

MEDC0037

Practical Nutritional Assessment
Anthropometry & Body Composition

Dr Adrian Slee

Introduction

- Anthropometry is the scientific study of the human body.
- It is the measure of proportions and physical dimensions of the body.
 - E.g. body size and shape
- Anthropometry plays a role in industrial design, the design of clothing and ergonomics.

Question

- In Nutritional Science and Dietetics why are we interested in anthropometry and body composition?

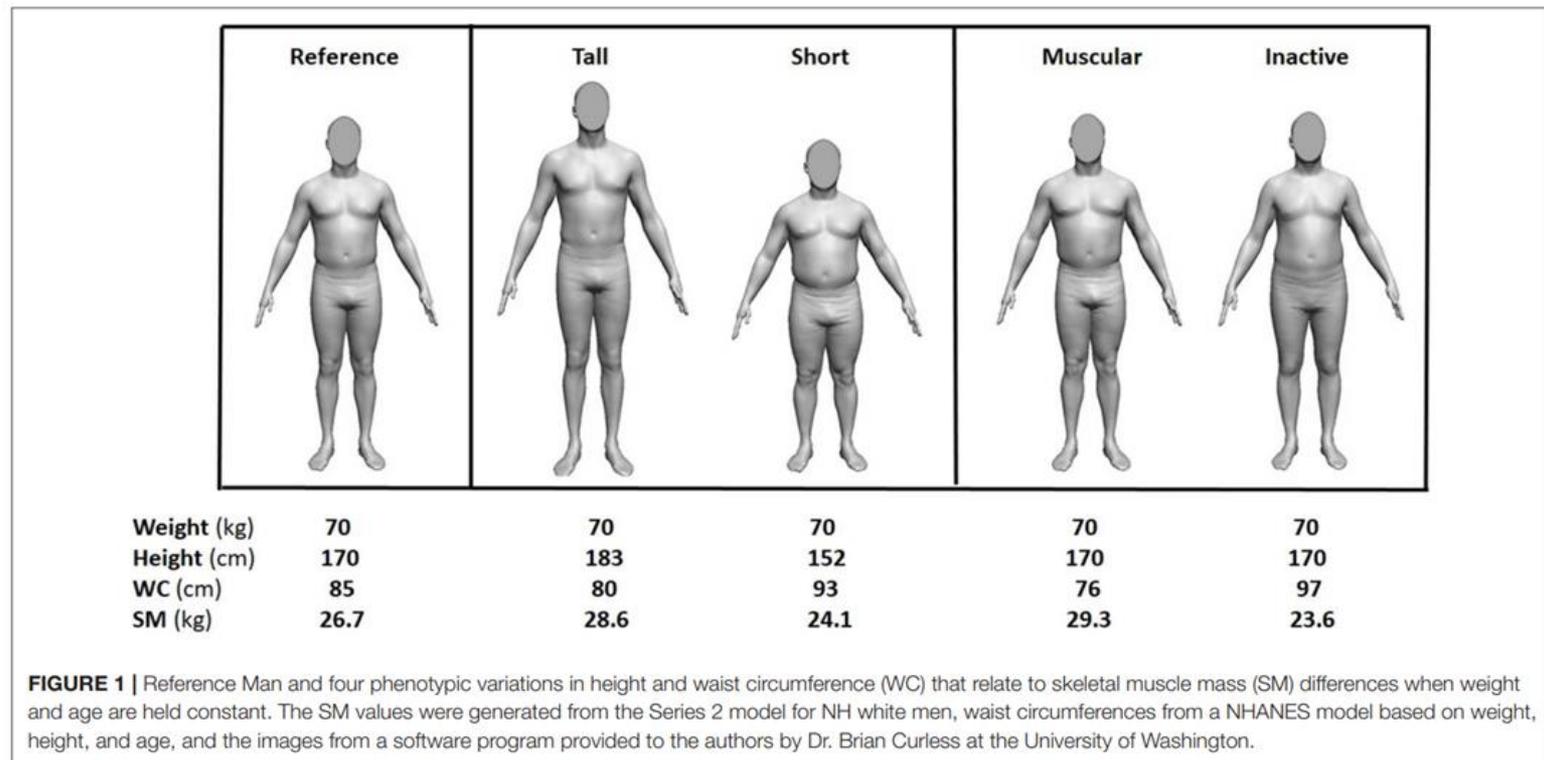
Reasons for Measuring Body Size and Composition

- Growth and development
- Obesity
- Wasting

Examples of different individuals with the same body weight (different height, waist circumference and skeletal muscle mass)

Heymisfield et al.

Predicting Skeletal Muscle Mass



Question

- Which body compartments can we look at and assess?

Body Composition Compartments

- There are different compartment models for body composition.
- E.g. fat free mass (FFM) and fat mass (FM) – 2 compartment model etc.
- We can also look at skeletal muscle mass specifically.

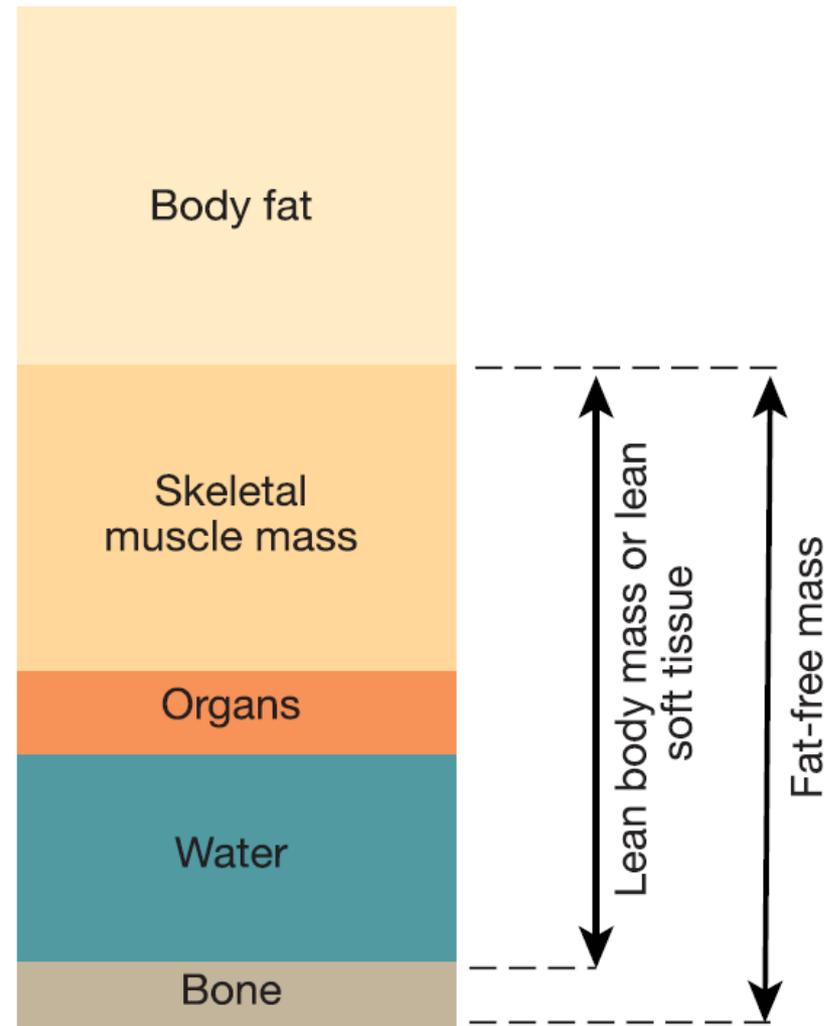


Figure 1 | Body composition compartments; differences in the estimation of fat-free mass and lean soft-tissue/lean body mass. Residual mass considers connective tissue and blood.

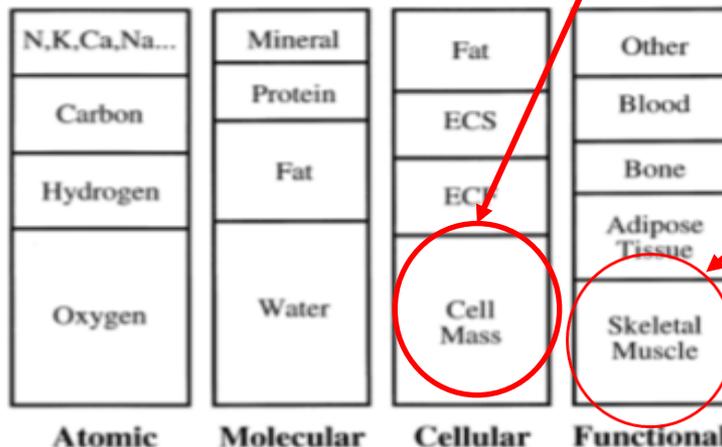
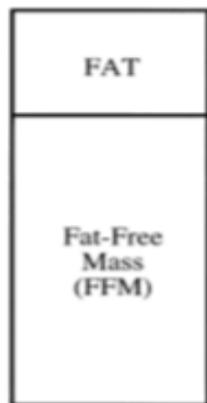
Body Composition & Compartment Models

- Basic **2-compartment model (FM and FFM)** and 5-compartment model of body composition. From Ellis, 2000.

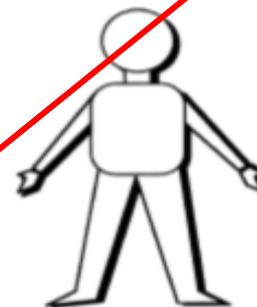
• **Body Cell Mass (BCM)** relates to the healthy cellular protein containing tissue, i.e. muscle and organ mass (minus fat, ECW and bone mineral).

• **Skeletal Muscle Mass (SMM)** – functional compartment involved in locomotion and physical function.

Basic Model
2-Compartment



Multicompartment Models



Whole Body

Question

- Which techniques can we use to measure body size and the different body compartments?

Examples of Methods



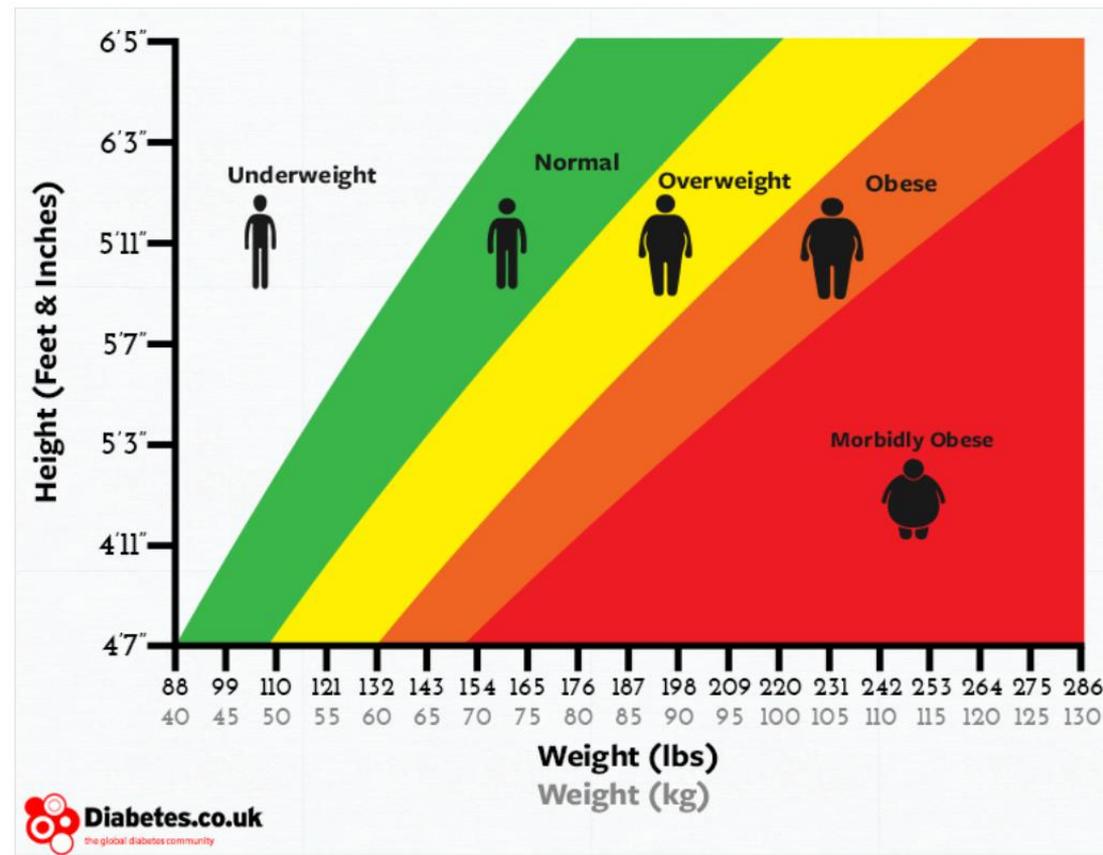
- Body mass index
- Body circumferences (e.g. waist, limbs)
- Skin fold thickness (using callipers)
- Scanning and imaging techniques (e.g. DEXA, CT, MRI)
- Bioelectrical impedance assessment (BIA)

MEDC0037 Assessment

- Next week you will have full details of the Anthropometry and Body Composition Practical Report.
- You will be analysing data on BMI, body fat (by skin fold callipers and BIA), body circumferences (e.g. mid upper arm) and other information e.g. hand grip strength (HGS).

Body Mass Index

- BMI or the Quetelet index is defined as $\text{weight}/\text{height}^2$ (kg/m^2).
- Typically used to measure presence of obesity and under-malnutrition



BMI and Disease Risk

- With increasing BMI there is increased fat mass and risk of disease e.g. CVD.

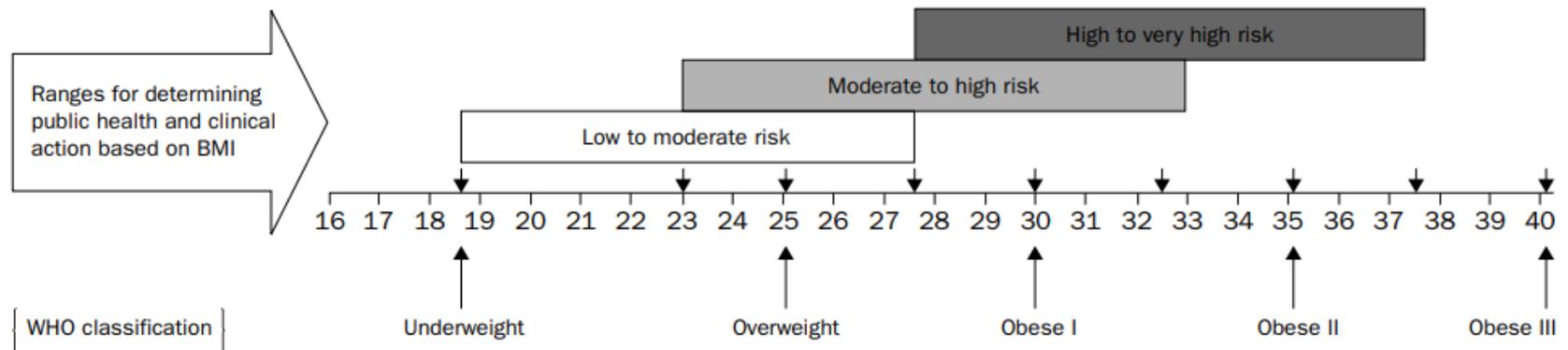


Figure 2: **Body-mass index (BMI) cut-off points for public health action**

Lancet 2004; 363: 157-63

BMI and Mortality

- Most studies show a J shaped curve relationship with BMI and mortality.
- E.g. recent UK study in 3.6 million adults aged 40 years at baseline.



Association of BMI with overall and cause-specific mortality: a population-based cohort study of 3.6 million adults in the UK



Krishnan Bhaskaran, Isabel dos-Santos-Silva, David A Leon, Ian J Douglas, Liam Smeeth

Summary

Background BMI is known to be strongly associated with all-cause mortality, but few studies have been large enough to reliably examine associations between BMI and a comprehensive range of cause-specific mortality outcomes.

Methods In this population-based cohort study, we used UK primary care data from the Clinical Practice Research Datalink (CPRD) linked to national mortality registration data and fitted adjusted Cox regression models to examine associations between BMI and all-cause mortality, and between BMI and a comprehensive range of cause-specific mortality outcomes (recorded by International Classification of Diseases, 10th revision [ICD-10] codes). We included all individuals with BMI data collected at age 16 years and older and with subsequent follow-up time available. Follow-up began at whichever was the latest of: start of CPRD research-standard follow up, the 5-year anniversary of the first BMI record, or on Jan 1, 1998 (start date for death registration data); follow-up ended at death or on March 8, 2016. Fully adjusted models were stratified by sex and adjusted for baseline age, smoking, alcohol use, diabetes, index of multiple deprivation, and calendar period. Models were fitted in both never-smokers only and the full study population. We also did an extensive range of sensitivity analyses. The expected age of death for men and women aged 40 years at baseline, by BMI category, was estimated from a Poisson model including BMI, age, and sex.

Findings 3 632 674 people were included in the full study population; the following results are from the analysis of never-smokers, which comprised 1 969 648 people and 188 057 deaths. BMI had a J-shaped association with overall mortality; the estimated hazard ratio per 5 kg/m² increase in BMI was 0.81 (95% CI 0.80–0.82) below 25 kg/m² and 1.21 (1.20–1.22) above this point. BMI was associated with all cause of death categories except for transport-related accidents, but the shape of the association varied. Most causes, including cancer, cardiovascular diseases, and respiratory diseases, had a J-shaped association with BMI, with lowest risk occurring in the range 21–25 kg/m². For mental and behavioural, neurological, and accidental (non-transport-related) causes, BMI was inversely associated with mortality up to 24–27 kg/m², with little association at higher BMIs; for deaths from self-harm or interpersonal violence, an inverse linear association was observed. Associations between BMI and mortality were stronger at younger ages than at older ages, and the BMI associated with lowest mortality risk was higher in older individuals than in younger individuals. Compared with individuals of healthy weight (BMI 18.5–24.9 kg/m²), life expectancy from age 40 years was 4.2 years shorter in obese (BMI ≥30.0 kg/m²) men and 3.5 years shorter in obese women, and 4.3 years shorter in underweight (BMI <18.5 kg/m²) men and 4.5 years shorter in underweight women. When smokers were included in analyses, results for most causes of death were broadly similar, although marginally stronger associations were seen among people with lower BMI, suggesting slight residual confounding by smoking.

Interpretation BMI had J-shaped associations with overall mortality and most specific causes of death; for mental and behavioural, neurological, and external causes, lower BMI was associated with increased mortality risk.

Funding Wellcome Trust.

Lancet Diabetes Endocrinol 2018; 6: 944–53
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See [Comment](#) page 916
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From: Bhaskaran et al, 2018

From: Bhaskaran et al, 2018

<https://www.thelancet.com/action/showPdf?pii=S2213-8587%2818%2930288-2>

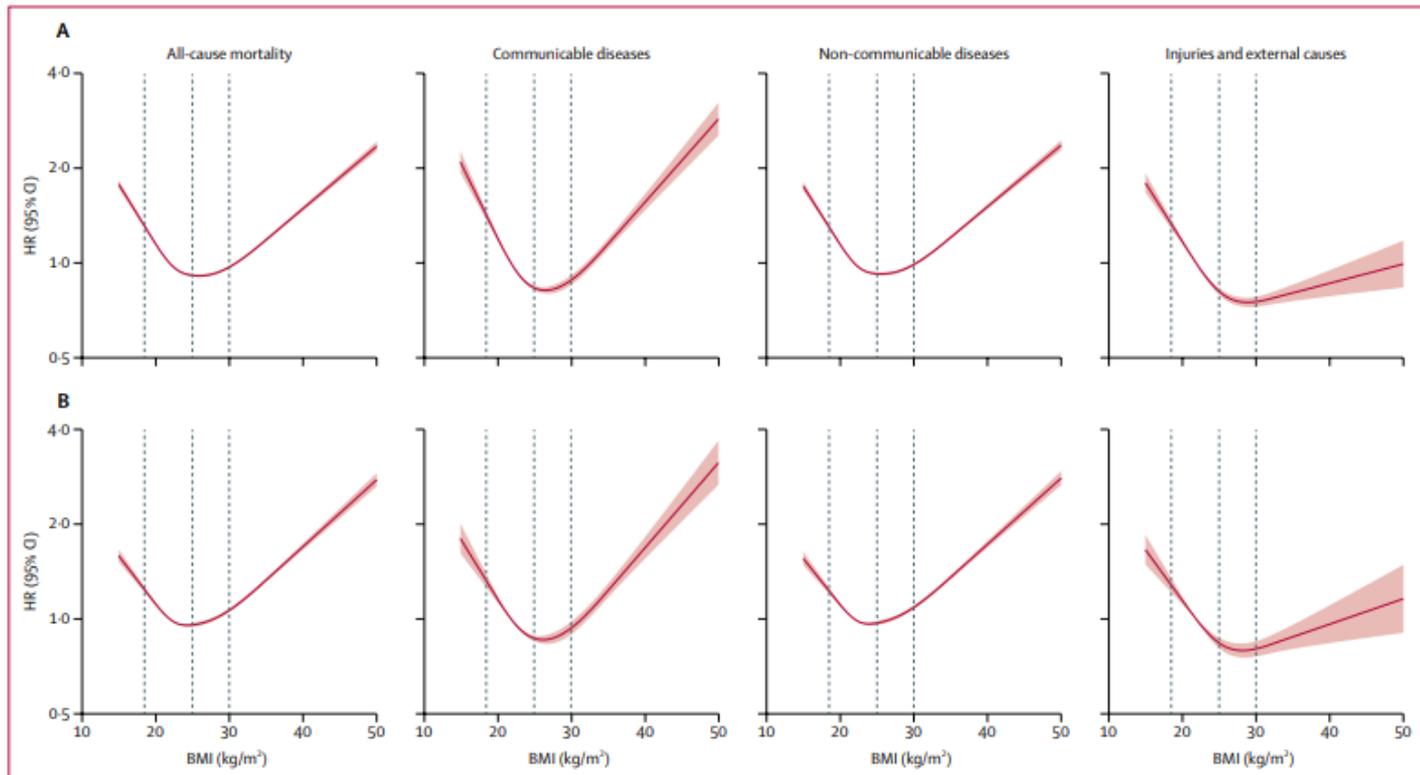


Figure 1: All-cause mortality and Level 1 cause-specific mortality outcomes in total study population (A) and in never-smokers only (B)

We used a three-level hierarchical classification of causes of death as used by the Global Burden of Diseases, Injuries, and Risk Factors Study.¹⁶ All Level 1 outcomes (communicable diseases, non-communicable diseases, and injuries and external causes) were studied. 5-year exclusion period applied for person-time and events after a BMI record. Dashed vertical lines represent WHO BMI category thresholds of 18.5 kg/m² (underweight to healthy), 25 kg/m² (healthy weight to overweight), and 30 kg/m² (overweight to obese). Estimates adjusted for age at BMI record, deprivation, calendar year, diabetes, alcohol status, and smoking (all as defined at date of BMI measure) and stratified for sex. The p values for overall association and p values for non-linearity were less than 0.0001 for all outcomes, in both full and never-smoker populations. HR=hazard ratio.

BMI Paradox

- Association between age and BMI on mortality.
- 62,116 men and 262,019 women.
- Never smoked and no history of heart disease, stroke or cancer at base line.
- No history of unintentional weight loss.

The New England Journal of Medicine

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THE EFFECT OF AGE ON THE ASSOCIATION BETWEEN BODY-MASS INDEX AND MORTALITY

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ABSTRACT

Background The effect of age on optimal body weight is controversial, and few studies have had adequate numbers of subjects to analyze mortality as a function of body-mass index across age groups.

Methods We studied mortality over 12 years among white men and women who participated in the American Cancer Society's Cancer Prevention Study I (from 1960 through 1972). The 62,116 men and 262,019 women included in this analysis had never smoked cigarettes, had no history of heart disease, stroke, or cancer (other than skin cancer) at base line in 1959–1960, and had no history of recent unintentional weight loss. The date and cause of death for subjects who died were determined from death certificates. The associations between body-mass index (defined as the weight in kilograms divided by the square of the height in meters) and mortality were examined for six age groups in analyses in which we adjusted for age, educational level, physical activity, and alcohol consumption.

Results Greater body-mass index was associated with higher mortality from all causes and from cardiovascular disease in men and women up to 75 years of age. However, the relative risk associated with greater body-mass index declined with age. For example, for mortality from cardiovascular disease, the relative risk associated with an increment of 1 in the body-mass index was 1.10 (95 percent confidence interval, 1.04 to 1.16) for 30-to-44-year-old men and 1.03 (95 percent confidence interval, 1.02 to 1.05) for 65-to-74-year-old men. For women, the corresponding relative risk estimates were 1.08 (95 percent confidence interval, 1.05 to 1.11) and 1.02 (95 percent confidence interval, 1.02 to 1.03).

Conclusions Excess body weight increases the risk of death from any cause and from cardiovascular disease in adults between 30 and 74 years of age. The relative risk associated with greater body weight is higher among younger subjects. (N Engl J Med 1998;338:1-7.)

WHETHER recommended body weight should remain constant throughout adulthood or should be higher for older adults is controversial. The Department of Agriculture's 1990 *Dietary Guidelines for Americans*¹ recommended age-specific ranges of weight for height, with heavier weights indicated for people 35 years of age or older, but age-specific weight recommendations were omitted from the 1995 *Dietary Guidelines for Americans*,² presumably because the information to support the need for different recommended weights was inadequate.

The debate sparked by the dietary guidelines made it evident that more studies were needed to clarify whether age modifies the relation between body weight and mortality. Studies that compare the relations between the body-mass index (the weight in kilograms divided by the square of the height in meters) and mortality among age groups in a single cohort provide evidence to confirm or refute the usefulness of age-specific guidelines, but studies of sufficient size to generate meaningful age-specific estimates are rare. Previous analyses from the American Cancer Society's Cancer Prevention Study I,^{3,4} a study of personal health habits and mortality, did examine the relation of body weight and mortality in a very large cohort; however, comparisons were made with use of the mean weight within each age group, a measure that varied by as much as 14 lb (6.4 kg) among age groups. Therefore, direct comparisons

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Relative risk of death from all cause and CVD in group

- At 30-44 and 45-54 years there is a strong relationship between BMI and relative risk of death.
- This disappears in very old age, e.g. > 85 years.

The New England Journal of Medicine

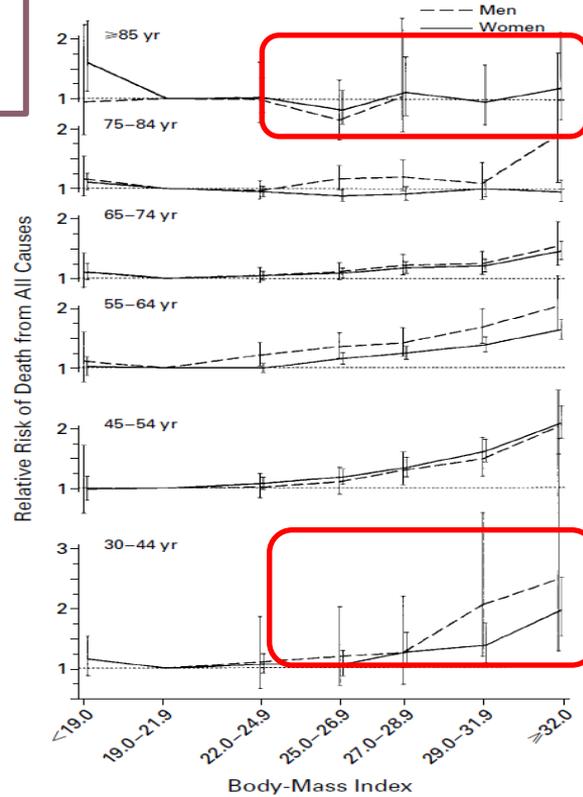


Figure 1. Relative Risk of Death from Any Cause According to Age Group and Body-Mass-Index Category among Healthy White Men and Women Who Had Never Smoked.

All relative risks were adjusted for age, education, physical activity, and alcohol consumption. The reference category was made up of subjects with body-mass indexes of 19.0 to 21.9. The bars represent 95 percent confidence limits. Relative-risk estimates are not shown for age-body-mass-index groups with five or fewer deaths.

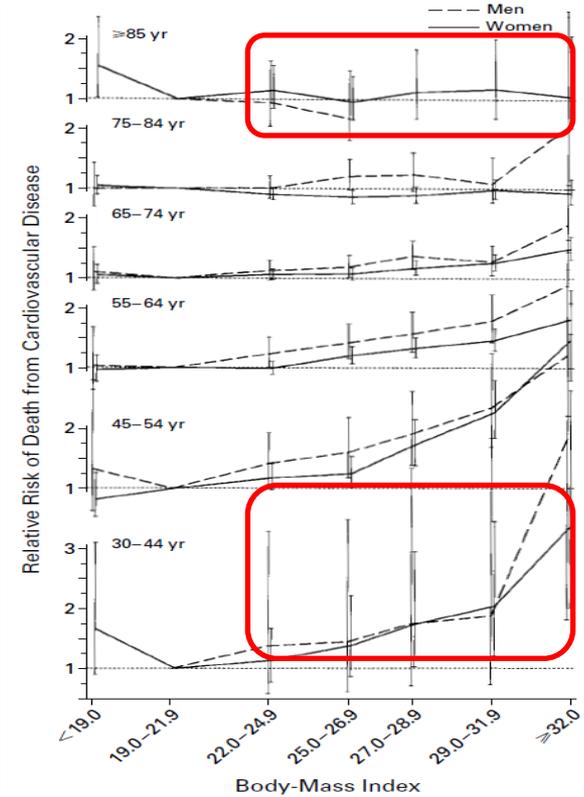


Figure 2. Relative Risk of Death from Cardiovascular Disease According to Age Group and Body-Mass-Index Category among Healthy White Men and Women Who Had Never Smoked.

All relative risks were adjusted for age, education, physical activity, and alcohol consumption. The reference category was made up of subjects with body-mass indexes of 19.0 to 21.9. The bars represent 95 percent confidence limits. Relative-risk estimates are shown for age-body-mass-index groups with five or fewer deaths.

The relationship between BMI and mortality in men (n=7604) and women (n=9107) over 65 years of age from Norway. (note lowest mortality in the overweight BMI range)

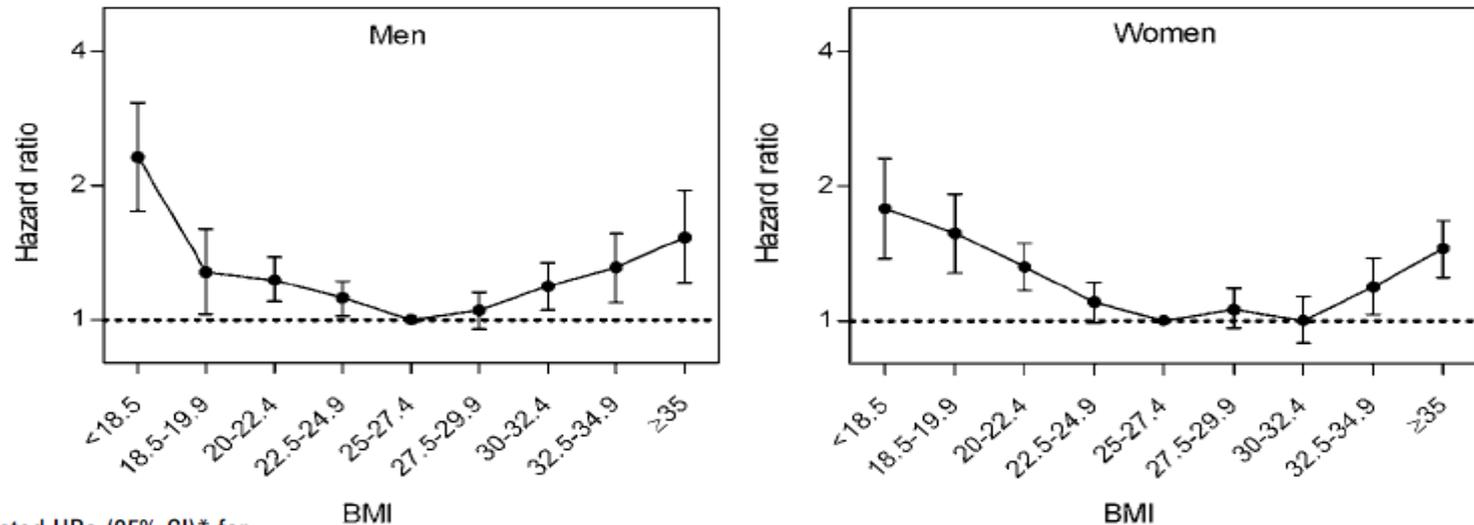


Figure 1 Adjusted HRs (95% CI)* for total mortality rate by body mass index (BMI; kg/m²) category in elderly men and women. BMI 25–27.4 constitutes the reference category. *Adjusted for smoking status, age, marital status, educational level and study site.

BMI Scale for Elderly Indicating Malnutrition Risk

Clinical Nutrition (1998) **17**(5): 195–198
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REVIEW

At which body mass index and degree of weight loss should hospitalized elderly patients be considered at nutritional risk?

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Abstract—The Subjective Global Assessment, the Nutrition Risk Score and a Danish counterpart are simple screening methods to detect patients at risk of nutrition-related complications. The cut-off points used in the screening are a body mass index (BMI) less than 20 kg/m² (18.5 kg/m² in the Danish version) and weight loss more than 5% during the last 1–6 months – regardless of age. This review of the literature indicates that the optimal range of BMI for elderly people is increasing from 20 to 25 kg/m² to 24–29 kg/m². It also suggests that a clinically significant weight loss for the elderly is around 5% annually, less than in younger age groups. And finally, even though intervention studies have shown an overall positive effect of nutritional support of the elderly patients, there seems to be a high percentage of the old, especially those initially malnourished, who will not benefit from the support. The conclusion is that other cut-off points should be used for the elderly (65+ years) patients, i.e. BMI less than 24 kg/m² or any degree of weight loss. This means that nutritional support will be initiated in time to reduce the nutrition related complications.

- There is a question as to whether there should be a different scale for the elderly to indicate malnutrition?
- Beck and Ovesen in 1998 published this.
- <24 kg/m² to indicate risk.

BMI Issues

- BMI as a measure of disease risk - This is not so straight forward when you consider certain populations such as older people, CKD and heart failure etc.
- Also, in athletic populations a person may have a high muscle mass and high BMI but have low body fat and reduced disease risk.
- Another issue is sarcopenic obesity or hidden malnutrition in specific disease states.

BMI in Athletes

- Athletes who are more muscular will have a higher BMI!
- E.g. **72% misdiagnosed as obese** in this study of 173 athletes!



ORIGINAL ARTICLE

Top level athletes with a body mass index of 30 or higher. Obesity or good muscle development?

Alicia Canda

Agencia Española de Protección de la Salud en el Deporte, Madrid, Spain

Received 9 August 2016; accepted 12 September 2016

KEYWORDS

Obesity;
Body mass index;
Skinfold thickness;
Waist circumference

Abstract

The aim of this paper is to examine athletes whose BMI is in the obesity range, and to determine the relationship between their adiposity indices and their body fat measured by anthropometry, while establishing which would be the most valid for this population.

A retrospective study was carried out on athletes with a BMI of 30 kg/m² or higher. The sample consisted of 173 athletes (151 males and 22 females), aged 23.3 ± 4.9 years, with 9.8 ± 5 years in competition, training 16.6 ± 7.1 hours/week. The protocol included 15 variables and the calculation of anthropometric indices related to adiposity and body fat. ROC curves were used to check the level of diagnostic accuracy in relation to obesity (high fat percentage).

The anthropometric variables with the greatest area under the curve were skinfolds and, in particular, supraspinale skinfolds (95% CI: 0.899-0.974), with a cut-off point of 21 mm. These were followed by waist circumference to height ratio (95% CI: 0.784-0.916) with a cut-off point of 0.57. As many as 72% of the athletes would have been wrongly classified as obese by their BMI. It was established that a BMI of up to 32.8 kg/m² may be considered as overweight for males, mainly due to their lean or fat-free mass.

In order to diagnose obesity in athletes, body fat should be assessed by means of skinfold measurements or, failing that, by measuring waist circumference to height ratios.
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SUPPLEMENT ARTICLE

Sarcopenic obesity: hidden muscle wasting and its impact for survival and complications of cancer therapy

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- Note – prevalence of sarcopenic obesity via use of CT scans.

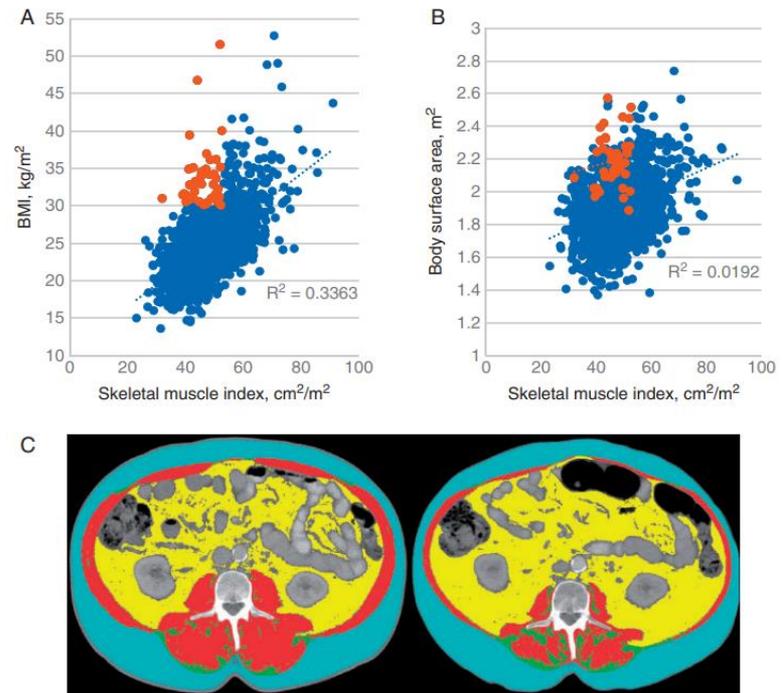


Figure 1. Variation in muscularity of patients with solid tumors. Data presented are for a population cohort of male patients with advanced solid tumors of the lung or gastrointestinal tract ($n=2760$). (A) Body mass index (BMI) and lumbar skeletal muscle index are poorly correlated. Orange dots represent sarcopenic obese patients. (B) Body surface area (BSA) and lumbar skeletal muscle index are poorly correlated. Orange dots represent sarcopenic obese patients. (C) Obesity with low and high muscle mass. Axial cross-sectional lumbar images are from a male with a diagnosis of non-small-cell lung cancer stage IV. Images are taken ~10 months apart. At both time points the BMI was 30.7 kg/m². At the first time point (left-hand image) the patients was muscular: muscle area=172.5 cm²; fat area=452 cm²; at second time point (right-hand image) patient was sarcopenic: muscle area=86.7 cm²; fat area=506 cm².

Sarcopenic Obesity

- Sarcopenic obesity is another major problem whereby people have a high level of body fat/BMI but reduced muscle mass and/or strength.
- Linked to poor clinical outcomes.
- Also, in diseases such as cancer.

Sarcopenic Obesity & Clinical Outcomes

Supplement article

SARCOPENIC OBESITY

Multivariate hazard ratio for death

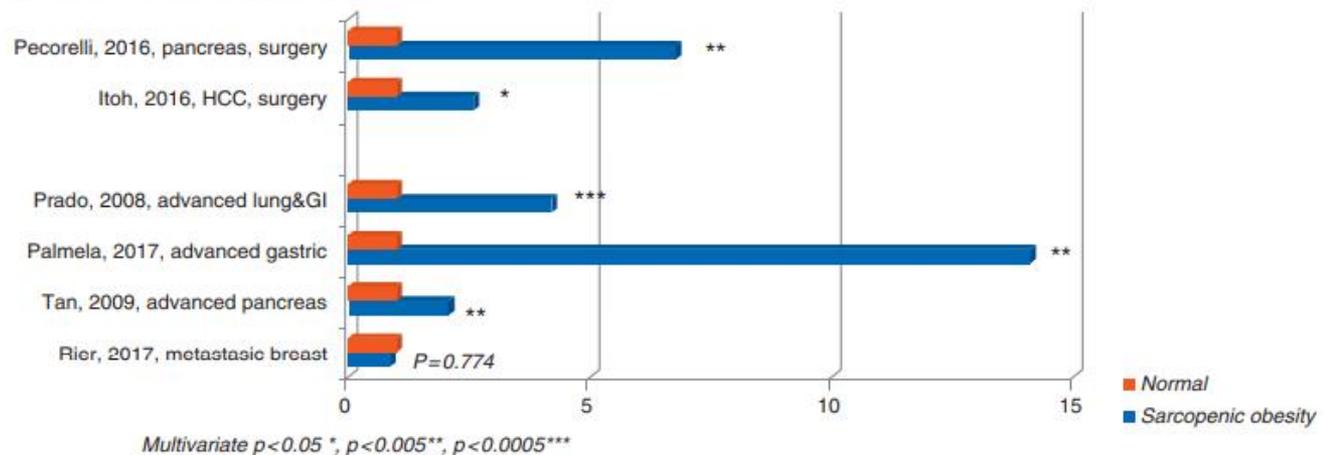


Figure 2. Multivariate odds ratio for mortality in sarcopenic obese patients.

SARCOPENIC OBESITY

Multivariate odds ratio for surgical complications

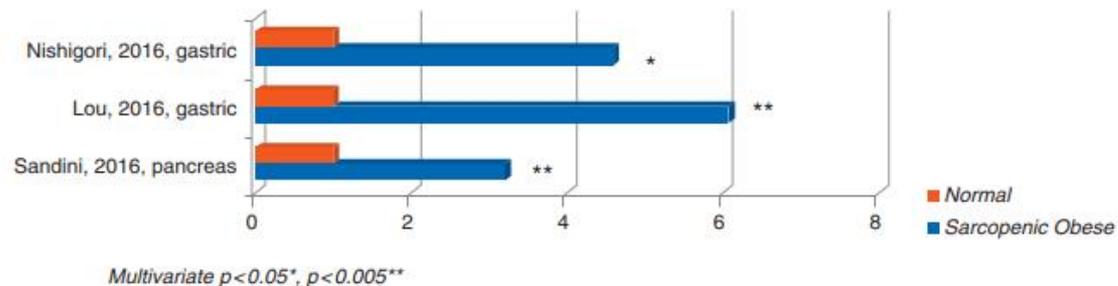


Figure 3. Multivariate odds ratio for surgical complications in sarcopenic obese patients.

Sarcopenic Obesity & Clinical Outcomes

- Greater risks of chemotherapy dose limiting toxicity

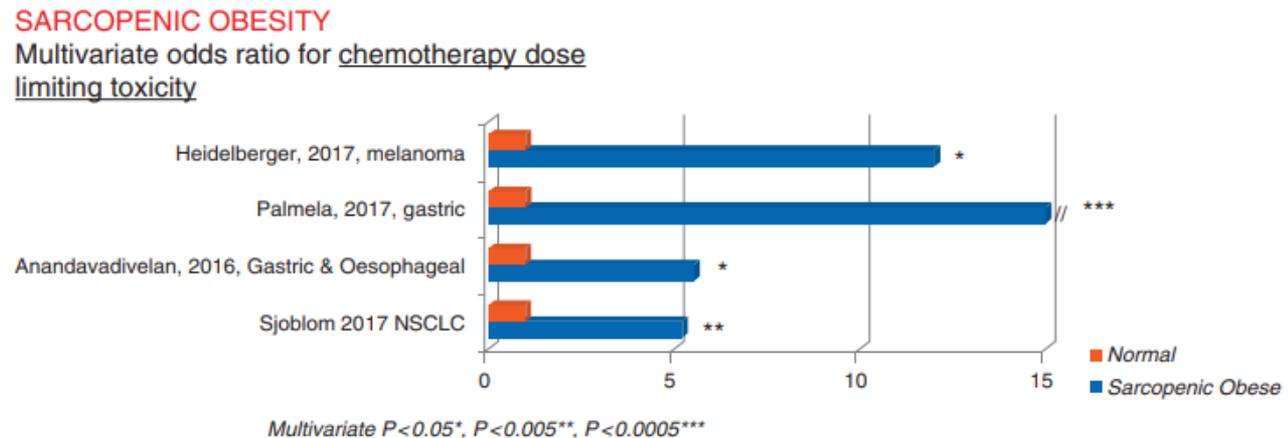


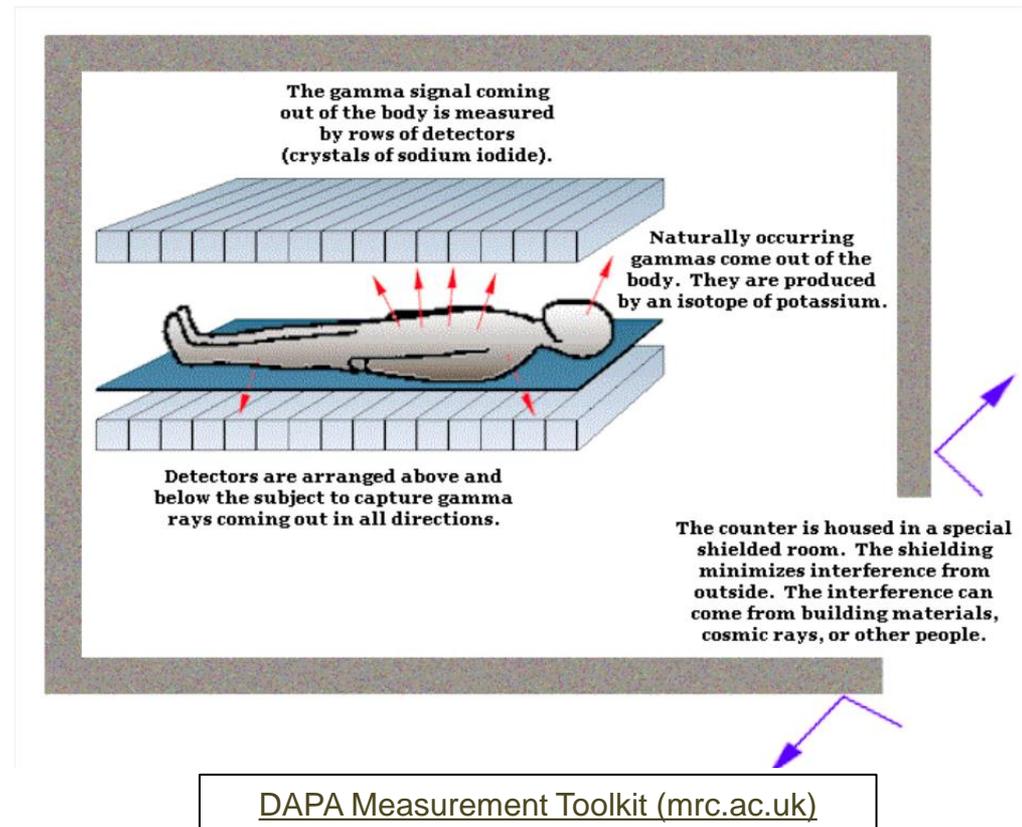
Figure 4. Multivariate odds ratio for dose-limiting toxicity of chemotherapy in sarcopenic obese patients.

Measuring Lean Body Mass/Fat Free Mass

- Many different techniques to measure lean tissue mass. Note that remember skeletal muscle mass is a component of lean mass.
- Important in the assessment of disease related malnutrition and wasting/cachexia.

Total Body Potassium Counting

- Total body potassium counting measures naturally occurring ^{40}K gamma radiation signals.
- Based on principle that ^{40}K makes up 0.0118% of total potassium.



From: Wang et al, 2004. *Am J Physiol Endocrinol Metab* 286: E123–E128.

- **Body cell mass (BCM)** can be measured using a gold standard technique such as total body potassium counting.
- i.e. the relationship between functional cells and potassium/K⁺ content (high K⁺ intracellular, low Na⁺) etc.
- This technique is rarely used now as it is difficult, cumbersome, expensive and lack of facilities.

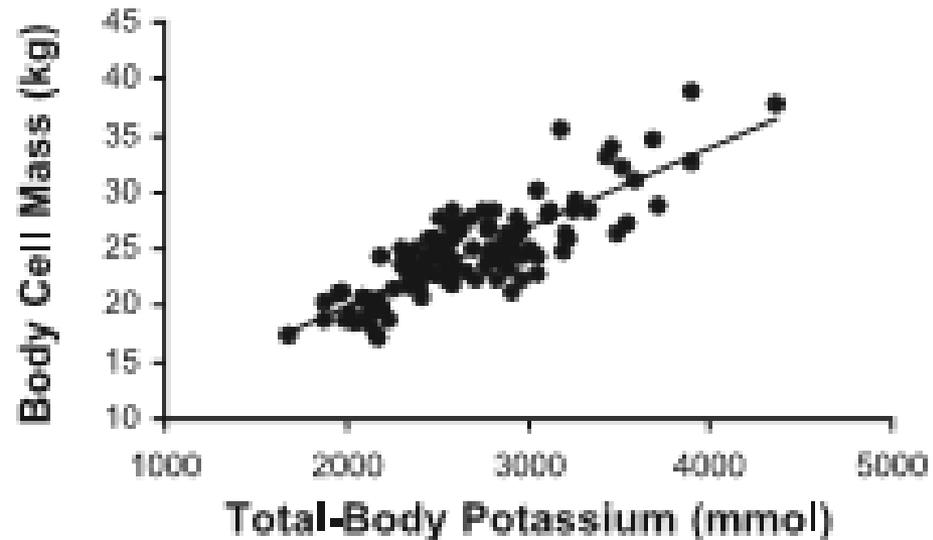


Fig. 1. Body cell mass (BCM, in kg), measured by the approach of Cohn et al. (4), improved here, on the ordinate and total body potassium (TBK), measured by whole body counting, on the abscissa. $BCM (kg) = 0.0071 \times TBK (mmol) + 5.75$; $r = 0.84$, $P < 0.001$; $SEE = 2.28$ kg, $n = 112$ healthy subjects.

Magnitude of body-cell-mass depletion and the timing of death from wasting in AIDS¹⁻³

Donald P Kotler, Anita R Tierney, Jack Wang, and Richard N Pierson, Jr

ABSTRACT The impact of malnutrition on survival in AIDS was evaluated by examining the magnitude of body-cell-mass depletion as a function of time from death. Body cell mass was estimated as total body-potassium content and determined by whole-body counting. There was progressive depletion of body cell mass as patients neared death. The extrapolated and observed values for body cell mass at death were 54% of normal. Body weight had a similar relationship to death, with a projected body weight at death of 66% of ideal. We conclude that death from wasting in AIDS is related to the magnitude of tissue depletion and is independent of the underlying cause of wasting. The degree of wasting seen in this study is similar to historical reports of semistarvation, with or without associated infections. This observation suggests that successful attempts to maintain body mass could prolong survival in patients with AIDS. *Am J Clin Nutr* 1989;50:444-7.

KEY WORDS Malnutrition, acquired immune deficiency syndrome, body-cell-mass depletion, total body potassium, wasting

Kotler et al, 1989 – showed using total body potassium measurement in AIDS patients a correlation with loss of BCM and death. 2nd Figure shows comparison of BCM line and above is % of Ideal Body Weight (IBW).

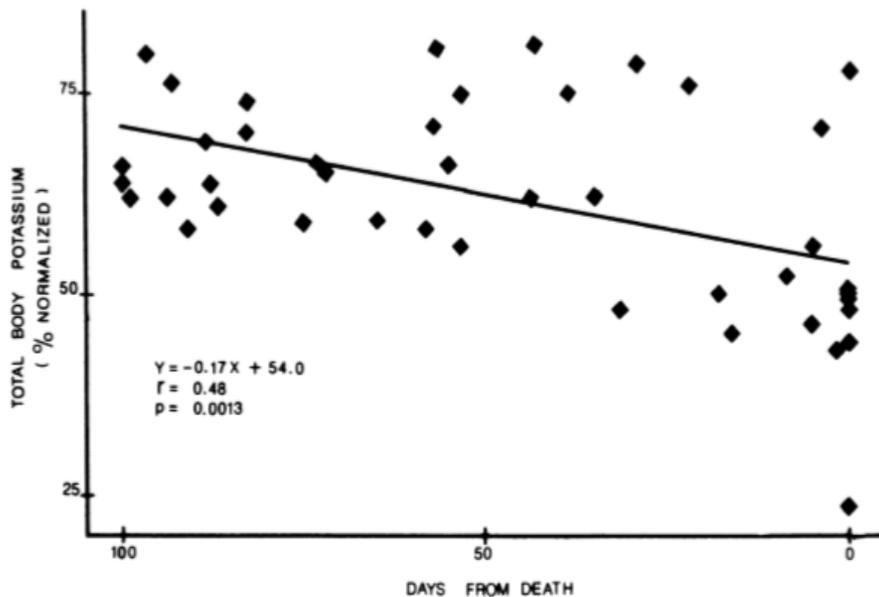


FIG 1. Total-body-potassium measurements in 43 AIDS patients dying of a wasting illness were normalized and analyzed as a function of days before death. The p value indicates that r is significantly different from 0.

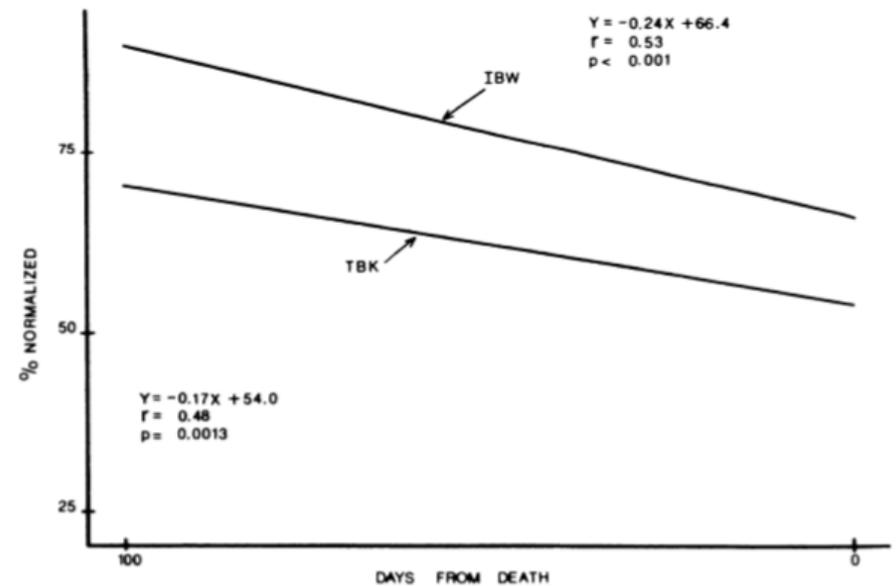


FIG 2. Comparison of the relationships of normalized total-body-potassium content (TBK) and body weight as percent of ideal (IBW) to the timing of death. The p value indicates that r is significantly different from 0.

40% loss of lean mass = high risk of death

- Classical studies such as Kotler et al, showed that losses of ~ 40% lean mass results in extremely high risk of/imminent death.

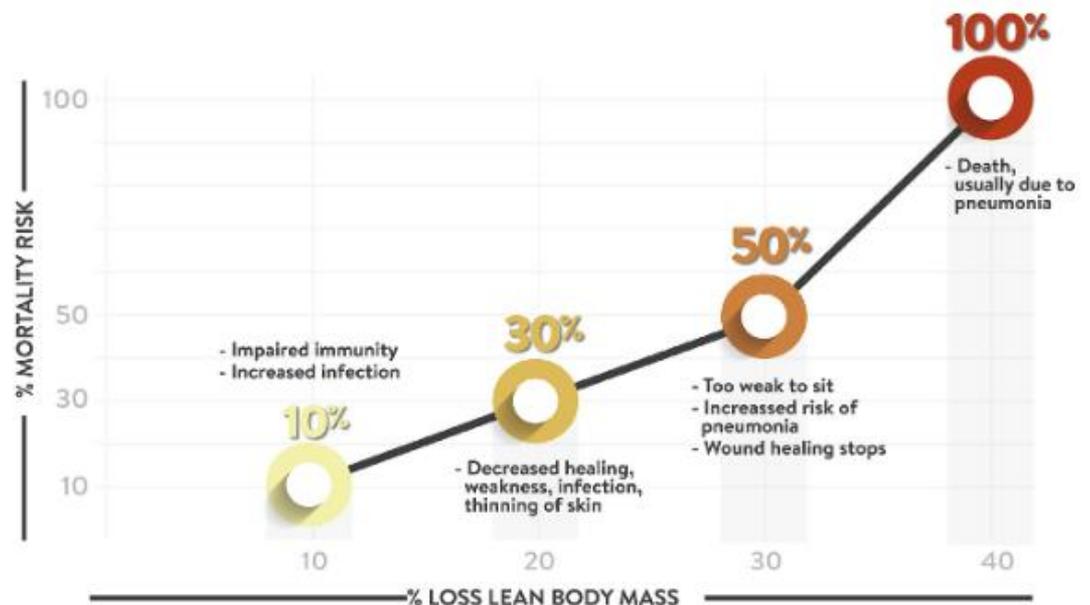


Fig. 1. Complications increase with greater lean mass loss. Assuming no preexisting loss. Adapted from Demling et al., 2009 []

Table 4
Impact of sarcopenia on clinical outcomes.

Muscle abnormality	Patient population	Outcomes	Reference
Muscle loss ^a	LC	↑ hepatic encephalopathy	98
Muscle loss	LC	↑ mortality	26
Muscle loss	Alcohol addiction	↑ mortality	99
Muscle loss	CKD – peritoneal dialysis	↑ mortality	100
Muscle loss	COPD	↑ mortality	101–103
Muscle loss	Cancer	↑ chemotherapy-related toxicity	104,105
Muscle loss	Cancer	↑ mortality	14
Muscle loss	Cancer surgery	↑ mortality	106,107
Muscle loss	Elderly	↑ mortality	108,109
Muscle loss	Elderly	↑ risk of falls	110
Dynapenia ^a	CKD	↑ mortality	111
Dynapenia	CHF	↑ mortality	112,113
Dynapenia	COPD	↑ mortality	114
Dynapenia	Surgery	↑ mortality	115
Dynapenia	Elderly	↑ mortality	116,117

^a Muscle loss and dynapenia are assessed with different methodologies and defined with different terms in references 14,26,98–117. LC, liver cirrhosis; CKD, chronic kidney disease; COPD, chronic obstructive pulmonary disease; CHF, chronic heart failure.

Sarcopenia on clinical outcomes

- End result is muscle loss and loss of strength associated with increased mortality.

Mid Arm Muscle Circumference and Mortality

- Landi et al showed that lowest tertiles of **mid arm muscle circumference (MAMC)** are associated with reduced survival in 357 Italian people over 80 years of age.

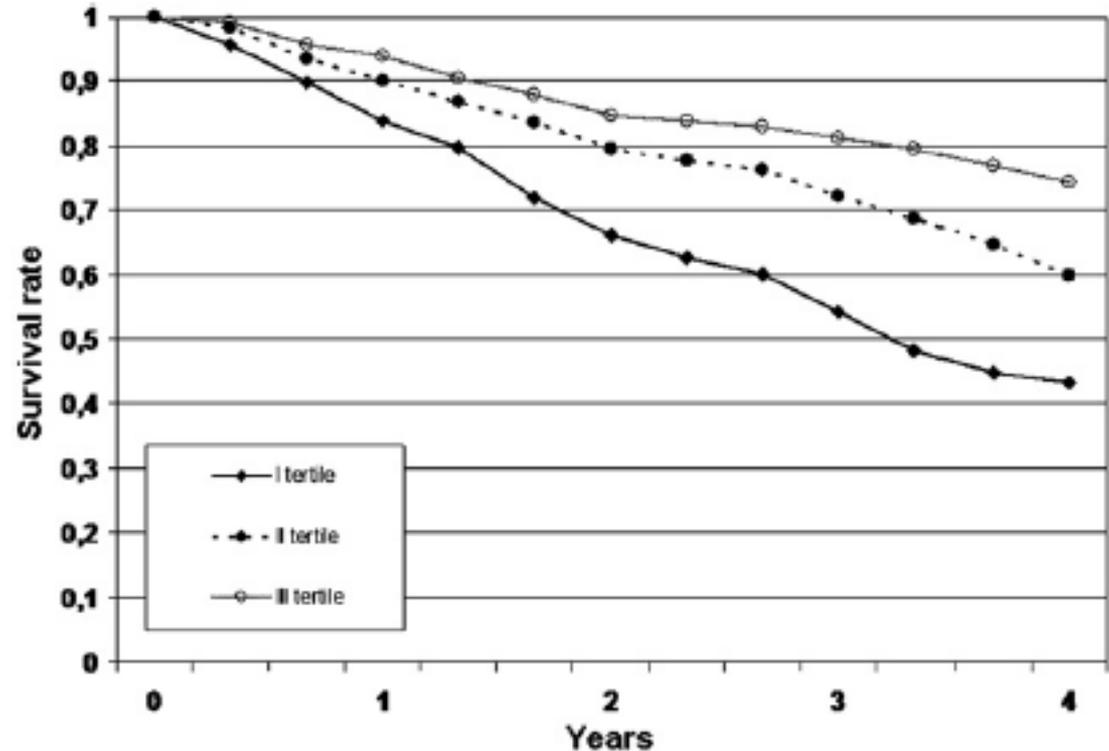
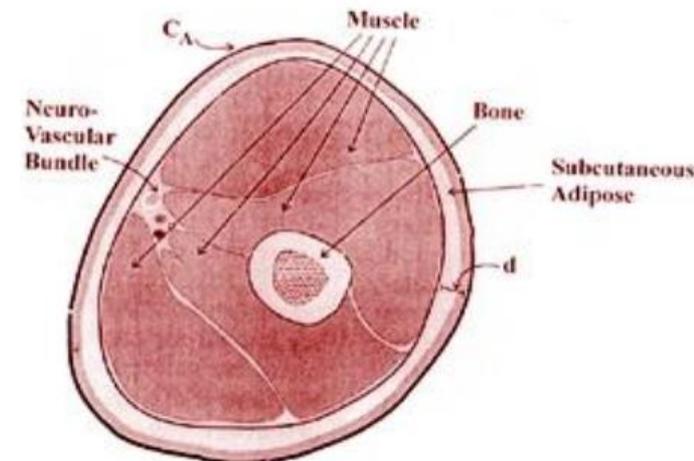


Fig. 1. Survival curves of study participants according to MAMC tertiles at baseline. Survival curves differed significantly at the log-rank test ($p < 0.001$).

Mid Upper Arm Anthropometry

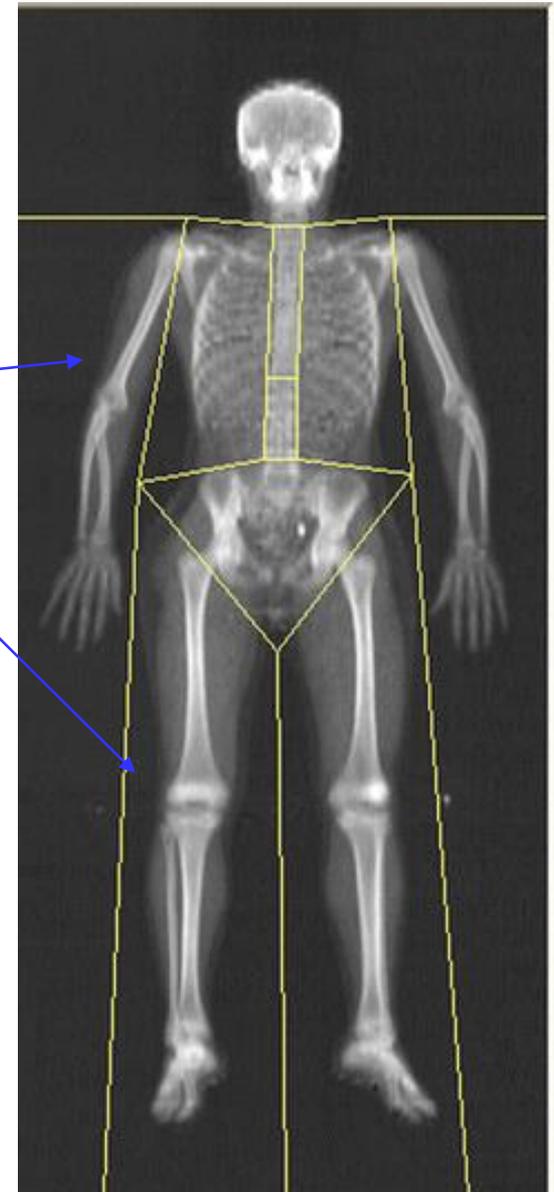
- For example, we can use measurements of the upper arm (circumference and tricep skinfold thickness) to estimate BMI, muscle mass and fat mass.
 - Mid arm muscle circumference (MUAMC)
 - Arm muscle area (AMA)
- Compare to published reference values for age and sex etc.
- Low cost, portable and non-invasive approach but **requires training experience** etc.



DEXA Scans for the Assessment of FFM and Muscle Mass

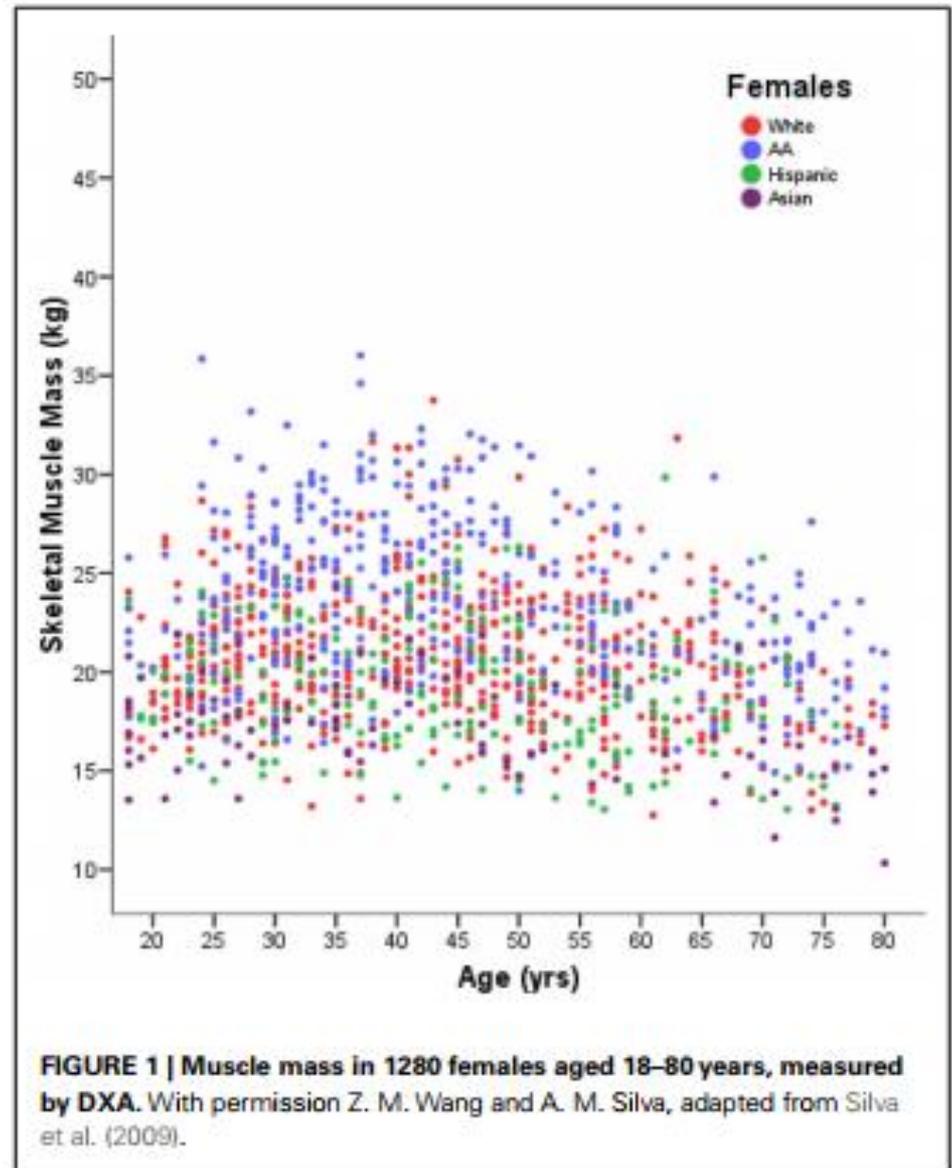
- DEXA is a reference standard technique for bone mass, FFM and FM.
- It is also estimate total or **appendicular muscle mass/lean mass**.
- E.g. sum of the 4 limbs.
- This has become a reference-standard technique for measurement of muscle mass for **cachexia** and **sarcopenia diagnosis**.

Limb
lean
mass



Muscle mass and age relationship

- There is a relationship that as we age we lose muscle mass.
- However, there is also variation in muscle mass/fat mass with ethnicity.



DEXA for Fat Mass Patterning and Distribution

- DEXA can also be used for estimating fat mass.
- E.g. patterns and distribution

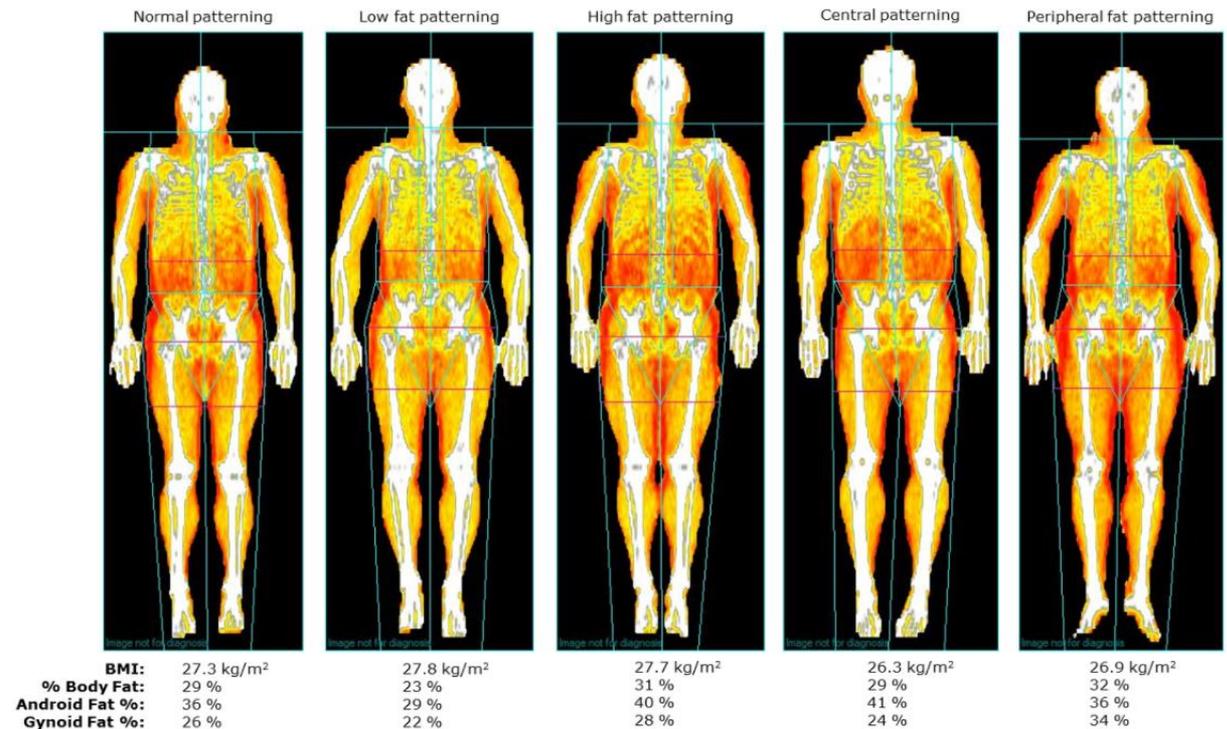


Figure 6 Fat patterning and distribution using DEXA.

Source: MRC Epidemiology Unit.

Bioelectrical Impedance Assessment (BIA)

- BIA is a relatively cheap and portable assessment technique.

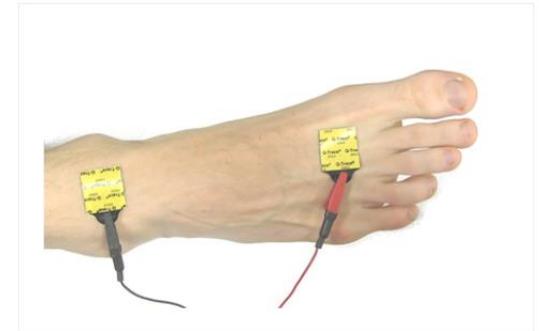


Figure 1 Electrodes placement on hand and foot.
Source: MRC Epidemiology Unit.



Figure 2 Participant's feet touching the electrodes on a foot to foot body composition monitor.
Source: MRC Epidemiology Unit.

Bioelectrical Impedance Assessment (BIA)

- A small harmless current is passed through the body and impedance (Z) in ohms is measured.
- Hydrated tissues conduct electricity and fat mass acts as an insulator./
- BIA principles assume the body to be like a cylinder e.g. trunk and limbs with length and cross sectional area.
- Resistance (R) relates to the length of conductor and CSA.
- Therefore, lean body mass/fat free mass (73% water) relates to Height^2/R

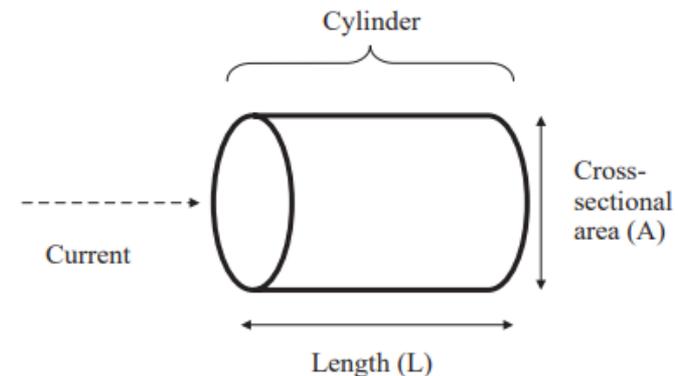


Figure 1 Principles of BIA from physical characteristics to body composition. Cylinder model for the relationship between impedance and geometry. The resistance of a length of homogeneous conductive material of uniform cross-sectional area is proportional to its length (L) and inversely proportional to its cross sectional area (A). Hence resistance (R) = $\rho L/A = \rho L^2/V$; and volume (V) = $\rho L^2/R$, where ρ is the resistivity of the conducting material and V equals AL .

Bioelectrical Impedance Assessment (BIA)

- There are two components to Z , resistance (R) and reactance (X_c).
- R is related to the amount of water present in tissues.
- X_c by contrast reflects the capacitive losses caused by cell membranes.
- Standard technique for single and multi-frequency BIA is placement of electrodes in hands and feet.

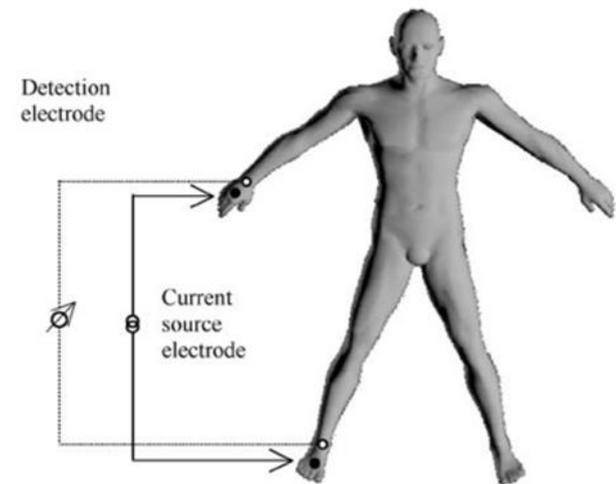


Figure 5 Standard placement of electrodes on hand and wrist and foot and ankle for tetrapolar single (SF-BIA) and multiple-frequency (MF-BIA) BIA.

Considerations - Ageing

- The assumptions behind BIA are that the body (limbs and trunk) can be considered as a single conductive cylinder, and the relationship between the main cross-sectional areas remains the same.
- This model changes with ageing, however, because older people experience a gradual reduction in the cross-sectional area of their limbs and a concomitant increase in that of their trunk.
- Therefore, we need to specifically validate BIA equations for different population groups such as older people.

Validation of BIA equations e.g. Appendicular Skeletal Muscle

- Equations that have been developed can be compared against reference standard techniques such as DEXA.
- Bland Altman analysis can be performed.
- E.g. in example here of estimating appendicular skeletal muscle mass (ASMM) in older Caucasian people.

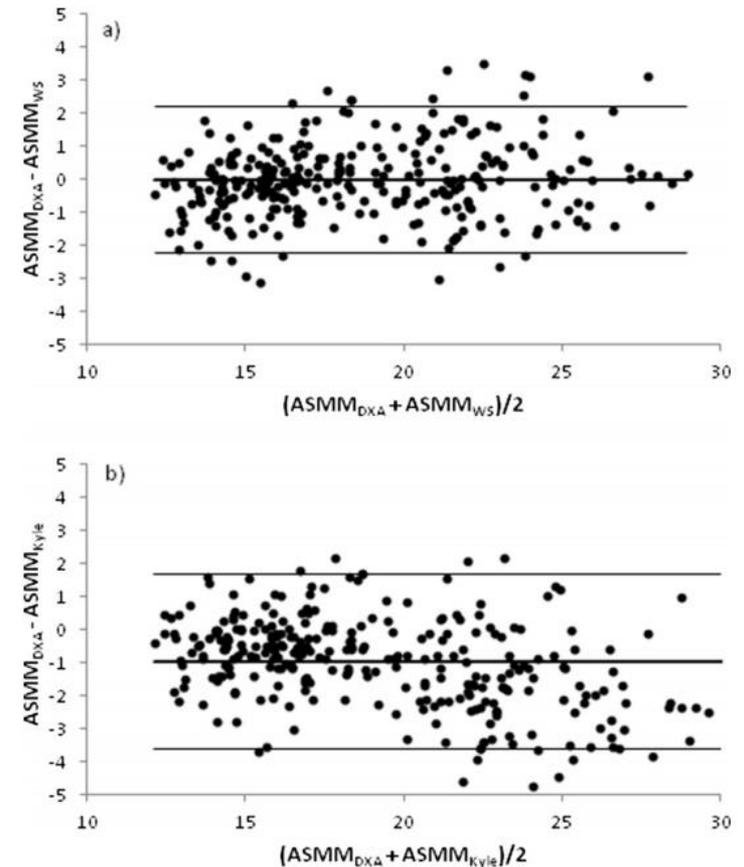


Fig. 2. Bland–Altman plot, for the sample as a whole, of the difference between the appendicular skeletal muscle mass measured by DXA and predicted with the BIA equation derived from the whole sample (plot *a*) and predicted using Kyle's equation (plot *b*). Footnotes: The thick line indicates the bias between the measured and predicted ASMM, the thin lines the limits of agreement. ASMM: appendicular skeletal muscle mass (kg); ASMM_{DXA}: ASMM measured by DXA; ASMM_{Kyle}: ASMM predicted using Kyle's equation; ASMM_{WS}: ASMM predicted with the BIA equation derived from the whole sample.

Validation of BIA Equations e.g. Total Skeletal Muscle Mass

- Example here is development of equation in 388 multiethnic participants, ages 18-86 years in two different laboratories.
- They compared equation with MRI as gold standard technique.
- Note the equation only uses resistive index Ht^2/R .
- See correlation and Bland Altman.

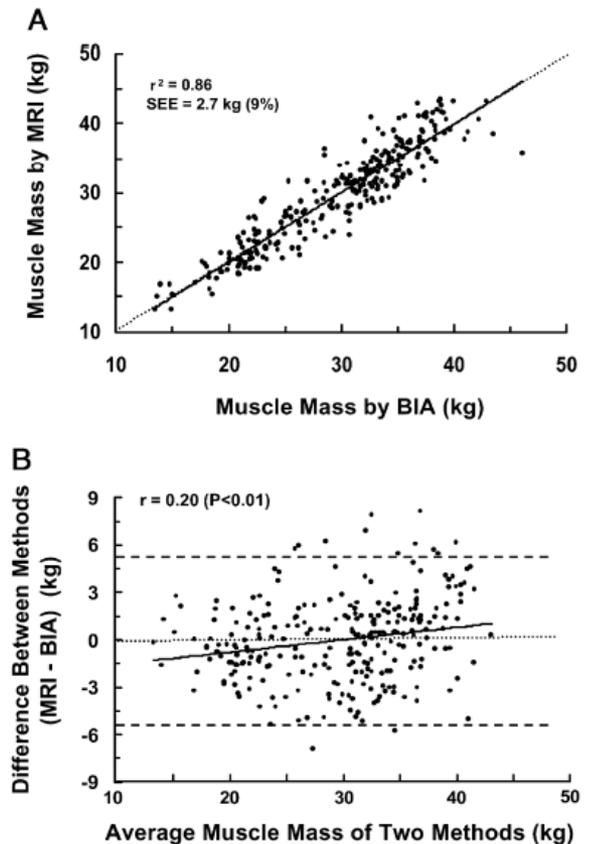
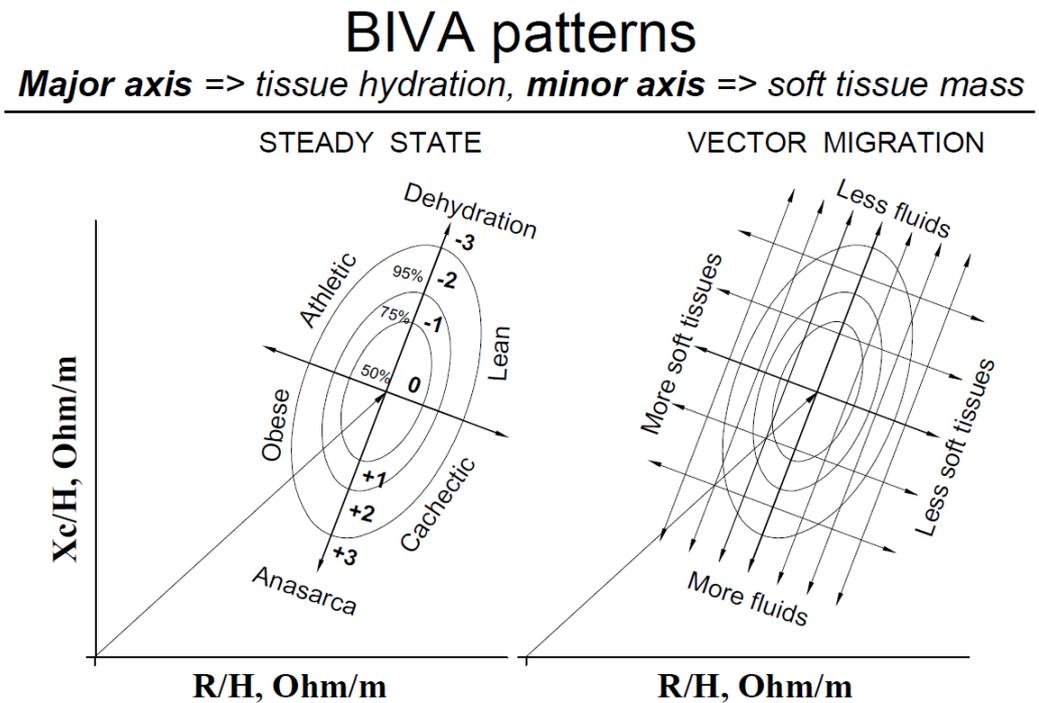


Fig. 3. A: prediction of skeletal muscle mass on the basis of the regression equation derived from the Caucasian subjects within laboratories A + B. Solid line, regression line; dotted line, line of identity. MRI skeletal muscle mass (kg) = $[(Ht^2/R \times 0.401) + (\text{gender} \times 3.825) + (\text{age} \times -0.071)] + 5.102$. For the regression equation, Ht is height in cm, R is BIA resistance in Ω ; for gender, men = 1 and women = 0; and age is in yr. B: difference between skeletal muscle mass measured by MRI and BIA vs. average skeletal muscle mass measured by the 2 methods for the Caucasian subjects. Solid line, regression line; dotted line, average difference between the 2 methods; dashed lines, 95% confidence intervals.

BIA: Raw Impedance Data Assessment

- However, there are some issues with use of BIA estimation equations.
- Depends on population group etc.
- Depends on hydration status and errors with estimation of body compartments.
- Other methods used includes analysis of raw impedance data, resistance (R) and reactance (Xc).
- E.g. BIA Vector Analysis (BIVA)
- Phase angle assessment Xc/R ratio



From: Piccoli and Pastori, 2002

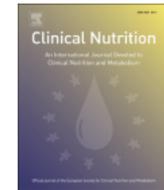


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Original article

Combined evaluation of nutrition and hydration in dialysis patients with bioelectrical impedance vector analysis (BIVA)



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SUMMARY

Background & aims: Body hydration changes continuously in hemodialysis patients. The Subjective Global Assessment (SGA) is used for the nutritional evaluation but it does not allow a direct evaluation of hydration. Bioelectrical impedance vector analysis (BIVA) is very sensitive to hydration. The potential of the combined evaluation of hydration and nutrition with SGA and BIVA is still lacking.

Methods: Observational cross-sectional study on 130 (94 Male) uremic patients undergoing chronic hemodialysis three times a week. Nutritional status was evaluated with the SGA. Each subject was classified as SGA-A (normal nutritional status), SGA-B (moderate malnutrition), or SGA-C (severe malnutrition). Body hydration was evaluated with BIVA. The two vector components resistance (R) and reactance (Xc) were normalized by the subject's height and standardized as bivariate Z-score, i.e. $Z(R)$ and $Z(Xc)$.

Results: Undernutrition influenced impedance vector distribution both before and after a dialysis session. In pre-dialysis, the mean vector of SGA A was inside the 50% tolerance ellipse. In SGA B and C, $Z(R)$ was increased and $Z(Xc)$ decreased, indicating a progressive loss of soft tissue mass. Fluid removal with dialysis increased both $Z(R)$ and $Z(Xc)$ in SGA A and B but not in C. With ROC curve analysis on the slope of increase, we found the cutoff value of 27.8° below which undernutrition was present, either moderate or severe. The area under the ROC curve was 77.7° (95% CI 69.5–84.5, $P < .0001$) with sensitivity 75.9%, specificity 78.6%, positive predicted value 74.6%, and negative predicted value 79%.

Conclusions: The distribution of impedance vectors is associated with the SGA classification of patients. The change in body hydration in each SGA category can be detected with BIVA.

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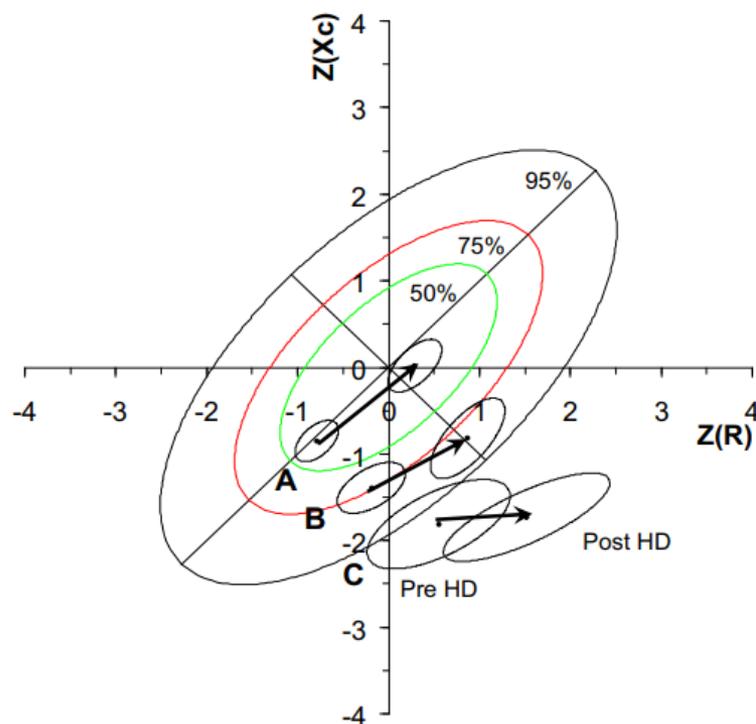


Fig. 2. Mean vector position with 95% confidence ellipse by SGA classes (A,B,C), pre and post hemodialysis. In classes A and B the dialysis session induced a significant vector lengthening parallel to the major axis due to a proportional increase in both $Z(R)$ and $Z(Xc)$. After dialysis the slope of the mean vector in the C class indicated a further increase in the $Z(R)$ component with no increase in the $Z(Xc)$ due to a decreased soft tissue mass.

Table 2

Variables are reported as mean values (SD) pre-, post-, and as a difference post-pre of one dialysis session. Differences in each vector component were tested with the Student's *t* test for paired data.

	Pre	Post	Post-pre	<i>P</i> (<i>t</i>)
<i>SGA-A, n = 70</i>				
$Z(R)$	-.79 (.79)	.29 (1.0)	1.08 (.38)	<.001
$Z(Xc)$	-.85 (.79)	.02 (1.0)	.86 (.62)	<.001
Body weight, Kg	72.2 (11.8)	69.8 (11.6)	-2.4 (.8)	<.001
SBP, mmHg	141 (24)	136 (26)	-5.7 (21.6)	.03
DBP, mmHg	75 (12)	74 (14)	-1.5 (13.5)	ns
MBP, mmHg	97 (14)	95 (16)	-2.9 (14.5)	ns
<i>SGA-B, n = 37</i>				
$Z(R)$	-.19 (.88)	.87 (.95)	1.06 (.43)	<.001
$Z(Xc)$	-1.39 (.69)	-.82 (1.09)	.56 (.74)	<.001
Body weight, Kg	68.5 (12.2)	66.1 (12.0)	-2.4 (.9)	<.001
SBP, mmHg	131 (22)	139 (22)	7.5 (21.1)	.04
DBP, mmHg	66 (11)	69 (11)	3.6 (11.4)	ns
MBP, mmHg	88 (12)	93 (11)	4.9 (12.0)	.02
<i>SGA-C, n = 23</i>				
$Z(R)$.55 (1.40)	1.52 (1.63)	.97 (.49)	<.001
$Z(Xc)$	-1.81 (.92)	-1.73 (.91)	.08 (.44)	ns
Body weight, Kg	59.7 (9.9)	57.9 (9.5)	-1.8 (.80)	<.001
SBP, mmHg	130 (27)	126 (26)	-4.4 (16.5)	ns
DBP, mmHg	67 (15)	65 (10)	-2.5 (14.4)	ns
MBP, mmHg	88 (17)	85 (13)	-3.2 (12.8)	ns

$Z(R)$: Z-score of resistance; $Z(Xc)$: Z-score of reactance; SBP: systolic blood pressure; DBP: diastolic blood pressure; MBP: mean blood pressure.

3. Results

Characteristics of patients by SGA classes are reported in [Table 1](#).

BIVA in Frail Older People

- Key characteristics include lower X_c/H indicating reduced BCM compartment.



Applied nutritional investigation

Bioelectrical impedance vector analysis, phase-angle assessment and relationship with malnutrition risk in a cohort of frail older hospital patients in the United Kingdom



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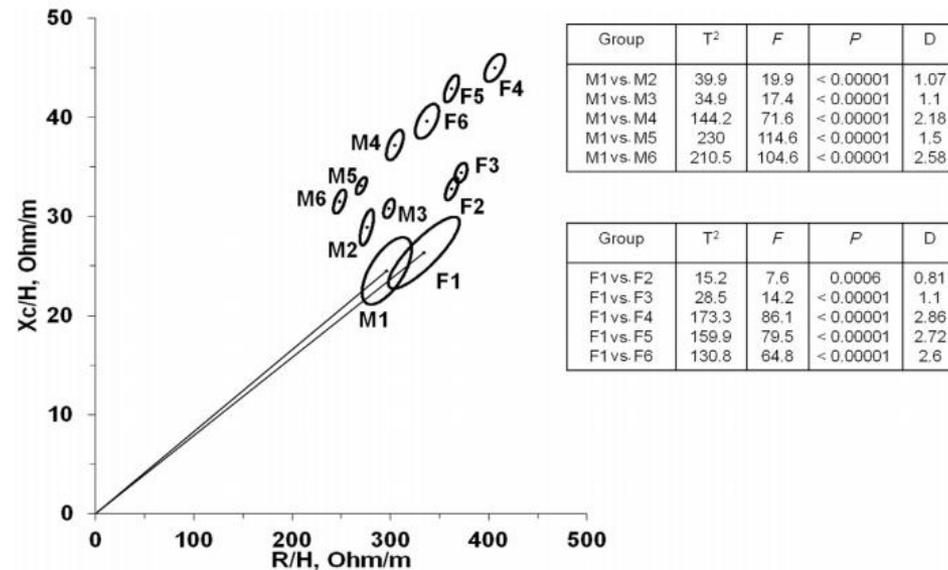


Fig. 1. BIA vectograph (R/H and x_c/H) showing relative bivariate vector positioning and confidence ellipses for participant study groups male, M1 ($n = 44$) and female, F1 ($n = 25$). Reference male and female population vectors are plotted (M2–6; F2–6) and full statistical analysis of group comparisons performed and presented including Hotelling's T² test, F and P values and Mahalanobis distance, D (see comparison tables in Fig.). Reference data set details are found in Table 2.

BIA Phase Angle

- The BIA phase angle (PA) is the arc tangent: $(Xc/R) \times 180/\pi$.
- It has been studied in research as a prognostic marker.

Table 2
Studies on prognostic impact of phase angle.

Study population	N	Cut-off value	BIA device	Clinical outcome of patients below cut-off value
<i>HIV/AIDS</i>				
HIV ⁶⁷	75	5.6°	101, RJL Systems	Decreased survival: parameter estimate in LR test: -0.799, $P < 0.0001$
HIV ⁶¹	469	5.3°	2000-1, Data Input	Decreased survival: 463 days (95% CI: 397–528) vs. 697 (95% CI: 690–705), $P < 0.0001$ Increased progression of disease: 406 days (95% CI: 330–483) vs. 670 days (95% CI: 652–688), $P > 0.0001$
<i>Tumour disease</i>				
Lung cancer ⁶⁰	63	4.5°	101, RJL Systems	Decreased survival: OR = 1.25 (95% CI: 1.01–1.55), $P = 0.04$ - Stage IIIb: 3.7 vs. 12.1 months - Stage IV: 1.4 vs. 5.0 months
Colorectal cancer ⁵⁷	52	5.57°	101Q, RJL Systems	Decreased survival: 8.6 months (95% CI: 4.8–12.4) vs. 40.4 months (95% CI: 21.9–58.8), $P = 0.0001$
Pancreatic cancer ⁵⁶	58	5.08°	101Q, RJL Systems	Increased mortality: RR = 10.75 (95% CI: 1.92–60.24; $P = 0.007$) Decreased survival: 6.3 months (95% CI: 3.5–9.2) vs. 10.2 months (95% CI: 9.6–10.8), $P = 0.02$
Breast cancer ⁵⁸	259	5.6°	101Q, RJL Systems	Reduction of RR 0.75 (95% CI: 0.58–0.96, $P = 0.02$) with every 1° increase in phase angle Decreased survival: 23.1 months (95% CI: 14.2–31.9) vs. 49.9 months (95% CI: 35.6–77.8), $P = 0.031$
Lung cancer ⁵⁹	165	5.3°	101Q, RJL Systems	Reduction of RR 0.82 (95% CI: 0.68–0.99, $P = 0.041$) with every 1° increase in phase angle Decreased survival: 7.6 months (95% CI: 4.7–9.5) vs. 12.4 months (95% CI: 10.5–18.7), $P = 0.02$
Mixed tumours ⁹³	195	-1.65 SPA	101Q, RJL Systems	Reduction of RR 0.79 (95% CI: 0.64–0.97, $P = 0.02$) with every 1° increase in phase angle Increased 3 years mortality: RR = 2.35 (95% CI: 1.41–3.90, $P = 0.001$)
Mixed tumours ⁴³	399	5th percentile of reference values ¹¹	Nutriguard M, Data Input	Increased six month mortality OR = 4.0 (95% CI: 2.4–6.8; $P < 0.001$)
<i>Dialysis</i>				
Haemodialysis ²⁹	131	♂ 4.5° ♀ 4.2°	101, RJL Systems/Akern	Decreased 2 year survival rate (59.3% vs. 91.3%), $P < 0.01$ Increased mortality: RR = 2.6 (95% CI: 1.6–4.2), $P < 0.0001$
Haemodialysis ⁹⁴	3009	3.0° 3–4.0°	Quantum, RJL Systems	Increased mortality: RR = 2.2 (95% CI: 1.6–3.2, $P < 0.05$) RR = 1.3 (95% CI: 1.0–1.7, $P < 0.05$)
Peritoneal dialysis ²⁵	45	6.0°	101, RJL Systems	Decreased 1 year survival ($P = 0.01$)
Peritoneal dialysis ⁶²	48	6.0°	101, RJL Systems	Decreased 2.5 year survival ($P = 0.008$); RR = 0.39, $P = 0.027$
Peritoneal dialysis ⁹²	53	6.0°	101, RJL Systems	Decreased 5 year survival ($P = 0.004$); RR = 0.536, $P = 0.01$
Haemodialysis ⁵³	149	6.0°	101A, RJL Systems	Increased mortality RR = 4.12 (95% CI: 1.09–15.53; $P = 0.036$)
<i>Other</i>				
Liver cirrhosis ¹⁵	305	5.4°	101, RJL Systems/Akern	Decreased 4.5 year survival, $P < 0.01$
Surgical patients ⁶⁶	225	-0.8 SPA	101Q, RJL Systems/Akern	4.3 fold increased risk of postoperative complication RR = 4.3 (95% CI: 1.6–11.8), $P = 0.02$
ALS ⁶³	168	2.5°	Analycor 3, Spengler	Decreased survival: 384 vs. 572 days, $P = 0.017$, HR = 0.80 (95% CI: 0.65–0.98), $P = 0.03$
Geriatric patients ⁹⁵	1071	3.5°	Nutriguard M, Data Input	4-fold increased hospital mortality of 20% (95% CI: 15–24%)
Heart failure ⁵¹	41	Absolute	101, RJL Systems	Decreased survival (AUC = 0.86; 95%CI 0.72–1.0; $P = 0.01$)
Systemic sclerosis ⁶⁴	124	3.9°	Nutriguard M, Data Input	Decreased survival (61% vs. 98.8%), $P < 0.05$

LR = likelihood ratio; CI = confidence interval; OR = odds ratio; RR = relative risk.

SPA = standardized phase angle = (observed phase angle - mean of reference value/standard deviation of reference value).

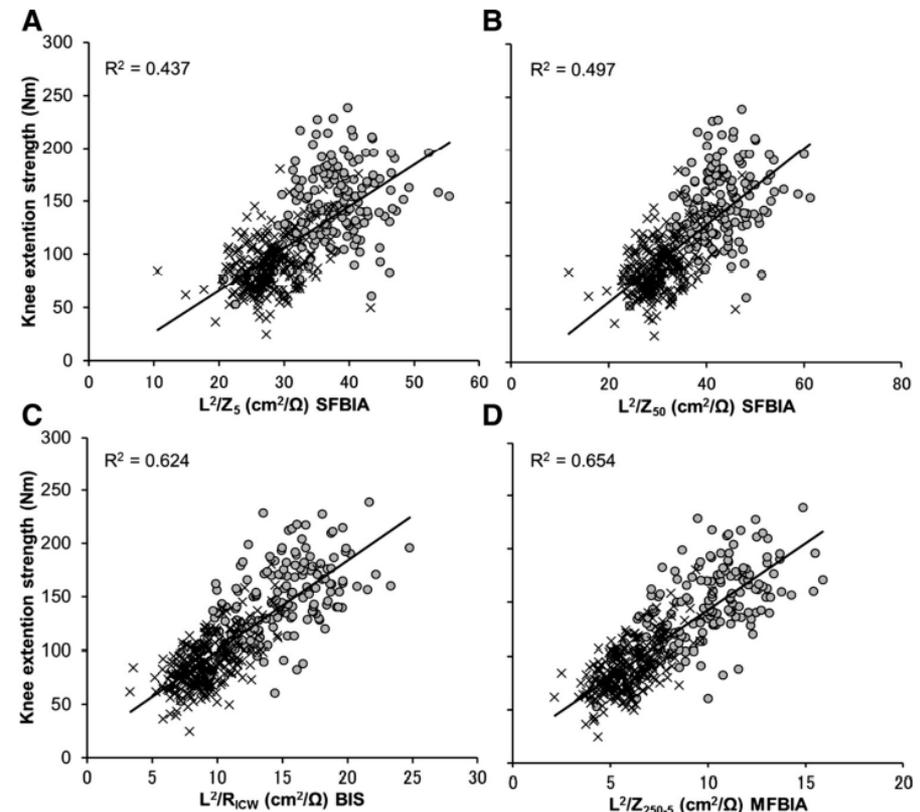
ALS = Amyotrophic lateral sclerosis; HR = hazard ratio; AUC = area under the curve.

BIA and Muscle Strength (Knee Extensor)

- Knee extensor strength versus L^2/Z for single and multi-frequency BIA.

In 405 older adults

Fig. 1. Relationship between knee extension strength (KES) and impedance (Z) indexes of squared segment length (L^2) divided by Z at 5 kHz (L^2/Z_5 ; A), L^2/Z_{50} (Z at 50 kHz; B), L^2/R_{ICW} [resistance of intracellular water component calculated from bioelectrical impedance spectroscopy (BIS); C], and L^2/Z_{250-5} [Z of the intracellular component calculated from multifrequency bioelectrical impedance analysis (MFBIA); D] in the upper legs. ×, Women; ●, men. The relationships between KES and BIS (L^2/R_{ICW}) or MFBIA (L^2/Z_{250-5}) were significantly stronger than the relationship between KES and single-frequency bioelectrical impedance analysis (SFBIA) (L^2/Z_5 and L^2/Z_{50}).



BIA and Muscle Strength (Hand Grip)

- Knee extensor strength versus L^2/Z for single and multi-frequency BIA.

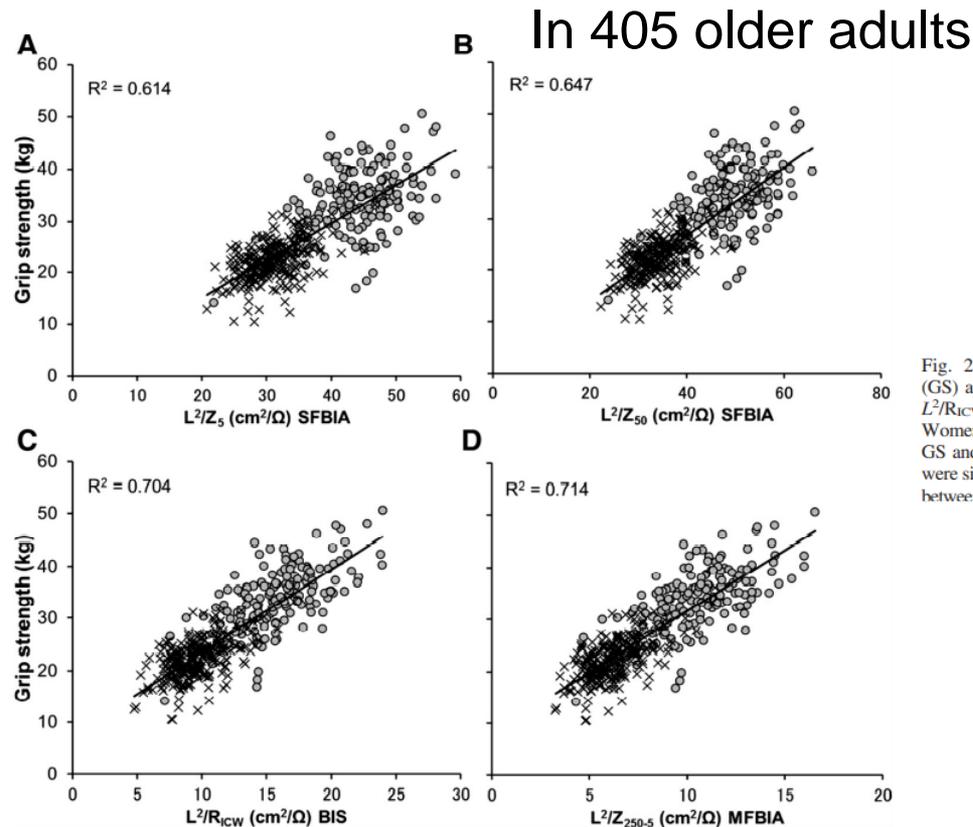


Fig. 2. Relationship between grip strength (GS) and Z indexes of L^2/Z_5 (A), L^2/Z_{50} (B), $L^2/R_{1c_{a}}$ (C), and L^2/Z_{250-5} (D) in the arms. ×, Women; •, men. The relationships between GS and BIS ($L^2/R_{1c_{a}}$) or MFBIA (L^2/Z_{250-5}) were significantly stronger than the relationship between GS and SFBIA (L^2/Z_5 and L^2/Z_{50}).

Hand Grip Strength (HGS)

- Marker of physical function and nutritional status.
- Key measurement for sarcopenia and frailty.
- Correlates with malnutrition risk for example.



Figure 1. Jamar Hand Dynamometer



Muscle strength: clinical and prognostic value of hand-grip dynamometry

Richard W. Bohannon

Purpose of review

Grip strength measured by dynamometry is well established as an indicator of muscle status, particularly among older adults. This review was undertaken to provide a synopsis of recent literature addressing the clinical and prognostic value of hand-grip dynamometry.

Recent findings

Numerous large-scale normative grip strength projects have been published lately. Other recent studies have reinforced the concurrent relationship of grip strength with measures of nutritional status or muscle mass and measures of function and health status. Studies published in the past few years have confirmed the value of grip strength as a predictor of mortality, hospital length of stay, and physical functioning.

Summary

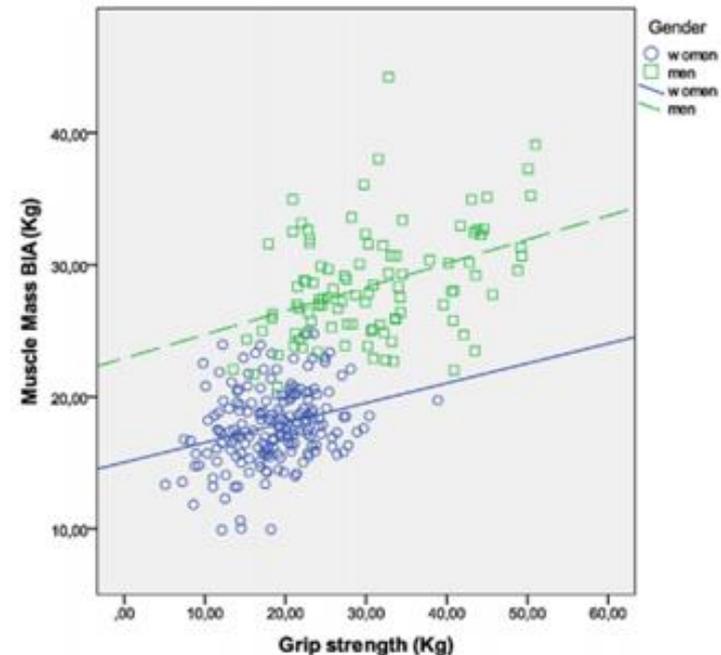
As a whole, the recent literature supports the use of hand-grip dynamometry as a fundamental element of the physical examination of patients, particularly if they are older adults.

Keywords

body composition, dynamometry, muscle, physical function

Considerations with HGS

- Very useful technique.
- However, note that muscle strength does not always correlate well with muscle mass.
 - Also depends on technique used for muscle mass.
- During ageing, disease and physical inactivity the mass of tissue can stay the same but have infiltration of fatty and fibrotic tissue.
- Further, neuromuscular activation patterns alter, e.g. motorneurones.



Note: Correlation between muscle mass and muscle strength in Belfrail study by gender.
In women $R^2 = 0.08$ and in men $R^2 = 0.16$

Fig. 1. Correlation between MM and muscle strength in the participants of the BELFRAIL study by gender.

Legrand et al, 2013. Archives of Gerontology and Geriatrics 5. 345-351.

Effects of Intermuscular Adipose Tissue (IMAT) on Mobility and Function

- Example depicted is of two women with similar:

- Age
- BMI
- Levels of lean mass

- **BUT, very different levels of IMAT, mobility and muscle function.**

MRI Images

	Timed up and go (s)	Stair up (s)	Stair down (s)	Lower extremity power (W)	Knee extension strength (N)
Subject 07	8.4	6.6	7.0	88.2	194.8
Subject 44	6.5	4.9	4.4	139.5	248.3
Difference	25%	29%	45%	45%	24%

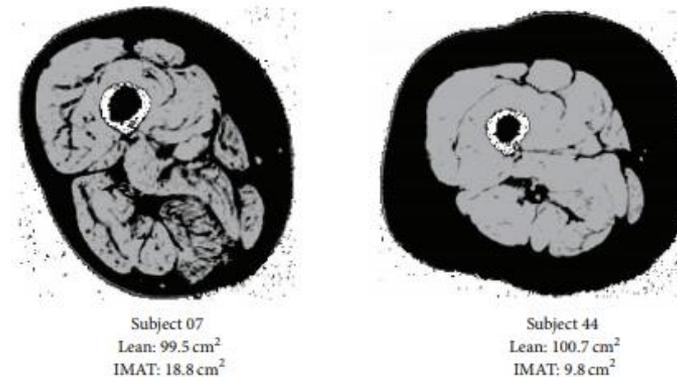
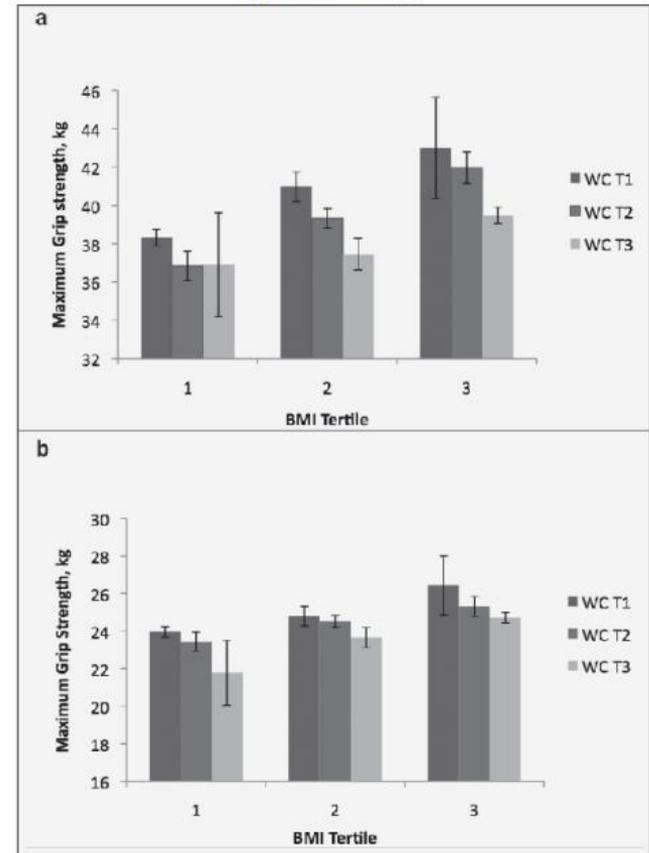


FIGURE 3: Two women with similar age, BMI, and levels of lean muscle mass but with differing levels of IMAT in a cross-sectional MRI image of the thigh. Subject 7 has double the level of IMAT (black within the muscle) in her thigh as subject 44. While both women have similar levels of lean tissue (seen in grey), they have different levels of mobility and muscle function. The increased levels of IMAT and decreased muscle and mobility function of subject 7 are consistent with literature that reports that increased levels of IMAT are associated with decreased muscle and mobility function.

HGS and Obesity

- Data from 8,441 men and women (European Prospective Investigation into Cancer-Norfolk study) aged 48-92 years.
- HGS increases with BMI as increase in weight is both FM and FFM/muscle.
- However, within BMI tertile those with higher WC have lower HGS.

Figure 2
Maximum grip strength* (kg) by tertile of BMI and WC in men (a) and women (b)



Maximum grip strength increases with increasing BMI. However, when BMI is held constant higher waist circumference is associated with lower grip strength. (Bars indicate 95% Confidence Intervals.) * Maximum grip strength adjusted for age and height at the 3HC. Body mass index (BMI) Tertiles (T)- Men: <25.4kg/m²; 25.4-28.1kg/m²; >28.1 kg/m²; Women: <24.2 kg/m²; 24.2-27.7 kg/m²; >27.7 kg/m²; Waist Circumference (WC) Tertiles (T)- Men: <96.1cm; 96.1-103.7cm; >103.7cm; Women: <83.5cm; 83.5-93.8cm; >93.8cm

MRI Scans

- Cross-sectional images have been used to identify **visceral obesity and poor muscle quality etc.**
- E.g. Infiltration of fat in muscle, intermuscular fat (IMAT).
- IMAT is defined is any fat in between muscle fibers and within muscle.

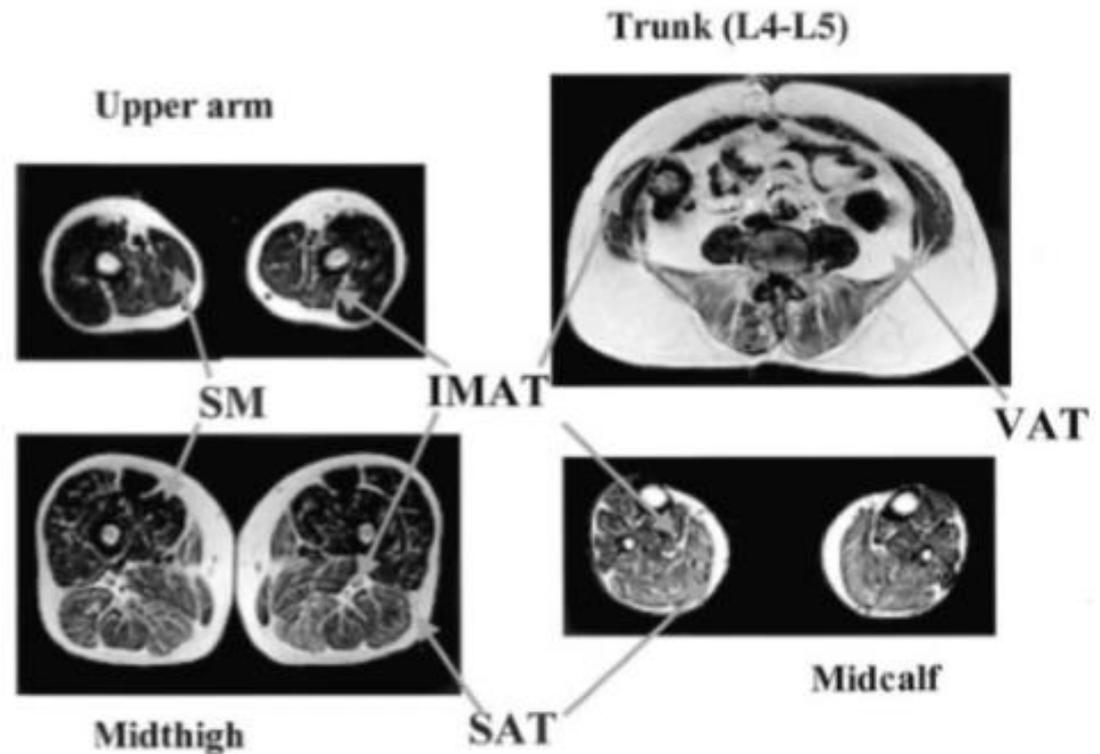


FIGURE 1. Cross-sectional images from upper arm, trunk, midthigh, and midcalf in a female participant aged 72 y. IMAT, intermuscular adipose tissue; SM, skeletal muscle; SAT, subcutaneous adipose tissue; VAT, visceral adipose tissue.

MRI Application – HIV Lipodystrophy

A standardized, comprehensive magnetic resonance imaging protocol for rapid and precise quantification of HIV-1-associated lipodystrophy

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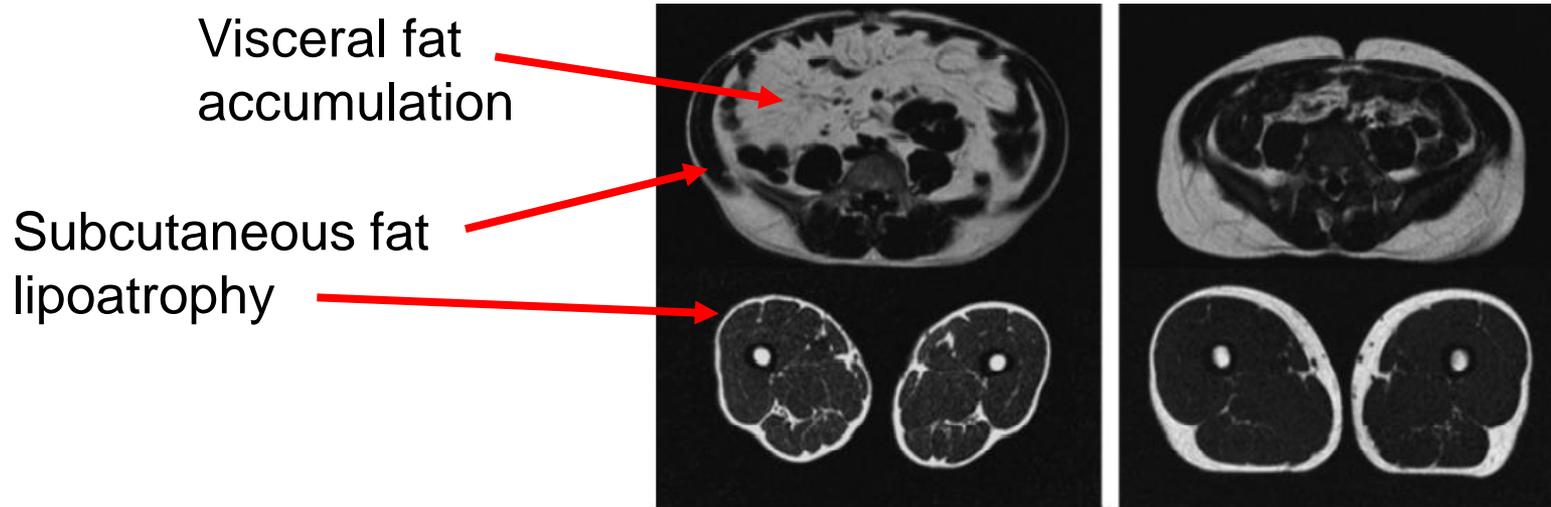


Fig. 1 Representative magnetic resonance imaging (MRI) slices of the face, neck, abdomen and mid-thigh of an HIV-infected patient with a mixed type of lipodystrophy (left panel, a) and of an asymptomatic HIV-infected patient (right panel, b). Fat is displayed in light grey.

Advantages and Disadvantages of Different Techniques (Deutz et al, 2019)

Table 1
Overview of Available Tools and Techniques to Measure Muscle Mass, Strength, and Function^{1,12,13}

Technique	Advantages	Disadvantages
Anthropometry (eg, skinfold thickness measurements, mid–upper arm circumference, calf circumference)	<ul style="list-style-type: none"> • Quick • Accessible 	<ul style="list-style-type: none"> • Lacks precision • Room for human error
Dual-energy x-ray absorptiometry (DXA)	<ul style="list-style-type: none"> • Quick • 3 body composition compartments • Appendicular muscle • Low radiation • Available in many hospitals • High precision with low errors 	<ul style="list-style-type: none"> • Accessibility in certain clinical or care settings eg, nursing homes, GP practices • Weight limitation of DXA table • Individual hydration levels can impact soft tissue readings
Bioelectrical impedance analysis (BIA)	<ul style="list-style-type: none"> • Accessible • Low cost • Portable • Enables phase angle measurement • Safe and noninvasive • Does not require highly trained personnel 	<ul style="list-style-type: none"> • Not portable • Fasting recommended • Assumes constant hydration factor for most equations to calculate body compartments • Not accurate for extreme BMIs (<16 or >34) • Lacks precision • Prediction error for estimated muscle mass • Multiple devices available with different body composition outputs
Ultrasonography	<ul style="list-style-type: none"> • Portable • Low/moderate cost • Quick • No radiation • Separate visceral and subcutaneous adipose tissues 	<ul style="list-style-type: none"> • Several anatomical sites needed for the analysis • Sensitive to hydration levels • Specific user protocols in place requiring trained personnel
Computerized tomography (CT)	<ul style="list-style-type: none"> • Precise • Muscle mass quantification • Frequently available in cancer and other conditions: critical illness, COPD, HIV, cardiovascular disease, kidney disease, and cirrhosis 	<ul style="list-style-type: none"> • Lack of cut-off values to diagnose low muscularity • Radiation exposure • Opportunistic only at this time • Healthy cohort reference values are scarce
Magnetic resonance imaging (MRI)	<ul style="list-style-type: none"> • Safe • Reliable • No radiation risk • High resolution of skeletal mass 	<ul style="list-style-type: none"> • High cost • Requires technical expertise and training for analysis of outputs • Multiple images are required to assess the composition of the total body

CALF CIRCUMFERENCE

Calf Circumference Measurement

- Good marker of malnutrition.
- Used as part of the Mini Nutritional Assessment (MNA)
- Less prone to fat infiltration deposits as opposed to say the thigh muscles for example.
 - i.e. fat infiltration increases with age and physical inactivity etc.
- New research shows good correlations with muscle mass in all ages.

Calf Circumference Measurement

- Different methods in research have used lying, sitting and **standing**.



Figure S1 Method of calf circumference measurement. The maximal calf circumference was measured to the nearest 0.1 cm with the use of a steel measuring tape while the participant was in the standing position, without the compression of the subcutaneous tissue.

- CC compared with muscle mass from MRI (gold-standard technique).
- 124 older men (>60 years of age).
- Good correlation found.

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Maximal calf circumference reflects calf muscle mass measured using magnetic resonance imaging



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ABSTRACT

Background: Calf circumference (CC) has been used as a surrogate for calf muscle mass, which facilitates venous blood return to the heart through active skeletal muscle. However, the correlation between CC and calf muscle mass has not been extensively examined. This study aimed to examine the relationship between CC and calf muscle mass considering differences in sex and physique in elderly individuals.

Methods: A total of 124 community-dwelling elderly individuals ≥ 60 years of age (61 men, mean [\pm SD] age 74.3 \pm 5.7 years) were enrolled. Maximal CC was measured using a tape measure with the subject supine. The cross-sectional area of skeletal muscle tissues was measured using magnetic resonance imaging from the point of greatest calf circumference to 5 cm proximal and distal. Calf muscle mass was calculated by multiplying the area of each slice by slice thickness (5 mm).

Results: CC was strongly correlated with calf muscle mass in male and female subjects (male: $r = 0.908$, $P < 0.001$; female: $r = 0.892$, $P < 0.001$). Multiple regression analysis revealed that CC and body mass index (BMI) were independent associate factors of calf muscle mass. The following estimation formulae were derived: (male) calf muscle mass (cm^3) = $47.82 \times \text{CC (cm)} - 12.50 \times \text{BMI (kg/m}^2) - 732.80$; (female) calf muscle mass (cm^3) = $32.23 \times \text{CC (cm)} - 4.85 \times \text{BMI (kg/m}^2) - 429.94$.

Conclusions: A strong correlation was found between CC and calf muscle mass according to magnetic resonance imaging. Sex differences and BMI should be considered for accurate estimation of calf muscle mass using CC.

Calf circumference and muscle mass by MRI

S. Zamboni et al.

Archives of Gerontology

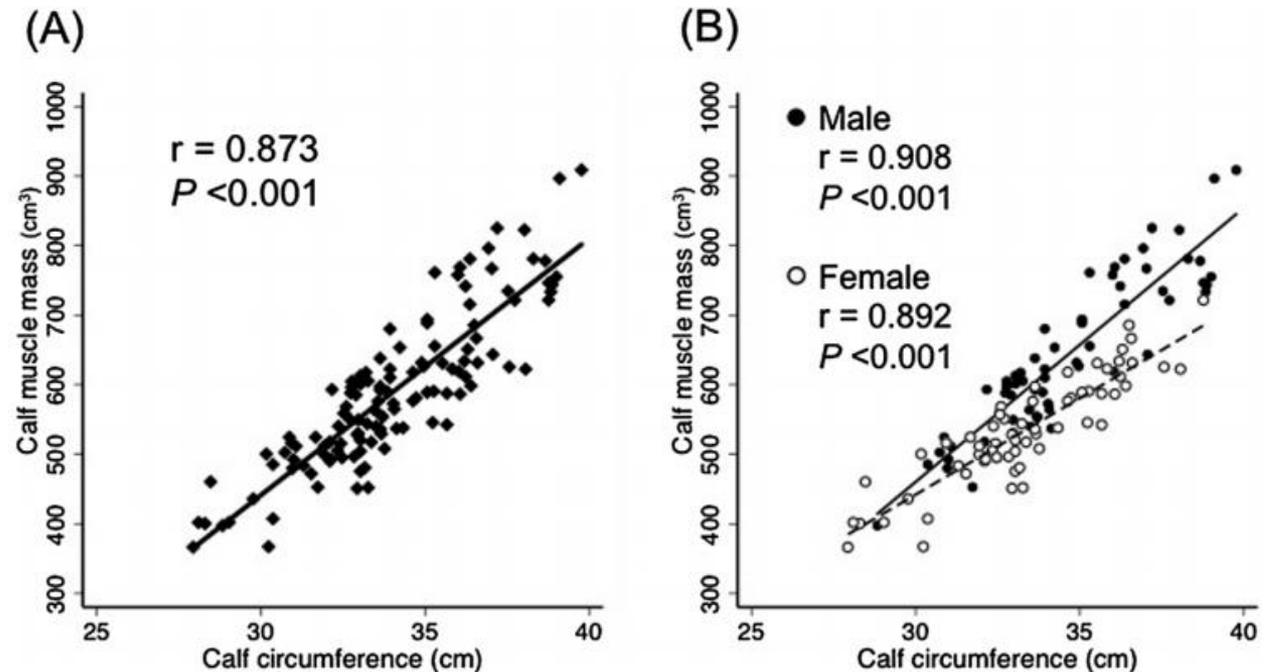


Fig. 1. Correlation between calf circumference and calf muscle mass in total subjects (A) and stratified according to sex (B). Male and female are shown as black circles + solid regression line and white circles + dashed regression line, respectively (B).

CC and low muscle mass

- Different groups have tried to determine CC cut off points for low muscle mass.
- E.g. study in 1249 Asian adults using BIA and DEXA.

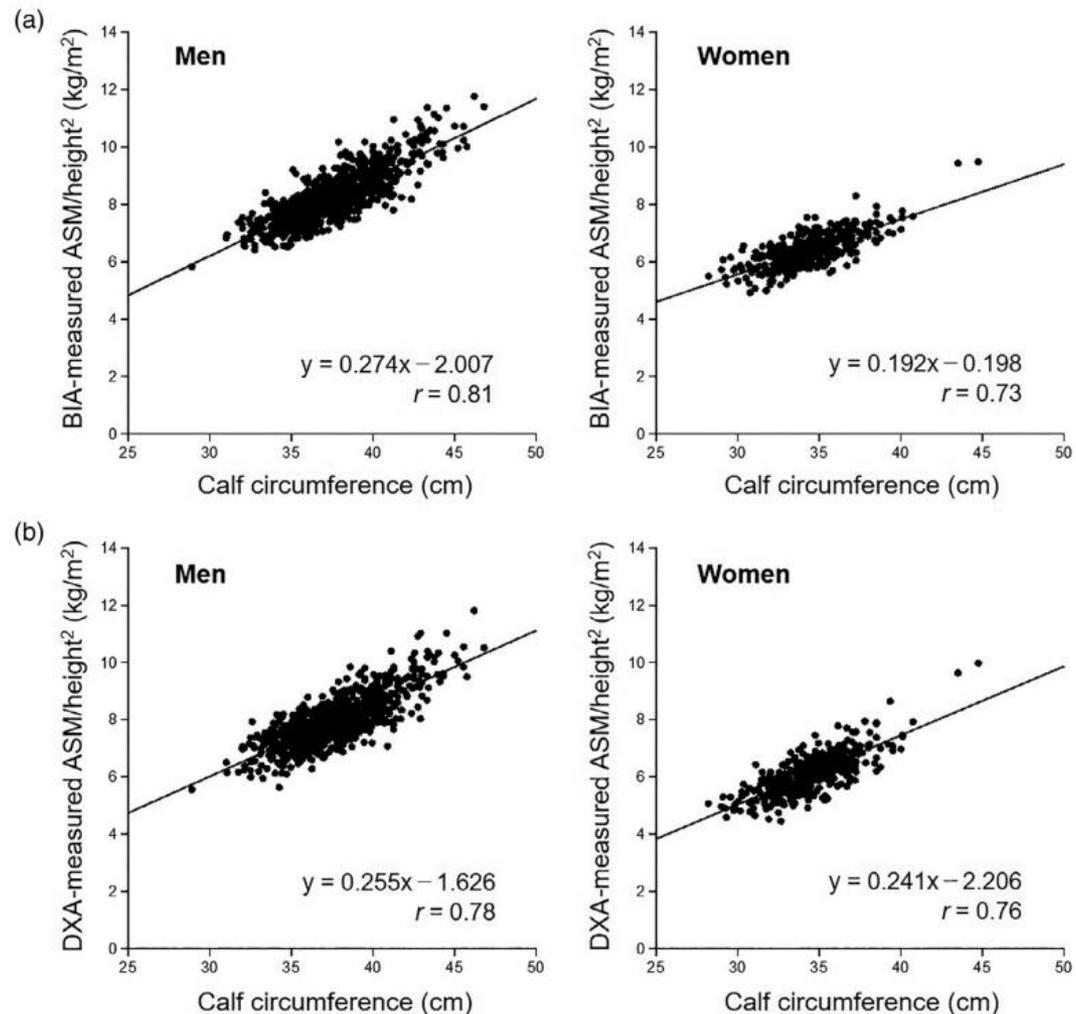


Figure 1 Correlation of calf circumference with (a) BIA and (b) DEXA-measured ASM/height² in men and women. *r* = correlation coefficient. ASM, appendicular skeletal muscle mass; BIA, bioelectrical impedance analysis; DEXA, dual-energy X-ray absorptiometry.

Prediction Equation for Appendicular Skeletal Muscle Mass using Calf Circumference

- Study data from US National Health and Nutrition Examination Survey (NHANES).
- 15,293 adult surveyed 1999-2006.
- Additionally, using DEXA as the reference method for estimating Appendicular Skeletal Muscle (ASM).
- Developed equation using CC, gender, age and race.

Premier Research Papers

New Prediction Equations to Estimate Appendicular Skeletal Muscle Mass Using Calf Circumference: Results From NHANES 1999–2006

Leonardo Pozza Santos, PhD^{1,*} ; Maria Cristina Gonzalez, MD, PhD^{2,3,*} ; Silvana Paiva Orlandi, PhD⁴; Renata Moraes Bielemann, PhD^{4,5}; Thiago G. Barbosa-Silva, PhD⁵ ; Steven B. Heymsfield, MD³; and On behalf of the COCONUT Study Group

Abstract

Background: Low appendicular skeletal muscle mass (ASM) is associated with negative outcomes, but its assessment requires proper limb muscle evaluation. We aimed to verify how anthropometric circumferences are correlated to ASM and to develop new prediction equations based on calf circumference and other anthropometric measures, using dual-energy X-ray absorptiometry (DEXA) as the reference method. **Methods:** DEXA and anthropometric information from 15,293 adults surveyed in the 1999–2006 NHANES were evaluated. ASM was defined by the sum of the lean soft tissue from the limbs. Anthropometric data included BMI and calf, arm, thigh, and waist circumferences. Correlations were assessed by Pearson's correlation, and multivariable linear regression produced 4 different ASM prediction equations. The concordance and the overall 95% limits of agreement between measured and estimated ASM were assessed using Lin's coefficient and Bland-Altman's approach. **Results:** Calf and thigh circumferences were highly correlated with ASM, independent of age and ethnicity. Among the models, the best performance came from the equation constituted solely by calf circumference, sex, race, and age as independent variables, which was able to explain almost 90% of the DEXA-measured ASM variation. The inclusion of different anthropometric parameters in the model increased collinearity without improving estimates. Concordance between the four developed equations and DEXA-measured ASM was high (Lin's concordance coefficient >0.90). **Conclusion:** Despite the good performance of the four developed equations in predicting ASM, the best results came from the equation constituted only by calf circumference, sex, race, and age. This equation allows satisfactory ASM estimation from a single anthropometric measurement. (*JPEN J Parenter Enteral Nutr.* 2019;43:998–1007)

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Prediction Equations

- Development of a prediction equation for skeletal muscle mass using weight, height, waist circumference and age.



Simple Skeletal Muscle Mass Estimation Formulas: What We Can Learn From Them

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One century ago Harris and Benedict published a short report critically examining the relations between body size, body shape, age, and basal metabolic rate. At the time, basal metabolic rate was a vital measurement in diagnosing diseases such as hypothyroidism. Their conclusions and basal metabolic rate prediction formulas still resonate today. Using the Harris-Benedict approach as a template, we systematically examined the relations between body size, body shape, age, and skeletal muscle mass (SM), the main anatomic feature of sarcopenia. The sample consisted of 12,330 non-Hispanic (NH) white and NH black participants in the US National Health and Nutrition Survey who had complete weight, height, waist circumference, age, and dual-energy X-ray (DXA) absorptiometry data. A conversion formula was used to derive SM from DXA-measured appendicular lean soft tissue mass. Weight, height, waist circumference, and age alone and in combination were significantly correlated with SM (all, $p < 0.001$). Advancing analyses through the aforementioned sequence of predictor variables allowed us to establish how at the anatomic level these body size, body shape, and age measures relate to SM much in the same way the Harris-Benedict equations provide insights into the structural origins of basal heat production. Our composite series of SM prediction equations should prove useful in modeling efforts and in generating hypotheses aimed at understanding how SM relates to body size and shape across the adult lifespan.

Keywords: sarcopenia, nutritional assessment, anthropometry, body composition, waist circumference

Resources

- <https://dapa-toolkit.mrc.ac.uk>