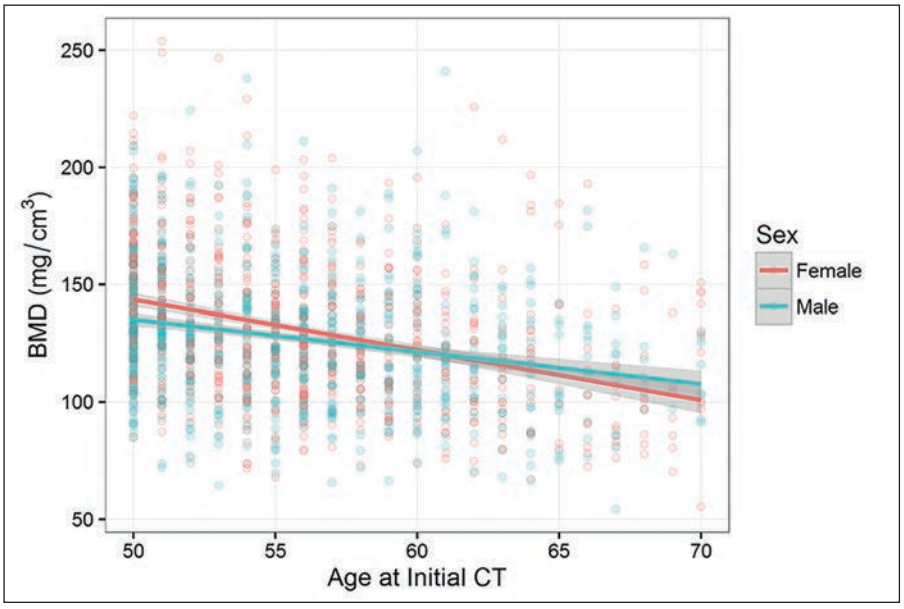
Patients who undergo screening CT examinations for lung [73, 74] or colorectal [75, 76] cancer may undergo opportunistic assessment for osteoporosis using CT images. One study in patients undergoing lung cancer screening found that BMD derived from CT, as well as the presence of vertebral fractures, independently predicts all-cause mortality [77]. Other studies using opportunistic automated body composition screening found that BMD predicted all-cause mortality in an asymptomatic screening population [22] and was equally as effective as the commonly used Fracture Risk Assessment Tool (FRAX) in predicting presymptomatic osteoporotic fractures in the general population [10]. Opportunistic BMD evaluation can also be used to assess for the development of osteoporosis and to stratify the risk of the future occurrence of fracture after cancer treatment, as shown in patients with prostate [78], gynecologic [79], and breast cancer [80].

Early research has also explored the role of osteoporosis in predicting oncologic outcomes, for example in breast cancer [81]. A decrease in BMD in combination with low skeletal muscle mass (osteosarcopenia), with or without obesity (osterosarcopenic obesity), may serve as a useful prognostic marker in oncologic patients. For example, a study of patients undergoing resection of colorectal cancer hepatic metastases found that osteosarcopenia and lymph node metastasis were independent predictors of worse OS [82].



Age	Median	Mean	SD
<30	223	226	44
30-34	212	212	40
35-39	206	206	42
40-44	202	201	48
45-49	191	192	39
50-54	179	182	40
55-59	163	166	38
60-64	153	157	38
65-69	139	144	50
70-74	132	137	48
75-79	117	123	43
80-84	111	116	44
85-89	98	106	47
≥90	84	89	38

A



B

Fig. 4—Age and sex variation of CT-based bone mineral density (BMD) in adults.
A, Graph shows data derived from large cohort of adults by use of both manual and automated ROIs placed in anterior trabecular space of L1 vertebral body. BMD measure progressively decreases with increasing age. Circles denote mean values, and vertical lines and whiskers indicate SD. (Reprinted with permission from [71])
B, Graph shows data derived from cohort of asymptomatic adults using automated tool for BMD measurement at L1 level. Compared with men, women show slightly higher L1 trabecular attenuation overall until approximately 1 decade after menopause, after which time measurement in women becomes slightly lower overall compared with that in men due to relatively accelerated bone loss. Circles denote individual data points, and solid lines denote best overall fit of data. (Reprinted with permission from [66])

Hepatic Steatosis

CT-based body composition analysis can also be used to evaluate hepatic steatosis. Although steatosis is an important marker of metabolic disease in general, it also has potential as a marker in the oncologic setting. Some cancer-related treatments can lead to an increase in hepatic fat content, as has been shown, for example, after chemotherapy in patients with pancreatic and breast [83] cancer. Unenhanced abdominal CT scans enable straightforward assessment of liver fat content, as mean attenuation via manual parenchymal ROI placement has a linear correlation with MRI-derived proton density fat fraction, both in phantoms and in human patients [84, 85]. Automated volumetric assessment of liver attenuation on unenhanced CT, as performed using deep learning tools, provides information similar to that provided by manual assessment and can be applied at population scale [86]. Liver fat quantification on contrast-enhanced CT is less precise but generally allows accurate categoric assessment of the severity of steatosis, particularly in the setting of moderate or severe steatosis [87]. A dual-energy technique using multimaterial decomposition may facilitate liver fat quantification on contrast-enhanced CT scans [88]. Fully automated deep learning tools have also been used to guide determination of the presence of hepatomegaly [89], which may provide an adjunct to steatosis assessment.

The prognostic roles of baseline hepatic steatosis and post-therapy changes in steatosis have yet to be studied in depth in oncologic patients. The development of automated deep learn-

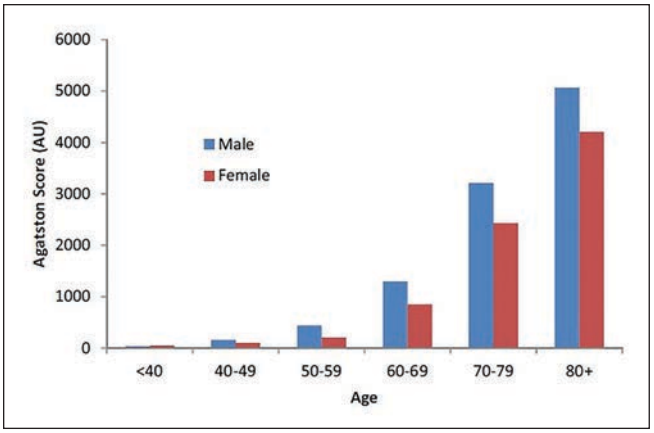


Fig. 5—Age and sex variation of automated CT-based aortic calcium load in adults. Graph shows data derived from cohort of asymptomatic adults using automated aortic calcium scoring tool. Progressive increase in load of atherosclerotic hard plaque is seen to occur with age. Women show overall trajectory similar to that shown for men, although aortic calcium load is delayed by approximately 1 decade. (Reprinted with permission from [91])

ing tools for hepatic fat evaluation will facilitate large-scale investigations of the possible prognostic role of this marker.

Aortic Calcium

Quantification of calcified atherosclerotic plaques of the abdominal aorta can be obtained manually or by use of semiautomatic segmentation tools that have traditionally been applied for evaluation of the coronary arteries [90]. However, fully automated deep learning tools have been developed for the specific purpose of CT-based aortic calcium segmentation and quantification [91]. CT-based aortic calcium measurements can be reported using the Agatston score, a metric conventionally used for reporting coronary artery calcification, or they can be reported in terms of aortic calcium volume (expressed as milliliters) or mass (expressed as milligrams) [91]. Aortic calcium can be quantified using either unenhanced or contrast-enhanced CT scans of the abdomen [92]. As with other body composition measures, cutoff values should account for patient age and sex. In a cohort of more than 9000 adults, Graffy et al. [91] found that mean aortic calcium Agatston scores were consistently higher in men than in women (Fig. 5). In addition, overall age-specific aortic Agatston scores showed an increase of approximately 10% per year.

Semiautomated and automated assessment of aortic calcification on CT has been shown to outperform the Framingham risk score in predicting adverse cardiac events in asymptomatic adults [22, 90]. An additional study of automated opportunistic CT-based body composition metrics found that aortic calcium predicted mortality independent of the other metrics in an asymptomatic screening population [22]. The longitudinal change in the aortic calcium load on CT also appears to be a useful prognostic measure in an asymptomatic screening setting [9].

Although the prognostic utility of aortic calcium has been shown in general screening populations, it has not been as well studied in oncologic patients as have other body composition metrics. Studies have found that higher levels of abdominal aortic calcium are associated with an increased risk of anastomotic leakage after resection of colorectal cancer [93, 94]. Aortic calcium is also associated with higher rates of noninfectious postoperative complications after colorectal resection [95]. Serial CT examinations may also show increases in aortic calcification, which has been shown for non–small cell lung cancer after chemoradiation [96] (though it is unclear whether this development directly impacts subsequent risk of cardiac events). Regardless of any specific association of aortic calcium with oncologic survival outcomes, aortic calcium is expected to remain an important predictor of the overall risk of mortality from cardiovascular events in oncologic patients; this risk may be taken into account during treatment planning.

Conclusion

A wealth of data supports the potential prognostic utility of CT-based body composition measures in patients with cancer. Limitations of research to date include the largely retrospective nature of the investigations and the focus on baseline rather than longitudinal metrics. In addition, body composition analysis has historically required manual or semiautomated segmentation of CT images. However, technologic advances in AI have enabled development of fully automated real-time tools for CT-based body composition analysis. Publications from the past 5 years have shown the feasibility of automatically extracting quantitative CT data for muscle, fat, bone, liver, and the aorta in large cohorts [10, 16, 20, 22, 62, 66, 86, 91]. This automated approach will provide a bridge for taking CT-based body composition from serving as a research tool to serving as a standardized and routine clinical method to help refine prognoses for patients with cancer, clarify risks associated with various therapies, and guide clinical colleagues in developing customized treatments. Through the use of fully automated body composition analysis, researchers should strive to integrate the individual metrics into comprehensive predictive models that outperform clinical decision tools. Opportunistic CT-based body composition analysis will need to be evaluated at large scales to refine the methodology and thresholds before clinical deployment and adoption into patient care. Ultimately, the automated tools should be embraced as a component of personalized oncologic treatment by providing more precise risk stratification and a novel means of longitudinal patient assessment.

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Editorial Comment: The Future Value of Automated CT-Derived Body Composition in Oncologic Patients

The ever-expanding role of imaging in the diagnosis, staging, and follow-up of patients with malignancy continues to evolve beyond the mere assessment of tumor measurements. Increasing utilization of novel treatment options that include specific tumor-targeted therapies expands the decision-making process regarding whether patients are ideally suited for surgery, radiation, chemotherapy, or other targeted therapy. This article provides a comprehensive summary of CT-derived parameters that may affect patient outcomes. These parameters include sarcopenia, body adiposity, bone density, hepatic steatosis, and atherosclerosis. Radiologists must become familiar with terms such as "sarcopenia," "myopenia," "myosteatosis," and "intermuscular adipose tissue."

Body composition measurements are not routinely performed on CT scans of oncologic patients, yet they can be easily obtained without additional acquisitions or increased radiation dose [1].

Rapid advances in artificial intelligence (AI) will enable the extraction of automated and semiautomated CT-derived body composition values from abdominal and thoracic CT scans [2]. This process moves away from manually measuring bone density, body adiposity, muscle mass, and muscle fat to provide quantitative values nearly as easily as through the use of the generation of sagittal and coronal reformatted images that are routinely included on CT scans today.

These body composition values provide prognostic information that alters the prediction of patient outcomes after surgery and chemotherapy as well as overall disease-free survival. As an example, a study by Martin et al. [3] found that among patients with lung and gastrointestinal cancer who had a high BMI, those with poor prognostic values of muscle attenuation, muscle index, and weight loss had a survival of 8.4 months compared with survival of 28.4 months for patients with normal body composition parameters.

Further prospective studies will be forthcoming on the use of CT-derived body composition parameters generated by automated AI for assessment of outcomes in patients with cancer. Radiologists should eagerly embrace these studies.

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