Imaging of body composition with CT: A review of its definitions, methods and clinical utility.

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Learning objectives

• To introduce the methods for CT segmentation in relation with body composition analysis.

• To highlight the value of a single slice CT scan to produce a good estimation of body composition.

• To introduce the concepts of visceral, subcutaneous, thoracic and epicardial fat and its relationship to different diseases.

• To sum up the current definitions of sarcopenia and the importance of CT in evaluating the sarcopenic patient.

• To summarize important clinical scenarios where sarcopenia plays a role as an independent risk factor.

• To make radiologists conscious of the added value of giving our clinical colleagues information in relation with patient's body composition.
Background

- Humans can differ a lot in their body composition. Gender, race and age plays major roles, but also diet, physical activity and their own genetic predispositions.

- Inspection of body habitus may give a clue about a given patient composition, but at the end we need to quantify in an objective manner to make clinical decisions.

- A lot of techines are available to the clinician to assess body composition. In this short review we will focus in CT and its use for fat and muscle mass quantification. It is important to remind, however, that bone also plays a role in numerous diseases states.
Findings and procedure details

FAT

• Body composition object of study is not only the raw measurement of fat and lean tissue but also of utmost importance its proportion and distribution in humans. The first to notice the importance of fat distribution in the outcome of obesity was Vague in 1947.

• Body composition parameters provide a more accurate approach than classic measurements such as weight or Quetelet's index, also known as Body Mass Index (BMI). This last measurement, although very popular, have proved to be weakly correlated to variables of interest and inferior to other measurements such as Waist to Hip Ratio (WHR) and visceral fat quantification by CT.

• A growing body of research provides insight on the clinical importance of body lean and fat tissue quantification on an important variety of clinical scenarios, mainly through prediction of morbidity and mortality.

• The reasons for visceral fat to confer a higher risk to human health is given by the fact that it is not an inert tissue to storage energy. It is rather a truly active endocrine organ with an important metabolism that decreases insuline sensitivity, increases serum tryglicerides, segregates adipocytokines and other vasoactive substances that promote metabolic syndrome and, when large, produces an adipocyte disfunction with release of pro-inflammatory molecules. These complex mechanisms confer a higher cardiovascular risk and susceptibility to some neoplasms (proved in endometrium, colorectal and breast cancer).

• Visceral obesity can be defined when at L3 level the ratio of visceral fat/subcutaneous fat > 0.4. Fig. 1 on page 11

• CT is considered to be a gold standard imaging technique for body composition analysis at tissue-organ level. Through attenuation values it is possible to make a clear distinction between muscle and adipose tissue. Moreover, its anatomical resolution allows also quantification by specific anatomic compartments.
• **Quantification can be done in multiple ways.** The most frequent one consists in selecting a single axial image (usually at L3 level, but L4 and L5 have also been used) and perform a segmentation using different Hounsfield units thresholds. Fig. 2 on page 9

• In a study by Shen et al., the best correlation between skeletal muscle area in a single slice and total volume was 5 cm above L4-L5 level, which roughly corresponds to L3. The best correlation between adipose tissue area and total volume was 5 cm below L4-L5. Multiple studies validate the use of a single abdominal CT slice for whole body composition analysis. This way is time savvy and easier to perform. **A single slice on L3 level have a reported correlation coefficient of r=0.94 with total visceral fat, and is the most frequently used in the literature.** Fig. 3 on page 15

• To note, inspiration increases intraabdominal pressure and overestimates (up to 20%) the amount of visceral fat. Subcutaneous fat remains the same. This is the reason to perform the study at the end of expiration.

• Images from contrast-enhanced or non-contrast studies can be used. **Fat segmentation is usually done with -190 and -30 Hounsfield units interval. Muscle segmentation is done with -29 and +150 Hounsfield units interval.**

• Popular and validated commercial software exists to perform segmentation in a semi-automated fashion. For this purpose, we can also use freely available and validated software.

**MUSCLE**

• Muscle is usually measured at L3 level too. Frequently, the psoas area is delineated after segmentation and this area is used for total muscle mass estimation. Others employ all the muscle in the slice (mainly psoas, paravertebral and abdominal wall muscles).

• The **European Society of Parenteral and Enteral Nutrition Special Interest Group** (ESPEN SIG) defines sarcopenia as requiring both a low muscle mass and an impaired muscular function. The ESPEN also sets sex-specific cut-offs based on CT analysis at L3: **52.4 cm2/m2 for men** and **38.5 cm2/m2 for women.**

• To date, there is no proved way to assess muscle function by imaging. More studies are needed to determine if imaging can accomplish a universal
definition of sarcopenia that includes muscle function as stated by the ESPEN.

RADIATION

- Radiation is always a matter of concern when employing CT technology. However, low-dose techniques, newer MDCT scanners, opportunistic use of imaging in different clinical scenarios and the technical possibility to perform a single axial image slice for whole-body quantification purposes will allow a more generalized use in the future.

CARDIOVASCULAR DISEASE AND FAT DEPOSITION Fig. 4 on page 9

- Visceral and especially epicardial fat is associated with a higher arterial stiffness.

- Epicardial fat, but not intrathoracic fat, is associated with coronary artery calcium even after adjustment for multiple variables and visceral adipose tissue. Intrathoracic but not epicardial fat is associated with calcification of aorta. This finding, among others, suggest a local toxic effect of fat deposits on arteries besides the systemic effects of visceral fat. Fig. 5 on page 10

- Perivascular fat contributes to formation of aortic aneurysms. The association of thoracic and abdominal fat with diameters of aneurysms was independent of other cardiovascular risk factors.

- Increased epicardial adipose tissue is associated with development of coronary atherosclerosis and especially with vulnerable plaques, even after adjustment for visceral fat. Increased epicardial fat is related to a higher likelihood of adverse cardiovascular events in asymptomatic patients.

- Interestingly, in the Framingham Heart Study, after adjustment for standard clinical measures, waist circumference and BMI, epicardial fat was more strongly associated with subsequent cardiovascular adverse effects than abdominal visceral fat, but the latter was more associated with stroke.
• These findings suggest that the toxic effects of fat is not only local in many cases but also a systemic one, especially for visceral fat.

• To note, increase in epicardial fat has been related to an increased risk for atrial fibrillation independent of age, gender, hypertension, left atrial enlargement, valvular heart disease, left ventricular ejection fraction, diabetes mellitus and BMI.

ABDOMINAL INFLAMMATORY DISEASES AND VISCERAL FAT

• Visceral fat deposition is thought to be a trigger element to develop severe pancreatitis instead of a milder form.

• Different studies have shown that visceral fat accumulation is a risk factor for complications and mortality in patients with acute necrotizing pancreatitis. Fig. 8 on page 14

• A growing interest in outcomes of acute inflammatory conditions of the abdomen and visceral fat and sarcopenia quantification may help elucidate pathogenic mechanisms and patient's risk stratification.

SARCOPENIA

• The number of clinical scenarios where sarcopenia have proved to be a significant and in many cases independent prognostic factor for mortality and morbidity is increasing exponentially. One of the most important applications of muscle quantification is in oncology. In this setting, important muscle loss in a very short period of time is a frequent problem. To note, sarcopenia is present in up to 15% of patients without weight loss, which demonstrates how important is an adequate muscle assessment by means other than direct weight measure or BMI.

• Sarcopenia lowers overall survival after surgery in patients with abdominal malignancies such as hepatocellular and colorectal carcinoma with a higher proportion of morbidity. Patients suffering from liver cirrhosis and sarcopenia have a lower survival rate compared with those without muscle depletion. Fig. 6 on page 12

• Sarcopenia and visceral fat accumulation is associated with complications in major thoracic and abdominal surgery. Fig. 7 on page 13
• Sarcopenia is also an independent risk factor for male patients with diffuse large B-cell lymphoma.

• Outside the abdomen, a lower muscle quantification of thoracic muscles involved in breathing is associated with a poorer prognosis in patients with chronic obstructive pulmonary disease.
**Fig. 2:** Abdominal CT scan slice at L3. After segmentation for fat (-190 to -30 HU we obtain the total fat area. Next, it is possible to draw a line that separates subcutaneous from visceral fat and obtain the inside (visceral) area. We can thus obtain subcutaneous fat.

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Fig. 4: Upper row: intrathoracic fat. Lower image: epicardial fat. Both behave differently in relation to cardiovascular health.

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Fig. 5: Left image: a soft coronary plaque. Right image: important coronary artery calcium. The relation of different fat depots in coronary and vascular health is complex. It seems that one way to produce vascular damage is by local toxic effect of fat.

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**Fig. 1:** Abdominal CT scan at L3 in a visceral obese patient with abdominal aortic aneurysm and mural thrombosis. Note the difference between the small subcutaneous adipose tissue (blue arrow) and the amount of visceral adipose tissue (white arrow). It is important to notice that retroperitoneal fat (red arrow) is included in the visceral fat compartment.
Fig. 6: Patient with stigmata of liver cirrosis and a hypervascular lesion on segment III in relation with a hepatocellular carcinoma.

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Fig. 7: Anastomotic leak. Visceral obese and sarcopenic patients suffer from more perioperative complications.

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**Fig. 8:** Severe necrotizing acute pancreatitis. Recently, a growing interest in visceral fat accumulation and a worse prognosis in various acute abdominal inflammatory diseases have produced interesting results.

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Fig. 3: Various methods to estimate total fat and fat-free mass volumes from single slice CT scan.

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Conclusion

- An important body of research highlights the crucial importance of body composition in various diseases.

- A simple method with a single slice at L3 can give a good estimation of overall muscle and fat volumes in a given patient.

- A growing interest in body composition analysis outside its classical applications in cardiovascular health opens new questions and research fields.

- It might come a day when body composition analysis become routine in a subset of patients, so radiologists should be familiar with its different methods.
References