Measuring body composition and regional fat mass accurately

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The last few decades have been defined by a surging number of overweight and obese individuals around the world.1 While the general population are aware that excessive adiposity increases their risk for developing type 2 diabetes (T2DM) and cardiovascular disease (CVD), only recently has the importance of body fat distribution, a far more important determinant of metabolic health, entered the public’s consciousness. Indeed, robust evidence from numerous large-scale epidemiological studies indicates that abdominal/central obesity is associated with a significantly increased risk of developing T2DM and CVD whereas lower body fat accumulation is protective.2,3

The importance of body fat distribution to metabolic health stems from initial observations made in the 1940s4 and 1950s5 which linked abdominal obesity to atherosclerosis, T2DM and gout. Evidently these early reports have since been vindicated but our current knowledge of the biological mechanisms involved remains incomplete. In order to better understand why upper and lower body fat accumulation exert opposing effects on metabolic health, it is vitally important to be able to accurately and reliably measure body composition and regional adipose tissue (AT) mass.

**Measuring body composition and adipose tissue distribution**

A burgeoning literature has highlighted how simple measures of body fat distribution, in which waist and hip circumference are used to represent upper and lower body AT depots respectively, are much better able to predict metabolic disease risk than body mass index (BMI), calculated as weight (kg) / [height (m)]².6 BMI has proven useful as an index of adiposity in population studies despite it having numerous limitations however.7

Firstly, BMI does not take into account musculosity so it is prone to overestimate adiposity in individuals with high lean mass (e.g. athletes) but underestimate adiposity in those with low amounts of lean mass (e.g. the elderly). Secondly, as BMI is calculated using the square – rather than cube – of height, it tends to overestimate adiposity in tall people of normal proportions but underestimate adiposity in short-statured people. Thirdly, BMI can actually change independent of weight owing to aging-related loss of height. BMI’s most notable limitation though is that it provides no information on AT distribution.

It is important to appreciate that a given body circumference reflects not only regional AT but also underlying bone structures and muscle. While the tape measure will always have its place, technological advances have provided several powerful methods that can precisely measure body composition and capture the spatial distribution of adipose, lean and bone tissue.8 The ability to accurately measure body composition and regional adiposity continues to play a crucial role in the study of (metabolic) disease pathogenesis, particularly T2DM, CVD and non-alcoholic fatty liver disease.9 There is also evidence suggesting that regional adipose accumulation can influence the risk of developing certain types of cancer, such as colorectal cancer, and may be a better predictor than BMI.10

While the various body imaging modalities are primarily used in a research setting (in the context of metabolic disease), the data they generate continue to make a significant impact on the stratification of patients according to their risk of developing T2DM, CVD etc. Although it is unlikely that body imaging will become a routine diagnostic procedure in metabolic clinics, the use of imaging tools has provided many opportunities to develop our ability to diagnose and treat metabolic disease, as well as understand the pathogenic mechanisms involved.

**Dual-energy X-ray absorptiometry**

Originaly designed to measure bone mineral density to aid the diagnosis of osteoporosis and other bone diseases, dual-energy X-ray absorptiometry (DEXA) has proven highly useful in the measurement of regional AT mass.11 By measuring the absorption of X-ray photons at two energies it can distinguish between fat and fat-free soft tissue. DEXA data can be collected conveniently (~15 minute scan duration) and safely due to the low dose of ionising radiation required (~1mSv per scan), meaning this method is suitable for almost everyone, barring pregnant women.

Although a DEXA scan captures data from the whole body (Figure 1), it is not a panacea in the study of AT distribution. As with most imaging methods, it is mainly limited by the size of the scanner bed and its weight capacity, meaning particularly large individuals may be excluded or subject to a less-than-ideal half-body scan. Regardless, DEXA has been reported to accurately determine body AT percentage across a range of body shapes and sizes (compared to the gold standard 4-compartment model7) in a highly reproducible manner.12

Numerous important contributions to our understanding of AT distribution have been made using DEXA. For instance, data collected using this method confirmed the observation that abdominal obesity increases CVD risk whereas lower body fat accumulation (corrected for total fat mass) is protective.13 The scalability of DEXA has also made large-scale studies examining how body composition and AT distribution are influenced by gender and ethnicity feasible.14,15

There is intense interest regarding the role that visceral AT plays in the pathophysiology of metabolic disease.16 Unfortunately, one of the key limitations of DEXA is its inability to discriminate between different types of AT. This frustration has led to the development...
of algorithms that predict visceral AT mass using regional AT DEXA data. While some uncertainty remains, the prediction software has been validated numerous times against computed tomography data, the gold-standard technique.\textsuperscript{18,19} Although DEXA might not be the method of choice to specifically measure visceral AT mass, the ability to accurately derive this parameter enhances the utility of this technique in the study of regional AT distribution.

**Computed tomography**

Similar in principal to DEXA but using much higher doses of radiation, computed tomography (CT) is the gold-standard technique used to determine body composition. CT scans comprise one or multiple 2D images (‘slices’) generated by making X-ray measurements from different projection angles at specific levels on an individual’s body. Software then processes the high resolution images to distinguish adipose from non-adipose tissue with exquisite sensitivity; contiguous or non-contiguous 2D slices can be used to calculate 3D tissue volumes.\textsuperscript{20} The main drawback of CT is the exposure of study participants to not-insignificant doses of radiation, which makes this technique unsuitable for vulnerable populations (e.g. pregnant women or growing children) and longitudinal studies involving serial measurements. Nevertheless, reports that lower radiation doses can be used to accurately measure abdominal\textsuperscript{21} and liver\textsuperscript{22} fat from a single slice have renewed interest in CT.

The ability of CT to discriminate between adipose and non-adipose tissue means it has proven highly useful in the study of ectopic lipid accumulation in relation to metabolic disease risk.\textsuperscript{17} For instance, CT has been used to highlight how visceral AT accumulation is associated with impaired glucose tolerance and reduced insulin sensitivity\textsuperscript{23} as well as how the relationship between visceral adiposity and metabolic health differs with respect to gender and ethnicity.\textsuperscript{24} Additionally, CT can be used to non-invasively evaluate hepatic steatosis\textsuperscript{25} and measure intramuscular lipid accumulation.\textsuperscript{26} CT’s impressive ability to discriminate adipose from non-adipose tissue makes it a highly useful tool in the study of body composition and AT distribution. However, the potential risk from radiation exposure means it is recommended that magnetic resonance imaging should replace CT where possible.

**Magnetic resonance imaging**

Magnetic resonance imaging (MRI) is a powerful imaging tool that distinguishes adipose from non-adipose tissues based on their distinct magnetic resonance properties. In contrast to CT and DEXA, this technique does not involve exposure to ionising radiation, making it suitable for use in vulnerable populations and for performing serial measurements in longitudinal studies.

Similar to CT, MRI takes single or multiple 2D slices at specific levels on an individual’s body. The images are then analysed to determine body composition and regional AT distribution. Development of image acquisition and analysis protocols mean that MRI is now able to perform most tasks that CT can to a similar standard without exposing individuals to ionising radiation. With MRI being increasingly used to investigate ectopic lipid accumulation in the liver, pancreas and heart\textsuperscript{27} it is emerging as a highly versatile clinical phenotyping tool that has the potential to become the new gold standard imaging modality.

![Figure 1. DEXA scanning has been used to elucidate the relationship between body fat distribution and metabolic health. The scans above demonstrate the principles of DEXA scanning. Regional body composition is determined by the dual X-ray absorptiometry within bony landmark defined areas. In each area the relative X-ray absorption will be used to calculate lean and fat mass. The selected images highlight how body fat distribution can vary significantly between individuals matched for BMI and body composition. Two men with the same BMI illustrate this case: the individual on the first panel displays a predominantly lower body fat accumulation phenotype compared to the centrally-obese individual on the second panel. Data courtesy of the Oxford BioBank (http://www.oxfordbiobank.org.uk)](http://www.oxfordbiobank.org.uk)
Some considerations

MRI, CT and DEXA are powerful tools that can accurately measure body composition and regional AT mass, but choosing the most appropriate imaging modality for a study is crucial as these techniques are not interchangeable. While what each imaging modality measures is correlated, DEXA has been reported to consistently underestimate total fat mass.\(^{28}\) And while visceral AT mass can be predicted fairly reliably using DEXA, CT or MRI should be the method of choice when measuring this specific depot.

Many factors can influence the choice of imaging modality and data collection protocol, with cost and time being primary limitations to a project’s ambitions. The response to these constraints inevitably entails collecting less data, i.e. fewer CT or MRI images. Choosing how to cut costs with minimal detriment to data collection involves making difficult decisions, with a key point of contention concerning the merits of multi-slice over single slice MRI or CT image acquisition protocols.

This debate is primarily driven by reports that visceral AT mass from (various) single abdominal slices correlates well with total AT mass, although no consensus exists over which anatomical landmark should be used to define where the single slice should be taken. Also, as the inter-individual distribution of AT is highly heterogeneous according to both MRI\(^{29}\) and CT,\(^{30}\) it is perhaps unsurprising that, for example, the magnitude of visceral AT mass reduction after an exercise intervention can differ substantially depending on where a slice is taken.\(^{31}\) Such observations highlight how there is no shortcut and that multi-slice protocols are better able to detect changes in AT mass, a feature that can translate to studies requiring fewer participants. It follows that multi-slice protocols are the preferred method when building large, robust datasets like the UK Biobank.\(^{32}\)

Conclusion

There is great promise in the formidable power of DEXA, CT and MRI to enhance our understanding of the relationship between body composition, regional AT distribution and metabolic health. Data from these imaging tools have already provided significant insights into how regional adiposity influences the risk of metabolic disease in an ethnicity-dependent manner. While body imaging may not become a routine procedure in metabolic clinics, combining accurate estimates of body composition and regional adiposity (derived from simple anthropometric measurements) with genetic and common clinical measures (e.g. blood pressure, lipid and/or liver enzyme profiles) could permit the development of powerful predictive models. Such models might inform patient stratification, optimise the efficacy of clinical interventions and potentially illuminate some of the mechanisms linking regional adiposity to metabolic health. Clearly, these imaging techniques are truly transforming the way we view body composition and regional AT distribution.

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Declaration of interests

There are no conflicts of interest declared.

References