Body composition and functional assessment of nutritional status in adults: a narrative review of imaging, impedance, strength and functional techniques.

Key words: Body composition; nutritional status; imaging; bio-electrical impedance; function

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Abstract

The accurate and valid assessment of body composition is essential for the diagnostic evaluation of nutritional status, identifying relevant outcome measures and for determining the effectiveness of current and future nutritional interventions. Developments in technology and understanding of the influences of body composition on risk and outcome provide practitioners with new opportunities to enhance current practice and lead future improvements in practice. This is the second of a two-part narrative review which aims to critically evaluate body composition methodology in diverse adult populations, with a primary focus on its use in the assessment and monitoring of under-nutrition. Part one focused on anthropometric variables (1) and part two focuses on the use of imaging techniques, bioelectrical impedance analysis, markers of muscle strength and functional status with particular reference to developments relevant to practice.

Introduction

The accurate and valid assessment of body composition is essential for the diagnostic evaluation of nutritional status, identifying relevant outcome measures and for determining the effectiveness of current and future nutritional interventions. Ongoing developments in technology and understanding of the influences of body composition on risk and outcome provide practitioners with new opportunities to enhance current practice and lead future improvements in practice. In turn, it is hoped that this will lead to an increased understanding of the effect of specific nutritional interventions on health outcomes and serve to further support the effectiveness of the dietitian.

Much attention has been given to identification and assessment of sarcopenia, originally defined as the age related loss of muscle mass (2) . This in turn, has driven an increased focus on identifying and using valid methods for the assessment of muscle mass. Furthermore, results of longitudinal studies have highlighted that the loss of mass and the loss of strength (or conversely gain) does not occur in a linear manner, thereby implying a disassociation in the relationship between mass and strength (3). For example in ageing it has been suggested that muscle strength is lost at a rate 2-5 times faster than muscle mass in men and women (4). Additionally, the rate of loss may not be uniform across the body with the rate of *loss* of lower limbs potentially more than twice that of the upper limbs and notable gender and ethnic differences have been observed (4, 5).

Increasingly it has been recognized, that whilst muscle mass is a key influence on muscle strength, it is not the sole influence and there are several other important factors (6, 7, 8). These include neural factors and factors affecting the functionality of the muscle itself, such as: the presence of an underlying disease e.g. myopathy, neuropathy, presence of intramuscular adipose tissue (IMAT), inflammation, hypoxia, peripheral vascular disease, oxidative stress, electrolyte imbalance and inactivity. In addition, particular nutritional factors such as vitamin D or iron deficiencies, disorders of fat and glucose metabolism, short or longer term starvation and repletion (feeding) (9-13).

In view of this increased understanding, the term dynapenia meaning ‘poverty of strength’ has been proposed (7) to differentiate between reduced muscle mass and

reduced muscle strength. Whilst it was proposed that this term be used to refer to age related loss of muscle strength, the concept of dynapenia is also likely to be applicable to the loss of muscle strength at any age which may be due to factors described above (8,11).

Further to this, it is increasingly being recognized that the functionality of muscle mass may be more important than absolute mass in terms of disability risk and mortality outcome (4, 8, 14). In terms of outcomes, this suggests that rather than solely focusing on changes in muscle mass, it may be more appropriate to aim for improvements in muscle strength, be that through the use of novel nutritional and/or pharmacological or exercise interventions (14).

In light of this increased understanding, it could be argued that the assessment and monitoring of body composition should increasingly focus on methods that can demonstrate impairment and improvement of muscle strength and function. It is also likely that such methods provide valuable early indicators of risk and mortality and are more sensitive to nutritional depletion and repletion than methods, which solely assess mass (4, 12, 15). However, in order to better understand the relationship between and the influences on muscle mass versus muscle function it appears prudent to use such methods in a complementary manner (16).

Computed tomography (CT) and magnetic resonance imaging (MRI)

The use of imaging technology, particularly computed tomography (CT) and magnetic resonance imaging (MRI), for the assessment of body composition, has undoubtedly led to an increased understanding of body composition and its influence on disease risk and outcome. These methods are considered to be gold standard reference technologies for body composition analysis at a tissue level (17). As such, they are considered to be valid, accurate, precise and rapid methods that have the potential to detect small changes in body composition (17, 18). These technologies have been used to identify ectopic and inter/intramuscular adipose tissue and develop an increased understanding of the difference between visceral adipose tissue (VAT) and subcutaneous adipose tissue (SAT). Furthermore the technology has assisted in elucidating the identification of sub phenotypes in the general population whose risks are not comparable to their body mass index (BMI) or waist circumference (19). As such, CT and MRI have highlighted the limitations of more

traditional methods of body composition assessment and the need to increasingly think beyond these.

The determination of, and distinction between tissues evaluated by CT, is based on known differences between tissues in terms of their density (3). CT images consist of pixels with assigned Hounsfield units (HU). Hounsfield units are measures of tissue attenuation and pre-defined radiation attenuation ranges are used to demarcate tissues. Typically, ranges of -190 to -30 HU define subcutaneous adipose tissue, -150 to -50 HU for visceral adipose tissue and -29 and +150 HU for skeletal muscle and more recently a range of -29 to +29HU to define low muscle attenuation (reflective of increased levels of fatty infiltration) have been proposed (20). The tissue area (cm^2) of cross-sectional images is then calculated by multiplying the number of pixels for a given tissue by the surface area, which can be determined manually or with specific automated software, with the latter considered to improve objectivity of the analysis (17, 21). In a manner, similar to CT, MRI is also able to quantify and determine adipose and skeletal muscle tissues (22). However, MRI differs from CT in how images are acquired. MRI does not involve the use of ionizing radiation, but instead relies on the tissue specific properties of proton density (i.e. density of hydrogen atoms) and longitudinal (T1) and transverse (T2) relaxation times (23). As a result, MRI in comparison to CT is considered to be safer, which has allowed whole-body and repeated measurements to be conducted. MRI uses the body's inherent magnetic properties to create detailed images. Hydrogen protons within tissues act like magnets and when participants are placed within an MRI scanner the protons within tissues align. Pulsed radiofrequency waves are then used to activate the atomic protons to absorb energy. (24). When the radiofrequency pulse is turned off, the protons release energy which is absorbed in the form of a radiofrequency signal. This signal is used to generate cross-sectional images from which the type and quantity of tissue can be determined in a manner similar to CT (22).

Although it is possible to perform whole-body CT and MRI scans, this is undesirable due to the time involved and the high levels of radiation exposure associated with CT. It is therefore common practice to perform regional abdominal single slice scans at the 3rd or 4th lumbar vertebra (L3-L4). MRI-derived single slices of the abdomen have been shown to have a strong relationship with MRI-derived whole-body

composition in younger healthy individuals (25) and CT-derived single slices with DXA-derived whole-body composition in a small group of cancer patients (26). However, this may not be the case across the spectrum of disease, age and ethnicity and may be particularly pertinent to studies of adiposity due to substantial individual variations in the volume and patterning of fat stores (27). Furthermore, single slices of lower extremities e.g. mid thigh, may be more appropriate when examining the effects of disease, ageing and interventions in relation to muscle quality, function, disability and nutritional status (28, 29).

Various CT and MRI-derived cut-offs have been proposed to determine risk. Currently there appears to be a lack of universally agreed cut-offs for adiposity that take account of differences in age, gender and ethnicity. For example in an American study of 233 women (mean age 59$\pm$6 years), a visceral adipose cut-off of >106cm^2 was associated with an increased risk of metabolic disease (30) and in another study of 11,561 Japanese men and women (mean age 52 $\pm$10 years men, 56 $\pm$10 years women), visceral adipose cut-offs of $\geq$102.4 cm^2 in men and $\geq$69.0 cm^2 in women were associated with an increased risk of metabolic syndrome (31).

Until recently, the majority of published cut-offs focused on visceral or subcutaneous adipose tissue. However, cut-offs pertaining to muscle are now beginning to emerge. For example, Weijs *et al.,* (32) in their study of mechanically ventilated patients, using abdominal CT scans, proposed a cut-off of 110cm^2 for women and 170cm^2 for men to be indicative of low muscle area and increased risk. However, further work is required in larger and more diverse populations to develop agreed cut-offs for regional muscle sites predictive of risk.

In addition to quantifying adipose and muscle stores, recent MRI interest has focused on magnetic resonance spectroscopy (MRS) which uses a series of scans to provide information on the specific metabolites within tissue, including lipid, glycogen and amino acids, using ^{1}H, ^{13}C and ^{31}P (34, 35). This has significance as a clinical research tool as MRS is able to identify and quantify lipid within muscles and the liver, i.e. intramyocellular and intrahepatic lipid, thus providing insight into insulin resistance and metabolic risk (36, 37).

Whilst CT and MRI are considered to be the most accurate methods for assessing body composition at a tissue or organ level, their use is not without concern in

clinical practice, not least because they are costly, require skilled personnel, aren't portable and are generally not routinely available for the purposes of body composition assessment (17, 22). However, the most significant issue relating to CT is the exposure to ionizing radiation. The effective radiation dose for an abdominal CT scan has been reported as approximately 5.6mSv, which is the equivalent to 370 chest x-rays (33). As there is an increased recognition of the risks of unnecessary radiation exposure (23), the use of CT for the purposes of body composition assessment alone may be difficult to justify. Whilst MRI doesn't expose individuals to radiation, scans generally take longer and those with ferromagnetic implanted devices (e.g. pace makers, defibrillators, brain aneurysm clips, intrauterine devices) may be unable to undergo an MRI scan (38). Both CT and MRI have limits in terms of size and weight, typically scanners have weight limits of up to 200 kg and a fixed bore diameter of 70cm, however, newer larger bariatric scanners are now available with weight limits increased to ~300 kg and the bore diameter increased to ~80cm (39, 40). Claustrophobia, anxiety and the ability to lie still for a period of time, can also preclude the use of CT and in particular MRI. . Furthermore, it has been reported that different methods of measurement (e.g. body position, selected measurement site) and different machines can provide different results (3).

Whilst the routine use of MRI and CT for the assessment of body composition remains unlikely, there is increasing recognition that CT scans undertaken for diagnostic purposes, could be used opportunistically for assessment and monitoring purposes (41). This has primarily emerged from developments in oncology, involving the use of CT-derived body composition data to predict tolerance and efficacy of chemotherapy (42,).Subsequent retrospective and prospective cross-sectional studies have also been published in this area 43, 44). Furthermore, the opportunistic use of such scans has developed into other areas where the use of diagnostic CT scanning can occur, such as liver cirrhosis and transplantation (45, 46, 47), intensive care (32) and respiratory failure (48). To date these studies serve to further highlight the important relationship between body composition, survival and the limitations of current screening and assessment methods. However the utility of this approach in determining the influence of nutritional interventions on body composition and outcomes requires further exploration.

Recent statistics suggest that almost 5 million CT scans were performed in England alone in 2012/13 (33), therefore there does appear to be an opportunity to utilise these. It is, however, unlikely that all such scans will provide the desired regional images (17) .In addition a lack of local knowledge and the non-routine reporting of fat and muscle tissues may currently prevent the use of such scans being used for body composition purposes (20, 49).

Dual energy X-ray absorptiometry (DXA)

DXA, another imaging technique, has been increasingly used for the quantification of body composition (17). Initially developed and used for the assessment of bone mineral density and is the gold standard in this regard (53). However, advancements in technology and software have meant that DXA can now provide estimates of three components: bone mineral, fat mass (FM) and fat-free soft tissue mass (FFSTM) (sometimes also referred to as bone-free fat-free mass) (17). Furthermore, as well as estimating body composition at a whole body level, DXA has the capability of providing regional e.g. abdominal, lower versus upper limb, as well as estimates of appendicular skeletal muscle. The latter of which are gaining attention particularly in relation to sarcopenia (17). However, it is currently unable to differentiate between different types of adipose tissue e.g. subcutaneous adipose tissue, visceral adipose tissue and intramuscular adipose tissue (17, 50).

DXA scans use low dose x-rays of two energies (typically 40keV and 70keV) which are passed through an individual (51). Estimates of body composition are derived based on the principle that the body is a two-compartment model (bone mineral and soft tissue) and that bone mineral has higher x-ray attenuation than soft tissue (52). Fat mass and fat-free soft tissue mass are then determined by mathematical algorithms, based on several assumptions, such as soft tissue overlying bone and soft tissue adjacent to bone have the same tissue composition; that there is a linear-based ratio of fat and fat-free mass in soft tissue and distribution throughout the body and a constant hydration of fat-free mass, potassium content and tissue density (52, 53).

DXA is considered to be a more accessible, quicker and a less expensive alternative to other imaging techniques such as MRI and CT (51). Whole-body scan times have decreased with advances in DXA technology and can now be as little as ~ 1 minute

for a specific site and ~5 minutes for a whole-body scan (52). DXA does expose individuals to radiation, but levels are significantly less than CT scans and approximately equate to between 1-10% of the exposure received via a chest x-ray, depending on the type of scanner, scanner speed and whether a whole-body or regional scan is being undertaken (56). DXA is also considered to provide more precise, accurate estimates of fat and fat free mass than those derived from anthropometry or bioelectrical impedance analysis (BIA) (28, 40).

Coefficients of variation for the precision of DXA-derived measurements have been reported as ~1.0% forwhole body lean mass between ~0.8-2.7% for whole-body fat mass and ~2.8-4.8% for regional (trunk) measurements (52). In terms of accuracy, the majority of DXA validation studies have been conducted in healthy, young fit populations. These studies have compared measurements made by DXA, using a two-compartment model, with those using a four-compartment model, which typically include values of total body mineral derived using DXA as well as total body water and density (57). Such studies demonstrate that at a population level DXA generally underestimates percentage body fat by ~ 2% and that the underestimation tends to be greater in leaner individuals (52). However, at an individual level, greater differences have been reported, with one study of 152 healthy adults, aged 18-59 years, reporting differences of approximately -2.6% to 7.3% body fat, with an observed underestimation in lean individuals and overestimation in those with higher levels of body fat (58). Furthermore, validation studies, primarily in athletic and weight-loss populations, examining the longitudinal use of DXA to monitor changes in body composition, whilst demonstrating non-significant differences in DXA measurements at population level, have demonstrated wide limits of agreement. This suggests that fat loss may be significantly overestimated and fat gain underestimated at an individual level (52). The accuracy of DXA measurements are also affected by the anterior posterior thickness of the body (59). Thicknesses of >25cm have been reported to alter the attenuation of tissues which can result in an overestimation of fat mass in obese individuals (23). Changes in hydration status can also affect the accuracy of DXA due to the inherent assumption that the hydration of fat-free mass is uniform and fixed at 0.73mL/g (17). This is of particular relevance to older adults, and in clinical populations where over hydration is common such as renal and liver disease (60). Increases in hydration of >5% have been shown to

result in an overestimation of fat-free soft mass and a corresponding underestimation of fat mass by ~1-2.5% (61, 62).

Different DXA machines can provide different results due to variations in software. Differences of ±7% for fat mass and ±4% for fat-free mass have been reported (23), which can present some difficulties in determining the validity and reliability of DXA or when comparing results from different intervention studies (17). Whole-body DXA machines also have upper weight limits and may not be able to accommodate larger individuals. Scanner limits have typically been reported as 193-198 x 58-65 cm and 136 kg (63) limiting the use of DXA in obese individuals. Some researchers have addressed this limitation by the use of half body scans in obese individuals (63, 64, 65). Initial results from such studies suggest small non-significant differences (±1%) for the estimation of fat mass and fat-free soft mass, from left or right side half scans in comparison to the results of whole-body scans. More recently, newer whole-body DXA scanners, which can accommodate larger individuals, have been developed (e.g. iDXA, Lunar GE Healthcare). These have wider and extendable bed platforms, higher torso thickness limits and weight limits (~200 kg), but the accuracy and precision of these newer models for the assessment of body composition, is currently limited (52).

Other practical considerations may also limit the use of DXA. These include lack of portability, not being routinely available for body composition purposes, contraindication in pregnancy, individuals needing to lie in the supine position, and the presence of metallic implants (17). It also requires trained operators and whilst radiation exposure is minimal, any non-essential radiation exposure, particularly when used for longitudinal purposes, requires justification as frequent indiscriminate use is discouraged (66).

Body composition reference data derived from DXA is also emerging. DXA scans were used as part of the 1999-2004 USA National Health and Nutrition Examination Survey (NHANES). This work involved the use of whole-body scans using a QDR 4500A fan beam (Hologic, Inc, Bedford, MA) densitometer and obtained data on a large sample (>20, 000) of adults and children (67, 68) which may be useful for comparative purposes.

In summary, whilst DXA is a considered to be less costly than CT or MRI and a more accurate and precise method than anthropometry or BIA, it is apparent that DXA is not without limitations and practical difficulties, which affect its application and use in clinical practice. However, the use of DXA scans for the estimation of body composition in practice could potentially increase in the future, as there is emerging interest in the secondary, opportunistic use of routine regional spine and hip DXA scans for body composition purposes (17). Preliminary studies (69, 70) suggest that such regional scans and subsequent predictions of whole-body composition are similar to those obtained from whole-body scans, but further validation work is required in larger more diverse populations before routine utilisation.

Ultrasound scanning

Ultrasound scanning (USS), another form of imaging, widely available for decades, has been used in medical practice , in areas such as pregnancy, cardiovascular disease (71) and for the diagnosis of conditions affecting organs and soft tissues (72). However, increasingly USS is being used as a method for the clinical assessment of body composition (73, 74, 75).

The principle of USS imaging is the reflection of sound waves from the tissue in the path of the beam. The level of sound reflected back is dependent on the changes in acoustic impedance between tissue interfaces (76). At the interface between tissues, some sound waves are reflected back as echoes which are translated into depth readings via a transducer. Acoustic impedance is the result of tissue density and acoustic velocity. As fat, muscle and bone have different impedance (0.138, 0.170, 0.78 $g.cm^{-1}.s^{-1}$ respectively), quantification and differentiation between tissues is therefore possible (76).

Brightness (B)-mode ultrasound technologies, at frequencies between 1-10MHz have commonly been used for the measurement of tissue thickness, but newer commercial type devices using amplitude (A)-mode at a frequency of 2.5MHz are also available (75). A-mode uses a narrow beam to scan tissue and produces spikes on a graph whereas B-mode uses a linear array (by combining A-mode signals from various directions) to produce two dimensional images (76). Tissue depths

(thicknesses) are typically determined by the subjective distinction of interfaces, followed by the quantification of the thickness of the relevant tissue using electronic (digital) calipers, and an average of three measurements (74).

There are many attractions to USS as a technique to assess body composition. It has the capability to provide regional information on adipose and muscle thicknesses, differentiate between visceral and subcutaneous adipose tissue, and provide information on muscle structure and quality (77). It is also widely available, portable, non-invasive, quick (~1-2 minutes per site), doesn't have limits in terms of size and weight, is less costly than other imaging techniques, , involves no radiation exposure and data can be stored electronically (66, 74, 78, 79). As such, it has significant potential for use in clinical settings where assessment of body composition is inherently more difficult, e.g. critical care, maternal health and spinal cord injury (80, 81).

Until recently, USS has been primarily used for the regional quantification of adipose tissue either for the assessment of subcutaneous adipose tissue in manner similar to skinfolds (e.g. at triceps, biceps, subscapular, suprailiac sites). It is alsoincreasingly used for the assessment of abdominal VAT and SAT (82). Such clinical studies have examined differences in subcutaneous fat patterning in pregnancy (81, 83), changes in upper and lower limb body composition following bariatric surgery (84) and the relationship between USS abdominal fat thicknesses, or indexes (such as abdominal wall fat index) with parameters of metabolic risk in diabetic and healthy populations (82, 85, 86).

Whilst results from clinical studies are promising, they have not examined the accuracy of USS-derived estimates of adiposity against appropriate reference methods. Although limited, validation studies are emerging. One such study (87) , used USS to measure subcutaneous adipose tissue at five anatomical sites, in 135 healthy young adults (mean age 22 ±3 years, BMI 25 kg/m^2).Body fat was estimated using a population-specific prediction equation and results compared to those obtained from DXA. Ninety five percent limits of agreement analysis between USS and DXA demonstrated individual differences of -3.6% to 3.8% body fat for men and -6.2% to 5.4% body fat for women (87). Another such study of 74 older men and

women aged 67-76 years examined the agreement between USS and CT measures of visceral and subcutaneous abdominal thickness (88). In this instance, 95% limits of agreement analysis demonstrated individual differences for visceral thickness of -2.26 to 2.94 cm in men and of -1.87 to 2.53 cm in women and limits of agreement for subcutaneous thickness –0.87 to 1.37 cm in men and -0.61 to 1.99 cm in women. Furthermore, it has been suggested that regional USS measurements of subcutaneous adipose tissue for predicting percentage body fat are of similar accuracy to skinfolds and possibly more sensitive to change over short period of times, as well as more reliable and reproducible in obese populations (66, 87). Whilst promising, further larger cross-sectional and longitudinal validation studies across diverse groups and clinical populations are required to determine the validity and reproducibility of USS-derived estimates of body composition.

Increased consideration is also being given to USS as a potential technique for the quantification of skeletal muscle thickness and for determining muscle quality (74). When used for the quantification of skeletal muscle, measurements taken at various regional sites, (e.g. biceps, triceps, mid thigh (rectus femoris) and calf (gastrocnemius)) are suggested to provide more accurate estimates of muscle mass than limb circumferences corrected for subcutaneous adipose tissue (89). Clinical studies in this area have examined the use of USS to quantify muscle mass in postmenopausal women (89); changes in muscle mass response to resistance training in chronic obstructive pulmonary disease (90); losses in muscle mass across a period of critical illness (80, 91) and following bariatric surgery to quantify and examine patterns of muscle versus fat loss (84). However, few studies have examined the agreement of USS-derived measurements of muscle with appropriate reference methods. One study, conducted in 45 overweight men with coronary artery disease (68 ± 6 years) who underwent USS and CT scans of their rectus femoris reported 95%limits of agreement of -0.24 to +0.25cm (92), but further larger, more diverse, cross-sectional studies and longitudinal studies are needed to explore the agreement between of USS with reference methods before routine ultilisation is considered (74).

In addition to evaluating muscle mass, USS echo intensities, measured using standard USS machines, have emerged as a potential marker of muscle quality.

Echo intensities, are however, more difficult to quantify and are determined either by visual scoring or by use of computer aided grey scale analysis (77, 93). Changes in fibrous tissue, intramuscular fat, and atrophy of muscle, along with inflammation and necrosis have been observed to influence echo intensity, with such changes resulting in increased echo intensities of muscle (93, 94). Furthermore, in a small study of 184 Japanese men (65-91 years) echo intensity measurements taken at the point of the mid thigh demonstrated a significant negative association of moderate strength with muscle strength ($r = -0.333$, $p < 0.001$) as determined by isometric knee extension strength (79). As such, echo intensity could provide a useful tool in the assessment of certain conditions such as sarcopenia, but further work is needed to establish the value of echo intensity measurements for quantifying muscle quality and for monitoring changes in response to interventions.

Whilst USS reference data, for the purposes of body composition, are currently limited, two separate small studies of healthy populations have published normative values based on age and gender for muscle thickness and echo intensity at various sites, (77). However, it should be noted, that although muscle thickness values can be applied independently of the type of USS device, echo intensities are device-dependent and whilst conversion factors are being developed, this currently limits the usefulness of echo intensity reference values. Furthermore, it would appear that there is a lack of universally accepted cut-offs for intra-abdominal fat thicknesses, with different cut-offs proposed for various risks (96, 97, 98). Therefore further work is required to validate USS measurements and develop universally agreed reference data, which is cognisant of age, gender and ethnicity.

From the literature, it is apparent that USS is not without several limitations and several methodological aspects currently lack definitive answers (Table 1). Training and experience can address some of these issues (99, 100), as will future developments aimed at the further automation of measurements. In addition, Toomey *et al.,* (101) have made suggestions for standardising USS measurements as follows: site identification and participant positioning using Internal Society of Advancement of Kinanthropometry guidelines, longitudinal scanning of sites, use of a high frequency linear transducer, and skin-wound closure strips to guide consistent screen measurement of images, close observation of real time imaging and

generous use of water soluble transmission gel to ensure minimal compression of underlying tissues.

Despite the current issues regarding validity and reproducibility, the interest in USS has been further enhanced by the development of portable commercial ultrasound devices. Aimed primarily at the fitness market, one such device (Body-Metrix BX-2000, Intelametrix, Livermore, CA) calculates regional fat thicknesses using fixed and assumed acoustic reflection coefficients of 0.012 for the fat-muscle interface and 0.22 for the muscle-bone interface (102). It can also predict percentage body fat using known skinfold prediction equations and has the apparent capability of estimating muscle thickness and differentiating subcutaneous from visceral adipose tissue. A recent, small study of this particular device in 47 healthy, young overweight/obese adults, demonstrated that the USS prediction of percentage body fat (29 ± 7% versus 34 ± 8%) was significantly lower and the USS prediction of fat-free mass was significantly higher (67 ± 13 versus 62 ± 13 kg) in comparison to air displacement plethysmography (75). How much of this error was due to the inherent limitations of the prediction equations is unclear. Despite these differences, the device demonstrated good reliability (intraclass correlation coefficients of 0.84-0.98), which could make it a cost effective method of monitoring longitudinal regional changes in response to various interventions (75). Overall, it is important to emphasis that whilst an increasing interest in USS is evident, and the technology can be applied to clinical practice, further work is required before USS should be considered a valid and appropriate body composition method.

Bioelectrical impedance analysis

Bioelectrical impedance analysis (BIA) has been used in public health and clinical practice for some considerable time, first being developed to estimate body water, then further developed to estimate body composition and latterly to predict disease severity and prognosis (103). BIA is considered to be safe, straightforward, minimally invasive, relatively inexpensive, and more reproducible (<1%) than skinfold measurements. Results are readily available, and several devices are portable, making it an attractive bedside method for the clinical assessment of total body water and body composition (104, 105). As BIA technology has advanced, several methods and devices are available. As these devices have different assumptions

and limitations, it is important that health care professionals using these devices have sufficient knowledge and understanding of these.

BIA involves the passage of painless low amplitude current through the body, allowing the measurement of resistance (R) and reactance (Xc). BIA assumes that the resistance of the length of a conductor of homogenous material and uniform cross-sectional area is proportional to its length and inversely proportional to its cross-sectional area. It also assumes that the resistance to a current is inversely proportional to the uniform distribution of total body water (TBW) and electrolytes. (106, 107). However, this is seldom true in practice, and it has been suggested that measurements are related to TBW by statistical association rather than biophysical principles (99). Another significant limitation to the use of BIA in clinical practice is the use of linear regression equations to derive body composition data. Published equations have largely been derived from healthy, non-obese Caucasian populations within a BMI range of 16-34 kg/m^2 (108), although others are available. As such, significant errors can occur when equations are applied to different populations. For example, when applied to ethnically diverse populations this can result in systematic bias of up to 3%, due to differences in relative leg and arm lengths, frame size and body build (105).

BIA does not determine body composition directly. Resistance and reactance values are used to determine body impedance (based on the vector relationship between resistance and reactance), then total body water (TBW), body cell mass (BCM) extracellular water (ECW), intracellular water (ICW), and phase angle (PA). Fat-free mass (FFM) and body cell mass (BCM) can thereafter be estimated by the use of linear regression equations, which are usually age- and gender-specific and based on the assumption that FFM is on average 73.2% TBW. Once FFM has been determined, fat mass (FM) can be estimated by subtracting FFM values from body weight (107). BIA can also be used to derive, by use of prediction equations, fat-free mass/fat mass indices (104) and appendicular skeletal muscle mass (110). This latter rapid non-invasive quantification of appendicular skeletal stores is increasingly attractive, and suggested to be more important than that of whole-body FFM stores, due to the greater direct link with functionality (104).

In controlled studies of healthy individuals, BIA has been reported to provide estimates of body composition within 3-5% of those provided by reference methods such as DXA (53). However, in clinical populations greater variability isobserved. For example, a recent review of different BIA devices in surgical and oncology populations, demonstrated significant variability for estimates of TBW from -19% to +7%, FFM from -15% to +4% and FM from -16% to +43% (111). The precision of BIA to monitor longitudinal changes in body composition has also been questioned with suggestions that changes <5 kg should be interpreted cautiously (112). Additionally, it has also been questioned as to whether BIA-derived FM, FFM is able to predict clinical outcome any better than BMI (113).

The first and most widely used method of BIA is single frequency BIA, (SF-BIA). Commonly used at a frequency of 50k Hz, it measures a weighted sum of extracellular water and intracellular water resistivity, whichcan be used to estimate TBW under normal conditions (101). SF-BIA cannot distinguish between the distribution of TBW in ECW and ICW and SF-BIA results are not considered to be valid in circumstances where hydration is significantly altered (106). In such instances an increase or decrease in TBW e.g. oedema, ascites or dehydration could result in a significant over or under estimation of FFM and FM (107, 114).

Traditionally, SF-BIA has involved the use of four electrodes attached to the hand, wrist, foot and ankle of one side of the body and requires individuals to be normally hydrated, placed in a supine position with measurements taken after a period of rest and voiding of urine. Newer SF-BIA monitors have subsequently been developed that can undertake whole-body measurements of individuals in the vertical position, take simultaneous measurements of both sides of the body from hand to foot and provide estimates of skeletal muscle mass of different individual segments of the body e.g. upper body (right and left arm) and lower body (right and left leg). However, further work is required to determine the utility of these latter measurements across diverse clinical populations. It is also worth noting that although the evidence is limited, measurements taken in the vertical versus supine position are likely to result in differences in ECW and ICW measurements, but not of total body water (115).

SF-BIA monitors that measure from foot-to-foot alone (which can also directly measure body weight) or, hand-to-hand alone are also available, which ake measurements in the vertical position. These devices are generally less costly than whole-body devices and are available to purchase and use in clinical and non-clinical and home settings. However, the data provided by such devices can be limited (e.g. may only provide % fat mass and not provide raw resistance and reactance data), and the use of foot-to-foot machines may be limited by manufacturers' upper weight limits. Like whole-body SF-BIA devices, the validity of these devices to accurately and reliably predict body composition has been questioned. Whilst, in healthy populations, foot-to-foot devices can be considered a useful alternative to whole-body devices, the validity of hand-to-hand devices has been particularly questioned (116) with one study of 81 healthy individuals, demonstrating a significant overestimation of percentage body fat in women of approximately 5% leading to potential misclassification of nutritional status (117). Furthermore, anecdotally the validity of any results obtained in the home setting may be questionable, as individuals may not consistently adhere to a standardised measurement process.

Several sources of SF-BIA-derived body composition reference data are available. These have mainly been derived from large healthy populations, (118, 119) and as such should be used with caution in clinical populations. It should also be recognised that values obtained from different devices can differ which may affect comparison across studies and the applicability of reference data.

Multi-frequency BIA (MF-BIA), uses multiple low to high frequencies (usually between 5-200 kHz) and empirical linear regression models to derive impedance values, TBW, ICW, ECW and FFM (106). Whilst MF-BIA is generally not considered to improve estimates of body composition, it can provide amore accurate determination of ECW and TBW due to the ability of the higher frequencies to overcome the capacitance of cell membranes (107). MF-BIA could be of value in populations and individuals where disease related alterations in hydration have occurred such as critical care, renal and liver disease but evidence to support this use is still limited. Developments in MF-BIA technology, as is the case with SF-BIA have resulted in the availability of a variety of multi-frequency monitors, which can measure individuals in a supine or vertical position, simultaneously measure both

sides of the body and provide estimates of individual body segments. However, the use and validity of these in clinical practice to date is limited.

Bioelectrical spectroscopy (BIS) is a method, that uses ≥50 frequencies and mathematical modelling to calculate the resistance at zero and infinite frequencies to allow the determination of impedance values and in turn ECW, ICW. To date, the use of BIS has been mainly limited to healthy individuals with no structural or hydration abnormalities. There is some suggestion that BIS may significantly over or under predict ECW and TBW, in certain clinical populations (120) and a lacks sufficient evidence to support its use for the quantification and assessment of body composition. From the limited data that does exist , the use of BIS could result in estimated differences of ±10 kg FFM in renal populations. It may also significantly underestimate FFM in oncology patients who have experienced significant weight loss and conversely may overestimate FFM in overweight and obese individuals (107,120).

Even though the use of BIA for the assessment of body composition in clinical populations has been regularly criticised (113), it is still frequently used due to its practicality and relative low cost. Therefore, in a bid to derive more valid assessments that directly reflect tissue hydration and integrity, there is increasing interest and support for the use of 'raw' resistance and reactance data (121). Two such variables are phase angle (PA) and bioelectrical impedance vector analysis (BIVA). Phase angle is derived from the relation between the direct measurements of resistance (R) and reactance (Xc) and calculated as follows: Phase angle (degrees) = arctangent (Xc/R) x (180/π) (121).

In healthy participants, PA values usually ranges between 5-7^{o} and whilst the physiological meaning of PA is not yet well understood, it is considered to be an indicator of intra- and extracellular water distribution and, as such, an indicator of cellular health. Higher values are considered to reflect greater cellular integrity and function, and it has also been used as an alternative to the gold standard potassium-40 to predict body cell mass (122). As PA is calculated independently of regression equations, weight and height, it could prove of value in situations where the use of

BIA for the purposes of assessing body composition would be invalid or not practically possible e.g in critical care, dialysis or liver disease populations (123).

Studies indicate that PA may be influenced by several factors. . Men have been observed to have higher PA values than women due to greater level of muscle mass and PA appears to decrease with increasing age. Furthermore, higher levels of physical activity correspond with higher PA levels and whilst PA values appear to increase up to a BMI 30 kg/m^2 they are observed to decrease >40 kg/$m^{2.}$.Additionally, higher levels of inflammatory / infection markers have been observed to correspond to lower PA values (122, 124). PA is predictive of clinical outcome and mortality in a variety of clinical populations including HIV, cirrhosis, chronic obstructive pulmonary disease, haemodialysis, sepsis and cancer (118). PA has also been shown to correlate, in clinical populations, with functional markers (e.g. handgrip), quality of life scores and nutritional risk, although the latter relationship has not been consistently found (122, 125). PA has also been used to assess wound healing, whereby resistance (R) is considered to be a biomarker of cell growth with increases in resistance, suggestive of healing (126). Furthermore, when used in the context of pressure ulcers, a low reactance (Xc) along with a low serum albumin was found to be a significant predictor of risk (127). However, despite this growing body of evidence, there is insufficient evidence examining longitudinal changes in PA in response to therapeutic interventions.

Several reference values for PA, derived from large healthy populations, have been published (128, 129). However, as values from different devices can vary, comparison between studies and the applicability of reference data to clinical populations isdifficult.Reference data are also emerging for clinical populations, with proposed cut-off values to predict clinical outcome. In a recent study of 399 oncology patients, those who had a PA <5th centile had significantly lower nutritional and functional status and impaired quality of life (130). Subsequently it has been suggested that the 5th centile could serve as a simple prognostic cut-off across all clinical populations (122).

The other variable, which directly uses resistance and reactance data obtained at a frequency of 50 kHz, is bioelectrical impedance vector analysis (BIVA). BIVA, in

contrast to PA, provides a more detailed understanding of tissue hydration and body cell mass, independent of regression equations and body weight and longitudinal changes can be interpreted more reliably than PA (122). BIVA plots impedance values as a bivariate vector from the components of R (x axis) and Xc (y axis), after being normalised for height, providing a qualitative measure of soft tissue, independent of body size (122). PA remains the arctangent of Xc/R and the 95% confidence interval of the mean vector is plotted for a population group to allow statistical analysis (121).

Single BIVA measurements can be compared with reference values adjusted for age, gender and BMI and are known as tolerance ellipses. Three tolerance ellipses have been determined which correspond to the 50^{th}, 75^{th} and 95^{th} centiles for a healthy population. Healthy individuals are usually positioned within the 75^{th} centile and values out with the 95^{th} centile are considered to be abnormal (131). BIVA reference values, from a large population of healthy German adults, standardised for height and stratified for age, gender and BMI are available ,(132) as well as USA data stratified for age, gender and ethnicity (133). Presently, practical guidance on interpretation and use of BIVA is limited and as such the value of this method in a clinical populations remains to be established. Of particular interest is the use of BIVA to aid the interpretation of changes in body weight and body composition (134) and to assist in determining the validity of deriving body composition from BIA (121).

All impedance measurements require standardisation of the measurement protocol and several aspects should be considered. These include the need for the accurate measurement of height and weight, body and limb position, resting before measurements, controlling for the presence of metal or silicone implants, electrode position, timing of measurements, prior physical activity, bladder voiding, diuretics, ambient temperature, dietary and fluid intake including caffeine. Pregnancy or the presence of pace makers, both precluding the use of BIA (105, 135, 136). The majority of these aspects are potentially difficult to standardise in the clinical setting and may provide other sources of error or act as barriers to use. However, some of these aspects may not be as crucial as once thought. For example, a minimum 4-hour fast prior to measurements has been commonly advocated. However, in a recent study of 55 healthy, young adults, of normal body weight demonstrated that

although eating and drinking a standardised drink/meal prior to foot-to-foot SF-BIA measurements resulted in statistically significant differences in the estimation of body composition, the differences were small (median percentage change of 1%) and within the imprecision of the BIA technique. This suggests that whilst a fasted state is ideal, the adherence to strict protocols may not be necessary (137), except when sequential measurements are made.

In summary, despite the advances in BIA and continued use in practice, its use in measuring body composition appears to not be without several limitations. Despite this, the use of raw BIA data, PA and BIVA, does appear promising and may have important applications for practice in the future, (113); particularly if longitudinal controlled studies within clinical populations can elucidate how these variables are influenced by therapeutic interventions. Other advancements in the wider field of impedance technology may also hold future value, for the assessment of muscle quality. Electrical impedance myography (EIM), used in the evaluation and monitoring of neuromuscular diseases, has the potential to provide non invasive data (resistance, reactance and phase) about the quality of specific muscles or muscle groups (138, 139)). However, as there is a lack of relevant clinical studies examining reliability, and sensitivity to change as well as the ability to practically interpret and apply findings, its clinical usefulness is currently limited(138, 139).

Muscle strength, function and physical performance.

As outlined in the introduction, there is an increasing need to consider markers of muscle strength, function and physical performance within the assessment and monitoring of body composition in response to nutritional interventions. Several methods are available which can be used within clinical settings to assess strength and function, but an understanding of their value, limitations and implications for practice is required. One of the most commonly used methods is handgrip dynamometry which measures upper extremity grip strength. It is a portable, simple and inexpensive method shown to predict post-operative risk, hospitalisation, disability (140), cardiovascular and all-cause mortality (141) independently of muscle mass (142). There are, however, some difficulties in interpreting results across studies due to differences in measurement protocols, participant position and the

choice of right or left hand. The American Society of Hand Therapists' (ASHT) protocol, considered by many as the gold standard, recommends grip-strength should be measured in a seated position, with shoulders abducted, elbow flexed at 90^{o}, forearm in a neutral position and with the mean value of three maximum grip efforts of both dominant and non-dominant hands (143). However, as other protocols exist which take measurements standing or in a supine position and utilize fewer or more handgrip efforts, the interpretation of data across studies can be difficult (144).

The type of dynamometer can also influence results. The majority of studies used a Jamar dynamometer (Lafayette Instruments, Layfayette IN), considered by ASHT as the gold standard, but as it is relatively heavy and requires an initial ~1.6 kg of force to move the indicator; it may confound measurements in older or frail populations (144). Therefore, alternative lighter dynamometers such as the Takei (Takei Scientific Instruments, Tokyo) or pneumatic squeeze dynamometer may be more appropriate in certain populations (145).

Until recently, there has been limited normative handgrip-strength across the life-course. Commonly, data derived from a meta-analysis of 12 (n=3317 adults, $\geq$20 years of age), primarily USA studies, which conformed to the ASHT protocol and used a Jamar dynamometer, has been used (143). However, normative centile curves derived from 12 UK studies of 60,803 observations of participants aged 5 to 90 years are now available (Tables 2a and 2b). Although the studies used varying measurement protocols and dynamometers, only maximum values were used to produce the centiles. In addition, sensitivity analysis of the data suggests that the centile curves accommodate the protocol differences between studies (145). A weak grip-strength has been defined as strength at least 2.5 standard deviations below the gender-specific peak mean. However the use of reference data to interpret individual results should be done with consideration of how handgrip was measured and the population the reference data was derived from. Furthermore, grip-strength can be affected by psychological factors such motivation, anxiety, depression, cognition, sedatives, diseases affecting the hands (e.g. rheumatoid arthritis) and inflammation (9), therefore these factors should also be considered when interpreting results.

As differences in muscle strength and responsiveness to interventions between upper and lower limbs have been observed (4, 146, 147), the strength testing of

lower versus upper limbs may be relevant. Knee extensor testing is commonly used in a range of populations and age groups and has been associated with disability and mortality. Various reference values are available. For example, in one large study of 2,784 older adults (mean age 74 ± 3 years), who were followed up for a median of 5.9 years, values of <1.13 Nm/kg for men, and <1.01 Nm/kg for women were associated with a high risk of future mobility limitation (148).

However, knee extensor strength testing can be difficult, costly, time-intensive and the equipment required may not be routinely available. Furthermore, whilst differences in upper and lower limbs have been observed there is a suggestion that in healthy individual's grip-strength and knee extensor strength share a common construct and either could be used to determine muscle strength, with handgrip the preferred option due to its simplicity (149). Whether this construct remains valid in the presence of disease requires further exploration.

The consequences of decreased muscle strength are functional impairment and reduced ability to perform activities of daily living (150). Functional performance tests, appearing to have a stronger relationship with muscle strength than muscle mass, can therefore provide valuable proxy assessments (6,151). Such performance tests are considered clinically relevant, as they in turn have been associated with disability risk and mortality (152). Common performance tests include walking / gait speed, 6-minute walk test, stair-climb test, timed up-and-go and chair-rise / sit-to-stand. All of these are relatively simple and inexpensive tests to perform in the clinical setting (153). Various reference data are available (Table 3). In the main, these apply to healthy older adults and further work is needed in more diverse populations to establish relevant cut-offs to aid comparison between studies, determine the prevalence of impairment and aid the development of targeted therapeutic interventions (154).

Walking / gait speed is of particular interest as this has been found to be predictive of adverse outcomes such as future health status, hospitalisation and risk of falling, particularly in older individuals (150, 155). Commonly measured as the individual's usual walking pace over a short 4-metre distance, it is a feasible and practical assessment within a clinical setting (156). A usual gait speed <0.6 m/sec has been proposed as a diagnostic cut-off for 'dismobility' (157) and in chronic kidney disease,

it has been demonstrated that each 0.1 m/sec decrease in gait speed is associated with a 26% higher risk of mortality (158). Therefore, a change in gait speed could serve as a useful outcome measure for assessing interventions, but appropriate cut-offs in younger and more clinical and ethnically diverse populations are currently lacking.

Self-reported methods provide a more subjective assessment of physical function. These include the sickness impact profile (159), the Barthel index (160), the Duke activity status inventory (161), the Lawton Instrumental Activities of Daily Living scale (162), the World Health Organisation Disability Assessment Schedule (163) or more generic questionnaires e.g. the short form 36 (164) and EQ5D (165), which capture functional related performance. Additionally, the subjective global assessment and the mini nutritional assessment tool which incorporate elements of functional assessment could be options for practice (166, 167). It is, however, important to note that self-reported functioning does not always correlate with objective measures of function (164). This could be because self-reported functioning is considered to be a dynamic, non-linear construct (168). In addition, factors such as gender, age, recent health problems, personality traits, depression, anxiety, cognitive impairment, pain and health literacy can also influence the accuracy of self-reporting (169,170, 171). 'Ceiling' and 'floor effects' of a questionnaire have been observed and may also influence results (150, 172).

Whilst these methods are applicable for the assessment and monitoring of muscle strength and physical performance *per se*, future work to elucidate the influence of nutritional interventions versus other interventions, such as exercise, on muscle strength and functional performance is required. In doing so, an integrated multidisciplinary approach will be necessary.

Conclusion

Advances in body composition techniques have undoubtedly led to an increased understanding of the role of tissue volume and mass, its quality, patterning, and functionality and how these reflect nutritional status and impact on health risk. These advances coupled with increasingly outcome-focused healthcare suggest that practice needs to evolve and move beyond current approaches (19, 173, 174). Although, developments in assessing body composition and function bring

challenges associated with limited validation and interpretation, this is an exciting, rapidly developing era with many opportunities to apply emerging knowledge and techniques to practice and thus influence future interventions and improve health outcomes.

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Table 1: Summary of current methodological issues relevant to ultrasound scanning when used for the assessment of body composition in clinical populations (66, 73, 74, 76, 80, 93, 99, 101)

- Greater operator dependency than other imaging techniques
- Requirement for anatomical knowledge to correctly identify interfaces and accurately measure tissues of interest
- Undetermined effects of dehydration and oedema on measurements of muscle thickness and echo intensity
- Undetermined effects of intramuscular fat and connective tissue on estimates of muscle thickness
- Undetermined effect of food and drink consumption, particularly on abdominal measurements
- Undetermined effect of levels of exertion on muscle blood flow and muscle size
- Undetermined effect of muscle contraction/relaxation on measurements
- Lack of standardised application of force applied to the transducer- applying maximal force can reduce measured thicknesses by 25-37% depending on the site of measurement and tissue of interest
- Lack of standardisation of scanning plane- scans can be made in the longitudinal or transverse plane
- Lack of standardisation of USS mode and frequency
- Lack of standardised subject positioning- measurements can be taken standing or supine, with suggestion that measurements taken in standing position may provide more accurate estimates
- Lack of standardised measurement sites- dimensions can vary with location

Table 2a: Male grip-strength values (145)

Male	Centiles (kg)					Mean (SD)
Age (years)	10th	25th	50th	75th	90th	
5	6	7	8	9	10	7.7 (2.9)
10	12	15	17	20	22	17.2 (4.1)
15	21	25	29	33	38	29.6 (5.6)
20	30	35	40	46	52	41.5 (7.3)
25	36	41	48	55	61	48.8 (8.7)
30	38	44	51	58	64	51.6 (9.6)
35	39	45	51	58	64	51.6 (10.1)
40	38	44	50	57	63	50.3 (10.3)
45	36	42	49	56	61	48.8 (10.3)
50	35	41	48	54	60	47.6 (10.1)
55	34	40	47	53	59	46.2 (9.8)
60	33	39	45	51	56	44.6 (9.2)
65	31	37	43	48	53	42.3 (8.6)
70	29	34	39	44	49	39.1 (8.1)
75	26	31	35	41	45	35.6 (7.6)
80	23	27	32	37	42	32.2 (7.3)
85	19	24	29	33	38	28.5 (7.0)
90	16	20	25	29	33	24.7 (6.8)

Table 2b: Female grip-strength values for women (145)

Female	Centiles (kg)					Mean (SD)
Age (years)	10th	25th	50th	75th	90th	
5	6	7	8	9	10	8 (3.1)
10	12	14	16	19	21	16.7 (3.8)
15	17	20	24	27	30	23.9 (4.5)
20	21	24	28	32	36	28.4 (5.1)
25	23	26	30	35	38	30.6 (5.6)
30	24	27	31	35	39	31.4 (6.0)
35	23	27	31	35	39	31.3 (6.2)
40	23	27	31	35	39	30.7 (6.3)
45	22	26	30	34	38	29.9 (6.4)
50	21	25	29	33	37	28.7 (6.4)
55	19	23	28	32	35	27.5 (6.4)
60	18	22	27	31	34	26.5 (6.2)
65	17	21	25	29	33	25.3 (6.0)
70	16	20	24	27	31	23.5 (5.7)
75	14	18	21	25	28	21.4 (5.4)
80	13	16	19	23	26	19.1 (5.1)
85	11	14	17	20	23	16.6 (4.7)
90	9	11	14	17	20	14.2 (4.4)

Table 3: Examples of reference values for selected functional performance tests

<table>
<tr><th>Performance test</th><th colspan="2">Male</th><th colspan="2">Female</th><th>Comments</th></tr>
<tr><td>Normal walking/gait speed over measured distance (metres/second)</td><td>Age

20-29
30-39
40-49
50-59
60-69
70-79
80-99</td><td>Mean:

1.36
1.43.
1.43
1.43
1.34
1.26
0.97</td><td>Age

20-29
30-39
40-49
50-59
60-69
70-79
80-99</td><td>Mean:

1.08
1.26
1.22
1.10
0.97
0.83
0.56</td><td>Systematic review & meta-analysis of 41 studies involving 23,111 healthy adults (175)</td></tr>
<tr><td>Timed up-and-go (seconds)
Time taken to rise from a chair, walk three metres, turn around, walk back to the chair & sit down.</td><td colspan="4">60-99 years: mean 9.4 (95% CI: 8.9-9.9)
60-69 years: mean 8.1 (95% CI: 7.1-9.0)
70-79 years: mean 9.2 (95% CI: 8.2-10.2)
80-99 years: mean 11.3 (95% CI: 10.0-12.7)

Individuals who exceed the upper 95% CI can be considered to have worse than average performance</td><td>Meta-analysis of 21 diverse studies (from across Europe, Australia, USA, Asia & Middle East) involving 4,395 apparently healthy individuals (176)</td></tr>
<tr><td>Sit to stand/chair rise (seconds)

5 sit to stand (Time taken to undertake 5 sit to stand transitions)</td><td colspan="4">60-69 years 11.4 seconds
70-79 years 12.6 seconds
80-89 years 14.8 seconds

Individuals with times exceeding the above can be considered to have a worse than average performance</td><td>Meta-analysis of 13 studies involving 20,617 community dwelling older adults from across USA, Australia & Japan (177)</td></tr>
<tr><td>30-second sit-to-stand

(number of sit to stand transitions in 30 seconds)</td><td colspan="4">Male</td><td rowspan="3">Study of 7,183 (2,135 men) community residing older adults across USA, aged 60-94 years with 65% performing moderate activity ≥3 times/week (178)</td></tr>
<tr><td>Age

60-64
65-69
70-74
75-79
80-84
85-89
90-94</td><td>Below average
<14
<12
<12
<11
<10
<8
<7</td><td>Average

14-19
12-18
12-17
11-17
10-15
8-14
7-12</td><td>Above average

>19
>18
>17
>17
>15
>14
>12</td></tr>
<tr><td colspan="4">Female</td></tr>
<tr><td>Age

60-64
65-69
70-74
75-79
80-84
85-89
90-94</td><td>Below average
<12
<11
<10
<10
<9
<8
<4</td><td>Average

12-17
11-16
10-15
10-15
9-14
8-13
4-11</td><td>Above average

>17
>16
>15
>15
>14
>13
>11</td></tr>
</table>

60-second-sit-to-stand (number of sit to stand transitions in 60 seconds)	**Male**	**Centile**					Cross sectional study of 6,926 Swiss adults as part of nationwide health promotion campaign (179).
	Age (years)	2.5th	25th	50th	75th	97.5th	
	20-24	27	41	50	57	72	
	25-29	29	40	48	56	74	
	30-34	28	40	47	56	72	
	35-39	27	38	47	58	72	
	40-44	25	37	45	53	69	
	45-49	25	35	44	52	70	
	50-54	24	35	42	53	67	
	55-59	22	33	41	48	63	
	60-64	20	31	37	46	63	
	65-69	20	29	35	44	60	
	70-74	19	27	32	40	59	
	75-79	16	25	30	37	56	
	Female	**Centile**					
	Age (years)	2.5th	25th	50th	75th	97.5th	
	20-24	31	39	47	55	70	
	25-29	30	40	47	54	68	
	30-34	27	37	45	51	68	
	35-39	25	37	42	50	63	
	40-44	26	35	41	48	65	
	45-49	25	35	41	50	63	
	50-54	23	33	39	47	60	
	55-59	21	30	36	43	61	
	60-64	20	28	34	40	55	
	65-69	19	27	33	40	53	
	70-74	17	25	30	36	51	
	75-79	13	22	27	30	43	