European Journal of Radiology 85 (2016) 1469–1480

Contents lists available at ScienceDirect

European Journal of Radiology

journal homepage: www.elsevier.com/locate/ejrad

Ultrasound: Which role in body composition?

Alberto Bazzocchi [a,*], Giacomo Filonzi [a], Federico Ponti [a,b], Ugo Albisinni [a], Giuseppe Guglielmi [c,d], Giuseppe Battista [b]

[a] Diagnostic and Interventional Radiology, The "Rizzoli" Orthopaedic Institute, Via G. C. Pupilli 1, 40136 Bologna, Italy
[b] Department of Specialized, Diagnostic, and Experimental Medicine, University of Bologna. Sant'Orsola—Malpighi Hospital, Via G. Massarenti 9, 40138 Bologna, Italy
[c] Department of Radiology, University of Foggia, Viale Luigi Pinto 1, 71100 Foggia, Italy
[d] Department of Radiology, Scientific Institute "Casa Sollievo della Sofferenza" Hospital, Viale Cappuccini 1, 71013 San Giovanni Rotondo, Foggia, Italy

ARTICLE INFO

Article history:
Received 1 November 2015
Received in revised form 1 March 2016
Accepted 13 April 2016

Keywords:
Ultrasound
Technical aspects
Metabolic disorders
Tissue characterization
Muscle
Abdomen

ABSTRACT

Ultrasound is a non-invasive, fast, relatively inexpensive and available tool for estimating adiposity in clinical practice, and in several research settings. It does not expose patients to ionizing radiation risks, making the method ideal for the evaluation, and for follow-up studies. Several parameters and indexes based on adipose tissue thickness have been introduced and tested, and these have been correlated with clinical and laboratoristic parameters. Moreover, ultrasound can also be directed to the estimation of adipose tissue and intracellular fat indirectly, at cellular-molecular level: an opportunity for many radiologists who already and sometimes unconsciously perform "body composition" assessment when looking at the liver, at muscle as well as at other organs. However, standardized procedure and parameters are needing to improve accuracy and reproducibility. The purposes of this review are: 1) to provide a complete overview of the most used and shared measurements of adiposity; 2) to analyze technical conditions, accuracy, and clinical meaning of ultrasound in the study of body composition; 3) to provide some elements for the use of ultrasound in the evaluation of intra-cellular lipids accumulation, in two hot spots: liver and skeletal muscle.

1. Introduction

Obesity, defined as the pathologic accumulation of fat in the body, is one of the most common diseases all over the world, with its prevalence increasing worldwide in developed and developing countries; it affects all ages, and is highly involved in the development of metabolic disorders such as type 2 diabetes mellitus (T2DM) and cardiovascular diseases (CVD). In 2010, overweight and obesity were estimated to cause 3.4 million deaths, 3.9% of years of life lost, and 3.8% of disability-adjusted life-years worldwide [1]; moreover, recent analyses estimate that the total economic cost of overweight and obesity amount to 90 billion dollars per year in the US and to 81 bilion euros per year in the EU. There is also increasing awareness of the influence of obesity in the pathogenesis of different disorders, apparently far from the field of metabolic or endocrinological diseases. As well, several diseases induce a metabolic change which is expressed by anomalous accumulation of fat in depots or organs. The terms "fat" and "adipose tissue" are often used as synonymous, but this is improper. According to the enlightening model proposed by Wang et al. [2] for body composition analysis, 5 levels of increasing complexity are described: atomic, molecular, cellular, tissue and total body level. Adipose tissue is a component of the tissue-organ body composition level, and in terms of weight is one of the most representative. This is a specialized loose connective tissue composed of adipocites (mainly), fibroblasts, collagen, capillars and extracellular fluid; it is the body's largest storage site for triglycerides (TG) and plays an important role as an endocrine organ in energy homeostasis. Historically, adipose tissue was considered as a passive reservoir for energy storage and a way to insulate and protect the body; however, more recently its critical role as body energy and homeostasis regulator, and as endocrinological active organ, has been recognized [3]. From an anatomical point of view, accumulating data support the idea that different sites and adipose tissues are organized to form a large organ with discrete anatomy, specific vascular and nerve supplies, complex cytology, and high physiological plasticity [4]; this is made up of several depots and can thus be considered a multi-depot organ [4]. On the other hand, at the molecular and cellular level, fat is usually found as lipids in the form of TG. Although fat is found primarily in adipose tissue, molecular fat also exists in other tis-

* Corresponding author.
E-mail addresses: abazzo@inwind.it, alberto.bazzocchi@ior.it (A. Bazzocchi).

http://dx.doi.org/10.1016/j.ejrad.2016.04.005
0720-048X/

sues, especially in pathological conditions such as hepatic steatosis and various forms of lipoidosis, in which fat accumulates inside the cells. Not to generate confusion, although improperly, the terms "fat" and "adipose tissue" will be considered synonymous, while the term "intracellular fat" will be used to describe lipids inside any kind of cells.

2. Body composition and "adiposity"

Vague, in the far 1947, was the first to notice [5] that the distribution of adipose tissue may influence the predisposition to metabolic diseases. Individuals with central obesity accumulate fat mainly in intra-abdominal and upper thoracic deposits; numerous epidemiological studies reported a close association between central obesity, insulin resistance (IR) and a cluster of different metabolic diseases. In contrast, individuals with peripheral obesity have a predominantly subcutaneous accumulation of fat in the femoral-gluteal region and seem to be less susceptible for metabolic complications, IR and dyslipidemia. These findings led to the hypothesis that accumulation of fat in specific locations may partially contribute to the association of adiposity with cardiometabolic risk. Among different adipose tissues, the one located inside the abdomen (and the thorax), around the abdominal organs, called "visceral" adipose tissue (VAT), has been recognized as the most dangerous, and several studies correlated this specific depot with several clinical and laboratoristic parameters of CVD and metabolic syndrome (MS). Multiple studies demonstrated that the visceral fat compartment is metabolically active, secreting a plethora of vasoactive substances as inflammatory markers and draining these substances directly into the portal circulation, which may contribute to its role in cardio-metabolic risks and manifestation [6]. Simultaneously, lipids in ectopic (non-adipose) tissues such as liver and skeletal muscle were associated with insulin resistance and adverse metabolic phenotypes, independently of total adiposity. Subcutaneous adipose tissue (SAT), on the other hand, plays a more uncertain and controversial role: many researchers see it as a passive reservoir for adipocites, with a neutral or protective role in the development of obesity-related disease [6,7], but some other studies questioned this role, finding an association between SAT and IR, especially at abdominal level [8]. For all these reasons, the evaluation and differential quantification of specific adipose tissue compartments in the body is of paramount importance, and several techniques have been proposed for this aim. Imaging has been propulsor in the clinical evaluation of body composition and this mainly happens on molecular and organ-tissue level. Computed tomography (CT) and magnetic resonance imaging (MRI) are usually considered the gold standard techniques, at organ-tissue level, but suffer from several limitations: high cost, low availability, elevated time consumption, and X-ray exposure for CT [9]. At the molecular level of body composition instead, other techniques have been proposed for estimating body fat percentage, with Dual-energy X-ray Absorptiometry (DXA) being the most widely used and validated [10]; however, DXA has a few limitations, for example it is not able to directly discriminate between visceral and subcutanous fat (2D technique). Ultrasonography is a non-invasive, fast and relatively available and inexpensive alternative for estimating adiposity in clinical practice [11]. It does not expose patients to ionizing radiation risks, making the method ideal for the evaluation of young people, and for follow-up studies or for large cohort of patients. Ultrasound is conventionally assigned to organ-tissue level, as it is able to measure different adipose tissue compartments, but this tool also allows an estimation of fat in terms of lipid content at both tissue and cellular-molecular level: indeed it can measure adipose tissues as thicknesses measurements, but it can also evaluate, in a few cases, intracellular fat content as change in tissue echogenicity.

3. Ultrasound imaging for body composition assessment

The first pioneering use of ultrasound for adiposity evaluation dates back to the 60′, focusing in particular on subcutaneous fat [12]. In 1990, Armellini et al. [13] were the first to describe a method for ultrasound evaluation of abdominal adiposity, and to compare this new assessment with CT. During the last three decades the interest in this technique for fat evaluation increased quickly and many ultrasonographic parameters and indexes have been proposed and tested. The aim of this review paper is to provide the reader with a complete overview of the most used and shared measurements of adiposity, and to analyze technical conditions, accuracy, and clinical meaning with their potential impact. We will also provide some elements for the use of ultrasound in the evaluation of intra-cellular lipids accumulation, in two hot spots: liver and skeletal muscle (Table 1 and Table 2).

3.1. Intra-abdominal fat

Intra-abdominal fat thickness (IAFT) is among the first measurements used in ultrasound evaluation of adiposity, and it is certainly one of the most important. Intra-abdominal fat is often used as synonymous for VAT, but this is misleading. VAT refers indeed to the fat depots surrounding the internal organs (viscera), and not to all intra-abdominal fat depots. Also from an anatomical point of view, there is no unanimous consensus on how ultrasonographic measures of IAFT have to be taken: in most articles, IAFT is measured from the posterior wall of the abdominal muscle (i.e. from linea alba) to the anterior wall of the aorta, as described by Armellini on his first work (Fig. 1) [13–17]. Anyway, some other authors measured IAFT from the abdominal muscle to the anterior wall of a lumbar vertebra, to the posterior wall of the aorta, or to the psoas muscle [18–20], or as the distance between the peritoneum and the lumbar spine [21]. Measurements are always taken in the supine position, with arms at sides. A recent study from our group pointed out that technical issues play an important role in the accuracy and reproducibility of measurements; it is very important to control breathing and fasting state of patients, as well as the pressure of the probe on the skin [14].

3.1.1. Accuracy and reproducibility

The first study aimed to compare CT and ultrasound measurements of adiposity, as performed by Armellini in 1990 [13], resulting in a good correlation between ultrasound thickness measurements and intra-abdominal fat area ($r = 0.669$, $p < 0.001$). Few years later, Tornaghi et al. found that ultrasonographic measurements of the abdominal depth correlated with CT-measured visceral fat area better than others anthropometric indexes ($r = 0.89$-0.91) [22]. Other studies in the subsequent years correlated and validated ultrasound measurements with CT and MRI, confirming a good accuracy [18–23]. However, in the vast majority of studies, linear measurements by ultrasound were correlated with measurements of areas or volumes of fat, detected by CT imaging or MRI. In recent years, some investigators moved to comparative evaluations of linear measurements of CT and ultrasound [9,19,21], finding very good agreement ($r = 0.89$-0.93). Data on reproducibility of IAFT, as for any ultrasound adiposity parameters, are less abundant on scientific literature, and they are expressed and analyzed with different statistical methods. In several studies a coefficient of variation (CV) is reported, ranging generally between 1 and 7% [22]. Stolk et al. [20] found an inter-observer correlation