Abdominal ultrasonography as a tool to quantify adipose tissue in critically ill patients

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ABSTRACT

Adipose tissue has important roles in both healthy and disease states. Quantifying adipose tissue composition and distribution may help predict outcomes and guide management in intensive care unit patients. Computed tomography is the preferred method for measuring adipose tissue but has drawbacks, such as radiation exposure and the need to transport patients. Ultrasonography is a safer, more convenient alternative for bedside assessment of body fat composition. This review examines the relevance of adipose tissue in critical illness and describes ultrasound techniques to quantify subcutaneous, visceral, and epicardial adipose tissue depots. Standardized protocols to measure subcutaneous fat thickness at multiple sites and approaches to estimate visceral fat using the supraumbilical or xipho-umbilical lines are discussed. A technique to quantify epicardial fat thickness using transthoracic echocardiography is also presented. While more research is needed, bedside ultrasonography shows promise for monitoring adipose tissue changes and their potential associations with outcomes in critically ill patients.

Keywords: Ultrasonography, critical illness, body composition, subcutaneous adipose tissue, visceral adipose tissue, epicardial adipose tissue

INTRODUCTION

Adipose tissue has many functions, especially in energy homeostasis and lipid metabolism. It also modulates other physiologic processes, including innate and adaptive immune responses, insulin sensitivity, and body temperature regulation. During periods of critical illness, adipose tissue can undergo significant changes in morphology, gene expression, and cytokine secretion.[1–3] These changes affect energy availability, steroid hormonogenesis, and immune system activity—all functions considered particularly significant in the intensive care patient. As the understanding of adipose tissue and its effects on normal and disease-state physiology continues to increase, the composition, distribution, and activity of adipose tissue in patients may interest critical care specialists.

Computed tomography (CT) is considered the preferred method for measuring adipose tissue mass in critically ill patients.[4,5] However, it has several disadvantages, namely its use of ionizing radiation and the inconvenience associated with transporting patients outside of the intensive care unit (ICU) to obtain scans. The convenience of performing scans at the bedside without exposing patients to ionizing radiation makes ultrasonography an attractive option for monitoring fat composition in critically ill patients. Currently there is no widely accepted protocol to quantify subcutaneous or visceral adipose tissue using point-of-care ultrasonography. This paper reviews the relevance of adipose tissue in critical illness and ultrasound techniques used to assess body fat composition in the ICU.

ADIPOSE TISSUE—COMPOSITION, TYPES, AND DISTRIBUTIONS

Adipose tissue is a loose connective tissue found throughout the body. It is composed of adipocytes, which make up 90% of adipose tissue by volume, and

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Table 1. Classification of Total Body Adipose Tissue

Adipose Tissue Compartment	Definition
Total adipose tissue	Sum of adipose tissue.
Subcutaneous adipose tissue (SAT)	Adipose tissue found between the dermis and the aponeuroses and fasciae of the muscles. Includes mammary adipose tissue.
Superficial subcutaneous adipose tissue	The layer of subcutaneous adipose tissue found between the skin and muscle fascia.
Deep subcutaneous adipose tissue	The layer of subcutaneous adipose tissue found between muscle fascia and a deeper fascial plane in the abdomen, pelvis, and gluteal-thigh area.
Marrow adipose tissue	Adipose tissue found within the bone marrow.
Internal adipose tissue	Total adipose tissue minus subcutaneous adipose tissue and marrow adipose tissue.
Visceral adipose tissue (VAT)	Adipose tissue found within the chest, abdomen, and pelvis.
Intrathoracic adipose tissue	Adipose tissue found within the chest.
Epicardial adipose tissue	Adipose tissue found on the surface of the myocardium. Contained entirely within the pericardium.
Pericardial adipose tissue	Adipose tissue found on the superficial surface of the parietal pericardium. Also referred to as "extrapericardial."
Intra-abdominopelvic adipose tissue	Adipose tissue found within the abdomen and pelvis.
Intraperitoneal adipose tissue	Adipose tissue found within the peritoneum. Includes omental and mesenteric adipose tissue.
Extraperitoneal adipose tissue	Adipose tissue found outside of the peritoneum but within the lower trunk.
Intraabdominal adipose tissue	Adipose tissue found within the abdominal cavity.
Preperitoneal adipose tissue	Adipose tissue found between the transversalis fascia and parietal peritoneum.
Retroperitoneal adipose tissue	Adipose tissue found posteriorly to the peritoneum. Includes perirenal, pararenal, periaortic, and peripancreatic adipose tissue.
Intrapelvic adipose tissue	Adipose tissue found within the pelvic cavity. Includes parametrial, retropubic, paravesical, retrouterine, pararectal, and retrorectal (presacral) adipose tissue.
Non-visceral internal adipose tissue	Internal adipose tissue minus visceral adipose tissue.
Intramuscular adipose tissue	Adipose tissue found between muscle fascicles.
Perimuscular adipose tissue	Adipose tissue found inside the muscle fascia (deep fascia), excluding intramuscular adipose tissue.
Intermuscular adipose tissue	Adipose tissue found between muscles.
Paraosseal adipose tissue	Adipose tissue found between muscle and bone (e.g., paravertebral).
Other non-visceral adipose tissue	Orbital adipose tissue; aberrant adipose tissue associated with pathological conditions (e.g., lipoma).

Modified from Shen et al. (2003)[6].

several other supporting cells, including mesenchymal stem cells, preadipocytes, fibroblasts, macrophages, T lymphocytes, and vascular endothelial cells. There are two main types of adipose tissue, white adipose tissue and brown adipose tissue. White adipose tissue is the most abundant type found in adults and is localized to the hypodermis (subcutaneous adipose tissue, SAT), intrathoracic and intra-abdominopelvic cavities (visceral adipose tissue, VAT), muscle compartments, bone marrow, and other distinct depots (Table 1). Brown adipose tissue is found abundantly in newborns and hibernating mammals but is absent or undetectable in most adult men and women.

While once considered only inert storage sites for lipids and lipid-soluble molecules, adipose tissue is now known to be an integral part of the human endocrinologic system. Adipocytes secrete hundreds of unique bioactive peptides (adipocyte-specific adipokines) capable of regulating mood, appetite, insulin sensitivity and secretion, blood pressure, hemostasis, wound healing, and humoral and cellular immunity. Macrophages and other cells within the stromal vascular fraction of adipose tissue secrete additional cytokines, including TNF-α, IL-1β, and IL-6, which modulate adipogenesis and immune system activity. Therefore, adipose tissue has been described as another endocrine organ.[7] Alterations in adipose tissue function inevitably lead to changes in other organ systems.

RELEVANCE OF ADIPOSE TISSUE IN THE INTENSIVE CARE SETTING

Patients with excess adipose tissue (i.e., obesity) have different respiratory, cardiovascular, and metabolic characteristics than patients with normal amounts of adipose tissue.[8–10] For example, patients with obesity expend more energy to breathe, have lower respiratory compliances, and may benefit from different mechanical ventilation strategies (e.g., higher positive end-expiratory pressures in the setting of acute respiratory distress syndrome) than patients without obesity.[8,11–12] Observational studies have demonstrated that people with more visceral adipose tissue have higher serum levels of acute phase reactants, including C-reactive protein, IL-6, and TNF-α.[13,14]
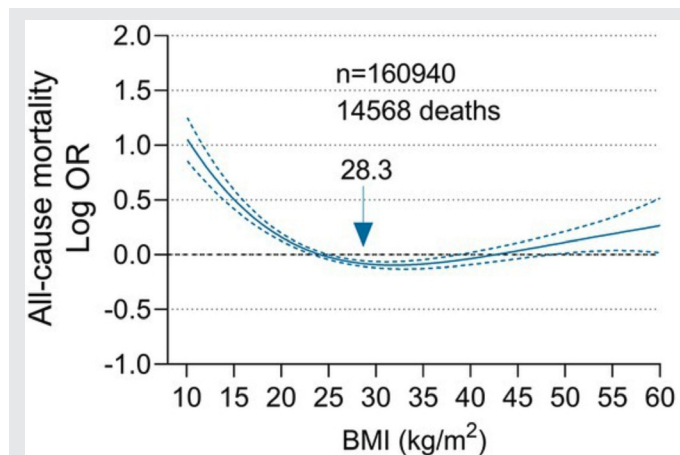

Figure 1. Association between BMI and all-cause mortality based on a sample of 160,940 patients in the eICU Clinical Research Database. Figure reproduced from Li et al. (2023) under Creative Commons 4.0 License.

Consequently, some authors have described obesity as a condition of "chronic, low-grade inflammation."[15]

Obesity confers an increased risk of all-cause mortality in the general population.[16] In the critically ill, however, obesity has been repeatedly shown to confer a paradoxical survival advantage. Recent meta-analyses have demonstrated that body mass indices (BMIs) between 25 kg/m^2 and 40 kg/m^2 are associated with decreased mortality from sepsis, acute respiratory distress syndrome (ARDS), and critical illness in general than BMIs less than 25 kg/m^2 or more than 40 kg/m^2.[17–19] A retrospective study of 160,940 ICU patients found the BMI associated with the lowest likelihood of all-cause mortality in the ICU is 28.3 (Figure 1).[20] This survival benefit exists even though patients with BMIs above 25 are more likely to develop acute kidney injury, ARDS, and catheter-related infections in the ICU, and may be less likely to be recognized as malnourished than patients with normal or underweight BMIs.[21–25]

Some authors have pointed out that when adjusted for confounding variables, such as nutritional status, the paradoxical survival advantage of higher BMIs disappears.[26] Others have shown that when adipose tissue mass is directly measured, excessive adipose

tissue in certain compartments (visceral, intermuscular, and epicardial adipose tissue) is actually associated with worse survival in critically ill patients.[27–29] The true relationship between body composition and outcomes in the critically ill remains uncertain. However, these studies suggest that quantifying adipose tissue directly with imaging techniques may be useful in predicting outcomes or assessing nutritional status in the ICU.

CURRENT TECHNIQUES FOR QUANTIFYING ADIPOSE TISSUE IN THE CRITICALLY ILL

Anthropometric techniques (e.g., height, weight, BMI, body circumferences, skinfold thickness) are the most commonly used methods to evaluate body composition in the critically ill. More advanced techniques, including bioelectrical impedance analysis, dual-energy X-ray absorptiometry (DXA), air displacement plethysmography (ADP), magnetic resonance imaging (MRI), CT, and ultrasound, have been used in pediatric and adult intensive care units (ICUs).[30] The ideal technique for quantifying adipose tissue in critical care settings should be safe and cost-effective for the patient, as well as accurate and reproducible. With 15–20% of ICU patients being obese, it is important to consider accessibility when choosing an imaging modality.

Anthropometric measurements, such as BMI, waist circumference, and waist-to-hip ratio offer convenient and accessible ways to categorize adipose tissue. However, these methods are unable to directly quantify adipose tissue mass or differentiate between visceral and subcutaneous adipose tissue. Although bioelectrical impedance analysis can be used to estimate total fat mass, it cannot differentiate between visceral and subcutaneous fat. It has also not been validated in critically ill populations and is unreliable in people with non-standard distributions of water and electrolytes, such as patients with chronic kidney disease and patients undergoing rapid changes in hydration status.[31,32]

Air displacement plethysmography and DXA provide indirect measurements of visceral adipose tissue volume. Air displacement plethysmography uses pressure-volu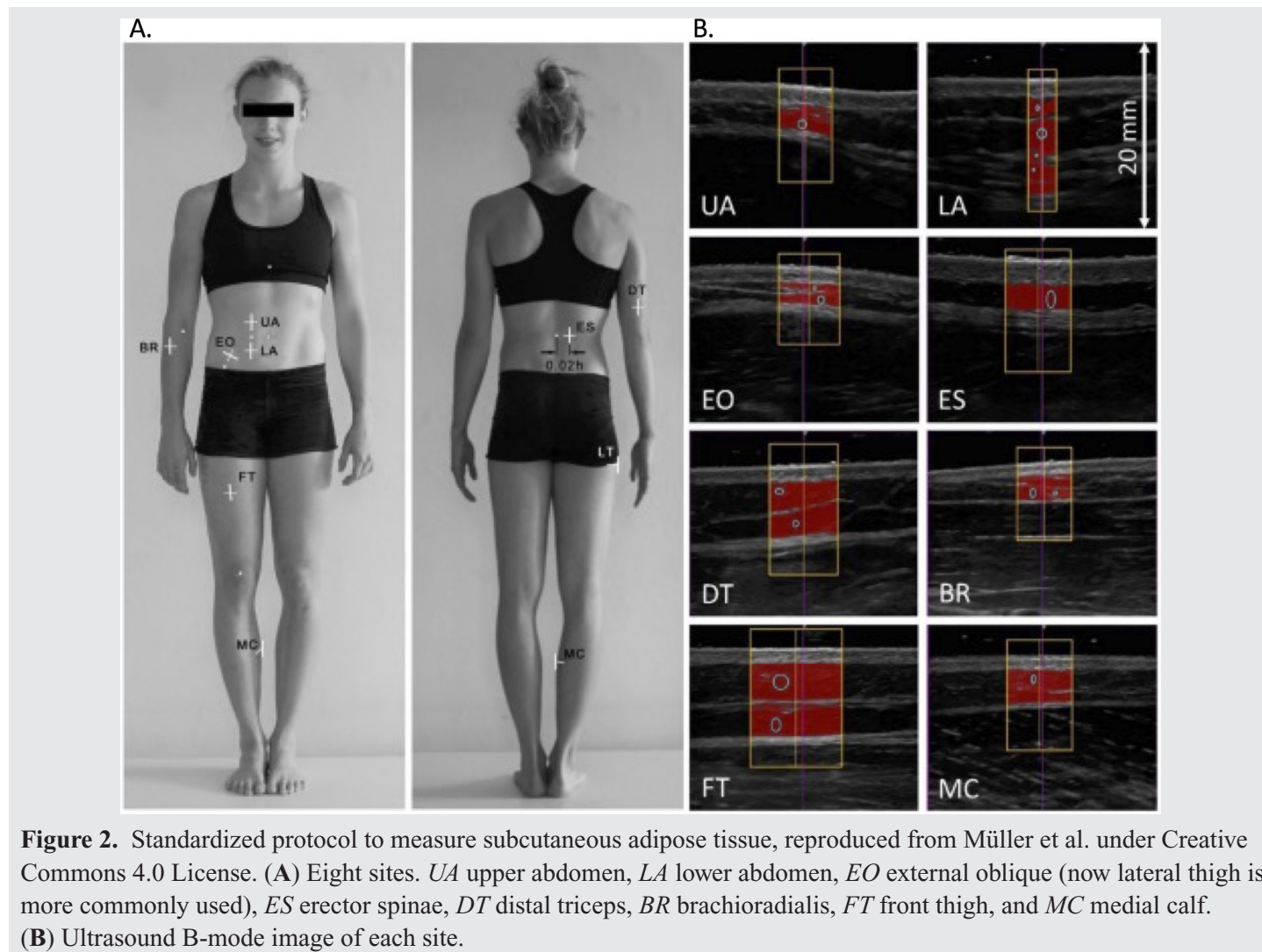me relationships to predict body volume and body density. While DXA is more commonly used to measure bone density, it also has the capacity to assess fat composition. Both air displacement plethysmography and DXA are promising methods for analyzing body composition; however, due to their inability to distinguish between different types of adipose tissue, they may have less utility than CT or ultrasonography. As ADP and DXA use becomes more common in clinical settings for measuring body composition, more research is needed to develop methods for accurate readings.

Computed tomography is currently considered the gold standard method for quantifying adipose tissue volumes in healthy and ill patients.[33,34] It can differentiate between all types of white adipose tissue and has proven accuracy in differentiation of visceral and subcutaneous adipose tissue; however, the expense, exposure to radiation, and inconvenience of the inability to perform the scan bedside are factors that make it a less useful as an imaging modality for monitoring fat composition in the critical care setting.

Ultrasound imaging can be performed at the bedside, does not expose patients to ionizing radiation, and can be used to quantify visceral, subcutaneous, and epicardial fat. At the moment, there is no widely accepted protocol to quantify adipose tissue using point-of-care ultrasonography. In the following section, we review the various ultrasound techniques currently used to assess body fat composition.

QUANTIFYING ADIPOSE TISSUE WITH ULTRASONOGRAPHY—A REVIEW OF TECHNIQUES

In 1965, Bullen et al. used ultrasonography to measure SAT thickness in 100 subjects—the first reported study of its kind.[35] They used a probe with an early, one-dimensional scanning mode called "A-mode" ("A" standing for "Amplitude") to record measurements at three sites: on the triceps, below the scapula, and two centimeters below and to the right of the umbilicus. The measurements were compared to those made by skinfold thickness and core needle biopsies. The results demonstrated an excellent correlation between ultrasonographic and needle puncture measurements, especially at the abdominal site (r = 0.98).

Figure 2. Standardized protocol to measure subcutaneous adipose tissue, reproduced from Müller et al. under Creative Commons 4.0 License. (**A**) Eight sites. *UA* upper abdomen, *LA* lower abdomen, *EO* external oblique (now lateral thigh is more commonly used), *ES* erector spinae, *DT* distal triceps, *BR* brachioradialis, *FT* front thigh, and *MC* medial calf. (**B**) Ultrasound B-mode image of each site.

Many methods have since been proposed to measure SAT thickness. The most accurate technique is the standardized protocol established by the International Olympic Committee Medical Commission.[36] This protocol measures SAT thickness at eight sites: upper abdomen, lower abdomen, erector spinae, distal triceps, brachioradialis, lateral thigh, front thigh, and medial calf (Figure 2). All sites have clearly visible fascial layers, no nearby complex structures, and little variation in SAT thickness around the site. Due to the high resolution of ultrasound, this protocol is considered more accurate and precise than other imaging methods, including MRI and CT.[37] However, due to the number of sites that require imaging, repeat examinations may

be cumbersome. A technique more suitable for repeat measurements of SAT thickness might be the one proposed by Suzuki et al., which involves scanning the xipho-umbilical line to determine the point of maximum SAT thickness (Figure 3).[38] This examination is accurate, repeatable, reproducible, and quick to perform. For these reasons it is one of the more common techniques used in clinical practice today.[39]

In 1990, Armellini et al. reported the first use of ultrasonography to measure VAT (more specifically intraperitoneal adipose tissue) thickness in 50 female subjects.[40] In their technique, a 3.5-MHz transducer was applied just superior to the umbilicus in subjects
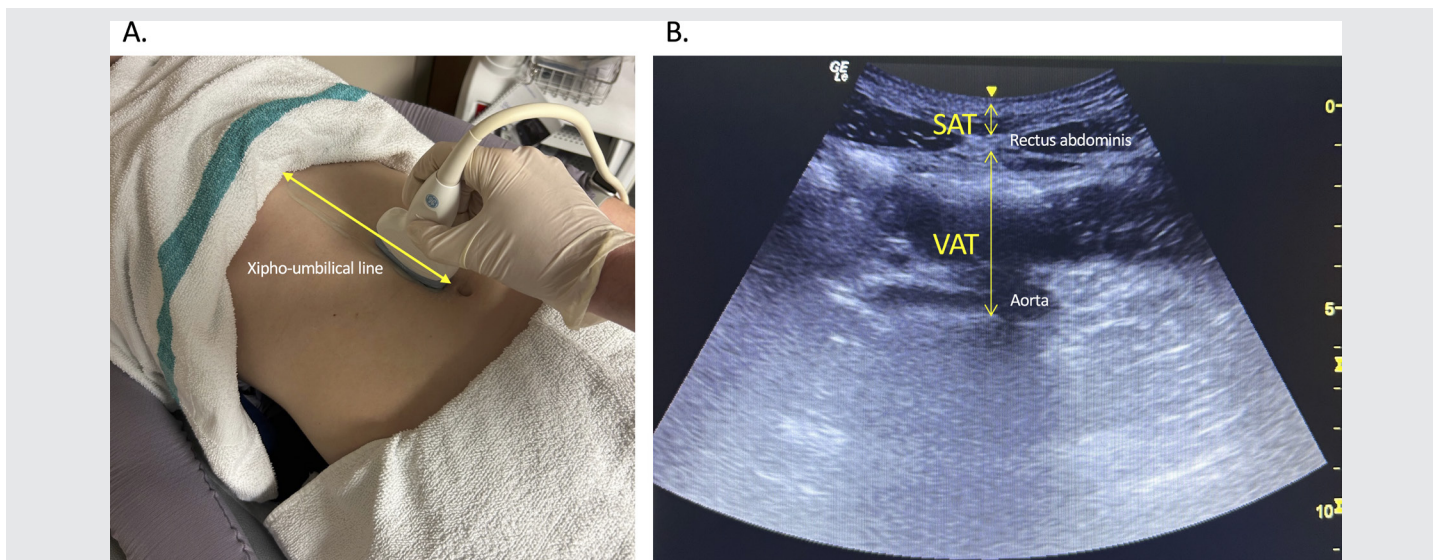
Figure 3. Xipho-umbilical approach to measure SAT and VAT. (**A**) Demonstration of xipho-umbilical line. (**B**) Labeled B-mode image.

lying in the supine position. Images were recorded using the B-mode. To estimate VAT thickness, the authors measured the distance between the posterior surface of the rectus sheath and the posterior wall of the abdominal aorta (Figure 4). Their ultrasonographic measurements correlated significantly with VAT measurements calculated from CT scans taken at the level of the fourth lumbar vertebra (r = 0.67,
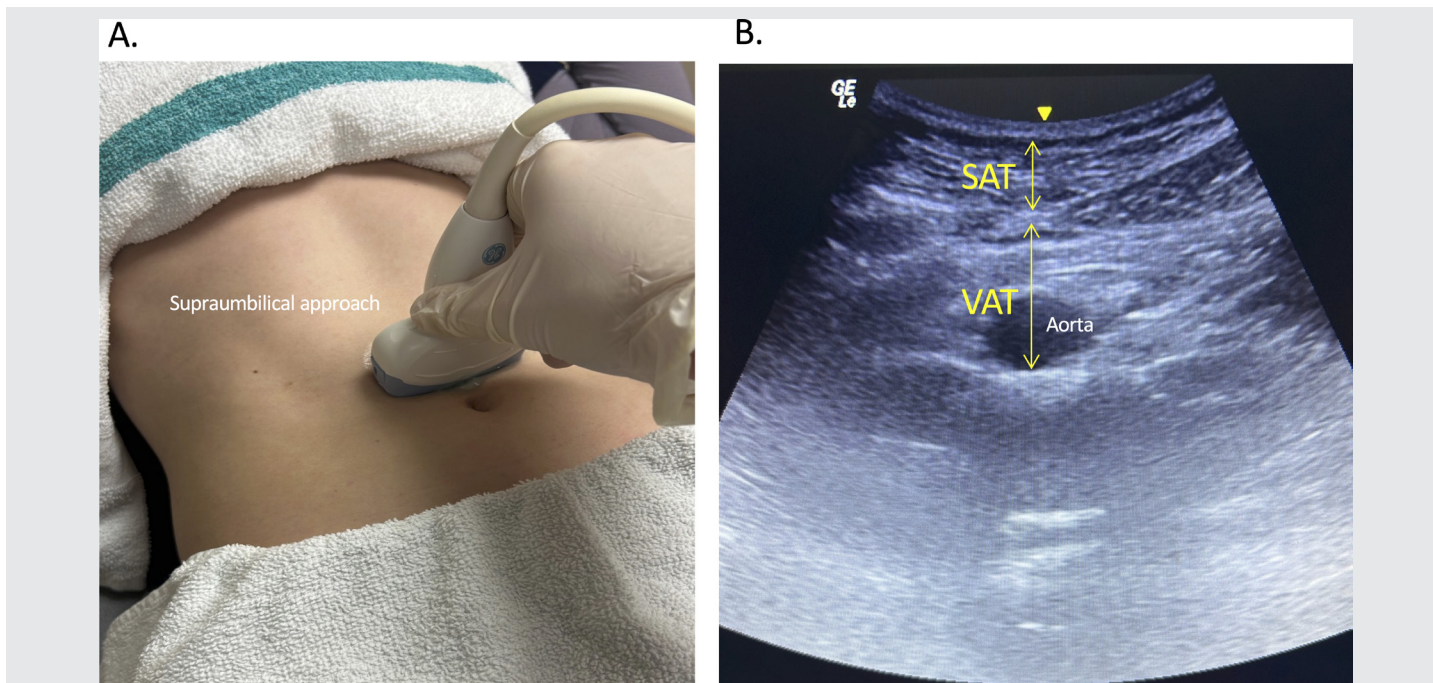

Figure 4. Supraumbilical approach to measure SAT and VAT. (**A**) Curvilinear probe applied 1 cm superior to umbilicus. (**B**) Labeled B-mode image.

p < .001). Further studies established the repeatability and accuracy of this technique in various patient populations.[41–43]

Epicardial adipose tissue is a topic of increasing interest in metabolic endocrinology. After an autopsy study of 200 hearts in 1989 found significant correlation between epicardial adipose tissue thickness and SAT thickness, researchers began investigating epicardial adipose tissue as a predictor of metabolic disease.[44] The first report quantifying epicardial adiposity *in vivo* was provided by Iacobellis et al. in 2003.[45] In this study, the authors performed transthoracic echocardiography on healthy patients lying in the left lateral decubitus position. While imaging the right ventricle in both parasternal short- and long-axis views, the authors measured the epicardial adipose tissue thickness originating on the free wall of the right ventricle. These measurements correlated well with epicardial fat measurements taken via cardiac MRI (r = 0.91, p = .001) and with VAT estimated by abdominal MRI (r = 0.84, p = .01). Further studies have validated the correlation between epicardial adipose tissue and VAT.[46] In critically ill patients, epicardial adipose tissue volume has been associated with early mortality in certain diseases, like COVID-19, but its relationship to survival in other critical illnesses is unclear.[47]

WHICH ULTRASONOGRAPHIC TECHNIQUE SHOULD BE USED IN CRITICALLY ILL PATIENTS?

The most accurate technique to measure SAT is the standardized, eight-site protocol used by the International Olympic Committee Medical Commission. In theory, it is the best method to assess baseline SAT volume and changes in SAT volume that occur throughout an ICU stay. However, this technique does not assess VAT, the adipose tissue depot that is considered most deleterious to health and may be too cumbersome to repeat frequently in the ICU due to its number of sites and the location of sites on both anterior and posterior surfaces that would require moving the patient to acquire. The Iacobellis (transthoracic) approach is the method of choice for imaging epicardial adipose tissue. However, while epicardial adipose tissue is an interesting adipose tissue depot that may

be important in cardiovascular and metabolic health, its importance in critically ill patients is not well characterized, and currently there is little clinical utility in using this approach.

The Armellini (supraumbilical) and Suzuki (xipho-umbilical line) approaches are the most suitable techniques for adipose tissue quantification in the ICU setting due to their ease of use, reproducibility, and relative accuracy. The Armellini method requires only one site of examination, whereas the Suzuki method may be more accurate and less likely to underestimate adiposity. While the Armellini approach was initially designed to measure VAT, and the Suzuki approach was initially designed to measure SAT, both techniques can be used to measure either adipose tissue depot.

CONCLUSION

Bedside ultrasonography offers a convenient, radiation-free way to quantify adipose tissue volumes in both healthy and ill patients. The Armellini (supraumbilical) and Suzuki (xipho-umbilical line) approaches appear to be the most suitable techniques for quantifying VAT and SAT in the intensive care setting due to their ease of use, reproducibility, and relative accuracy. Establishing standardized protocols to serially measure adipose tissue using these point-of-care ultrasound techniques may provide valuable insights into the dynamic changes in body composition occurring in critical illness and help uncover the true relationship between obesity and outcomes in the critically ill.

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